Evaluating Cane Pruning Decision Criteria and the Identification of Grapevine Pruning Styles

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Winter pruning is the highest yearly expenditure in the typical New Zealand vineyard budget, yet few attempts have been made to bring quantitative measurement tools into its management. The research presented here constitutes first steps towards this end, in tandem with University of Canterbury researchers working towards an artificially intelligent pruning robot. In pursuit of information regarding cane pruning preferences and decision-making criteria, a two-part survey was conducted in the regions of Marlborough, Hawke’s Bay, Waipara and Central Otago. Part One of this survey asked participants to rate a set of already-made cane pruning decisions for one *(cv.) Sauvignon Blanc* vine. Participants rated these decisions on 24 individual pruning criteria and also provided two overall assessments. One of these overall assessments was recorded before participants rated the decisions on the 24 individual criteria, and a second overall assessment was recorded after such time. All ratings were collected via Qualtrics software, either online or via the Qualtrics offline survey application. Part Two of the survey asked participants to indicate, with highlighter pens on paper, their own preferred pruning decisions for the same vine.

Linear Models, based on the relationship between the individual criteria and overall assessments (Part One), have revealed spur and cane position to be the dominant influencing factors in the pruning of the subject vine. Participant first impressions, as measured by the first overall assessment (before the individual criteria ratings), were almost exclusively reflective of participant attitude towards spur and cane position. The dominance of position was corroborated by Correspondence Analysis of the preferred pruning decisions (Part Two), which suggested that the decision to modify the vine’s cane or spur position was a fundamental point of divide within participant responses. In a related finding, results from Principal Component Analysis (Part One) have suggested that overall impressions were a heavy influence throughout the course of participant responses to Part One of this study. By extension, this finding suggested that attitudes towards position, which were strongly linked to participant overall assessments, permeated into participant attitudes towards other aspects of the presented decision set (Part One). Generally speaking, the dominance of a single group of

decision-making criteria calls for further investigation into how pruning is conceptualised as a task. Results from this study suggest that there exists a somewhat broad, non-specific, view of whether or not a particular set of spur and cane selections are acceptable. This finding, while perhaps not immediately impactful for practitioners, has considerable implication for the design of future pruning research, as well as for the evaluation of artificially intelligent pruning.

This research also reports the detection of pruning preference (Part One and Part Two) groups, based on region and organisational role. Correspondence Analysis and Multiple Correspondence Analysis (Part Two) have revealed that participants from Hawke's Bay and, particularly, Central Otago tended towards a decision to restructure the subject vine by not leaving a spur from its existing right half. This was in contrast to those participants from Marlborough and Waipara who tended towards a maintaining of the current vine configuration. Aside from these differing propensities to restructure the vine, several regions were associated with unique spur and cane selections. It is unclear at present whether regional differences are due to social influences, regional viticulture conditions, cultivar familiarity, or some unknown factor. Participants also differed in their preferences when grouped based upon their organisational role. Those participants identifying exclusively as labourers were considerably less likely to restructure the vine, compared to those participants identifying as supervisors, managers, or proprietors. Managerial implications of this finding are discussed, with several potential remedies explored.

Keywords: Cane Pruning, Double Guyot, Pruning Decisions, Viticulture Region, Pruning, Style, Vineyard, Sauvignon Blanc, Cane Spur, Qualtrics, Winter Pruning

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In all, 218 participants took the time to complete the pruning survey. This time commitment ranged anywhere from 5 to 35 minutes per person, which adds up to a staggering amount time collectively spent helping this study. I cannot thank these individuals enough, both for their participation and for their friendliness towards me as a visiting researcher. It goes without saying I will never forget the time spent on the road visiting more than 90 vineyards throughout New Zealand. A special “thank you” goes to those participants (and I’m sure there were a few!) who were not quite convinced about our study, but were polite and friendly all the same. I very sincerely hope the outcome will be of some gratification, given your considerable time investment.

Arranging visits to over 90 vineyards was no minor task, and it could not have been successful without the noteworthy assistance of some industry members. Particular thanks in this regard are owing to Andrew Naylor, Martin Tillard, Glenn Kirkwood, Joanne Brady, Tim Creagh, Dr. Rengasamy Balasubramaniam, Graham Bartleet, and Associate Professor Roland Harrison. I would also like to acknowledge the assistance of Andrew Naylor in working out a template for data collection visits. Likewise, Julian Smith of the Camshorn Vineyard in Waipara was a major influence in the formulation of pruning criteria for the Qualtrics decision ratings part of the survey.

For a few personal notes, I would like to take the opportunity to thank my parents, Jane Kirk and Joseph Kirk for their support of my education over the years. I am often reminded by my Mother that this Master’s thesis actually began at age four when I would walk out to the mailbox every morning for the newspaper, needing to keep up with the latest baseball statistics. In any case, I feel fortunate to have had such supportive family and friends over the years. I would like to conclude with a special thank you to Ashley Cooper, who kept me full of joy and laughter after many long days.

Andrew Kirk

February 2016

Table of Contents

List of Tables

List of Figures

Table 1-1: Supplementary Reading Guide for Thesis Document

Chapter Title	Purpose	Key Notes
1. Introduction	Initiates reader to context of winter pruning	
2. Literature Review	Review literature in two domains	Two-part literature review A. Review of relevant methodologies and statistics B. Explores physiological setting of winter pruning
3. Materials & Methods	A detailed account of a new methodology for the evaluation of winter pruning decisions.	Two Part Survey A. Evaluation of a previously-made set of pruning decisions, overall and on 24 individual criteria B. Participants indicate their own preferred pruning decisions
4. Results: General Response Profile	Provides general picture of survey responses	
5. Results: Assessment of Pruning Criteria	Reports results of statistical procedures aimed at exploring the importance of pruning criteria	Analyses Reported A. Multiple Linear Regression B. Partial Least Squares Regression
6. Results: Group Differentiation	Reports results of statistical procedures aimed at identifying pruning preference groups	Analyses Reported A. Chi-Square Tests B. Correspondence Analysis C. Multiple Correspondence Analysis D. Hierarchal Cluster Analysis
7. Results: Prediction of Pruning Preferences	Reports results of statistical procedure aimed at predicting participant decisions, based on other parameters	Analyses Reported A. Binary Logistic Regression B. Multinomial Logistic Regression
8. Discussion	Builds on Chapters 4-7 to formulate arguments regarding pruning decision-making criteria and the existence of pruning preference groups.	See section 8.6 for a summary of presented arguments.
9. Post-Examination of Methodology	A reflection on those methodological decisions outlined in Chapter 3, with suggestions for future research.	A number of adjustments are recommended, many of which would decrease the necessary time investment from participants.
10. Conclusions	Summary of key points from Chapters 8 and 9	

Chapter 1

Introduction

Winter pruning, in its most basic definition, is the removal of excess shoot growth prior to the beginning of a new growing season (Jackson 2008). Conversely, and perhaps more appropriately, winter pruning may be defined as the deliberate selection of buds for retention, based upon their perceived fruitfulness and suitability for purpose (Zabadal et al. 2002). In cool climate growing conditions, such as those observed in most viticulture regions of New Zealand, winter pruning is seen as an essential means of regulating yield and managing the structure of the vine (Howell 2001). Structure, and to some extent crop load, dictate the light, temperature, and humidity of the canopy environment (Smart and Robinson 1991). As such, conscientious and skilful pruning, in conjunction with appropriate vine training systems, can increase bud fruitfulness (Smart et al. 1982), mitigate disease risk (Reynolds and Vanden Heuvel 2009), promote vine balance (Howell 2001), and optimise fruit quality parameters (Howell et al. 1987). Likewise, the manipulation of carbohydrate dynamics through pruning may have positive secondary effects such as frost avoidance (Trought et al. 1999), reduction of apical dominance (Jackson 2008), and the control of canopy vigour through inter-shoot competition (Reynolds et al. 2005).These and other benefits, with the associated risks of poor pruning, illustrate the central importance of pruning decisions.

Its considerable physiological impacts aside, winter pruning is a significant cause of financial strain for the typical New Zealand vineyard. The 2013 and 2014 Viticulture Monitoring Reports, published by the Ministry for Primary Industries (MPI), placed winter pruning as the single largest expense in the typical yearly budget (New Zealand Winegrowers 2013, New Zealand Winegrowers 2014). Even more concerning, the additional and lingering cost of poor pruning has thus far eluded assessment. Unlike some vineyard tasks, satisfactory cane pruning has proven difficult to mechanise, due to the inherent complexity of the task (Morris and Cawthon 1981, Zabadal et al. 2002). Meanwhile, those embarking on manual pruning can expect to spend 60 to 100 man-hours pruning a single hectare of V*itis vinifera* (Andersen et al. 1996), and subject workers to numerous occupational health hazards (Roquelaure et al. 2002, Wakula and Landau 2000).

Despite the central importance of pruning, few attempts have been made to comprehensively evaluate pruning decisions or the criteria that inform them. To date, much of the literature has broadly focused on the attributes of training systems (Kliewer and Dokoozlian 2005, Koblet et al. 1994, Reynolds et al. 1996), rather than the highly specific pruning options that exist within such systems. Perhaps the nearest exception is the body of research that surrounded the adoption, mostly for V*itis labrusca* (L.) juice grape production, of mechanical pruning regiments. (Keller et al. 2004, Morris and Cawthon 1981, Reynolds 1988, Zabadal et al. 2002) These studies, while relevant and timely in their hour, deal with an indiscriminate pruning technique and therefore utilise yield and fruit quality parameters that are influenced by factors other than pruning decision quality.

The present research is part of a larger project that aims to bring robotic pruning to the viticulture industry. As part of this project, and to aid the development of a cane pruning algorithm, an attempt at pruning evaluation was previously undertaken by a supervisor of the present study (Corbett-Davies et al. 2012). Although the evaluation exercise served its purpose adequately, several areas for improvement were identified by the researcher. Most crucially, the evaluations were subject to the ratings of one person, and as such cannot be said to reflect the opinions of the industry as a whole, or any segment. Secondly, the ratings were given a general one to five rating, without published information as to why the decisions scored well or poorly.

Building upon this work, with a continued emphasis on supporting the development of artificially intelligent cane pruning, an industry-wide survey was conducted to gather information regarding pruning preference and relevant decision criteria. The survey asked participants to rate the pruning of a vine via colour photos, both overall and on 24 individual criteria, and also to indicate how they would have ideally pruned the vine. A key point of emphasis is that the study looked at a single vine throughout, in an effort to approximate a model system and to facilitate clear analysis. As a further limitation on scope, it must also be noted that the present study deals only with Two-Cane Pruning, also known as Double Guyot, which may induce decision priorities that differ from those found in other systems.

With the lack of research precedent in this area, hypotheses were forgone in favour of objectives, which may be described as follows:

- Modelling the relationship between individual pruning criteria and overall pruning quality
- Analysing fit-for-purpose of the criteria set currently in use for pruning evaluation
- Identifying and characterising pruning style groups, based on background variables
- Prediction of pruning decision preferences, with a view to future applications

Chapter 2

Literature Review

2.1 Part One: A review of relevant statistics and methodologies

2.1.1 Introduction

The first segment of this chapter will focus on that literature which directly influenced the design of this study. Without an established framework, many concepts were borrowed from other disciplines and adapted for purpose. In other cases, parallel lines of enquiry existed in other areas of grape and wine science. Where possible, the relevant literature will be organised according to a corresponding research objective. As such, literature presented within part one of this review will fall loosely into one of four categories: linear modelling, group identification and differentiation, outcome prediction with logistic regression, and scale construction. As techniques employed in this study have not been applied previously to the area of pruning preference, a particular effort will be made to provide supporting evidence for procedural decisions, which are outlined in Chapter 3. It is also hoped that the detailed explanations contained within will serve as an interpretative aid to those who are less than familiar with some multivariate statistical techniques commonly referenced throughout Chapters 4-8.

2.1.2 Linear Model Building

Linear Regression

Linear Regression is a tool for the assessment of relationship between a set of independent variables and a dependent variable. (Tabachnick and Fidell 2001) In viticulture, this technique has modelled a variety of relationships including that between seed size and overall berry size (Friend et al. 2009), the carbohydrate status of various plant organs at budburst (Bennett et al. 2005), and the influence of leaf removal on carbohydrate status (Petrie et al. 2000). These models may include a single predictor and dependent variable, as in the case of simple regression, or may incorporate more than one predictor, as in Multiple Linear Regression (Tabachnick and Fidell 2001).

Assumptions and Violations

As with any statistical technique, the myriad assumptions built into Linear Regression are part of what enable meaningful interpretation. While a violation of these assumptions does not necessary disqualify any subsequent analysis, it seems at least appropriate to acknowledge the implications. Perhaps foremost of these assumptions is that pertaining to sample size. While there are a number of guidelines in this area, this study will adhere to the commonly cited recommendations of Green (1991), who suggests ($N \geq 50 + 8m$) for multiple correlation analysis, and ($N \geq 104 + m$) for indicator analysis, where m is equal to the number of independent variables in the model. (Green 1991) Hair et Al. (2006) offers another sample size guideline for Multiple Regression Analysis, holding that a ratio of 5:1 should be observed between cases and independent variables. Tabachnick and Fidell (2001) note that the required cases to independent variable ratio is subject to some fluctuation, depending on the effect size. If a ratio of questionable magnitude is present, both Tabachnick and Fidell (2001) and Hair et Al. (2006) recommend power analysis.

Another assumption of primary concern to this study is that the data are normally distributed (Tabachnick and Fidell 2001). Most sources contend that only the residuals of the model, or deviations from predicted values, must approximate normality (Hair et al. 2006, Kleinbaum et al. 2013, Tabachnick and Fidell 2001). In recent years, work has been done to explore the implications of a violation of residual normality (Lumley et al. 2002, Maas and Hox 2004). Lumley et Al. (2002) demonstrated, with sample simulation of extremely non-normal data sets, that estimates of model fit are robust for data with heteroscedastic residuals. These authors note, however, that with sample sizes less than 130, there may be a reduction in power for the estimation of regression coefficients (Lumley et al. 2002). Maas and Hox (2004) confirmed that model fit is relatively insensitive to non-normality, but identified a potential bias in standard error outputs for very small sample sizes.

Methods for Distributing Variance

Once it has been established that Linear Regression can be carried out with confidence, a means of configuring the model must be established. In uncomplicated terms, it must be decided which predictor variables have the most in common with the dependent variable. To do this, a decision is made as to what should be done in instances where two or more predictor variables overlap in how much of the dependent variable they explain (Tabachnick and Fidell 2001). Several types of these regression procedures exist, each of which may be most appropriate in a particular scenario.

Standard Multiple Regression builds a linear prediction model based solely on the amount of unique, and significant, explanatory power each predictor variable can provide. In Sequential Regression, often referred to as Hierarchal Regression, the researcher makes decisions about the order in which predictor variables should enter the regression equation. Stepwise Regression, a somewhat controversial technique, makes these entry order decisions based on the correlations between independent variables and dependent variables (Hair et al. 2006, Meyers et al. 2006, Tabachnick and Fidell 2001). The controversial aspect of this technique is the possibility that two predictor variables, with nearly identical correlation to the dependent variable, could be assigned drastically different importance in the final solution. On the other hand, in instances where it is necessary to sift through the effects of many predictor variables, the ability of stepwise regression to suggest a model makes it an attractive option(Kleinbaum et al. 2013). Controversial nuances aside, it is widely accepted that Linear Regression is a useful and powerful tool for creating explanatory models.

Partial Least Squares Regression

As an alternative Multiple Linear Regression, Partial Least Squares Regression (PLS) can provide many of the same insights with a less demanding set of assumptions. This technique has proven especially valuable in the sensory science segment of wine research, where often the number of measured variables is greater than the number of cases (Frøst and Noble 2002, Lattey et al. 2010, Robinson et al. 2011). Beyond the relaxed constraint for case number, PLS is also appropriate for data in which there is collinearity between predictor variables. In recent decades, PLS has further cemented its appeal in the sensory and social sciences due to its ability to handle large and complex models, often with seemingly opaque relationships (Tobias 1995). On that note, its particular appeal to this project lies in its ability to readily incorporate more than one dependent variable into its modelling procedure.

2.1.3 Group Identification and Differentiation

Cluster Analysis

A central goal of this research is to identify and profile pruning style groups. There are a number of tools available to achieve such a goal, with each offering a unique set of advantages and perspectives. One such available tool is Cluster Analysis. Cluster Analysis has been used extensively in the wine industry for various applications including the grouping of wines based on sensory and compositional attributes (Robinson et al. 2011), profiling winemaker and consumer peer groups (Lattey et al. 2010), and examining the progress of anthocyanin development in Cabernet Sauvignon and Tempranillo (Ryan and Revilla 2003). A Cluster Analysis solution, defined in quantitative terms, involves the formation of case groupings based on one or more variables, such that in-group variance is minimised, and between-group variance is maximised (Ketchen and Shook 1996). In simple terms, cluster analysis results in a number of groups that contain like cases. One particularly valuable attribute of Cluster Analysis is that it can establish natural groupings within a sampled population, rather than groupings based on a background variable of hypothesised importance (Hair et al. 2006).

Once it is decided to perform Cluster Analysis, one of the key decisions is which, and for what reasons, observed variables are selected for the grouping of cases. In some cases, an existing framework might exist that will act as a starting point for cluster determination. This, of course, has the potential to introduce researcher bias into the analysis. Another critical issue is the matter of standardisation and scale of variable units. The matrix algebra responsible for the cluster analysis solution treats all variables as if they were given in the same units. In reality, this is not often the case. However, standardisation of units may exclude relevant information from the analysis

(Aldenderfer and Blashfield 1984, Ketchen and Shook 1996). Ketchen and Shook (1996) recommend cluster analysis with and without standardisation be carried out to illuminate any discrepancies in the results.

Upon establishing which variables should inform the cluster analysis, next one must to decide upon an algorithm for assigning cases to their new groupings. Hierarchal algorithms for cluster analysis form groups by either adding “elements”, often cases, to a cluster one at a time starting from zero, or subtracting them one at a time from one big cluster (Ketchen and Shook 1996). Within this broad definition of Hierarchal Clustering, different techniques exist for calculating the similarity within clusters, and for choosing which clusters to combine at each step of the procedure. Ward’s Method for clustering, which holds the minimisation of the sum of squares error as its guiding principle, is commonly found throughout the wine science literature (Lattey et al. 2010, Robinson et al. 2011, Ryan and Revilla 2003).

An alternative to Hierarchal Clustering is an iterative method, known as K-Means clustering. In contrast to Hierarchal methods, which outline each possible number of cluster configurations, the K-Means method allows for a pre-specified number of clusters. A series of centroids, or cluster centre-points, are established based on the required cluster number, and the natural grouping within the data. After these centroids are initially determined, each case will be categorised into the cluster with the closest centroid. The centroid is then recalculated, and the process repeats until no cases change to a different cluster, thus indicating a solution (Aldenderfer and Blashfield 1984, Ketchen and Shook 1996). It might be noted here that there are indeed a number of ways to verify the results of cluster analysis, including targeted Analysis of Variance, Factor Analysis, and Partial Least Squares Regression. This can be observed in the sensory science literature (Lattey et al. 2010, Robinson et al. 2011), where a cluster analysis solution has the unique property of being valuable in its own right, while also having the potential to serve as a categorical input in other statistical analysis.

Correspondence Analysis

While the ability of cluster analysis to create groups without an existing framework is valuable, there are many instances when it may be desirable to link groups to particular levels of a categorical variable. In these situations, Correspondence Analysis is likely a more suitable choice. Correspondence Analysis can be regarded as similar to Principle Components Analysis, but for categorical data (Clausen 1998, Greenacre 2010). Indeed, the matrix algebra for both of these dimension reduction techniques are based on very similar mathematical principles (Greenacre 1984). While relatively uncommon in wine literature due to the predominance of ratio-level data, Correspondence Analysis has been used with success to characterise the wine of particular regions, based on associated descriptive characteristics of the respective wines (Schlich and Moio 1994, Tomasino et al. 2015).

The process typically begins when prospective categorical variables are vetted with Chi Square Analysis to look for interactions between the variables in question (Greenacre 2010). Critically, it is possible to profile the relationship between more than two variables, in what is known as Multiple Correspondence Analysis. While the results of these two procedures are arrived to similarly, there are some subtle differences. In particular, the matrix algebra in simple, one-way correspondence analysis is performed on the contingency table containing frequency distributions. When more than two variables are involved, a binary matrix is created to indicate either yes or no to every category of each variable in the analysis. This matrix, appropriately known as the indicator matrix, is then the subject of the singular value decomposition(Greenacre 1984, Greenacre 2010). Computational nuances aside, both simple and multiple correspondence analysis are useful tools for the characterisation of groups, based on categorical variable membership.

2.1.4 Outcome prediction with Logistic Regression

Given the impetus for this research, considerable amounts of energy were expended considering what types of information would be helpful to the development of an artificially intelligent pruning robot. When the notion was entertained that there might be background-based differences in pruning preference, it followed that it might be possible to predict these preferences based on said background variables. Logistic Regression is one tool for achieving such an outcome (Hair et al. 2006, Tabachnick and Fidell 2001). The technique has been used elsewhere in viticulture and oenology to predict, among other things, consumer attitudes towards screwcap enclosures (Marin and Durham 2007) and threshold identification for Multi-Coloured Asian Lady Beetle-related taint (Galvan et al. 2007). In most fields of study, logistic regression was relatively unknown until recent decades. It is gaining wider popularity due to its range of applications and relative freedom from parametric restrictions (Tabachnick and Fidell 2001).

Interpreting a Logistic Regression Model

While the potential for application of Logistic Regression is relatively clear, there is also a well-documented potential for poor interpretation, or misinterpretation at worst (Hair et al. 2006, Tabachnick and Fidell 2001). With that in mind, and the relative absence of this technique in the literature, it is worth emphasising a few keys to the interpretation of the model. The first, and perhaps most critical point when evaluating the fit of a Logistic Regression model is to assess whether incorporating the supposed predictor variables improves the ability to make a correct outcome prediction. This is accomplished by essentially comparing the frequency distribution of the outcome, first with no predictors in the model, and then with all the predictors in the model.

Test statistics are available to assess whether the predictive power is significantly increased (Tabachnick and Fidell 2001). Goodness-of-fit is relatively difficult to assess in logistic regression models, but with large sample sizes, Hosmer and Lemeshow's test is a recommended addendum. Several descriptive measures of goodness-of-fit are available, which attempt to approximate the r^2 value of linear regression, are available. These measures, particularly Cox and Snell R^2 and Nagelkerke R^2 are commonly reported, but some authorities on the subject urge that they should be of supplementary use only (Peng et al. 2002). That the Cox and Snell R^2 is not on a scale from zero to one is a source of particular confusion (Hair et al. 2006).

Another bi-product of logistic regression analysis is the ability to forecast the odds of an outcome occurring, within the constraints of a given model. This figure, known as the odds ratio, is given as Exp(B) in SPSS. A value above one indicates that, with a one unit increase in the predictor variable, there is an odds increase for the outcome in question. For example, and conversely, an Exp (B) value of 0.5 would indicate that the outcome odds have been decreased by half, when the given predictor variable increases by one unit. While this ratio is commonly reported in the literature, several authors emphasise that changes in odds are meaningful only in the context of the other constraints of the model, and cannot necessarily be generalised to a different context (Hair et al. 2006, Tabachnick and Fidell 2001).

2.1.5 Scale Construction

Much of the direction for the current experiment has been sourced from literature regarding the construction of scales to measure multi-dimensional concepts, similar to pruning quality. The steps for multidimensional scale construction outlined by Spector (1992), and mirrored in the creation of scales to measure service quality (Parasuraman et al. 1988) and wine quality (Verdú Jover et al. 2004), have informed the current work. These steps, in brief summary, are: defining the construct, designing the scale, conducting item analysis, and validating the scale, and testing for reliability (Spector 1992). Pruning quality, as a construct, has been informally defined through consultation with industry experts as striking an appropriate balance between the selection of fruitful wood and the protection of vine's future structure. According to Babbie, a construct can then be broken down into dimensions and then indicators, which can help capture more fully the concept in question (Babbie 2013). Indicators, in turn, are measured by items on a scale. With respect to the present study, the generation of indicators for the pruning survey occurred during a 2014 pilot study. During this process, the item generation processes outlined by Parasuraman et al. (1988), Verdú Jover et al. (2004), and Spector (1992) were the primary sources of consultation.

Item Analysis

In the case of multi-dimensional scales, groups of related questions ideally function as uni-dimensional subscales (Spector 1992). With that being the case, it is necessary to ensure that items in a subscale are each contributing to the measurement of their respective dimension. One tool in this type of analysis is Cronbach's Alpha (Spector 1992). It follows that this is a measure of inter-correlation between groups of variables. Interestingly, Cronbach's alpha has also been used to measure concordance between panellists themselves (Bland and Altman 1997, Tavakol and Dennick 2011). In both the creation of SERVQUAL and the red wine quality scale, an item that reduces the Cronbach's alpha for a subscale was seen as fit for deletion (Parasuraman et al. 1988, Verdú Jover et al. 2004). However, Spector (1992) points out that there may be external reasons for the inclusion of a scale item, such as simply representing a variable of interest. It must also be noted here that the above analyses are predicated on establishing dimensionality within the set of survey items (Spector 1992).

Scale Validation through Factor Analysis

Factor Analysis and Principal Components Analysis (PCA) are the primary tools for establishing dimensionality in a scale. In non-statistical terms, dimensionality refers to content sub-groupings that underpin a particular set of indicators (Babbie 2013). In the creation of Servqual, Exploratory Factor Analysis (EFA) was undertaken several times as item analysis and iterative deletion progressed, in order to re-establish groupings among scale items (Parasuraman et al. 1988). The ability of Principal Components Analysis to achieve similar outcomes has been established elsewhere in the literature (Dunteman 1989) . The findings of factor analysis in the Servqual example prompted the regrouping of some indicators, as well as a reduction in the total number of dimensions. This regrouping lead to a streamlined, but still effective version of the scale (Parasuraman et al. 1988).

There is some discrepancy in the literature as to whether item analysis through Cronbach's alpha should come before EFA (Parasuraman et al. 1988), or the other way around (Verdú Jover et al. 2004). In the work of Verdú Jover et al. (2004), the authors point out that when the generation of scale items is the result of exploratory work, an initial EFA is advisable to establish dimensionality. Once this occurs, the iterative deletion process of item analysis may continue. In the case of the red wine quality scale, a separate process known as Confirmatory Factor Analysis (CFA) was later applied to verify the findings of the EFA (Verdú Jover et al. 2004). For this particular research, the 2014 pilot study (unpublished data) has suggested a six dimension structure, corresponding roughly to position, composition, and number for both the cane and spur quality subscales.

2.2 Exploring the Physiological Setting of Cane Pruning

2.2.1 Introduction

While the present research proposes to address cane pruning with behavioural science tools, pruning inevitably finds itself at the centre of vine physiology as well. At the heart of grapevine pruning is the pursuit of vine balance, which can be described as an equilibrium between vegetative growth, crop load, and optimal fruit quality (Gladstones 1992, Howell 2001). In this three-part equation, a number of factors exert some measure of influence. An undulating flow of natural forces and human decisions ultimately determines the initial state of a particular vine at pruning. What follows is a description of some of these forces as they relate to pruning, a topic that could fill many volumes.

2.2.2 Vine Capacity and Vigour

Winkler et Al (1974) define vine capacity as the "total growth and total crop of which the vine or a part of it is capable [of producing]". Vine vigour, on the other hand, has seen conflicting definitions, many of which overlap with vine capacity to some extent. In its most common usage, vine vigour refers, rather circularly, to the average vigour of the shoots on a particular vine (Dry and Loveys 1998). As documented by a number of authoritative works (Howell 2001, Kliewer and Dokoozlian 2005, Winkler 1962), vine capacity, vigour, and balance are inextricably linked to vine pruning decisions. They are, however, not entirely endogenous to the internal workings of the plant system, but rather are influenced by many factors of both human and environmental origin. These factors, it follows, have the potential to affect the pruning decision-making paradigm.

2.2.3 Climate and Site Selection

Regional macroclimate is undoubtedly one of the main determinants of vine capacity. Within the domain of macroclimate, the primary contributors to vine capacity are growing season length, heat accumulation, and sunlight intensity (Howell 2001). Increasing amounts of heat accumulation, within the range of 5 to 30 degrees Celsius, are connected to increases in photosynthesis and cellular respiration (Winkler 1962). Sunlight, on the other hand, provides the substrate for the conversion of carbon dioxide gas to plant sugars. It has the additional role in photosynthesis of signalling for the opening and closing of stomata, and thus regulating the intake of carbon dioxide (Smart and Robinson 1991, Winkler 1962). Light intensities in various grape growing regions are known to differ quite dramatically, which impacts the productive capacity of vines within these regions (Howell 2001). Smart (1985) notes that, while sunlight radiation intensity is tied to increases in photosynthesis, there is a sunlight saturation point, beyond which photosynthesis ceases.

Rainfall and, by association, irrigation are also primary drivers of vine vigour and capacity. The inhibiting effect of water stress is complex in grapevine, but can mostly be attributed to loss of turgor pressure, with its associated impact on nutrient flow, cell elongation, and rate of photosynthesis (Hardie and Considine 1976, Thomas et al. 2006). Guard cells of the stomata play a key role in the response of the vine to water stress. Upon desiccation of the interior cells of the stomata, including the guard cells, there is a corresponding loss of turgidity. A loss of turgidity in the guard cells effectively closes the stomata to the exchange of gases, which include water vapour. As noted above, the closing of the stomata results in a cessation of carbon dioxide intake which has a slowing effect on photosynthesis (Creasy and Creasy 2009).

As such, growth will be stunted, and pruning choices limited, in drought-prone regions that fail to compensate with irrigation. Conversely, in an area of high rainfall and deep, well-structured soil, a vine is likely to produce vigorous growth (Smart and Robinson 1991). If the vine has a relatively low crop load in these conditions, it is likely to push shoots from the centre area of the head (Winkler 1962). While this has the potential to create more options for cane pruning, it may also create shading which will lower the fruitfulness of buds and create conditions which are conducive to fungal diseases (Smart 1985). It is plausible that such divergent conditions could form the basis of regional differences in pruning strategy.

At a site-specific level, both the elevation and aspect of vineyard plantings affect the rate of vine photosynthesis (Gladstones 2011, Winkler 1962). These effects are due to air movement dynamics, differences in sunlight angles, and changes in atmosphere composition with increasing altitude (Gladstones 1992, Gladstones 2011). Furthermore, exposure to wind alters rate of water loss through the stomata, as well as the temperature of both leaves and berries, and therefore the rate of photosynthesis (Creasy and Creasy 2009). Also at the site level, soil field capacity (ability to hold water) is both highly variable and fundamentally significant to grapevine water relations and therefore productive capacity (Gladstones 2011, Winkler 1962). Likewise, soil composition is a major determinant of vine access to mineral nutrition, which is critical to a number of cell functions relevant to shoot and fruit development (Creasy and Creasy 2009, Smart and Robinson 1991).

2.2.4 Cultural Practices and Vine Vigour

A number of cultural practices, some ongoing and some solidified at the time of planting, also have an impact on the average shoot vigour for a particular vine. Planting density, a logical place to start this discussion, is known to be inversely related to shoot vigour in situations of low soil fertility (Dry and Loveys 1998). A similar, perhaps more robust, effect can be observed with choice of vine training system, as some systems allow for higher shoot numbers per vine, which results in less vigorous shoots (Smart 1992). Likewise, Howell (2001) offers an insightful overview of the carbohydrate dynamics characteristic of various training systems. In general, systems that encourage relatively high amounts of perennial wood have demonstrated increases in measures related to vine capacity

(Howell et al. 1987). The varying ability of training systems to efficiently capture sunlight has also been linked to fluctuations in vine capacity (Smart 1985), through previously outlined mechanisms.

Some of the most important practical decisions, with respect to vine capacity, play out below ground. In particular, choice of rootstock is known to exhibit a noticeable effect on vine vigour. In a New Zealand context, significant differentiation in pruning weights has been observed among six rootstocks of varying parentage (Creasy and Wells 2010). Relative to the literature surrounding other horticultural crops, there is currently a surprising lack of exploration into the vigour imparting qualities of grapevine rootstocks (Dry and Loveys 1998). What is known is that rootstock choice affects soil penetration, regulation of plant growth hormones, and mineral uptake (Nikolaou et al. 2000, Pouget 1986). On the subject of mineral uptake, it would be remiss not to mention that fertiliser applications drastically alter the supply of available nutrients, which have a key, promotive role in many cell functions (Creasy and Creasy 2009). If one can support its substantial cost, root pruning may be a suitable option for those interested in limiting vine vigour, as root volume has been linked to shoot vigour (Dry and Loveys 1998). In reality, the practical decisions described above are just a few of the myriad ways in which managerial decisions affect vine capacity and vigour, and therefore pruning conditions.

2.2.5 Frost Avoidance

In many areas of cool climate viticulture, pruning technique is leveraged as a means of protection against spring frost damage. The damage, itself, in grape tissue is caused by one of either the piercing of the cell wall through the expansion of ice crystals, or the loss of cell structure due to osmotic cell dehydration (Levitt 2012). Much of the manoeuvrability introduced during pruning stems from the observation that buds in a less advanced stage of phenological development are less vulnerable to cold damage (Howell and Wolpert 1978). In simpler terms, this amounts to the notion that holding back buds as long as possible will maintain their ability to withstand cold temperatures.

This principle is manipulated in a number of ways. Delaying pruning has been demonstrated to reduce bud development in basal buds of shoots, due to the effects of apical dominance (Friend and Trought 2007). By extension, delaying bud break by several weeks can reduce the risk of frost damage dramatically, due to the coinciding arrival of warmer spring temperatures (Howell and Wolpert 1978). This practice, as one might reason, is readily adaptable to spur pruning systems. A somewhat related practice, known as double pruning, calls for the pruner to leave twice as many canes as necessary, as a means of insurance. If frost damage occurs, some basal buds will likely survive, meaning some amount of crop is still viable. Should there be no frost damage, these canes are simply removed from the vine as soon as temperatures improve (Trought et al. 1999). While these investigations have provided some much-needed support, much of the knowledge around manipulating pruning to avoid frost exists at a practitioner level, and has not yet been formalised.

2.2.6 Mitigation of Disease Risk

Consideration of disease enters into the pruning thought process in a number of ways. The presence of powdery mildew (*Uncinula necator*), for example, reduces whole vine photosynthesis, carrying with it the numerous downstream effects of a less productive vine (Lakso et al. 1982). Beyond reduced efficiency, the most damaging effects of powdery mildew include loss of serviceable crop due to infection on the berries of the grape, and the production of dysfunctional flag shoots (Cortesi et al. 1997, Creasy and Creasy 2009, Pearson and Gadoury 1987). The disease survives in dormant wood, either primarily in its mycelium form, or in the form of cleistothecia, in areas of low winter temperature such as New York and Continental Europe (Cortesi et al. 1997, Pearson and Gadoury 1987). Bearing in mind that powdery mildew is but one disease, from one kingdom of pathogens, the short term effects of selecting diseased pruning wood should be readily apparent.

The presence of powdery mildew, however, is a relatively short-lived problem compared to some of wood diseases that regularly plague vineyards. Worth particular mention among this list of pathogens is *Eutypa lata,* the causal agent of Eutypa Dieback. Symptoms of the disease include variably stunted shoot growth and compromise of vascular tissue, which gradually leads towards mortality for the infected vine (Creasy and Creasy 2009). Fungal spores are released shortly after rainfall from perithecia structures and proceed to infect vulnerable tissue exposed by recent pruning cuts. A common means of combatting this disease is to apply paint, containing either a fungicide or Bio-Control Agent, to the pruning wound (Weber et al. 2007). Delaying of pruning, in California, has also been established as an effective means of reducing the risk of Eutypa infection (Petzoldt et al. 1981). A unique pruning philosophy has also emerged, from the Loire Valley of France, aiming to achieve improved vine sap flow and reduced potential for dieback proliferation, by way of cuts in a very particular style and position (Dal 2008). While this is yet another dimension of pruning needing further investigation, it is clear that practitioners are seeking remedies, through pruning, to a serious problem.

2.2.7 Differential Bud Fruitfulness

When a bud unfolds in the springtime, upon the arrival of warmer temperatures and increasing daylight, a shoot emerges with typically one to four flower clusters, which eventually become clusters of grapes (Winkler 1962). Over the span of an entire vineyard, the difference between one and four clusters per shoot makes an enormous difference to the total quantity of crop. As such, a considerable effort has been put forth to understand the patterns that influence how many clusters, and separately how many berries, will emerge out of every node retained during pruning. Without dwelling excessively on the effects of temperature and light intensity, any tactic that delays the time of flowering until more conducive photosynthetic conditions are present will increase the probability of robust fruit in a cool climate (Friend and Trought 2007). Beyond these effects, the vine exhibits a number of intrinsic tendencies, with respect to bud fruitfulness.

First and foremost, apical dominance is a primary driver carbohydrate distribution in Vitis v*inifera*. In most cases of cane pruned *Vitis vinifera* vines, distal node positions produce riper fruit and are higher yielding than basal positions (Naylor 2001, Vasconcelos et al. 2009). Within the shoot itself, primary bunch positions in (cv.) *Sauvignon Blanc* yield significantly riper fruit, and exhibit a higher percent of flowering than secondary bunches (Naylor 2001). It is widely known anecdotally, with some empirical support (López-Miranda et al. 2002, Rives 2000), that the fertility of basal buds varies naturally between *vitis Vinifera* cultivars. Considering the implications, more work is needed to explain this phenomenon.

While establishing intrinsic varietal differences in positional fruitfulness is a work in progress, there is ample evidence to assess the relationship between fruitfulness and the physical characteristics of a particular shoot. Several studies have identified a positive relationship between shoot internode diameter and bud fruitfulness (Bennett et al. 2005, Eltom et al. 2014, Sánchez and Dokoozlian 2005). Such differences are thought to be a reflection of the increased capacity for carbohydrate storage observed in thicker canes (Bennett et al. 2005, Howell 2001). The effect of cane length, with respect to positional fruitfulness, has also been investigated. Somewhat predictably, the effects of apical dominance supersede any inhibitory signalling effect on basal node positions, as distal positions on short canes are more fruitful than the same position on a longer cane (McLoughlin et al. 2011).

As grapevine pruning is subject to social influences, and also predates viticulture science by millennia, a number of untested beliefs are held with respect to cane pruning practice. While it would be well out of the scope of this research to identify all such tenets, several are of particular relevance. One such belief is that canes emerging from one year-old spurs are more fruitful, as pruning wood, than canes emerging from older wood. This belief is thought to emerge from the supported observation (Howell et al. 1987) that non-count shoots, including those directly from the head of the vine, are less fruitful in the year of their emergence. It is unclear, at this time, whether canes from one year old spurs are, in fact, significantly more fruitful as pruning wood than those shoots from non-count positions.

A similar such doctrine holds that bull canes, which are defined as rapidly growing shoots with long internode spacing (Christensen 2000), are unsuitable for pruning purposes in the following year. This particular point is under investigation by Lincoln University researchers, with preliminary results calling into question long held notions about the inferiority of bull cane wood for pruning applications (Dr. Valerie Saxton, personal communication, January 2016). Such discrepancies are emblematic of the vast amount of conventional pruning wisdom that has yet to receive attention in the scientific literature. In light of this condition, a secondary objective of this research is to identify points of particular dissension, for further investigation.

Chapter 3
Materials & Method

3.1 Pruning Survey Overview

Upon the completion of several preliminary investigations in 2014, a survey was prepared to collect information regarding the nature of cane pruning preferences in New Zealand. The survey consisted of two parts (Figure 3-1). First was a digital survey that asked participants to rate a set of already-made pruning decisions, both overall and on 24 individual criteria. These decisions were presented as colour photos, which were presented with Qualtrics survey software. As Part Two of the survey, participants were asked to indicate their own pruning preferences for the same vine, by marking their decisions with highlighter pens on a printed colour photo of the unpruned vine.

A key point of emphasis in this study, one that defines both its utility and limitation, is that only one vine was used throughout. Preliminary investigation in 2014 offered a number of indications, some practical and some theoretical, that justified the use of only one vine in the present study. Foremost of these reasons, was the impracticality of collecting enough survey responses to perform statistical analysis on a large number of vines. Additional comments on the issue of vine number may be found in Section 9.2.

Figure 3-1: Overview of two-part survey structure

Part One: Participants rate a set of already-made pruning decisions, via Qualtrics →	**Part Two: Participants indicate their own pruning decisions for the same vine**
Part 1a: *Background Questions*	**Part 2a:** *Instructions for decision-indication exercise*
Part 1b: *Participants make a first overall assessment of the already-made pruning decisions*	
Part 1c: *Participants rate the decisions on 24 individual pruning criteria*	**Part 2b:** *Participants indicate their own preferred pruning decisions, with highlighter pens on paper*
Part 1d: *Participants make a second overall assessment of the already-made pruning decisions*	
[a]***Most participants would then move on to Part Two of the survey***	**Where a respondent only participated in part two, a background information sheet was administered before the decision-indication exercise**

[a]**See Section 4.1 for a detailed account of how many participants completed each part of the survey**

On the subject of response number, there were three methods of data collection utilised for this study. Most responses, the extent to which is detailed in the next chapter, were collected in person, by way of vineyard visitation. A small number of responses to the ratings portion of the survey were obtained online with Qualtrics, as a result of requests placed in industry body newsletters. Another fraction of the sample, this time consisting of pruning decisions only, was gathered at the 2015 Marlborough Silver Secateurs competition.

On the subject of complex procedural decisions, it must be emphasised that, as the first study of its kind, this methodology was viewed as somewhat exploratory. The design of this survey required many decisions to be made without the foothold of direct precedent. Compounding the lack of precedent in this research area is the innate complexity of conducting behavioural experiments in an agricultural field setting. Where a difficult decision has been made, and supporting literature is unavailable, efforts have been made to provide elaboration.

By chronicling the methodology here in detail, it is hoped that others will be able to build and improve upon this foundation. To that end, one of the four stated objectives of this study relates to providing guidance for future methodological frameworks. Having addressed the many challenges encountered, an account of the methodology will thus be presented, with optimism that the value of the information collected will supersede its interpretative limitations.

3.2 Participant Invitation

Although the ambition of this research was to survey the New Zealand wine industry as a whole, for practical reasons, responses are primarily from four regions: Marlborough, Hawke's Bay, Waipara, and Central Otago. This was, in part, a recognition of the constraints of budget, time, and multivariate statistics, with particular attention to the challenge of achieving a large enough sample to validate comparisons between regions. These particular regions were chosen for a variety of practical and theoretical reasons that include contribution to the national grape hectarage, prevalence of cane pruning, ease of access, and perceived likelihood of exhibiting unique pruning tendencies. According to the 2015 New Zealand Winegrowers Annual Report, these regions represent roughly 87.5 per cent (Marlborough: 64.7 %, Hawke's Bay: 13.3 %, Canterbury (including Waipara): 4.0 %, and Central Otago: 5.4 %) of the producing vineyard area in New Zealand (New Zealand Winegrowers 2015). A more thorough investigation of the pruning tendencies found in New Zealand's other wine regions will hopefully be the subject of future work.

A small amount of ratings data was collected through general invitation in the New Zealand Winegrowers newsletter. Similar such notices ran in the Wine Marlborough newsletter and the Hawke's Bay Winegrowers newsletter. Industry bodies for the other two targeted regions were contacted without result. Wine Marlborough further assisted by permitting data collection at the 2015 Marlborough Silver Secateurs competition. At this competition, a table was set up near the activity, where interested parties were invited to offer their own preferred pruning decisions for the vine in question.

All remaining data were collected through vineyard visitation. Figure 3-2 displays the typical flow of events for visits to participating vineyards. In general, contact with participating vineyards was initiated in one of three ways. Scenario one occurred when someone at the organisation was known to the researcher or supervisors, and therefore served as a point of contact. Often this was a vineyard supervisor or manager. After such contact, visitation would typically be arranged, at which point the researcher was often allowed to speak to other members of the organisation and invite them to participate. In many of these cases, however, the initial contact was the only person surveyed. A second scenario developed, in which a contacted person would suggest a colleague or industry acquaintance who might be willing to participate.

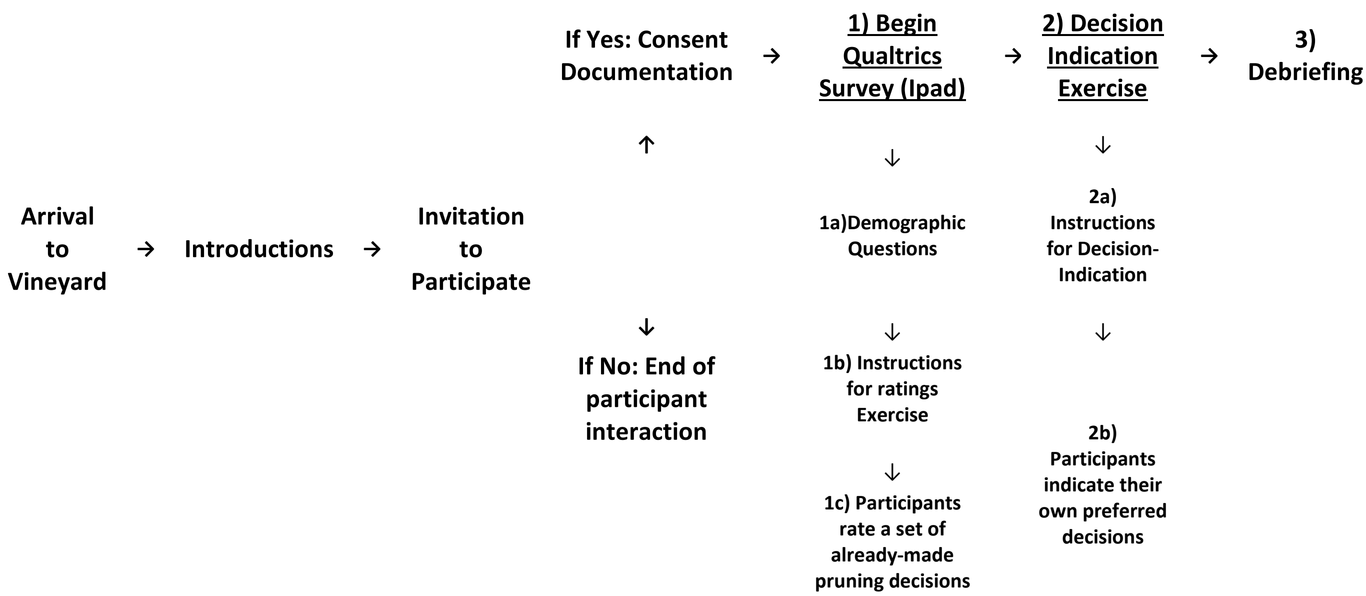


Figure 3-2: Flow of events for typical vineyard visit

A third contact scenario emerged out of some degree of necessity. Each of the four winegrowing regions has a directory of some description, found publicly on the regional industry body website. Particularly in Hawke’s Bay, Waipara, and Central Otago, these resources were utilised to directly contact winery and vineyard operations. As much as possible, attempts were made to engage in this process at random. Due to the supplicatory nature of these interactions, visitations occurred at the convenience of the contact in question. With this being the case, environmental and lighting conditions varied from visit to visit.

3.3 Vine Selection, Pruning, and Photography

As part of the preliminary study conducted in 2014, before-and-after pruning photos were collected for tens of vines to create a pool of potential vine subjects for future usage. Cuts were made and photos taken using garden secateurs, a Lumix DMC-FZ18 camera, and a white plastic board backdrop, respectively. The vine chosen for this study was pruned and photographed during early August 2014 (late-winter), in the early evening sun. These particular conditions, particularly the low angle of the sun, provided a high resolution view of the wood in question, at the cost of a shadowing effect on the backdrop.

The vine itself was chosen based upon several criteria. A primary attribute of the vine was that it presented a number of seemingly viable pruning options, which may be examined in Figure 3-3a. This was a key point of emphasis during the selection process, as it was thought that little information could be gained from a vine with only one plausible option. Likewise, the vine was not, by all accounts, in such dire condition that the coming year's decisions were irrelevant or impossible to reconcile satisfactorily. While these considerations were purely subjective, they represent something akin to a hypothesis, that the vine's attributes would reflect meaningful information about New Zealand pruning tendencies. Section 9.3 will explore implications of this particular selection, and offer direction for future vine selection.

Pruning of this vine was carried out during the 2014 pilot study (unpublished data), by the researcher, in accordance with principles gleaned from several sessions of preliminary, immersive field work at three Waipara vineyards. Principles for spur selection were that, wherever possible, renewal spurs should be located roughly three quarters of secateurs-length below the wire, to the inside of fruiting canes, and in a position that will not create undue crowding with cane selections. For the particular vine in question, a decision was made to forgo a lower spur, in favour of one that would potentially induce less shoot crowding. Canes, on the other hand, were to ideally come out of a previous year's spur, to be located to the outside of spurs, and sit low enough to enable tying down. Section 9.3 explores some of the implications of the selected pruning decisions, and explores potential considerations in future research.

It must also be noted that, in supplementary printed photos and those used for the indication of preferred pruning decisions (Part Two), Photoshop software was utilised to eliminate some tendrils and rachii (Figure 3-3a and Figure 3-3c) that, upon photo enlargement, were obscuring features of the vine. These adjustments were not deemed necessary for those photos presented within the Qualtrics system, due to the level of enlargement and the placement of multiple, side-by-side views. Participants were informed verbally that some tendrils and rachii had been removed in the printed photos.

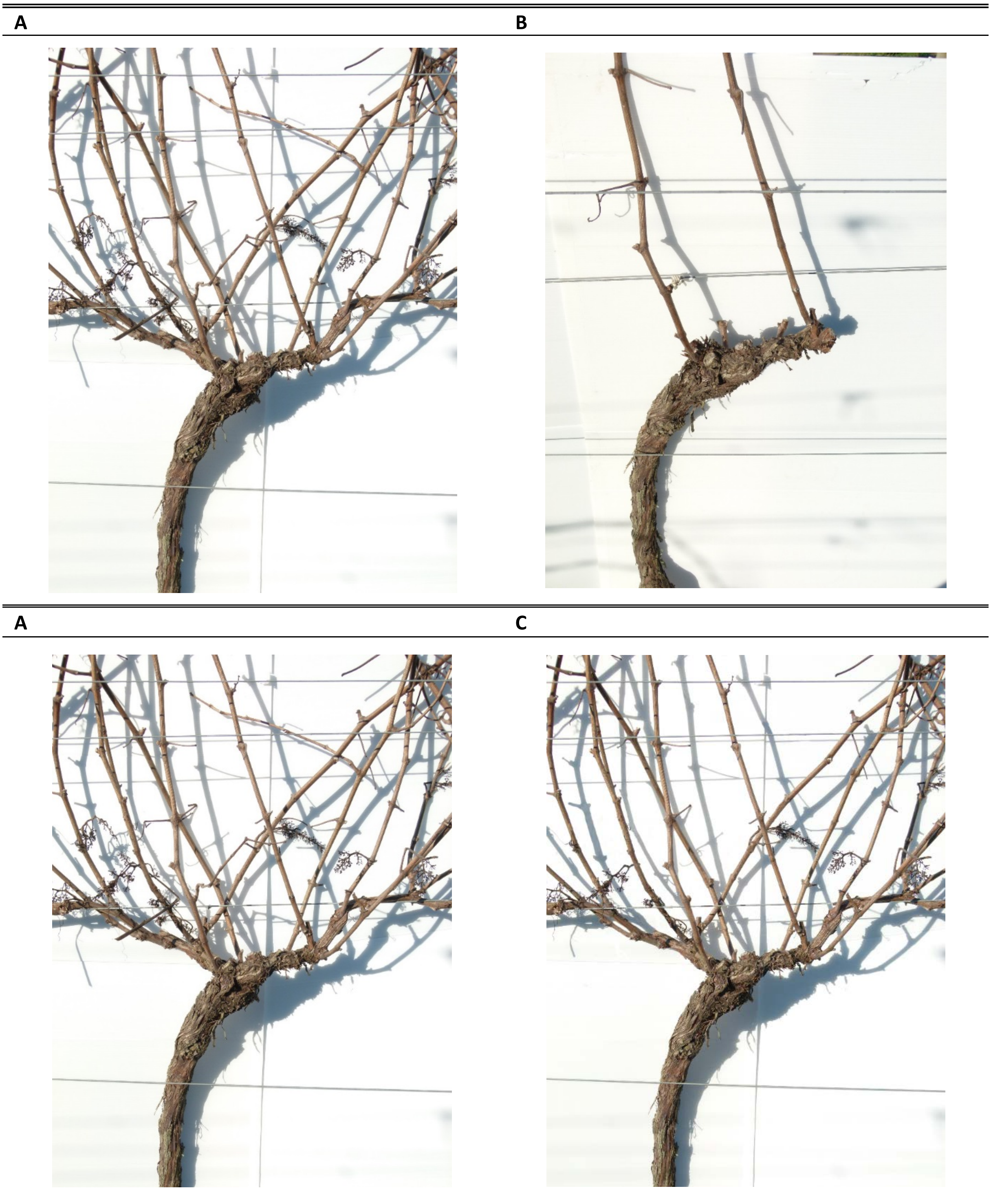


Figure 3-3: Vine photos before and after pruning and photoshop alteration

Image A: Vine before pruning and photoshop alteration; Image B: Vine after pruning; Image C: Unpruned vine after Photoshop alteration

3.4 Participant Identification System

A simple system of numeric identification provided several benefits to this study. Primarily it served as a linkage between Qualtrics responses and paper-based decision data. As the first prompt of the Qualtrics interface, prior to giving the device to the participant, the researcher would enter the ID number assigned to that particular participant. Directly after, this number was recorded on a decision indication form, which was also provided to the participant at this time. For data collected at the Silver Secateurs competition, an ID number was written on the paper decision form and, separately, to all attached forms. The second function of the ID number was to provide a simple and anonymous method for participant withdrawal at some later date, although this right was not exercised by any participant.

3.5 Demographic and Background Questions

After recording consent to participate in the study, participants provided several answers regarding their background, both personal and professional. Participants in both the qualtrics and silver secateurs portion of the sample pool were asked for this information. These survey items may be viewed in Table 3-1. Background questions were presented in a multiple choice format. All questions allowed the participant to proceed without answering. No items allowed more than one response, with the exception to the item relating to role in the vineyard. The items relating to tertiary viticulture education and region had an additional option of “unsure” and “other”, respectively. In several instances, a participant opted to engage in only the decision making part of the survey during an in-person visit. These participants were given a paper-based version of the background questions, as was also provided to those at the Silver Secateurs competition.

Table 3-1: Background variables and choices

These questions appeared as frames in the Qualtrics portion of the survey. [a]For this question, participants were allowed to select more than one response. Participants were permitted to skip questions.

Please select the category of how many years pruning experience you have. · 1-2 Years · 3-5 Years · 5-10 Years · 10-20 Years · More than 20 years
Please select the category (-ies) that best describe your role in the vineyard[a]. · Labourer · Supervisor · Manager · Proprietor
Please select the category that best describes the size of the vineyard you most often work with. · 0-25 Hectares · 25-75 Hectares · 75-100 Hectares · More than 100 hectares
Have you done a year or more of tertiary level study (University, technical institute, poly-technical institute) in viticulture, horticulture, or a related discipline? · Yes · No · Unsure
Which viticulture region do you primarily work in? · Marlborough· Hawke’s Bay · Waipara · Central Otago · Other

3.6 Use of Supplementary Photos

As suggested in the section on photography, supplementary photos were made available to participants completing either or both parts of the study in person. These were photos enlarged to fill A4 sized sheets of paper. Photos included a close-up angle and one that was zoomed out to capture roughly the entire vine. The relatively small number of participants who completed the study online did not have the benefit of these supplementary photos. In Section 9.6, the possible influence of this distinction will be explored.

3.7 Survey Part One: Assessment of Already-Made Pruning Decisions

3.7.1 Visual format of ratings prompts

An example of the visual format for Qualtrics ratings can be viewed in Figure 3-4. Notably, this format has adopted a Visual Analogue Scale for the purpose of recording ratings on a continuous scale. In addition to its frequent appearance in other disciplines, the VAS has successfully been used in sensory-based trials seeking to characterise regional wines (Parr et al. 2007, Parr et al. 2010, Tomasino et al. 2015). Starting from a fixed middle position, participants would slide the touch dial in the direction that corresponds to their opinion of the pruning decisions. On this scale (Figure 3-4), all the way left corresponded to a rating of "extremely bad decision", and all the way to the right indicated a rating of "extremely good decision"

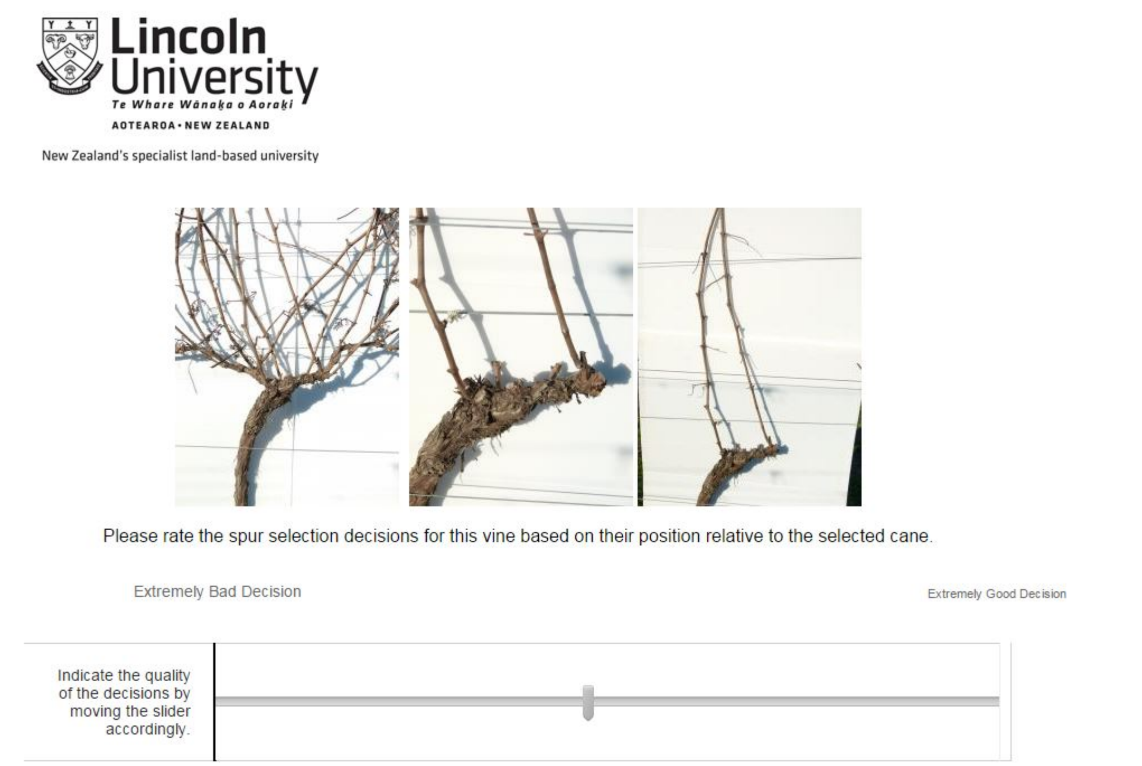


Figure 3-4: Qualtrics visual format[a]

[a]The image presented is a condensed screen capture of the first overall rating, found in the Qualtrics portion of the survey

Either two or three photos, depending on the substance of the question, were positioned above the text and the VAS. The researcher's subjective judgement was exercised as to what combination of photos, and size thereof, provided the best ability to make an assessment on a particular criteria.

Aspects of this decision process, particularly those which pertain to limitations and idiosyncrasies of Qualtrics software, will be discussed in Section 9.5 and, to a lesser extent, Section 9.7. The VAS was anchored by two text boxes, on either extreme of the dial. To the far left, the text read “Extremely Bad Decision”, while to the far right was “Extremely Good Decision”. While the choice of anchor phrasing is somewhat discretionary, the selected wordings are thought to be consistent with available guidelines and perspective on the topic (McCormack et al. 1988).

3.7.2 Instructions and Assumptions

The Qualtrics format allowed for instruction frames to be included in the survey presentation. These pages came directly after the sequence of demographic questions, but before participants were presented with the vine. Three frames of instructions were included in the survey, the wording of which can be viewed below in Table 3-2. The first of these frames was a reminder as to what is generally understood by Two-Cane, Double Guyot pruning. Frame two addresses the issue, as alluded to above, that vines can be found at radically different levels of difficulty over the span of a vineyard. Participants were asked to place a particular emphasis on rating decisions based on what options were available, rather than indicating their level of the satisfaction with the outcome, in general.

Frame three asked participants to assume that the vine in question was (cv.) *Sauvignon Blanc*. The preliminary investigation, conducted in 2014, suggested that some practitioners might prune a vine in several ways, depending on the variety. To control for this ambiguity, the variety that represents 68 per cent of New Zealand’s grape production was chosen (New Zealand Winegrowers 2015). Although it was strongly considered, alternating grape variety between respondents would have potentially doubled the amount of responses needed for some analyses, and was opted against. This particular point will be addressed further at various points in Chapter 8 and Chapter 9.

It should also be noted that basic instructions were re-enforced verbally throughout the in-person data collection process. Particularly, an effort was made to ensure that participants understood how to operate the Qualtrics interface. This included an explanation of which way to slide the Visual Analogue Scale (VAS) to indicate a good or bad rating. Attempts were also made to ensure that participants understood that one had to touch the dial on the VAS to record a response. The absence of this verbal assistance is a primary reason for gauging online-based data for abnormality, relative to the rest of the sample.

Table 3-2: Qualtrics written instructions: these instructions appeared as frames in the Qualtrics portion of the survey.

Frame 1	The vines you will see in this survey are managed under a two-cane pruning system, also known as Double Guyot pruning. As a quick refresher, that means there will be one cane and one spur on either side of the head. The canes will be trained down to the fruiting wire, forming a T-shape, and the spurs will serve as renewal positions for future years.
Frame 2	When rating the pruning decisions, please focus only on how good the decision was, given what was available. Did the pruner select the best possible canes and spurs? Likewise, please assume that there is enough time to make the most ideal decision for the vine.
Frame 3	Please assume this vine is Sauvignon Blanc.

3.7.3 Generation of pruning criteria

Taking some precedent from the creation of scales for the measurement of service and red wine quality, 24 items were generated to capture the decision-making criteria for cane pruning (Parasuraman et al. 1988, Verdú Jover et al. 2004). Preliminary investigation in 2014 (unpublished data) indicated that a larger number was infeasible, due to constraints of time and participant goodwill. This set of 24 criteria was devised in 2014, and was based mostly on immersive field work done in Waipara. Videos published by Winegrowers New Zealand were also reviewed for potential criteria.

The set of twenty-four criteria utilised in the evaluation exercise (part one of survey) may be seen in Table 3-3. Twelve of these criteria relate to the selection of spurs and, likewise, twelve relate to cane selection. In addition, an overall assessment of the pruning decisions was solicited, both at the beginning and end of the ratings exercise. Scanning the list of criteria, it is soon evident that the criteria are similar for spurs and canes. A number of them relate to position of the selections, relative to other aspects of the vine. Others might be said to relate to the quality of the plant material, itself, rather than the position. It is worth noting that the twelve spur criteria were presented, in succession, followed by the twelve cane criteria. Future work might consider the arguments for and against the randomisation and duplication of survey items.

It must also be explicitly noted that some areas of pruning interest were not covered. A number of considerations that come up during pruning are procedural in nature, rather than relating to the selection of material for retention. An example of such a consideration would be how close to the trunk a cut is made when removing undesired wood. Likewise, and of much relevance, participants were asked to overlook the common practice of leaving extra canes as insurance against breakages. While such considerations are demonstrably important, they were excluded as an attempt to isolate the pruning selection process from pruning protocol-at-large. These artificial assumptions, with a particular focus on the complications introduced by insurance canes, will be further examined in Section 9.5.

Table 3-3: Pruning evaluation criteria used for part one of survey

Question Number	Survey Criteria
Spur Selection Criteria	
S1	Please rate the spur selection decisions for this vine based on their position relative to the selected cane.
S2	Please rate the spur selection decisions for this vine based on their height relative to the fruiting wire.
S3	Please rate the spur selections based on the horizontal distance of the spurs away from the head.
S4	Please rate the spur selections based on the angle from which the spur leaves the head?
S5	Please rate the spur selections based on the direction to which the buds of the spur are pointing?
S6	Please rate the spur selections based on diameter (width) of the spur.
S7	Please rate the spur selections based on the node spacing of the spur
S8	Please rate the spur selections based on the colour of the wood on the spur.
S9	Please rate the spur selections based on the integrity of the wood on the spur.
S10	Did the pruner leave the appropriate number of spurs for this vine?
S11	Please rate the spur selection decisions based on the number of nodes left on the spurs.
S12	Please rate the spur selection decisions based on the length of the spurs.
Cane Selection Criteria	
C1	Please rate the cane selections based on the height relative to the fruiting wire.
C2	Please rate the cane selections based on the position relative to the spur for that side.
C3	Please rate the cane selections based on the horizontal distance from the centre of the head.
C4	Please rate the cane selections based on the angle of the cane relative to fruiting wire.
C5	Please rate the cane selections based on the amount of permanent wood between the head and the start of the fruiting cane.
C6	Please rate the cane selections based on the diameter (thickness) of the canes.
C7	Please rate the cane selections (as best you can) based on the colour of the wood.
C8	Please rate the cane selections based on the structural integrity of the wood?
C9	Please rate the cane selections based on the node spacing on the cane.
C10	Were the appropriate number of canes left for this vine?
C11	Please rate the cane selections in terms of the number of nodes on each cane.
C12	Please rate the cane selections in terms of how well they reflect last year's vigour.

3.8 Survey Part Two: Indication of Preferred Decisions

Upon completion of the qualtrics portion of the survey, participants were asked to turn their attention to part two of the survey, in which they would indicate their own preferred decisions for the vine. Participants were provided with an enlarged, printed colour photo of the vine, with brief written instructions and their participant ID in the top left corner of the A4 sheet. Written instructions were:

> *"Please highlight your cane selections in yellow and your spur selections in blue. Please highlight the entire shoot to avoid confusion. "*

Participants were further instructed that they could leave any combination of canes and spurs they wished, and were not restricted to the number or configuration of canes and spurs exhibited in the Qualtrics decisions. They were also asked to assume that it was not necessary to leave extra canes as insurance. As alluded to above, this supposition was often counter-intuitive, and its implications will be addressed in Section 9.5. Throughout the Qualtrics evaluation and decision-making portions of the survey, participants were allowed to make use of the supplementary photos.

3.9 Summary of typical vineyard visit protocol

Due to the tedious nature of the above description of methodology, an abridged summary of the typical vineyard visit will be provided to illustrate how the components generally fit together. Visitation to a vineyard was usually arranged either late in the previous week or at the beginning of the week in question. In most cases, visits were arranged around morning, lunch, and mid-afternoon breaks to better accommodate the vineyard schedule. The researcher would arrive to the vineyard, meet with the contact person or persons, and establish a location for the survey to be conducted.

As participants entered the location, which was often near a break room, the researcher would speak to them about the survey and gauge their interest in participation. If interested, they would be provided with an information sheet with full details of what constituted participation. After understanding what their involvement would mean, participants would decide if they would like to take part.

Those participants wishing to take part were provided with a consent form, an Ipad to use, and supplementary photos of the vine. Completion of the Qualtrics portion of the study generally took anywhere between 5 to 25 minutes. After Qualtrics responses were recorded, participants were provided with a numbered decision form, as well as a blue and yellow highlighter pen. They were asked to indicate their own preferred selections, with spurs in blue and canes in yellow. Instructions were given to assume that it was not necessary to leave extra canes as insurance. After indicating their preferred decisions, participants were debriefed and thanked for their attentiveness. Contact information was recorded for those wishing to hear about results of the study.

3.10 Data Entry and Statistics

A system of codifying decisions was created to facilitate quantitative analysis. This system is illustrated in Figure 3-5. The vine was conceptually divided into two halves, corresponding to that wood which emerges from the left and right side of the head, relative to the centre of the vine. On each side, from the centremost shoot to that furthest away from the centre, shoots were numbered starting with one. Their position was assessed at a point just above the fruiting wire, as indicated in the figure.

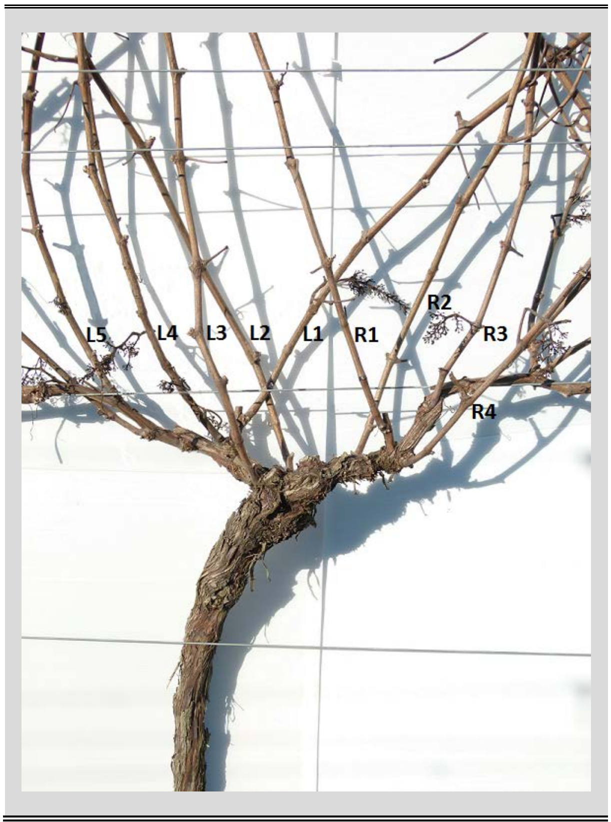


Figure 3-5: Coding system for pruning decisions

Note: Corresponding label appears to the right of the shoot.

Qualtrics-based data were downloaded into Excel and formatted for conversion to SPSS. Each set of participant decisions had an associated Participant ID number, which allowed for the aggregation of both ratings and decision data. All analyses were carried out in SPSS version 22 except Multiple Correspondence Analysis (MCA) and Parital Least Squares Resgression (PLSR), due to lack of availability of the procedures. For these procedures, XLSTAT-Base was used. Table 3-4 displays the name of each statistical analysis that was conducted, along with its corresponding rationale and computer software program.

Table 3-4: Overview for statistical procedures appearing in this study

Statistical Procedure	Statistical Software	Rationale	Data Type (Survey Part)	Appears in Chapter(s):
Chi-Square Analysis	SPSS	To differentiate between groups or test for interaction between categorical variables	Categorical (Decision-Indication)	Chapters 4, 6, 8
Correspondence Analysis	SPSS	Dimension-reduction and visualisation for categorical variables	Categorical (Decision-Indication)	Chapters 4, 6, 8
Shapiro-Wilk Test for Normality	SPSS	To determine whether observed responses differed significantly from those expected in a normal distribution	Continuous (Ratings)	Chapter 4
T-Test	SPSS	To detect whether responses differed between the before-and-after overall assessments	Continuous (Ratings)	Chapter 4
Missing Values Analysis	SPSS	Identifying non-random patterns among missing responses	Continuous (Ratings)	Chapter 4
Mahalanobis Multivariate Distance	SPSS	To reveal the existence of multivariate outliers	Continuous (Ratings)	Chapter 4
Multiple Linear Regression	SPSS	To identify which decision-making criteria factored most heavily into overall perception	Continuous (Ratings)	Chapters 5, 8
Principal Component Analysis	SPSS	Identify dimensionality among spur decision-making criteria	Continuous (Ratings)	Chapters 5, 8
Partial Least Squares Regression	XLSTAT	Same as above, but allows for analysis of both overall assessments simultaneously	Continuous (Ratings)	Chapter 5
Multiple Correspondence Analysis	XLSTAT	Dimension reduction and data visualisation for two or more categorical variables	Categorical (Decisions)	Chapters 6, 8
Logistic Regression	SPSS	Predictive modelling of binary and multinomial decision variables	Categorical and Continuous (Decisions and Ratings)	Chapters 7, 8

A Note on Statistical Terminology

Many of the analyses reported in the results chapters (Chapter 4 through Chapter 7), and discussed in Chapter 8, incorporate statistical data reduction techniques. These techniques are Principal Components Analysis (PCA), Correspondence Analysis (CA), Multiple Correspondence Analysis (MCA), and Partial Least Squares Regression (PLS). While it is acknowledged that each technique has a unique set of terminology to refer to the output of its particular data reduction matrix algebra (*see* Dunteman (1989) for PCA, Greenacre (2010) for CA and MCA, and Tobias (1995) for PLS), this thesis will adopt the word "component" to mean what is also referred to in these various analyses as a "dimension" or "factor". The decision was made as an attempt to eliminate some confusion around the sometimes interchangeable nature of these terms, as well as confusion pertaining to their meaning in non-statistical speech. Efforts have also been made to avoid the term "component" in any other context than the statistical one described above. However, for lack of an adequate alternative, the term "dimensionality" will still appear in reference to the existence, or lack thereof, of a distinct component structure.

Several other analyses in the results chapters (Chapter 4 through Chapter 7) involve various regression modelling techniques (Multiple Linear Regression, Partial Least Squares Regression, and Logistic Regression). The term "predictor" plays a central role in the reporting of each of these analyses, as well as in the discussion found in Chapter 8. In the Multiple Linear Regression and Partial Least Squares Regression models described in Chapter 5, the term "predictor" will refer only to those pruning criteria (Table 3-3) that were evaluated as Part One (*see* Figure 3-1) of the survey. In the logistic regression models described in Chapter 7, the term predictor will refer to either a pruning evaluation criteria, as described above, or a background variable, such as region. Due to the technical nature of this report, many efforts have been made to clarify the meaning of terminology within the text, where possible. For additional assistance with statistical nomenclature, the works of Tabachnick and Fidell (2001) and Hair (2006) are recommended.

Chapter 4

Results: General Response Profile

4.1 Pools of Responses

Between May and October 2015, 87 vineyard visits were conducted throughout Marlborough, Hawke's Bay, Waipara, and Central Otago, yielding 174 responses to both the ratings and decision portions of the survey and 3 additional responses to the decision-indication exercise. Attendance at the Marlborough Silver Secateurs competition yielded 18 additional responses to the decision-only section of the survey. An additional 30 Qualtrics-only responses were collected in person, including 12 responses from trial vineyard visits during February 2015, and 18 responses collected by a supervisor of this research during overseas travel to France and Canada. A total of 11 responses to the Qualtrics ratings exercise were collected online, with the assistance of regional and national winegrower organisations. These six data sources form the basis of three response pools Table 4-1, which will be used throughout the following chapters. This division of responses arises out of requirements inherent to the intended multivariate analyses, which may utilise that data from the ratings portion, the decision-indication portion, or both portions of the survey. A response pool will be specified prior to each analysis for purposes of clarity.

Table 4-1: Response pool composition and function

Response Pool	Pool A	Pool B	Pool C
Responses Included (number)	Participated in both Ratings and Decisions (177)	Participated in both Ratings and decisions (177)	Participated in both ratings and decisions (177)
		Decision-only data from in person visits (3)	Ratings-only data from 2015 trial visits (12)
		Decision-only data from Silver Secateurs (18)	Ratings-only data from overseas travel (18)
			Ratings-only data from online format (11)
Total Number of Responses	**177**	**198**	**218**
Function of Pool	Some analyses required data input from both part one and two of the survey	Some analyses required data input from part two of the survey	Some analyses required data input from part one of the survey

4.2 Decision Preferences

Making use of Pool B, which corresponds to all those participants who indicated their own preferred pruning decisions, it is possible to dissect which pruning choices were generally the most popular. As intimated in the materials and methods chapter, the vine has been divided into two halves, as a starting point for analysis. While pruning convention would often think of a set of pruning decisions as being one entity for the whole vine, the amount of choice combinations in that lens diminishes the ability to perform meaningful analysis. Where suitable, whole vine analysis will be included as a supplement.

4.2.1 Spur Selection

On the left side of the vine, combinations of spur selections including shoot L3 were by far the most popular, registering nearly 76 per cent of the total selections. Combinations including shoot L2 were also popular, with combinations including L2 accounting for 40 per cent of total selections. This sum is possible due to the fact that nearly a quarter of respondents chose to keep both L2 and L3 as renewal spurs. Table 4-2 displays an account of all those selections that were selected by more than one per cent of participants. On the left side, less than one percent of participants selected L1, L5, L6, and the combination of L3 and L4.

Table 4-2: Spur selection responses by side[a]*(Pool B)

Left Side	
Option	**Percentage Selected**
No Spur from Left	4.0
L2	15.2
L3	51.0
L4	2.5
L2 and L3	24.2
L2 and L4	1.0
Cumulative	**97.9 %**
Right Side	
No Spur from Right	44.9
R2	40.4
R4	14.4
Cumulative	**99.7 %**

[a]Corresponding label appears to the right of the shoot;

*Selections with frequencies less than one percent not included

The right side of the vine produced considerably less diversity of renewal spur choices (Table 4-2). By a narrow margin, the decision to leave no spur on this side of the vine was the most popular decision, with R2 closely behind. Eight participants chose not to leave a spur from either side, and no participants chose either R1 or R3 as a renewal spur option. One participant chose to leave both R2 and R4 as spur selections, a decision which has been excluded from Table 4-2 due to lack of popularity.

A chi-square test of independence was performed and demonstrated a significant interaction between spur choices (as listed above) from either side of the vine (chi-square analysis, $p < 0.001$). In particular, participants who left both L2 and L3 as spurs were more than twice as likely to leave no right spur, compared to what would be expected in an independent chi-square distribution. Conversely, those participants who left R2 as a spur were more likely than expected to leave one of either L2 or L3 as a spur on the left side of the vine. These participants, however, were considerably less likely to leave both L2 and L3 as spur selections.

4.2.2 Cane Selection

Participants selected a relatively wide variety of fruiting canes and combinations of canes, from both sides of the vine (Table 4-3). On the left side, over half of the participants selected either L4, or a combination of L4 and another cane. Selection combinations containing either L2 or L3, or in some cases, both, were also frequently chosen. For the right side of the vine, there was a relatively close split as to whether R1 or R2 was the preferred potential cane. More than ten per cent of participants selected not to leave a cane from the right side of the vine at all. Of these 21 respondents, all but one chose to leave multiple canes on the left side of the vine, suggestive of a desire to a reconfigure the vine towards the centre. Those opting to bring a cane across from the left side most commonly opted for L1 or L2 as their right-most cane.

In all, 47 participants left multiple canes on the left side of the head, which was considerably more than the 12 instances of multiple canes on the right side. As noted in the Materials and Methods, participants were instructed not to leave extra canes as insurance. Possible complications surrounding this assumption, and suggestions to mitigate uncertainty in the future, will be briefly addressed in Section 9.5. Due to the large number of cane combinations on both sides of the vine, a statistical test for interaction between left and right cane decisions was not feasible due to minimum cell count restrictions in chi-square analysis (Hair et al. 2006, Tabachnick and Fidell 2001).

Table 4-3: Cane selection responses by side[a*] (Pool B)

Option	Percentage Selected
Left Side	
Option	**Percentage Selected**
L1	4.5
L2	20.2
L3	12.6
L4	39.4
L1 and L2	2.0
L1 and L3	1.0
L1 and L4	9.1
L2 and L3	4.5
L2 and L4	4.5
L3 and L4	1.5
Cumulative	**100 %**
Right Side	
No Cane from Right	10.6
R1	29.8
R2	35.9
R3	3.0
R4	14.6
R1 and R3	1.5
R1 and R4	2.5
R2 and R3	1.0
R3 and R4	1.0
Cumulative	**100 %**

[a]Corresponding label appears to the right of the shoot; *Participants were asked not to select extra canes as insurance

4.3 Interaction between Spur and Cane Selection

Chi-square Analysis and Correspondence Analysis were performed to observe how spur and cane selections from a given side interacted in this study. For the purposes of this particular analysis, instances of multiple cane selections were excluded due to the ambiguity described above. Those leaving no spur on the right side were more likely than expected to leave either no cane from the right side or R2 as a cane selection (chi-square analysis, $p<0.001$). Both of these scenarios represent avenues for restructuring the vine, either in the current year or in the following year, respectively. Those leaving R2 as a spur were more likely than expected to leave either R1 or R4 as cane selections (chi-square analysis, $p<0.001$). For the left side of the vine, the diversity of options precluded robust statistical analysis, due to minimum cell count requirements. However, it can be said that participants selecting both L2 and L3 as spurs exhibited a general trend towards L4 as a cane. Those that left only L3 as a spur were almost equally likely to leave either L2 or L4 as a cane selection.

Correspondence Analysis further illustrated this interdependent relationship between right-side spur and cane selections. Excluded from this analysis are the 12 cases where a participant chose multiple canes on the right side. Options relating to the restructuring of the vine loaded similarly on a very powerful first component (Figure 4-1). R2, as a cane selection, was closely linked, on both components, to the decision to leave no spur on the right side. The option to leave no cane from the right side had a similar Component 1 score as the option to leave no spur, but was separated by component two. For those choosing to leave either R1, R3, or R4 as a right side cane, the bi-plot illustrates a tendency towards R2 as a spur selection. As in the previous example, there is considerable separation within these groups of options, based on a second component of much smaller proportions.

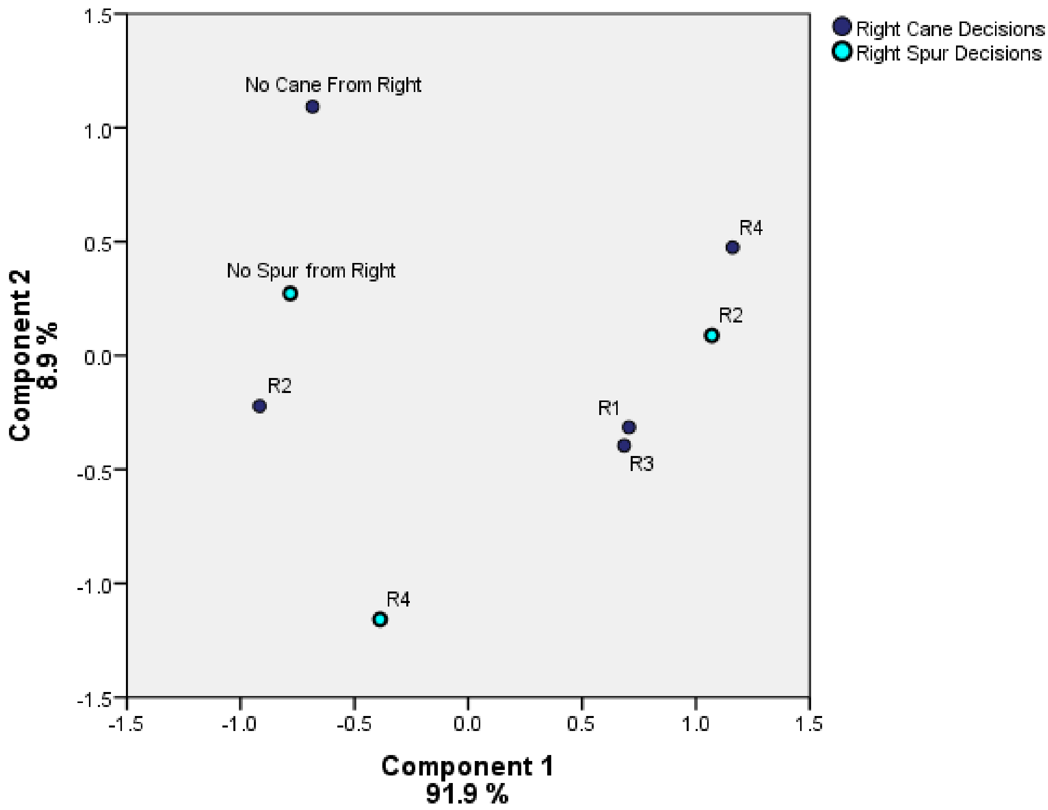


Figure 4-1: Correspondence analysis of interaction between right side spur and cane selections (Pool B)

Note: The purpose of this analysis was to demonstrate how participant spur and cane selections interacted, with respect to the right side of the vine. Proximity between points indicates similarity on Components 1 and 2. Horizontal position in the two-component visual space indicates score on Component 1. Vertical position in the two-component visual space indicates score on Component 2.

4.4 Distribution Trends in Qualtrics Ratings

Participants were asked, before indicating their own decision, to rate the pruning of a previously pruned vine (see Figure 3-1 for survey structure), on 24 individual criteria and two overall assessments. In total, participants thus were asked to provide 26 ratings of the pruning decisions.

Ratings were recorded on a 100 point scale, as mediated by a Qualtrics VAS instrument. Pool C represents all those who participated in this part of the study. Within Pool C, a high level of variance, relative to the respective mean, characterised the responses to many criteria assessments (Figure 4-2). Across the 26 criteria, a highly negative correlation was observed between the standard deviation and the mean assessment on the criteria (R=-.676, p<0.001). In other words, those criteria which had a lower level of agreement, tended to also have lower average rating.

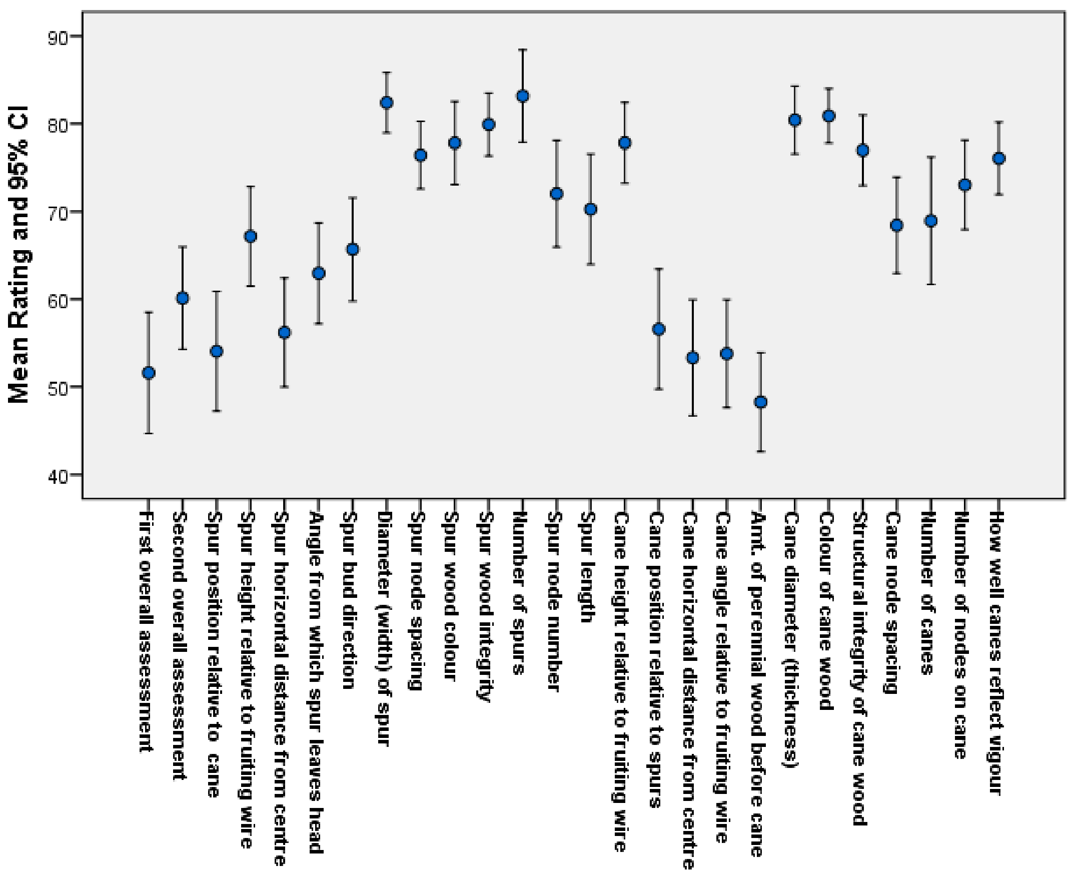


Figure 4-2: Mean rating of pruning criteria, with confidence interval (Pool C)

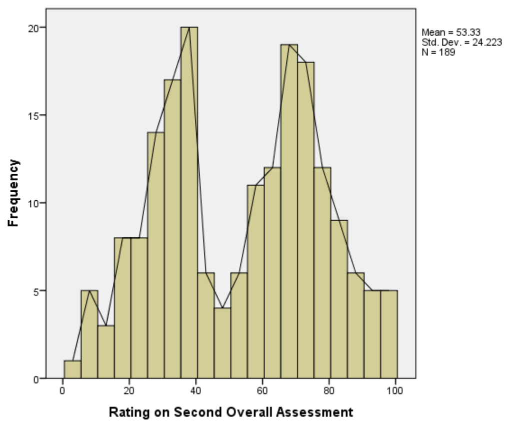
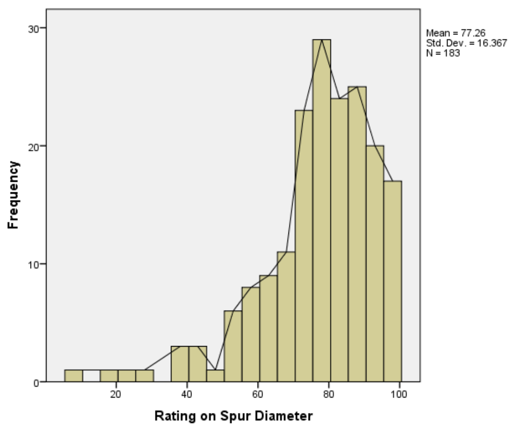
Blue circles represent the mean rating on each pruning criteria (listed at the bottom). Error bars indicate the confidence interval range for the given mean estimate (α=0.05). Participants rated (part one) the pruned vine on 24 individual criteria, and recorded two overall assesments (before-and-after).

All survey items pertaining to ratings of individual criteria or overall quality tested positively for non-normality (Shapiro-Wilk Test, p<0.05). Generally speaking, responses followed either a roughly bi-modal distribution, or negatively skewed distribution (Table 4-4Table 4-4: Distribution types among responses). Ratings on the criteria relating to the amount of perennial wood before the start of a selected cane were an exception to this trend, exhibiting a positively skewed, somewhat bi-modal distribution.

Responses to the second overall assessment were generally higher than responses to the first overall rating (t-test, $p<0.001$). In other words, participants positively adjusted their overall rating of the already-pruned vines, when asked to provide a second overall assessment. For the comparison of variables of similar, large sample size, Lumley et al. (2002) has found the t-test to be robust despite non-normality of data. Both overall assessments were found to be positively correlated ($r=0.156$, $p<0.05$; and $r=0.214$, $p<0.01$, respectively) with perception of vine difficulty, as recorded at the beginning of the rating portion of the survey. In non-statistical terms, indicating a higher level of difficulty typically meant a more favourable rating of the decisions.

The lower and upper 95 per cent confidence interval limits for the degree of difficulty variable were 2.98 and 3.21 ($p=0.05$), respectively, indicating that participants felt the presented vine was ‘somewhat ideal’ for pruning purposes. Inspection of the histogram for degree of difficulty revealed a slight negative skew, with very few participants opting to label the vine as ‘very difficult’. Degree of difficulty was strongly correlated with responses on criteria relating to position of the canes ($p<0.01$), and moderately correlated with several criteria relating to position of the spurs ($p<0.05$).

Table 4-4: Distribution types among responses to part one assessments of the already-pruned vine (Pool C)

Bi-Modal Distributions	*Negatively Skewed Distributions*
	
Overall 1 Overall 2 (pictured above) Spur position relative to cane for that side Horizontal position of spur relative to centre Bud direction on the spurs Length of the spur Cane position relative to the spur for that side Angle of the cane relative to wire Spur height relative to wire Spur node number Horizontal position of the canes relative to centre **Not listed: Amount of perennial wood before start of cane (positive skew)**	Angle of the spur leaving the head Diameter of the spur (pictured above) Node spacing of the spur Colour of the spur Colour of the cane Height of the cane relative to the fruiting wire Number of spurs left Integrity of the wood on the spurs Diameter of the cane Integrity and structure of cane wood Number of canes left Number of nodes on the cane How well cane selections reflect vigour Node spacing of the Cane

4.5 Missing Values and Outliers-Redefining Pool C

Four cases from Pool C were not accepted on the basis that they were missing values on over half the Qualtrics survey. This brought the total pool size down to 214. The criterion described as "position of the spur, relative to the cane for that side" registered the lowest number of missing values at ten. Three criteria were missing 26 responses (Table 4-5), which was the highest such number recorded. Guideline thresholds range from five to ten per cent as to what percentage of missing values becomes problematic in multivariate analyses. Authorities on the matter, however, agree that the pattern in which data are missing is more critical than the amount (Hair et al. 2006, Tabachnick and Fidell 2001).

Table 4-5: Missing values for part one assessments of the already-pruned vine (Pool C)

Spur Criteria	Count	%	Cane Selection Criteria	Count	%
Position relative to canes	12	5.6	Height relative to fruiting wire.	14	5.6
Height relative to fruiting wire	15	7.0	Position relative to chosen spurs	16	7.5
Horizontal distance from the centre of the head	10	4.7	Horizontal distance from the centre of the head.	21	9.8
Angle from which the spur leaves the head	16	7.5	Angle of the cane relative to fruiting wire.	21	9.8
Direction to which the buds of the spur are pointing	26	12.1	Permanent wood between the head and the start of the fruiting cane.	13	6.1
diameter of the spur	23	10.7	Diameter of the canes.	18	8.4
Node spacing of the spur	18	8.4	Colour of the cane wood.	22	10.3
Colour of the wood on spur	20	9.3	Structural integrity of cane	22	10.3
Structural integrity of spur	26	12.1	Node spacing on cane.	19	8.9
Number of spurs	17	7.9	Appropriate number of canes	16	7.5
Number of nodes	14	6.5	Number of nodes on canes.	14	6.5
Length of the spurs	15	7.0	How well cane selections reflect last year's vigour.	26	12.1
Overall 1	11	5.1			
Overall 2	17	7.9			

Missing Values Analysis (MVA) was conducted in SPSS, essentially to determine whether those that left a particular question unanswered exhibited trends in their responses to other criteria (Hair et al. 2006). Entering the complete set of ratings into the analysis yielded a non-significant result, meaning that no discernible pattern was present among the 26 assessment prompts. Due to the fact that some of the forthcoming analyses treat spur and cane criteria as subscales, a separate MVA was conducted for each set of criteria. The spur criteria subscale yielded a significant result for data "Missing Not at Random" MNAR (Little's MCAR test, $p<0.05$).

As this result diminishes confidence in a number of multivariate techniques, a remedy was sought. Upon trial and error with MVA, it was discovered the Spur Colour criterion was contributing most to this positive test for MNAR data. Tabachnick and Fidell (2001) and Hair et Al. (2006) suggest that the most effective remedy, with the least methodological fallout, may be the exclusion of the problematic variable. In light of the novelty of the visual presentation format, the colour impairment introduced by photo alteration, and the above recommendations, it was decided to proceed without Spur Colour as a variable in subsequent multivariate analyses. Both the patterns and the amount of missing data will be further addressed in Section 9.8.

4.6 Identification of Outlier Cases

For data sets of survey origin, Tabachnick and Fidell (2001) and Hair et Al. (2006) recommend the use of Mahalanobis Distance for the detection and removal of multivariate outliers. A particular problem in this instance was that only 70 participants, or less than a third of the total, recorded a response on all 26 rating fields. After addressing the issue of MNAR data and consulting with the relevant literature (Hair et al. 2006, Meyers et al. 2006, Tabachnick and Fidell 2001), imputation with Expectations-Maximisation (EM) was conducted to alleviate this problem. Imputation included all 25 variables, in an effort to provide maximum contextual information to the algorithm.

With the imputed data set, Mahalanobis Distances for each case were calculated and saved through the Linear Regression functionality in SPSS. This procedure also included all 25 variables. Each distance was then assessed based on its likelihood of occurrence in a chi-square distribution, as commonly supported in the literature (Filzmoser 2004, Garrett 1989). Six cases emerged as multivariate outliers ($p<0.001$). Four of these cases were missing a single response, and as such, could not have been identified without imputation. The remaining two cases were missing zero responses, and registered a low probability of occurring in a chi-square distribution ($p<0.01$), even with two thirds of cases discarded. Thus, the 6 cases in question were deleted from Pool C, resulting in a new pool size of 208 Table 4-6.

Table 4-6: Summary of excluded cases and variables (Pool C)

A total of 10 participant cases and one variable were excluded from subsequent analyses.

Number of Cases/Name of Variable	Reason for Exclusion
4 Cases	Did not respond to over half of questions
Spur Colour Variable	Exhibited patterns of non-random missing data
6 cases	Identified as multivariate outliers ($p<0.001$)
Updated Pool C: 25 criteria and 208 participants	

Chapter 5

Results: Assessment of Pruning Criteria

5.1 Introduction

A primary objective of this project was to provide an assessment of cane pruning criteria, both of their relationship to overall pruning quality and of their internal structure. While it is acknowledged that a broadly conclusive model would require larger sets of vines and pruning decisions, it was proposed that the present vine could serve as a model system to begin to explore these relationships. This research utilised Multiple Linear Regression (MLR) and Partial Least Squares Regression (PLS) to model the relationship between individual criteria and overall quality (*see* Table 5-1). Principle Components Analysis (PCA) has facilitated the exploration of relationships among the criteria, themselves. As a note to the reader, the intent of this chapter is to report the conductance and outcome of statistical procedures, rather than to explore the implications to viticulture of said results. These results will partially serve, along with those from Chapter 4, Chapter 6, and Chapter 7, as the basis of the discussion presented in Chapter 8.

Table 5-1: Statistical procedures included in this chapter with description

Procedures in Order	Purpose	Response Pool Utilised	Viewable in:
1) Stepwise Multiple Linear Regression	To determine which combinations of pruning criteria (out of 23) were significant predictors for each of the two overall assessments	Pool C (All possible data from Part One of Survey)	Table 5-2
2) Standard Multiple Linear Regression	With only those criteria selected by Procedure 1, linear regression was repeated to obtain the correct degrees of freedom	Pool C	Table 5-3
3) Visual Analysis Of Residuals	To investigate model fit through visual inspection of those error residuals resulting from the procedure 2 models	Pool C	Figure 5-1
4) Partial Least Squares Regression (PLSR)	To create a linear model that accounts for both overall assessments simultaneously, rather than separately	Pool C	Figure 5-2
5) Principal Components Analysis	To analyse internal relationships and structure within the pruning criteria, themselves	Pool C	Table 5-5

5.2 Linear Models of Pruning Quality

5.2.1 Background and Procedural Notes

Responses from Pool C (N=208) were the subject of this analysis. The purpose of this series of analyses was to ascertain information as to which criteria were most influential in participant overall perception of the pruned vine, as recorded by the first and second overall assessments. The variable relating to Spur Colour was excluded from this analysis because of concerns over Missing Not at Random (MNAR) patterns in the data (*see* Section 4.5). With concerns over missing values addressed, pairwise deletion in SPSS was chosen as the method for handling missing data, as accepted in numerous statistical texts (Hair et al. 2006, Meyers et al. 2006, Tabachnick and Fidell 2001). As a reminder to the reader, participants were asked to make an overall assessment of the presented pruning decisions, both before and after they rated the decisions on individual pruning criteria. Section 4.4 noted the significant difference between the two overall quality assessments, which was a matter of concern with regard to linear modelling. Therefore, separate linear models for each set of overall assessments will be included in this chapter, as well as a Partial Least Squares Regression model that incorporates both measurements. To address the issue of non-normality of variables in the model, residual plots will be examined for homogeneity of variance. The ratio of cases to independent variables was approximately between *6.5:1* and *9:1*, depending how one classifies the pairwise deletion method. In either case, the ratio was well above *5:1* (Hair et al. 2006, Tabachnick and Fidell 2001), and thus adequate power for a moderate effect size was assumed for this analysis.

5.2.2 Criteria Selection for the Linear Model

Preliminary investigation in 2014 (unpublished data) suggested that a broad model with 24 predictor variables would yield a model with limited interpretability. In less statistical terms, the relationship between individual pruning criteria and assessments of overall quality were found to be diluted when placed in a model with 24 predictors. Stepwise regression, while not without criticism (Thompson 1995), is a widely-applied tool to parse variables for a model, based on the strength of bi-variate correlations (Tabachnick and Fidell 2001). As such, a stepwise regression was conducted in this study with 23 (*see* Table 4-6) predictor variables, separately onto both overall ratings, in order to determine which criteria were most predictive of the two participant overall assessments. The criteria selected by the stepwise deletion technique are displayed in Table 5-2. Section 8.3 of this document discusses potential limitations of the linear modelling technique, as a means for criteria evaluation.

Interestingly, there were criteria in each model with negative beta coefficients. Negative beta-weights would indicate that a positive change in a criterion score would predict negative changes in the overall rating (Hair et al. 2006, Tabachnick and Fidell 2001). This aspect of the result was nonsensical in practice, as improvements on a particular pruning criterion should not predict a decrease in overall quality. In other words, it does not pass face validity that a more positive score on the "number of nodes on a spur" criterion, for example, should predict a lower overall score for that set of pruning decisions. Supporting the notion that these negative beta coefficients were an idiosyncrasy of variance distribution is the fact that no criterion had a negative bivariate correlation with either overall assessment ($p<0.05$). These negative predictors were, therefore, eliminated from their respective linear models. After removal of negative predictors, stepwise regression was re-conducted iteratively until it was confirmed that no more significant, positive predictors existed for either model.

Table 5-2: Criteria selected for linear models of overall quality assessments (Pool C)

Note: Participants were asked to assess the overall quality of the presented pruning decisions (see Figure 3-1[cde]), both before and after rating the pruning decisions on the 24 individual criteria. The Linear Models displayed below were formulated to determine which criteria most heavily influenced the two overall assessments.

Linear Model of First Overall Assessment[ab]	Linear Model of Second Overall Assessment [ab]
Spur Position relative to selected Canes	Spur position relative to selected canes
Horizontal distance of cane away from centre	Horizontal distance of cane away from centre
Angle from which the spurs leave the head	Angle from which the spurs leave the head
Cane Position Relative to Spurs (negative predictor)	Cane Position Relative to Spurs
	Number of Canes
[c]df=158; Adj. R^2=0.472	*Number of nodes on Spur (negative predictor)*
	How well canes reflect vigour
	[c]df=158; Adj. R^2=0.642

[a]Criteria in italics were deleted from subsequent models
[b]23 criteria (see Section 4.5) were entered into the model with stepwise regression
[c]Cases with missing values were excluded pairwise

5.3 Model Results

Criteria from Table 5-2 were then re-entered into a standard multiple regression with their respective overall assessment. This step was taken in order to obtain the appropriate degrees of freedom for each model. Results of each model are displayed in Table 5-3. At first glance, the difference in the coefficient of determination between the two models is particularly striking. The first three predictors listed in Table 5-3, all relating to the position of the spurs, were significant predictors in both models. Interestingly, the criterion relating to cane position relative to spurs, which registered as a negative predictor of the first overall assessment, was the single largest predictor of the second overall assessment.

The linear model relating to the first overall assessment, taken on its own, would be classified as having moderate explanatory power, with an adjusted R^2 value of 0.461 (Tabachnick and Fidell 2001).

All three of its significant predictors were also predictive in the second overall assessment model. The rating for “spur position relative to selected canes” was strongly predictive in the first model, and moderately predictive in the second model (Table 5-3). Potentially of note was that this individual criterion was the first of the survey, and was separated from the first overall assessment by only two survey frames. From a bi-variate perspective, however, this criteria rating was only slightly more correlated with the first overall assessment than the second overall assessment (R=0.638 and 0.610, n=189 and 182, respectively).

Table 5-3: Linear models and significant predictors of overall quality assessments (Pool C)

Note: After establishing which criteria were significantly predictive of the two overall assessments (see Table 5-2 [a*]), these same criteria were re-entered, by themselves, into a multiple regression model with pairwise deletion. This step was taken in order to establish the correct degrees of freedom for the final linear models.

First Overall Assessment (Adj. R^2=0.461)			*Second Overall Assessment (Adj R^2= 0.622)*		
Predictor (Criterion)	***Beta*** *	**Sig. of predictor (p)**	**Predictor (Criterion)**	***Beta*** *	**Sig. of predictor (p)**
Spur position relative to selected canes	0.506	<0.001	Cane position relative to spurs	0.357	<0.001
Angle from which the spurs leave the head	0.209	<0.001	Spur position relative to selected canes	0.280	<0.001
Horizontal distance of cane away from centre	0.152	0.027	Horizontal distance of cane away from centre	0.201	0.001
			Angle from which spurs leave the head	0.156	0.012
Df=171			Number of canes	0.115	0.021
			How well canes reflect vigour	0.100	0.062
			Df=164		

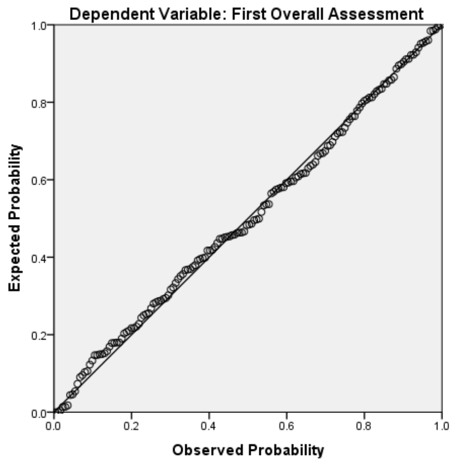
[a]Standard Multiple Regression, Pairwise Deletion *Standardised Beta-weights

A number of factors may have contributed to the considerable differences in explanatory power of these two models. Particularly of interest are potential explanations as to why the second overall assessment was more aligned with an additional three criteria. All three of these criteria were related to cane selection. These discrepancies will be explored further in the discussion chapter, particularly in the context of Section 8.4.

As suggested in Hair (2006), and particularly in light of the non-normal distributions of responses, normal probability plots were visually examined for obvious signs of heteroscedasticity. Observed residuals in these plots (Figure 5-1), roughly follow the course of expected residuals. Residuals for the second overall assessment model appear to be slightly more irregular than those for the first overall assessment model. With acknowledgement to the work of Lumley et Al. (2002), which established that only extremely non-normal residuals significantly affect beta-weights in samples where N=150, these models were accepted as adequately homoscedastic to proceed with further analysis.

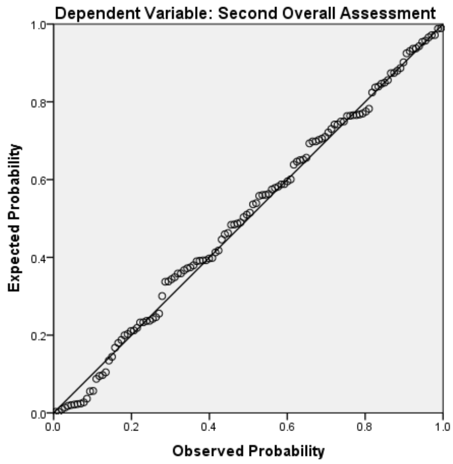
While the ratings displayed in Table 5-2 and Table 5-3 performed best in linear modelling procedures, they were not the only variables to be correlated with the overall assessments. All spur and cane criteria were significantly correlated with the second overall assessment ($p<0.05$). Ratings of spur number, spur node number, and spur length were not significantly correlated with the first overall assessment. All other spur and cane criteria were correlated with that assessment ($p<0.05$). Generally speaking, there was some level of internal correlation between the ratings criteria, themselves. This trend was noticeable enough to prompt diagnostic tests for multi-collinearity. For those criteria included in the above models, the Variance Inflation Factor (VIF) was under 2.0. Hair (2006) lists a VIF value of 10.0 as an upper limit for acceptability in regression analysis, meaning that VIF values in the vicinity of 2.0 are not alarming. Multicollinearity was deemed, therefore, not to be exhibiting a problematic effect on the regression models.

Linear Model: First Overall Assessment



Df=171, Adj. R^2=0.461

Linear Model: Second Overall Assessment



Df=164, Adj. R^2=0.622

Figure 5-1: Normal probability plot of standardised residuals (Pool C)

Note: Visual inspection of the residual plot consists of scanning the distribution of residuals for considerable deviations away from the reference line of y=x (Hair et al. 2006).

5.4 Partial Least Squares Regression Model

In the interest of examining both the first and second overall assessments together in the same model, Partial Least Squares (PLS) Regression was conducted in XLStat with the overall assessments as dependent variables, and the pruning criteria as independent variables. PLS regression finds a set of latent factors for the independent variables (t) that explains the highest possible amount of variance in a set of latent factors (u) for the dependent variables (Tobias 1995). These latent factors will here be referred to as components (*see* “A Note on Statistical Terminology”). The PLS analysis revealed a two component solution for the independent variables, or spur and cane criteria. These two spur and cane component accounted for 50.8 per cent of the variance in the overall assessment component (u). This number is interpreted in a similar fashion to the coefficient of determination, r2, produced by multiple linear regression (Tobias 1995). Of this explained variance total, 38.4 percent was attributed to the first component and 12.4 to the second.

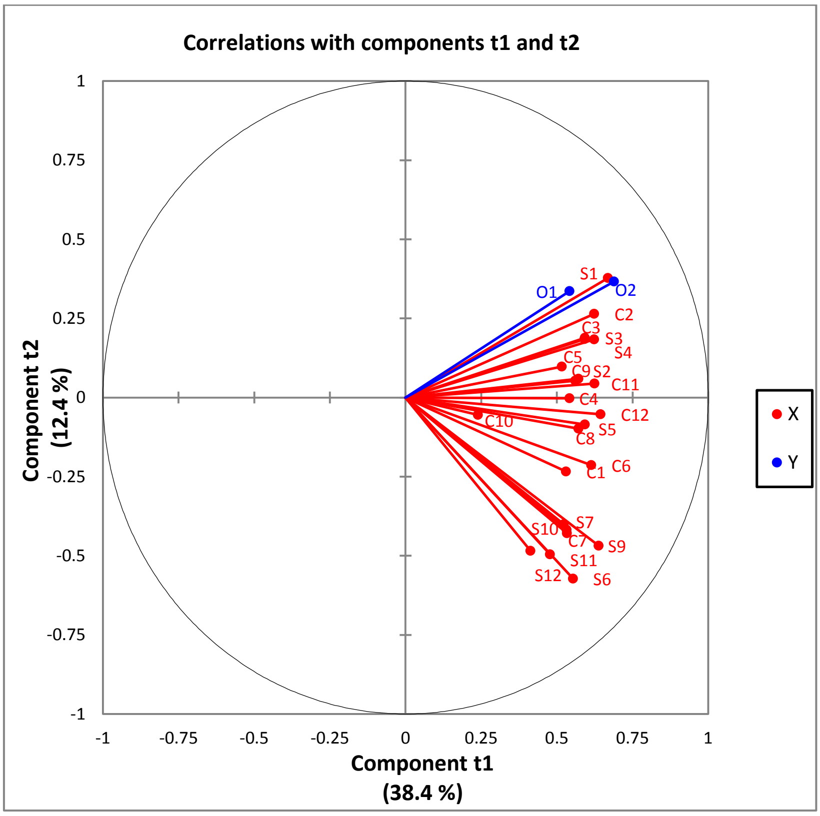


Figure 5-2: Bi-plot of overall and criteria ratings, as they correlated to components t1 and t2 (Pool C)

Note: Overall Assessments 1 (O1) and 2 (O2) appear in blue, with individual criteria appearing in red. Proximity in the above figure indicates strength of relationship, in terms of shared correlation to latent components t1 and t2. Criteria abbreviations are displayed in Table 3-3. See section 2.1.2 or Tobias (1995) for more information on PLSR.

Perhaps the most useful feature of a PLS model is the biplot (Figure 5-2) of correlations between the independent variable components (t) and the complete set of variables in the model. This visually illustrates the relationship between the overall ratings and the various criteria ratings. Please refer to Table 3-3 for a reiteration of pruning criteria abbreviations. The first and second overall ratings were similar in this two-component visual space, but not identical. Also of note was that the criterion relating to spur position relative to canes was nearly indistinguishable from the second overall rating. Those criteria that were closely correlated with the overall assessments in this space were all to do with spur or cane position.

PLS provides ratings of Variable Importance in Projection (VIP), which are analogous to beta weights in multiple regression (Figure 5-3). A VIP value of 1 is the widely accepted threshold for predictor significance (Mehmood et al. 2012). An examination of Figure 5-3 reveals that many of the criteria that were selected in multiple linear regression also registered high impacts in the PLS model. The diameter of spurs again appeared as an important predictor in this analysis, due to its strong negative correlations with overall ratings. This aspect of the result is nonsensical in practice, for the same reasons provided in Section 5.3. Possible explanations for the appearance of negative predictors will be explored further in Section 9.8.

It must also be noted that the first component (t1), which accounted for over three quarters of the variance explained by the model, was at least moderately correlated with most of the pruning criteria (Figure 5-2). Only the criterion relating to cane number was correlated with Component t1 at a level below r=0.30. This result is indicative of a considerable amount of widely shared variance, a subject which will be explored further in the following section and in Section 8.4. Whereas most variables in the PLS regression model had high scores on Component t1, Component t2 provided separation and interpretability to the model (Figure 5-2). The overall ratings, and those criteria closely associated with them, exhibited moderate to strong correlations with Component t2. Relatively weak predictors exhibited negative scores on the second component (t2).

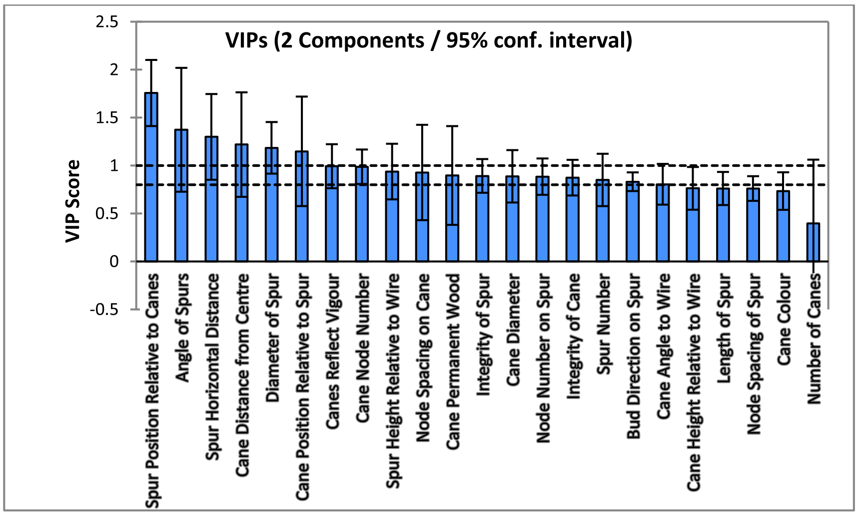


Figure 5-3: Variable Importance in Projection (VIP) score for individual pruning criteria (Pool C)

Note: Predictors with Variable Importance in Projection (VIP) scores above 1.0 are generally accepted as significant (Mehmood et al. 2012). This threshold is illustrated with a dotted line, together with a less stringent threshold of 0.8 VIP. Error bars represent confidence intervals for VIP score (α=0.05).

5.5 Principle Components Analysis of Pruning Criteria

5.5.1 Background and Procedural Notes

As noted in Section 2.1.5, this research intended to employ scale validation techniques, as outlined in Parasuraman (1989), Spector (1992), and Verdu-Jover et Al. (2004). The purpose of this analysis was to explore the internal structure of the pruning criteria, in order to identify criteria sub-groupings. This line of analysis requires the establishment of criteria dimensionality (sub-groupings), through

Principal Component Analysis (PCA). With Pool C (N=208), PCA was performed separately for the spur and cane subscales. Pairwise deletion was the method chosen for the handing of missing values. Spur colour was again excluded from this analysis, over concerns around MNAR patterns.

An important consideration in Principal Component Analysis is the decision of how many components to accept from the analysis. Monte Carlo simulation was undertaken with the O'Connor syntax for parallel analysis of raw data, to ensure that those components accepted were robust beyond what would be expected in a simulated random data set (O'Connor 2000). For Parallel Analysis, N=180 was entered into the syntax as a conservative estimate of average shared cases, as pairwise deletion results in a correlation matrix with varying amounts of shared cases (Tabachnick and Fidell 2001).

5.5.2 Results

PCA of the spur and cane subscale yielded two components for each subscale (Table 5-4) above the 95% confidence threshold established by the Parallel Analysis. In each subscale, one component was remarkably large, accounting for 43.44 % and 38.46%, respectively, of the total variance observed within the subscale criteria. The second components for each subscale were considerably smaller, and narrowly surpassed the 95% confidence threshold. An investigation of the component matrix revealed that all 11 spur criteria had loading scores on Component One (Table 5-5) higher than 0.577, which is indicative of high inter-correlation between the spur criteria. A similar result was observed within the 12 cane criteria, with the exception of the criterion relating to the number of canes.

Table 5-4: Two component PCA solutions for cane and spur criteria ratings (Pool C)

Note: Principal Component Analysis was conducted[ab] separately for spur and cane criteria. Parallel Analysis for raw data was conducted with the O'Connor Syntax (O'Connor 2000), in order to determine the appropriate number of components.

Component	Eigenvalue	% Variance Explained
Spur Selection		
Component One	4.779	43.44
Component Two	1.373	12.48
		55.92
Cane Selection		
Component One	4.615	38.46
Component Two	1.498	12.48
		50.94

[a]Extraction Method: Principal Components Extraction; [b]Pairwise Deletion, starting from N=208

Component Two for the spur subscale, upon a scanning of its component matrix, amounted to an additional display of shared variance between those criteria relating to position (Figure 5-4). Again a similar result appeared within the cane criteria relating to position (Figure 5-5). Oblique rotation in the two-component space (Figure 5-4 and Figure 5-5) illustrates the particularly close relationship between position criteria and component two, in the PCA for both spur and cane criteria. As a caveat to over-interpretation, it should be noted that this bi-plot does blur the general finding that all spur criteria, and almost all cane criteria, loaded strongly onto their respective Component One.

Table 5-5: Unrotated component loading scores for the first component of spur and cane criteria subscales

The component scores listed below indicate how strongly each pruning criterion loaded onto components one, which resulted from PCA of spur and cane criteria subscales, respectively. Component scores have a possible value of 0.0 to 1.0, with higher values indicating stronger correlation. The displayed component scores were obtained prior to Oblique rotation.

Spur Criteria Component One			Cane Criteria Component One		
Eigenvalue: 4.779 Variance Explained: 43.44 %			Eigenvalue: 4.615 Variance Explained: 38.46 %		
Criteria	**Code**	**Component Score**	**Criteria**	**Code**	**Component Score**
Spur Diameter	S6	0.733	Cane Diameter	C6	0.743
Spur integrity	S9	0.753	Reflection of vigour	C12	0.696
Spur Node spacing	S7	0.706	Cane colour	C7	0.686
Spur Angle	S4	0.694	Cane integrity	C8	0.686
Spur node number	S11	0.682	Distance from centre.	C3	0.645
Spur number	S10	0.647	Cane Angle	C4	0.640
Length of the spurs	S12	0.631	Cane node number	C11	0.637
Distance from Centre	S3	0.609	Perennial wood before cane	C5	0.625
Pos. Relative to cane	S1	0.601	Cane node spacing.	C9	0.612
Bud Direction	S5	0.589	Position relative to spur	C2	0.545
Height relative to wire	S2	0.577	Height relative to wire.	C1	0.535
Spur colour	S8	excluded	Number of canes left	C10	0.244

[a]Extraction Method: Principal Components Analysis [b]Pairwise Deletion, starting from N=208

These results differed considerably from the 2014 pilot study (unpublished data), in which both spur and cane selection criteria fell into three components, roughly equating to position, composition, and quantity. The sample size for said analysis was comparatively small and contained responses on seven different vines. Those conditions may have altered the observed relationships between subscale variables. Results from this investigation suggest a much more broadly defined perception of pruning quality. This finding will be explored in further detail in Section 8.4.

5.5.3 Implications for Scale Validation

Spector (1992) suggests, as also found in Parasuraman (1989) and Verdu-Jover et al. (2004), item analysis through Cronbach’s alpha upon the establishment of dimensionality. In the present study, each subscale had one large component and one much smaller component with additional shared variance relating to position. Only with considerable Oblique rotation did criteria have an interpretable component structure. Therefore, item analysis was not conducted, as there were no other distinct component. Potential explanations for this lack of clear component structure will be examined in Sections 8.4, 9.9, 10.2 with Section 10.2 having an additional emphasis on its research implications.

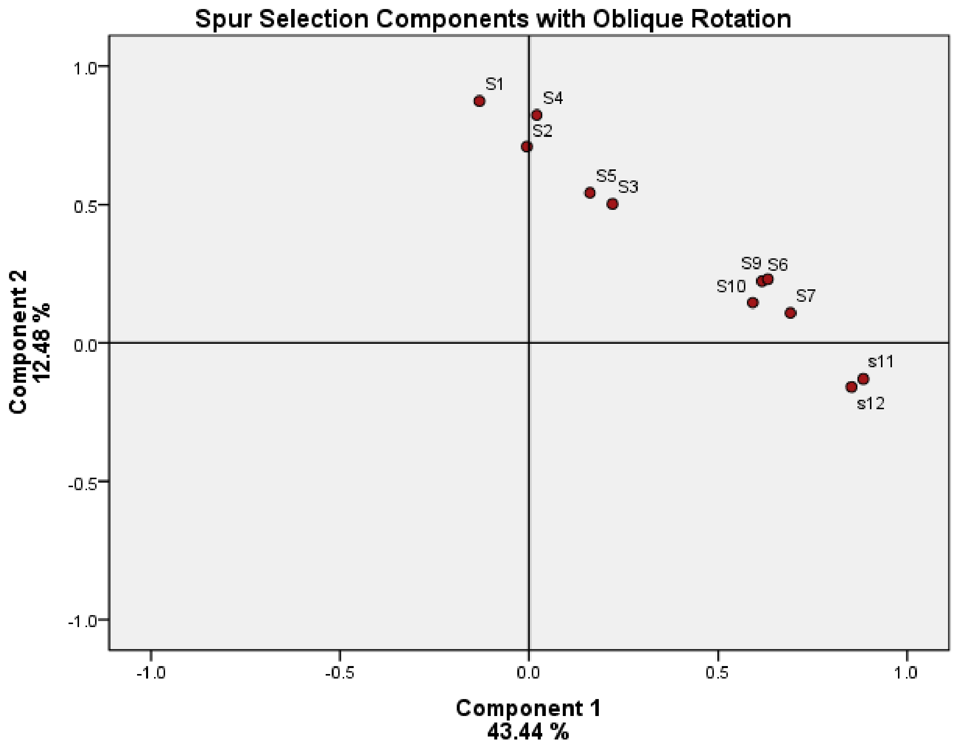


Figure 5-4: PCA bi-plot of spur evaluation criteria (Pool C)

Note: The purpose of this analysis was to explore the relationships that exist within pruning criteria relating to the selection of spurs. See Table 5-5 for a list of criteria abbreviations. Proximity between points indicates similarity of pruning criteria within the obliquely rotated two-component space. In the above image, horizontal position indicates obliquely rotated loading score onto Component 1 from PCA. Vertical Position indicates obliquely rotated loading score onto Component Two from PCA.

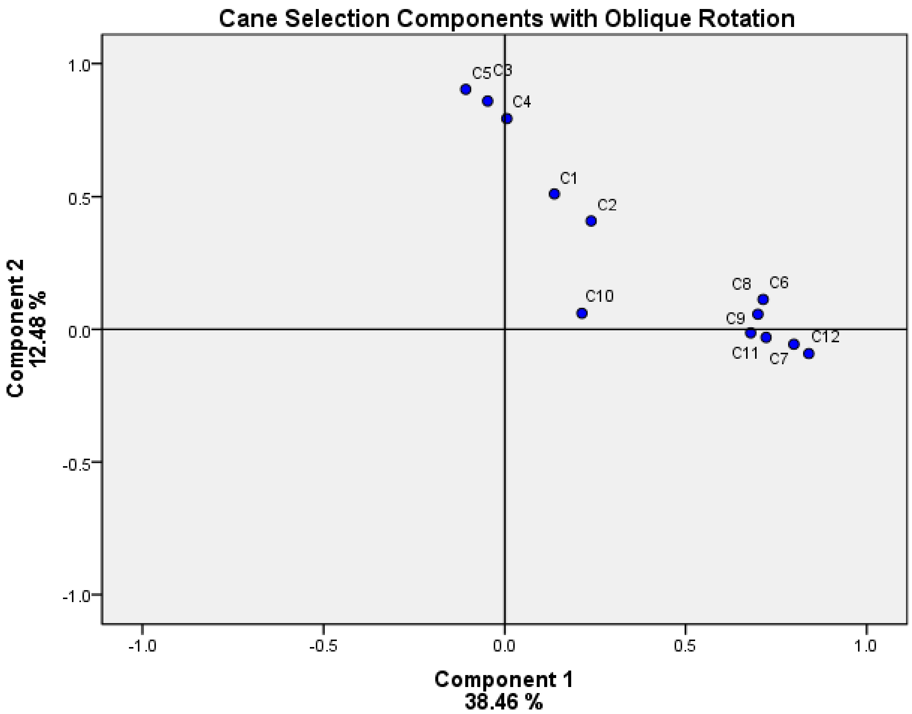


Figure 5-5: PCA bi-plot of cane evaluation criteria (Pool C)

Note: The purpose of this analysis was to explore the relationships that exist within pruning criteria relating to the selection of canes. See Table 5-5 for criteria abbreviations and Figure 5-4 for assistance with the interpretation of PCA bi-plots.

Chapter 6
Results: Group Differentiation

6.1 Introduction

While reflecting on the 17 preliminary vineyard visits completed in 2014, it seemed that conventional cane pruning wisdom fell into two categories. One line of thinking held that, for any particular vine, there may be countless ways to satisfactorily cane prune. During the same 2014 period, other growers described unique and meticulous thought processes, with some expressing displeasure at views held by others within the industry. Based on this experience, it was decided in 2015 to also analyse the preferred pruning decisions of those who participated in the Qualtrics ratings. Given the extensive number of participants required for other analyses, it would also be possible to track whether factors such as region, organisational role, vineyard size, experience level, and education level had an impact on pruning preferences. The interaction of these factors, it was proposed, could potentially constitute pruning styles. Thus, a number of analyses have been undertaken (*see* Table 6-1), towards the objective of identifying and characterising pruning styles. As was the case in Chapters 4 and 5, readers are referred to Chapter 8 for a discussion of those results presented here. Also as a reminder to the reader, at various instances in this chapter the terms “dimensional” and “dimensionality” will be adopted to refer to the existence, or lack thereof, of distinct components produced by Correspondence Analysis or Multiple Correspondence Analysis.

Table 6-1: Statistical procedures appearing in this chapter, with description

Procedures in Order	Purpose	Response Pool Utilised	Viewable in:
1) Chi-Square Analysis	To test for interaction between two categorical variables	Pool B (All available data from part two of survey)	In-text
2) Correspondence Analysis	Similar to PCA (Table 5-1), but for categorical data. Reduces categorical data matrices to components, to which the categories of the two variables are correlated to differing levels.	Pool B	Figure 6-1 Figure 6-2 Figure 6-5

3) Multiple Correspondence Analysis	Similar to Correspondence Analysis, but allows for analysis of more than two categorical variables.	Pool B	Figure 6-3 Figure 6-4 Figure 6-6
4) Analysis Of Variance (ANOVA)	Test for differences in mean rating, between the levels of a categorical variable	Pool C (All available data from part one of survey	**Table 6-5**
5) Hierarchal Cluster Analysis	To identify groupings of participants within the population-at-large, based upon their ratings to several items on part one of the survey	Pool C	Figure 6-6 Table 6-6

6.2 Regional Pruning Preference

To the best of this author's knowledge, this research is the first to report region as an influencing factor on cane pruning preferences. Table 6-2 provides a compositional breakdown of Pools B and C, with regard to region. Within Pool B, corresponding to all of the decision indication responses, region exhibited a significant interactive on right-side spur selections (chi-square analysis, $p<0.05$). Chapter 4 described one of the major decision points for this vine, which was whether or not to restructure the vine by not leaving a spur on the right side. Those from Hawke's Bay and, particularly, Central Otago were considerably less likely to leave a spur on this side, relative to expected chi-square table values. Those from Marlborough and, particularly, Waipara were more likely than expected to leave a spur on the right side of the vine.

Table 6-2: Pool B and C, response composition by region

	Pool B (198 Responses)	*Pool C^{a} (208 Responses)*
Region	**Number of Participants (%)**	**Number of Participants (%)**
Marlborough	66 (33. %)	60 (28.8 %)
Hawke's Bay	47 (23.3 %)	45 (21.6 %)
Waipara	52 (26.3 %)	51 (24.5 %)
Central Otago	33 (16.7 %)	32 (15.4 %)
Other	None	20 (9.6 %)
		[a]10 cases removed (see Sections 4.5 & 4.6)

Region also exhibited an effect on the cane selections (chi-square analysis, $p<0.01$) for the right side of the vine. While this effect was also observed in those instances where multiple cane selections were made (chi-square analysis, $p<0.05$), these cases will be excluded due to ambiguity described in Section 4.2.2, and explored in Section 9.5. Particularly of note within this result was that those from

Marlborough were more likely than expected to select R1 as a cane selection. Participants from Waipara were less likely to select this option, but were doubly more likely than expected to select R4 as a cane.

Correspondence Analysis confirmed the trend of interaction between region and pruning decisions (Figure 6-1). In the correspondence analysis of interactions between region and spur preference, Waipara and Marlborough anchored the negative end of a very large Component 1, with Central Otago positioned at the opposite pole. Analysis of the cane selections (Figure 6-2) grouped Central Otago and Hawke's Bay together, and linked each of Marlborough and Waipara with a distinct cane selection (R1 and R4, respectively). As another caveat to over-interpretation of this figure, it must be emphasised that these regional tendencies derive their meaning out of the departure from expected frequencies, rather than constituting an assessment or prediction of absolute frequencies.

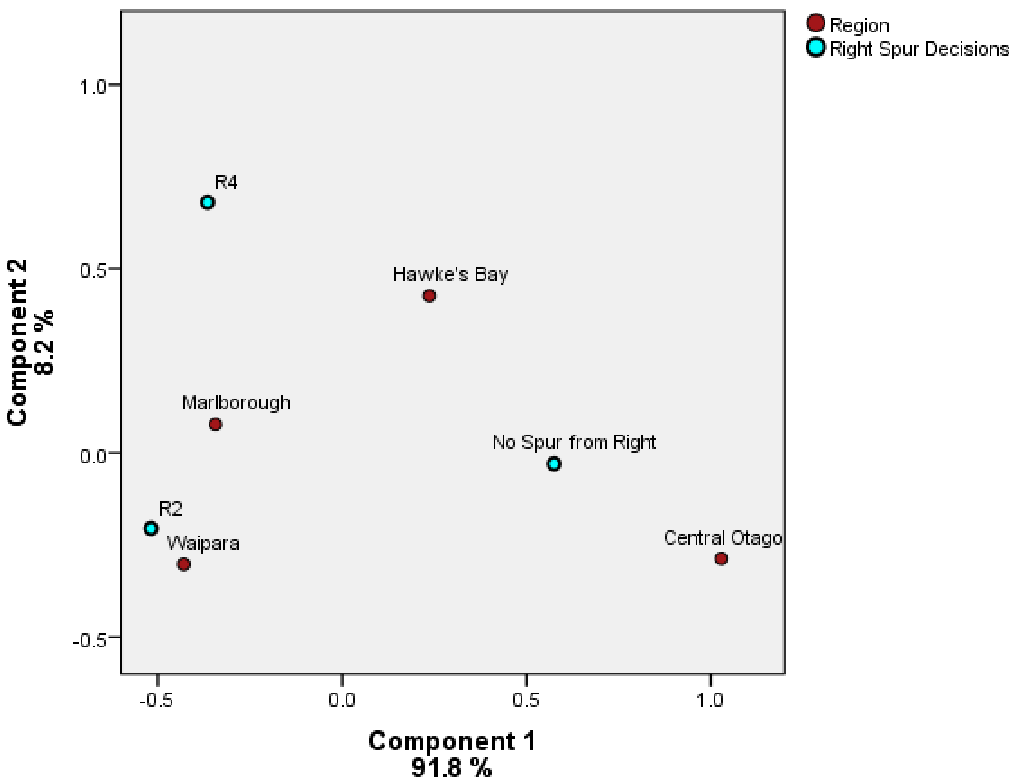


Figure 6-1: Correspondence Analysis of region and right spur decisions (Pool B)

Note: The purpose of this analysis was to explore the interaction between participant region and their spur selection decisions for the right side of the vine. Proximity between points indicates similarity on Components 1 and 2 resulting from Correspondence Analysis. Horizontal position in the two-component visual space represents score on Component 1. Vertical position in the two-component visual space indicates score on Component 2.

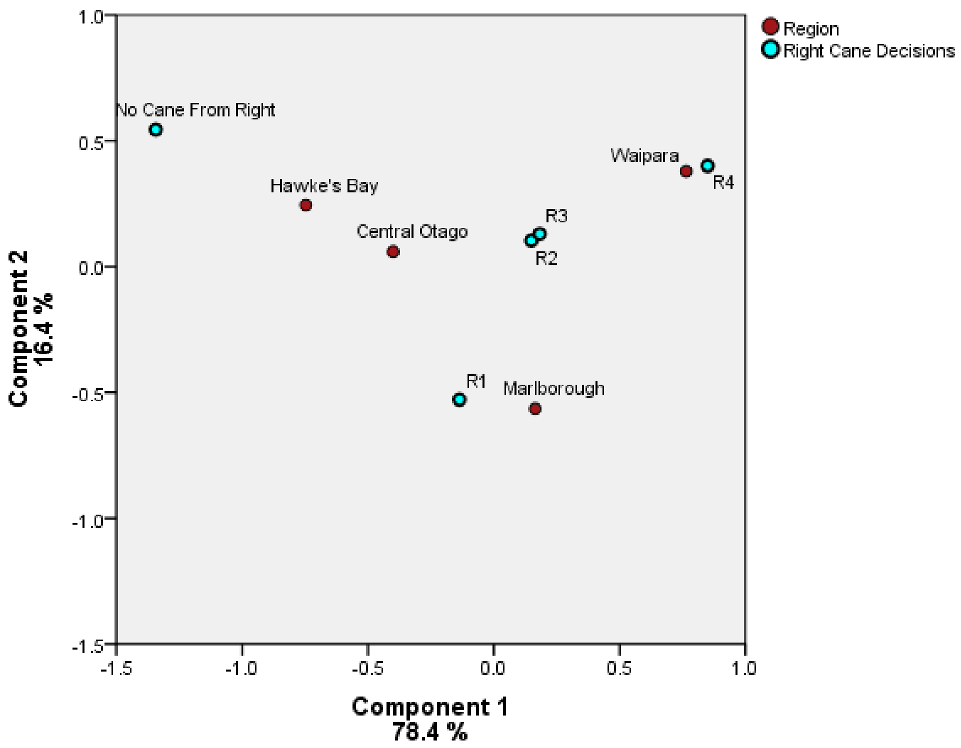


Figure 6-2: Correspondence Analysis of region and right cane decisions (Pool B)

Note: The purpose of this analysis was to explore relationships between participant region and their right side cane selections. Proximity between points indicates similarity on Components 1 and 2 resulting from Correspondence Analysis. Horizontal position in the two-component visual space indicates score on Component 1. Vertical position in the two-component visual space indicates score on Component 2.

Multiple Correspondence Analysis (MCA) was conducted to profile the entirety of right-side decision trends for each region. As noted in Table 6-1, the advantage of this procedure is the capability to simultaneously search for interaction between three or more categorical variables. Component 1 (F1 in Figure 6-3) in this analysis accounted for 64.14 % of observed variance. Central Otago and Hawke's Bay loaded negatively onto Component 1 at a relatively similar level, but were slightly separated on the basis of Component 2. Both regions were close in proximity and tended towards the option of not leaving a right-side spur. Waipara and Marlborough, whereas, had similar loadings onto both components.

The option to leave a spur at R2, which was a primary means (Section 4.2) of maintaining the vine's current structure, was represented at the highly positive end of Component 1. On the highly negative end of Component 1 were located several options corresponding to restructuring the vine. This indicates that, as in the case of the One-way Correspondence Analyses represented in Figure 4-1, Figure 6-1, and Figure 6-2, a high proportion of variance was represented by the divergent courses of action associated with either restructuring or maintaining the current head positions of the vine.

Whereas Hawke's Bay and Central Otago exhibited tendencies towards restructuring the vine, Marlborough and Waipara demonstrated tendencies that edged towards maintaining the current shape.

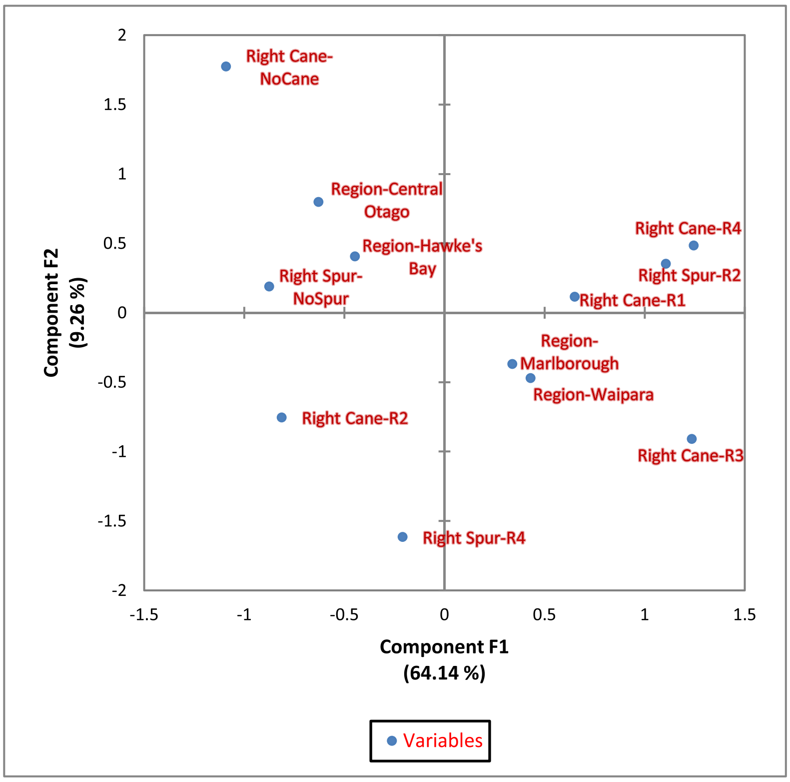


Figure 6-3: MCA bi-plot of region, right side spur selctions, and right side cane selections (Pool B)

Note: The purpose of this analysis was to explore relationships existing between: a) participant region b) right side spur selections, and c) right side cane selections. Proximity between points indicates similarity on Components 1 and 2 resulting from Multiple Correspondence Analysis. Horizontal position in the two-component visual space indicates score on Component 2. Vertical position in the two-component visual space indicates score on Component 2.

Region also cast an effect on Qualtrics ratings of the pruning decisions made for this vine. For the criteria relating to horizontal distance of the spurs away from centre, Waipara and Marlborough were more likely to rate the decisions higher ($p<0.05$). This matched the tendencies described in the above paragraph, as the decision presented in the Qualtrics study was to maintain the current shape of the vine with R2 as a spur. Region had a similar association, nearing statistical significance ($p<0.10$), with those criteria relating to the horizontal position and origin of the cane. Sections 8.5 and 9.3 will explore whether the inconsistency of regional effect was substantive or related to methodology.

6.3 Organisational Role

The effects of organisational role on pruning preferences were nearly as pronounced as those produced by region. For the purpose of analysis, participants were divided into groups (Table 6-3), corresponding to their highest self-identified role within the organisation. Those who identified as a labourer exclusively constituted their own group. Participants who identified as a supervisor, or as both a labourer and a supervisor, made up the second group. Finally, anyone who identified as a Manager or a Proprietor was placed into a third group, which from now will be referred to as 'management'. With respect to spur decision preferences, separation was observed between all three groups (chi-square analysis, $p<0.01$). The largest gap in preferences was between those who identified as a labourer exclusively and anyone who identified as management. Those identifying as labourers left a spur on the right side at a much higher than expected rate. Conversely, the management group was relatively unlikely to leave a spur on the right side. On the left side of the vine, management was more likely than expected to choose both L2 and L3 as spurs, whereas labourers opted for L3 alone in higher than expected numbers (chi-square analysis, $p<0.01$). Significant bi-variate interactions were not observed between organisational role and either the left or right cane selection decisions.

Table 6-3: Pool B and C, composition by organisational role

	Pool B (198 Participants)	*Pool C[a] (208 Participants)*
Organisational Role	**Number of Participants (%)**	**Number of Participants (%)**
Labourer exclusive	62 (30.3 %)	48 (23.1 %)
Supervisor exclusive	50 (25.3 %)	58 (27.9 %)
Manager or Proprietor	79 (39.9 %)	100 (48.1 %)
Did not respond	9 (4.5 %)	2 (1.0 %)

[a]10 cases removed (see Sections &^.&)

Multiple Correspondence Analysis of the interactions between organisational role, right-side spur selection, and right side cane selection yielded two Components which accounted for 78.8 % of observed variance (Figure 6-4). While the relatively high level of separation in this space might spawn a number of interpretations, a few points may be highlighted with reasonable confidence. In the two-dimensional space, the options most characteristic of management pertained to restructuring the vine. Supervisors, in this light, were relatively proximal to the options of not leaving a right spur, and leaving R2 as a cane selection. This combination was one of the most popular avenues for vine restructuring. In two-dimensional space, the labourer group was not closely associated with any one cane selection option, indicating a diversity of responses amongst this group. In general, though, the labourer group tended towards those options that were means of preserving the current shape of the vine.

With respect to Component 1 (F1 in Figure 6-4), which represented 62.77 % of variance, management and supervisors were closely aligned. In the two-dimensional space, however, supervisors were nearly at the mid-way point between labour and management. As in previous examples, highly negative and positive scores on Component 1 roughly lined up with those options pertaining to restructuring or maintaining the head, respectively. A clear interpretation of Component 2 is more elusive, other than to suggest that Component 2 may illustrate the various ways in which one might proceed after addressing the fundamental decision described above. A more thorough presentation of this argument may be found as part of Section 8.1 of the discussion chapter.

Organisational role also exhibited significant interaction with ratings on five Qualtrics criteria. Four of these criteria related to spur selection and one to cane selection. Of these five criteria, it was possible to statistically separate means (Tukey's B, p<0.05) for three criterion, those which pertained to the height of the spurs relative to the fruiting wire, the length of the spurs, and the angle of the canes relative to the fruiting wire. For the criterion relating to spur height, participants identifying as supervisors or management rated the decisions more favourably (p<0.05). Management tended to rate more harshly than the other groups on the criterion relating the angle of the canes (p<0.05).

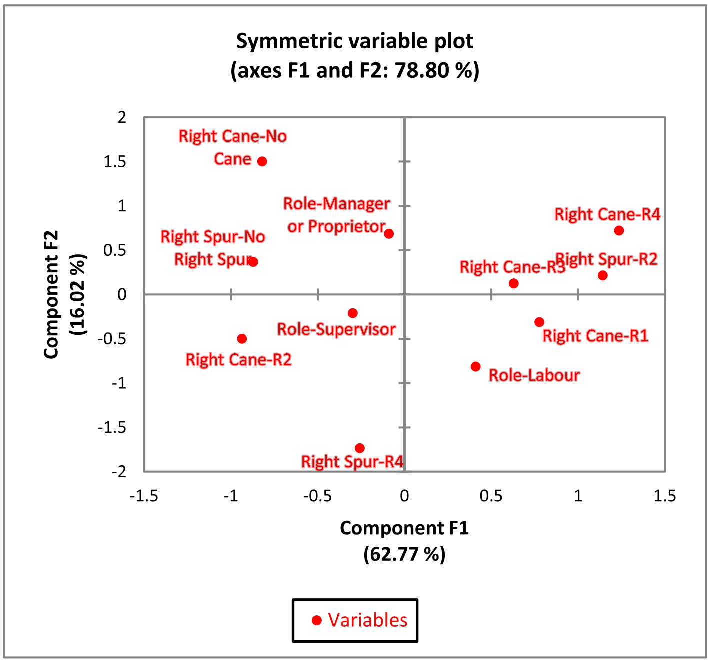


Figure 6-4: MCA bi-plot of the Interaction between organisational role and right side preferences (Pool B)

Note: The purpose of this analysis was to explore relationships that exist between: a) organisational role b) right side spur selections, and c) right side cane selections. Proximity between points indicates similarity on Components 1 and 2 resulting from Multiple Correspondence Analysis. Horizontal position in the two-component visual space indicates score on Component 1. Vertical position in the two-component visual space indicates score on Component 2.

6.4 Experience Level and Pruning Preference

Level of experience demonstrated a weaker, but mentionable interaction with pruning preference, particularly for right-side spur selections (p<0.08). Those participants with less than 2 years (Figure

6-5) of experience were more likely to leave R2 as a spur, relative to expected frequencies. Those who had between 10-20 years left this spur less frequently than expected. Those with either 3-5 years or 10-20 years were slightly more prone towards not leaving a spur on the right side. Left side spur and right side cane decisions also approached significant interaction with experience level, but expected cell counts in these analyses did not meet requirements to make a valid assessment of significance.

Correspondence Analysis (Figure 6-5) of experience level and right side spur selections provided some illustration of the patterns reported above. Those participants with one or two years of experience were relatively isolated in terms of preference, but were most associated with a decision to leave R2 as a spur. These participants also opted to restructure the vine less frequently than expected. The portion of participants with over twenty years of experience also tended towards an R2 spur choice. Participants with between 5 and 20 years of experience scored similarly on Component 1, clustering in the general direction of the decision to leave no right side spur. produced means separation through Tukey's wholly significant difference. For all five of these criteria, the 3-5 years of experience demographic rated the presented as low or lower than any other experience subgroup. Statistical significance aside, this group recorded the lowest or next-to-lowest mean rating (Table 6-5) for all 26 criteria. In other words, they were less approving of the presented set of decisions. Conversely, those participants with 20 years or more of experience were a part of the higher ratings subgroup (Table 6-5) in all 5 instances of separable means.

Table 6-4: Pool B and C, composition by experience level

	Pool B (198 Participants)	*Pool C (208 Participants)*
Experience Level	**Number of Participants (%)**	**Number of Participants (%)**
1-2 Years	15 (7.9 %)	16 (7.8 %)
3-5 Years	23 (12.1 %)	26 (12.7 %)
5-10 years	53 (27.9 %)	56 (27.5 %)
10-20 Years	73 (38.4 %)	76 (37.3 %)
More than 20 years	26 (13.7 %)	30 (14.7 %)
Did Not Respond	8 (4.0 %)	4 (1.9 %)

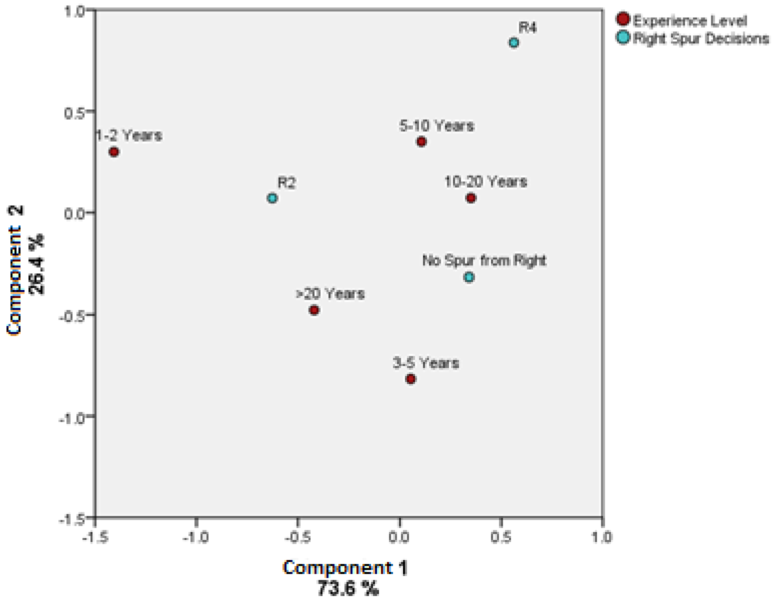


Figure 6-5: Correspondence analysis of experience and right side spur selection (Pool B)

Note: The purpose of this analysis was to explore relationships that exist between participant experience level and their right side spur selections. Proximity between points indicates similarity on Components 1 and 2 resulting from Correspondence Analysis. Horizontal position in the two-component visual space represents score on Component 1. Vertical position in the two-component visual space indicates score on Component 2.

Table 6-5: Experience level interacts with pruning criteria ratings (Pool C)

This table displays the group mean rating* and confidence interval, based on experience level, for four individual criteria and the second overall assessment. Ratings were assessed on a (0-100) scale. Significant differences, based on experience level, were not observed for other ratings criteria. See Table 3-3 for criteria abbreviations.

	Mean^{ab} + S.E.				
Experience Level	**S1**	**S3**	**S7**	**S11**	**O2**
1-2 Year	52.33^{ab} ± 7.729	55.29^{ab} ± 5.646	74.47^{ab} ± 3.044	71.64^{a} ± 6.275	71.13^{a} ± 5.978
3-5 Years	39.04^{b} ± 5.12	48.69^{b} ± 4.911	64.25^{b} ± 4.073	53.17^{b} ± 5.505	47.75^{b} ± 4.357
5-10 Year	45.06^{ab} ± 3.58	55.81^{ab} ± 3.312	69.27^{ab} ± 2.86	67.96^{ab} ± 3.63	56.02^{ab} ± 3.00
10-20 Years	45.97^{ab} ± 3.248	47.08^{b} ± 2.893	72.31^{ab} ± 1.932	71.65^{a} ± 2.936	47.42^{b} ± 2.909
20 Years	63.04^{a} ± 5.939	67.59^{a} ± 4.877	78.93^{a} ± 3.107	73.62^{a} ± 4.675	61.54^{ab} ± 4.684

***ANOVA: ($p<0.05$) ^{ab}Tukey-B ($\alpha=0.05$), with ^{a} indicating a significantly higher subgroup**

6.5 Non-significant Predictors of Pruning preference

Vineyard size and completion of tertiary viticulture qualifications demonstrated no discernible influence on pruning decision patterns or Qualtrics ratings. For the question relating to Tertiary qualifications, participants were given the option of “unsure”. Five participants selected this option, which was not sufficient to analyse the group separately. The result that 127 participants had completed tertiary viticulture qualifications was higher than expected. The discussion in Section 8.6.2 will address potential issues relating to the interpretation of this question. Section 8.6.2 will briefly discuss the significance that vineyard size, in particular, was such a poor predictor of pruning preference.

6.6 Results of Unmediated Cluster Analysis

6.6.1 Background Notes

While the focus of this chapter thus far has been on the separation of groups based on background variables, this project also endeavoured to profile natural separation that may exist on the subject of cane pruning. To assess this, Hierarchal Cluster Analysis with Ward’s method was conducted on the Pool C assessments of spur horizontal position and the second overall rating. Spur position, based on what has surfaced repeatedly throughout these chapters, was a major consideration in the pruning of this vine. The second overall assessment was chosen to provide some reflection of considerations other than spur position. As noted in Sections 4.4 and 5.2, the second overall assessment was more aligned with criteria perceptions recorded throughout the study (also see Section 8.4), compared to the first overall assessment. While inclusion of more criteria would have provided more information to the clustering solution, the number of shared pairs was seen as a limiting factor in this analysis. In light of this, and with the high level of system variance explained by variables relating to position, the analysis was limited to the two aforementioned variables.

6.6.2 Four Cluster Solution

The Cluster Analysis output was visually examined, at which time it was determined that the level of cluster dissimilarity exhibited a spike at the step from four to three clusters. Thus, a four cluster solution was accepted and membership values in the four solution were saved as a variable. Mean ratings for each cluster group may be found in Table 6-6. The four groups roughly corresponded to combinations of low and high ratings for each criteria. Participant number varied from cluster to cluster, with the majority of participants either fitting into the “Low-Low” and “High-High” categories.

Multiple Correspondence Analysis of cluster membership and right side pruning selections revealed a consistency between cluster group and decision tendencies (Figure 6-6). As a reminder, participants were presented with the decision to make R2 a spur, and R1 a cane selection. Cluster 1, characterised by high satisfaction (Table 6-5) with the presented decisions, tended to choose the same spur as that which was presented. Their cane preferences varied, but were most proximal in the two-dimensional space to R1 or R2. Cluster 2, which rated the presented decisions poorly on both S2 and O2 (Table 6-5), exhibited a tendency towards not leaving a spur. Cluster 4 was characterised by a low assessment of the spur position, but a rather neutral assessment of the overall pruning quality. This cluster was also near the "no spur" decision, in the two-dimensional space.

Table 6-6: Pruning criteria ratings based on cluster group (Pool C)

Hierarchal Cluster Analysis yielded four clusters, based on the individual rating, S2, and the second overall assessment. The group mean of each cluster was then calculated and is psented here with Standard Error. An approximate description of each cluster has also been provided, based upon mean participant rating of S2 and O2. Participant ratings were based on a (0-100) scale.

	Group Mean ± S.E.			
Cluster	**Spur Horizontal Distance from Centre (S3)**	**Second Overall Assessment (O2)**	**N**	**Cluster Description**
1	78.43 ± 1.636	77.16 ± 1.648	56	High-High
2	23.03 ± 1.761	25.62 ± 1.761	37	Low-Low
3	70.36 ± 1.861	32.80 ± 1.680	25	High-Low
4	37.25 ± 1.354	56.25 ± 2.219	52	Low-Medium

***Hierarchal Cluster Analysis conducted on Pool C (170 shared pairs)**

Interestingly, Cluster 3 did not gravitate towards any of the decision options (Figure 6-6). This group was characterised by reasonably high ratings on the spur position criterion, but low ratings on the overall assessment. It would follow that perhaps this group disagreed with the cane selections, but the group was no less associated with R2 as a cane option than they were for any other possibility. Nor was this group particularly associated with an alternative spur selection. As in previous examples of Correspondence Analysis and Multiple Correspondence Analysis, a single component characterised a large proportion of the variance observed between cluster membership and right side decisions.

In this instance, Cluster 1 and Cluster 2 were situated on mirror ends of Component 1 (F1 on Figure 6-6). With knowledge of the mean ratings that constitute these two clusters, it might be said that these positions on Component 1 represent either generally agreeing or disagreeing with the presented decisions. Component 2, in this context, becomes a means of separation to distinguish between preferences in the two cluster groups. Clusters 3 and 4 tended towards negative views of the decisions made, but were less strongly pulled to a particular set of options, compared to Clusters 1 and 2.

This analysis differs from others presented in this chapter in that it illustrates that the divide over restructuring the vine existed also within the population-at-large, as opposed to being exclusively a function of participant background. Those options pertaining to the decision to maintain the vine shape scored moderately to highly positively on Component 1, together with membership in Cluster 1 (high approval). Conversely, as was the case in other analyses presented in Chapter 6, those options associated with a restructuring of the vine registered as moderately to highly negatively on Component 1, together with membership in Cluster Two.

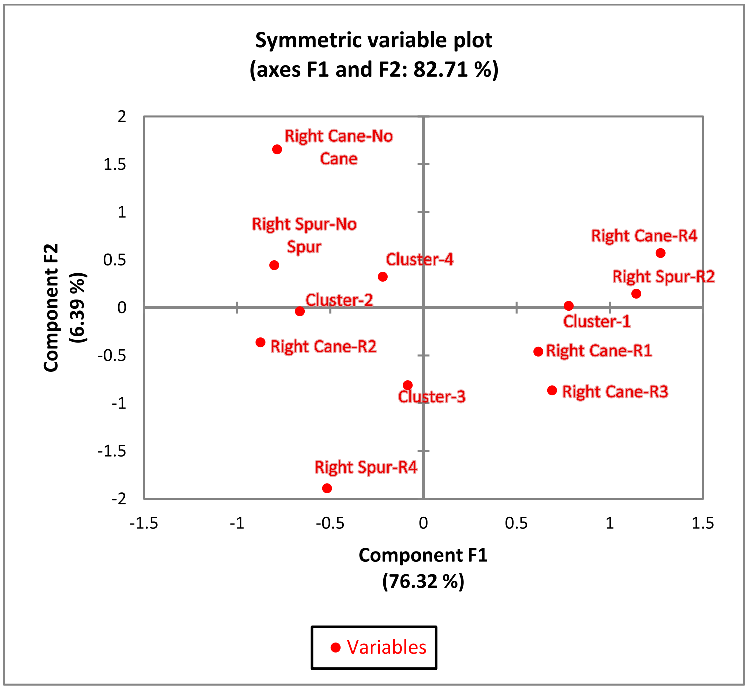


Figure 6-6: MCA bi-plot of cluster membership and right side preferences (Pool B)

Note: The purpose of this analysis was to explore the relationship between a) cluster membership (Table 6-6) b) right side spur selections, and c) right side cane selections Proximity between points indicates similarity on Components 1 and 2. Horizontal position in the two-component visual space indicates score on Component 1. Vertical position in the two-component visual space indicates score on Component 2.

Chapter 7

Results: Logistic Regression Models of Pruning Decision Probability

7.1 Introduction

Throughout the design and implementation of this project, a recurring theme was the need to consider which type of information and analysis would be beneficial to those pursuing artificially intelligent cane pruning. While hypothesising about the existence of pruning preference groups, at least one potential application stood out. The capacity to make predictions regarding the decision preferences of a particular manager or organisation could allow for more customisable A.I. configuration once fully operational. Such a capacity would require meaningful predictors, which could stem either from background information or from a series of trial ratings for calibration. While the current analysis pertains to one vine, and perhaps a unique one at that, the intention of this Chapter is to demonstrate the possibility for such capabilities. Results from this chapter will also serve, in arguments presented in Chapter 8, as an important linkage between Part One and Part Two of the conducted survey (see Sections 8.1 and 8.2.3).

Table 7-1: Statistical procedures in this chapter with description

Procedures in Order	Purpose	Response Pool Utilised	Viewable in:
1) Binary Logistic Regression	To determine which pruning criteria ratings (part one of survey) and background variables were significant predictors of the choice whether or not to leave a right side spur	Pool A (All possible cases where both part one and two of the survey were completed)	Table 7-2
2) Multinomial Logistic Regression	To determine which pruning criteria ratings (part of survey) and background variables were significant predictors of which right side cane would be selected	Pool A	Table 7-3

7.2 Background and Procedural Notes

As suggested above, several predictive models for right side decisions were formulated based on criteria ratings and background information. An eligible case, it follows, needed to have complete information regarding participant background, preferred pruning decisions, and relevant criteria ratings. This description coincided with the use of Pool A (Table 4-1), as described in Section 4.1. Logistic Regression models the likelihood of an outcome, and as such, dependent variables must be amenable to either binary or multinomial expression. In this analysis, the decision to leave a right side spur was identified as an ideal target for binary logistic regression. A multinomial logistic regression was also produced, with the aim of predicting right side cane choices. Predictor variables were chosen according to the subject matter of the prediction target.

Spur selections for the right side were re-coded into a binary indication whether or not the participant preferred to leave zero spurs or one spur for that side. Region, organisational role, and the criteria relating to horizontal cane and spur positions were identified as suitable predictors, based on fit for content and the results obtained in Chapter 4 and Chapter 5. Organisational Role was expressed in the model as a binary variable, which indicated whether participants identified exclusively as labour, or had responsibilities as a supervisor, manager, or proprietor within the organisation. For the entry of a categorical variable, such as region, a reference category must be chosen. Waipara was chosen as a reference category due to its relatively distinct preferences, compared to Central Otago and Hawke's Bay.

As one would expect, creating a model for the prediction of a multinomial decision variable, such as right side cane selection, is more complex. A particular problem in creating such a model was the fact that only six participants selected cane R3. With the view that the primary goal of this chapter is illustration, rather than prognostication, the six cases where R3 was chosen will be excluded. To maximise shared pairs in this demonstration, one categorical variable and one continuous variable were selected. These variables were region and the rating for cane position relative to centre, respectively. Central Otago was chosen as the reference category in the multinomial prediction model. The 'no cane from the right side' option served as a reference category for the cane selection variable.

7.3 Binary Logistic Model for Right Side Spur Choices

A null model, based on the assumption that all participants will leave a right side spur, would have been correct 52.4 % of the time. Incorporation of the predictive model significantly improved capacity (X^2=38.41, df=6, p<0.001) by almost 20 per cent to a level of 72.0 per cent accuracy. A common statistical gauge of model fit is the Hosmer and Lemeshow test, which measures the difference, through chi-square interaction, between actual and predicted values of the dependent variable. A non-significant result on the test indicates no significant differences between observed and predicted outcomes. (Hair et al. 2006)

In this instance, a non-significant result was observed ($p=0.31$), which suggests an adequate model fit. Other measures of model fit include several pseudo-R^2 values, including Cox & Snell R^2 and Nagelkerke R^2, both of which are sometimes interpreted as measures of explained variance. Cox & Snell R^2 values theoretically range from 0 to 0.750, whereas Nagelkerke R^2 values are transformed to a 0 to 1 scale (Hair et al. 2006). On these metrics, the model fit was moderate, but acceptable, at 0.236 and 0.314, respectively

Three of the four chosen predictors (Table 7-2) yielded significant improvements to predictive capacity ($p<0.05$). The fourth predictor, a criteria rating on cane horizontal position away from centre, was nearly significant in that role ($p<0.10$). In light of its near significance as a predictor, together with its observed contributions to correct prediction percentage and pseudo R^2 values, this criterion remained in the model. Ratings on the spur distance from centre rating, as well as membership in the Central Otago subgroup, were the strongest predictors of the decision to leave a spur ($p<0.01$ for both).

A helpful feature of logistic regression models is the odds ratio, which calculates the change in outcome odds, based on a one unit increase in a given predictor variable. Table 7-2 provides the 95 per cent confidence intervals for the odds ratio of each predictor. As a first example, a participant from Central Otago was somewhere between 5 and 50 per cent as likely to leave a spur, compared to a participant from Waipara. Participants identifying as labour exclusively were between 1.2 and 7.8 times more likely to leave a spur, or in the previous terms, between 20.4 and 682 per cent more likely. While these categorical variables are readily interpretable in the model, the continuous ratings variables from Qualtrics require sharper focus, due to the larger range of values.

To interpret the role of the criteria ratings, the standardised beta weight (Table 7-2) is an appropriate place to start. Interpretation here is predicated on the fact that the spur selection variable was re-coded to indicate, with 0 and 1, whether a spur was selected from the right side. For S3, therefore, the beta-weight is interpreted to mean that, for every one point of increase in S3 rating, an increase of 0.025 is expected in the binary value for right side spur selections. While this may seem a negligible amount, it is important to bear in mind that ratings were on a continuous scale of 1 through 100. This particular predictor registered as highly significant in the model, at a confidence level of $p<0.01$.

Odds ratios for the criteria ratings are, of course, interpreted similarly as for binary and categorical predictors. In the case of S3, a one unit increase in the rating corresponded to somewhere between a 0.7 and 4.4 per cent increase in the likelihood of the participant leaving a spur. While this again may seem like a small change, it is highly significant in light of the continuous 1 to 100 scale. C3, which related to the horizontal position of cane selections, was near significance as a predictor of the right side spur decision. This ambiguity is observed in the confidence interval for the odds ratio, in which the lower and upper limits are on either side of the neutral value of one.

Table 7-2: Logistic Regression model for predicting whether a spur will be selected from right side[a] (Pool A)

Notes: The purpose of this analysis was to explore the ability of background variables and ratings from part one of the survey to predict whether or not participants would leave a spur on the right side of the vine. Waipara was selected as the reference category within the region variable. Participant spur selections were re-coded as a binary variable to indicate whether or not a right side spur was retained.

Predictors	Sub-categories	βeta (standardised)	S.E.	Significance	95 % C.I of Odds Ratio	
					Lower	Upper
Region				**		
	Waipara vs. Central Otago	-1.749	0.589	***	0.055	0.552
	Waipara vs. Marlborough	-0.614	0.525	NS	0.194	1.514
	Waipara vs. Hawke's Bay	-0.538	0.531	NS	0.206	1.654
Labourer Exclusively		1.122	0.477	**	1.204	7.825
Horizontal distance of spur from centre (Rating S3)		0.025	0.009	***	1.007	1.044
Horizontal distance of cane from centre (Rating C3)		0.014	0.009	*	0.997	1.031

[a]Right Side Spur Decisions: 0=No Spur from Right 1=Spur selected from right
*p<0.10, **p<0.05, ***p<0.01

7.4 Multinomial Logistic Model for Right Side Cane Selections

The multinomial logistic model reveals how changes in region and incremental changes on the C3 criterion rating predict right side cane preferences. As noted in the introduction, this model was intended to serve primarily as a technical demonstration, in particular recognition of the number of excluded cases. Based on likelihood ratio of model fit ($p<0.05$) and Pearson tests for goodness-of-fit ($p>0.05$), the model provided adequate specification. Cox and Snell, as well as Nagelkerke, Psuedo-R^2 values were 0.220 and 0.237, respectively, which indicates moderate explanatory power. Overall, the model correctly predicted cane pruning preferences in 40.4 % of opportunities. Both predictors registered as significant overall predictors, based on a chi-square test of likelihood ratio ($p<0.05$).

Table 7-3: Multinomial Logistic model for right side cane selections (Pool A)

Notes: The purpose of this analysis[ab] was to utilise background variables and ratings from part one of the survey, in order to predict whether participants would choose to leave a particular cane on the right side of the vine. All fluctuations in the likelihood of a particular choice are relative to the selection of 'No Cane from the Right Side'. Likewise, Central Otago was selected as the reference category within the region variable. Refer to Tabachnick and Fidell (2001) for additional assistance with the interpretation of logistic regression outputs.

Right Side Cane Selection[c]	Predictors	β	S.E.	Significance	95 % C.I Odds Ratio Lower Limit	95 % C.I Odds Ratio Upper Limit
R1						
	C3 Rating	0.028	0.012	**	1.005	1.052
	Marlborough=1 Central Otago=0	0.708	0.843		0.389	10.596
	Hawke's Bay=1 Central Otago=0	-0.393	0.689		0.175	2.606
	Waipara=1 Central Otago=0	1.603	1.179		0.493	50.120
R2						
	C3 Rating	0.009	0.011		0.987	1.032
	Marlborough=1 Central Otago=0	.849	0.829		0.460	11.874
	Hawke's Bay=1 Central Otago=0	-0.213	0.660		0.222	2.949
	Waipara=1 Central Otago=0	2.281	1.154	**	1.020	93.832
R4						
	C3 Rating	0.033	0.014	**	1.007	1.061
	Marlborough=1 Central Otago=0	1.119	1.042		0.397	23.594
	Hawke's Bay=1 Central Otago=0	-0.743	1.070		0.058	3.872
	Waipara=1 Central Otago=0	3.157	1.274	**	1.936	285.111

[a]Based on 122 shared pairs [b]Nagelkerke R^2= 0.237 [c]Reference Category set to 'No Cane from Right'
[**]p<0.05

Table 7-3 displays the power of individual category differences to predict participant right side cane selections. Beta-weight and odds ratio values have a somewhat subtle interpretation here. For instance, the last partition of the table illustrates that a change in region from Central Otago to Waipara is accompanied by a significantly greater likelihood of R4 as a cane choice, compared to the reference category of 'No Cane from Right'. A similar change, this time in the likelihood of R2 as a cane selection, is observed when those participants from Waipara are again compared to Central Otago. Likewise, increases in the C3 rating, which related to the horizontal distance of the cane from the centre of the vine, significantly increase the likelihood that either R1 or R4 will be chosen as a cane selection, rather than no cane.

Perhaps most notable of all from this table is the odds ratio for the likelihood of R4 as a cane selection. A change of participant region from Central Otago to Waipara resulted, within the context of the model, in an increase in the likelihood of R4 as a cane selection, by a factor of somewhere between 2 and 285. While these figures indicate a positive predictive relationship, the wide range of the confidence interval is evidence of considerable variance in the system. Despite these interpretative limitations, the notion of predictive models for multinomial decision preference certainly has appeal. These initial efforts, for both binary and multinomial outcomes, have hopefully demonstrated some potential application for an industry that continues to work towards artificially intelligent pruning.

Chapter 8

Discussion

8.1 Vine restructuring: a major decision point

Throughout the results presented in Chapters 4-7, the decision to restructure the vine, or conversely to maintain its shape, emerged as a fundamental dividing line in participant responses. Of the 198 participants who indicated their own preferred decisions, 89, or 44.9 per cent, of them preferred to leave no spur on the right side. Correspondence Analysis, in five different configurations, (Figure 4-1, Figure 6-1, Figure 6-3, Figure 6-4, and Figure 6-6) also revealed the central importance of this decision. In each of these analyses, a large Component 1 accounted for over 60 per cent of the observed variance, and was highly loaded onto negatively and positively by those options corresponding to restructuring or maintaining the vine shape, respectively. In these instances, the restructuring decision appeared to form the basis of relationships between right side spur selection and cane selection, region, organisational role. Importantly, this divide among participants over restructuring was also present in the population-at-large (Figure 6-6), rather than just serving to differentiate between participant demographic groups.

Most, or possibly all, of the debate around restructuring is specific to the right side of the vine. In comparison to the 89 who did not leave a spur from the right, only 8 participants chose to leave no spur from the left side of the vine. In each of these cases, the participant left no spur for either side, which suggests that those participants had a general aversion to spurs. Thus, it can be inferred that the right side of the vine had unique properties that prompted participants to avoid leaving a spur. These unique and divisive properties were reflected in the criteria ratings for the presented pruning decisions.

In the binary logistic model, described in Section 7.3, the ratings of spur and cane horizontal position, relative to centre, were directly predictive of the choice to leave a right spur, or not. Linear models, which were presented in Section 5.2, illustrated that considerations of spur and cane position were the most predictive of the overall pruning quality perception. In fact, it could be argued that all three significant predictors in the linear model for the first overall assessment were directly related to the restructuring decision. Evidently, something about the position of the right side spur options caught the attention of participants, whether they concurred with or opposed the decisions. These findings warrant an exploration into what exactly divided participants, with regards to the position of right spur options. Between the contentious right side options, and the contrasting popularity of L3 as a spur, perhaps it is possible to glean some concept of what constitutes an acceptable spur.

8.2 Options L3, R2, and the attributes of an ideal spur

8.2.1 Spur Height, Relative to the Fruiting Wire

More than three quarters of Pool B chose to leave L3 (see Figure 3-5 for coding system) as a spur, or some combination of L3 and another spur. This was, by far, the most popular cane or spur selection, and is even more impressive in light of the relative wealth of left side spur options. An assessment of the positional attributes of L3 might start with its height. Notes from preliminary vineyard visits (unpublished data, 2014), reveal that the length of a pair of secateurs is an often-used means of assessing preferred spur height. This practical exercise requires the pruner to place the tip of the secateurs at the height of the fruiting wire and hold the implement down, or perpendicular to the wire. The handle area of the secateurs, in this line of thinking, is the appropriate relative height for a renewal spur. Another practical guideline espoused during these preliminary visits, was to visually scan one's eyes up the trunk of the vine, looking for the lowest emerging shoot. With the assumption that "bud-rubbing" has been employed during the growing season, this lowest shoot is typically considered to be the best spur, unless it is actually too low to be a renewal spur.

L3 would likely fit the ideal spur description in either process described above. It is, by all indications, the lowest originating shoot available. While it is possibly higher than the handle of a pair of secateurs, it does not appear to be far from such a designation. L2, the next most popular left side spur choice, originated at a similar height to R2, the primary right side spur option. While the origin of neither is completely clear, they each appear to be slightly higher than L3. Interestingly, both L2 and R2 were selected for the pruning decisions that were presented to participants for rating. Figure 4-2 illustrates that the mean rating on the height criteria was relatively positive, compared to other criteria relating to position. Nor was this criterion among those most predictive of overall assessments of quality. This would seem to indicate that height was not the primary flaw with R2 as a renewal spur.

8.2.2 Spur Angle

The angle at which the spur protrudes from the head (S4), however, is somewhat related to height and was a significant consideration. Assuming for a moment that the head of the vine was a horizontal plane, both L2 and R2 emerge from the head at angles approximating ninety degrees. Criterion S4, which related to this issue, was a significant predictor in both linear models, indicating that a number of participants took issue with this particular aspect of the spur decision. L3, on the other hand leaves the head with a slight curve, albeit relatively similarly to the other shoots.

Given that L3 was relatively similar in angle of protrusion, perhaps there is another explanation for the linear model significance of spur angle as a pruning criterion. One possibility is that participants simply felt unsatisfied with the angle of options L2 and R2, regardless of whether a better alternative was available. The issue of separating participant satisfaction with decisions, from satisfaction with outcomes, was a recurring concern, and will be further addressed in Chapter 9. Another possibility is that some participants utilised this question to express displeasure with the fact that the spurs were chosen from the back of the head, rather than the front, where L3 was located. As a third potential explanation, later in this chapter it will be argued that general perceptions to some extent influenced answers to all criteria evaluations.

8.2.3 Spur Horizontal Position

Regardless of any ambiguity about the importance of spur angle, the main driver of spur selections and ratings would appear to be horizontal position, relative to centre. As noted in Section 7.3, the ratings criteria corresponding to horizontal position were significantly predictive of the decision to leave a right side spur. Correspondence Analysis (Figure 6-1 and Figure 6-5) and Multiple Correspondence Analysis (Figure 6-3, Figure 6-4, and Figure 6-6) also suggested a participant divide as to whether option R2 was excessively distant from the centre of the head. Option L3 was, in a sense, the antithesis to the divisive right side options, in that it was widely popular and located in a central position. Likewise, L2 was a highly popular spur and was, in fact, even more centrally located than L3. A number of available viticulture handbooks also state a preference for a renewal spur that is closer, in horizontal distance, to the centre of the vine (Galet 2000, Pongracz 1978, Winkler 1962). Winkler (1962) explains the impetus as preventing the elongation of the head position.

Why exactly the elongation of the vine head is undesirable is more elusive in the literature, but several possible reasons are plausible. A number of participants mentioned (unpublished data, 2015) the sheer unprofitability of losing out on potential yield by allowing the origin of cane positions to shift outward. Others suggested a need to maintain uniformity for the purpose of instructing and managing the pruning work force. Another encountered line of thought emphasised the ability to facilitate pesticide spray penetration through optimising vine architecture. Regardless of why, the totality of evidence suggests that maintaining a central vine head is an important consideration in cane pruning.

According to preliminary vineyard visits (unpublished data, 2014), the avoidance of shoot crowding through the selection of well-spaced canes and spurs is a critical pruning concept. Smart (1991) outlines the many benefits, through both increased sunlight and airflow, of a well-spaced canopy. An increase in canopy crowding would appear to be the primary trade-off in maintaining a highly centralised head. Interestingly, nearly a quarter of participants chose to leave both L2 and L3, which are relatively close to one another. Of these 48 participants, 12 chose to leave L1 and L4 as cane selections, which would leave four bearing units in a very narrow proximity. One interpretation of the popularity of these choices, and other tightly configured options, would be that shoot crowding is a secondary consideration, relative to maintaining spurs at optimal height and position. While it is perhaps not possible to reach conclusions about the contours of this trade-off, shoot crowding does represent a potential limitation to the value of vine head centrality.

Another element in the restructuring debate is the supposed need to sacrifice this year's canes, in order to encourage renewal in prime locations. This notion may be somewhat counter-intuitive. Bud burst, however, and therefore shoot development, is known to be strongly influenced by apical dominance in (cv.) *Sauvignon Blanc* and other varieties (Antcliff and Webster 1955, Naylor 2001, Zelleke and Kliewer 1989). Selecting this shoot as a renewal spur effectively shifts the point of apical dominance, thus promoting earlier phenological development in the emerging shoots of basal buds. The result is an increase in the likelihood that a quality replacement shoot will develop from one of these prime positions (Naylor 2001, Pongracz 1978). This line of thinking matches the attributes and popularity of L3 as a spur. The inverse of this argument might hold that there is no point in leaving a spur at an undesirable renewal position, which may explain why nearly half of participants decided not to leave a spur from the right half.

It should also be noted that 28 people indicated a preference for R4 as a spur. Interestingly, diagrams in at least two technical handbooks place their spurs at a similar position, albeit slightly lower and considerably closer to the head (Pongracz 1978, Winkler 1962). The fact that such a selection was relatively unpopular might also be viewed as evidence to the perceived importance of centrally located spur positions. Anecdotally, several growers of European tutelage actually favoured this selection, due to concerns over dieback and the disruption of sap flow. This line of thinking is consistent with those pruning views expressed by Dal (2008). These philosophies appear to be growing in popularity with the prevalence of Eutypa Dieback, and warrant an examination in sharper detail.

8.2.4 Bud Direction

At least two sources note that the top bud of a spur should be pointing in a direction amenable to tying down (Galet 2000). Winkler (1962) further specifies that if the first bud of a spur is in a conducive position, the spur should be cut to one bud to ensure its development. In the present example, the second bud of L3 and L4 are pointing in the direction of the fruiting wire, albeit at a relatively close height to the fruiting wire. L2 was a popular spur selection, despite its second bud pointing in the opposite direction. This observation, together with the lack of popularity of L4 as a spur, suggest that bud direction on spurs was not a primary driver of selection. Spur bud direction was also the subject of the ratings criteria S5, which did not register as an important predictor in the multiple linear regression or PLS models for overall quality.

8.3 High levels of disagreement foretold criteria significance

Bud direction was just one of many criteria that did not register as a significant predictor of overall pruning quality. However, this research does not conclude that other criteria were unimportant in the pruning of this vine, or that they would be unimportant in future examples. Rather, a closer investigation of Table 4-4 reveals an interesting trend. The presence of a bi-modal distribution indicates that participants were heavily divided as to whether the decisions were good or bad, with respect to the criterion in question. In addition to nine individual criteria, both overall assessments were bi-modally distributed. Eight of the nine criteria with bi-modal distributions registered as a significant predictors at some point in the linear modelling process. Two of these, corresponding to spur length and node number, were negative predictors, and were thus excluded from the models (see section 5.2.2).

These two criteria notwithstanding, this argument holds that criteria which produced high amounts of disagreement were generally the most predictive of the overall quality assessments. That relatively high amounts of variance were explained within these linear models (Table 5-3 and Table 5-3) is supportive of the notion that the overall ratings primarily reflected those individual criteria which were contentious. Likewise, the residuals of these models indicate reasonably good model fit (Figure 5-1). As a supplementary, albeit rudimentary, validation to the notion that dissension predicted importance, a supplementary linear regression was performed, and revealed that the standard deviation observed on each ratings criteria was a significant predictor of the bi-variate correlation between each criteria and the second overall assessment (R^2=.122, $p<0.05$). In less statistical terms, this is another indication that the level of disagreement on a particular criterion was predictive of how explanatory the criterion would be, with respect overall satisfaction. In a similar exercise, though, standard deviations on individual criteria were not predictive of correlations between the criteria and the first overall assessment. This fits a recurring pattern, described in section 5.3, in which the first overall assessment was reflective of criteria relating to position, and little else.

To both the future of pruning research and the understanding of pruning task conceptualisation, the observation that linear modelling procedures primarily reflected those criteria which were contentious is of considerable consequence. The reverse of this statement is that those criteria which did not produce disagreement did not register as significant predictors of overall quality. While it must be noted that this finding may be the result of coincidence, it raises concern nonetheless. In a hypothetical scenario, a crucial decision-point may be poorly reflected in the outcome of linear modelling procedures, due to the uncontroversial nature of the presented options. Expressed in another way, some decision-making criteria may be too fundamental to engender disagreement among pruners.

Reflecting only contentious decision points would stand as a potential limitation to the application of these linear models, and to the utility of the technique in general for pruning research purposes. However, the ratings criteria that emerged as significant predictors (Table 5-3 and Figure 5-3) in this study matched the divisions observed in the decision indication data (Figure 4-1, Figure 6-3, Table 4-2, and Table 4-3). Such an observation serves as a rough form of validation, in the sense that the same substantive conclusion was reached from data obtained through separate exercises. While this cohesion is helpful in the context of this particular study, it seems plausible that the most contentious criteria may not always be the most fundamentally important. Furthermore, as noted previously, some important decision criteria may be so fundamental as to not prompt high levels of disagreement. More replication is needed to determine whether linear modelling techniques, applied in this context, provide a consistent picture of priorities during the conceptualisation of the pruning task.

8.4 General Impressions were dominant, and related to position

The prevalence of bi-modal distributions, as detailed above, serves as a starting point for a related argument. This argument holds that responses to the ratings assessments were driven strongly by general impressions. In each of the 11 bi-modal distributions, there were distribution peaks in both the negative and positive areas of the 100 point perception scale. This trend was usually observed in tandem with a sharp decrease in the middle areas of the spectrum. Such a distribution suggests that participants felt that decisions, at least on these 11 criteria, were either bad or good, with relatively little room in between. While this was only observed in 11 out of 26 total assessments, these 11 included both overall assessments and every significant predictor.

Aside from the frequency distributions, the outcome of Principal Component Analysis supports the notion that responses were strongly influenced by general impressions. As a refresher, PCA was conducted separately for the spur and cane criteria subscales. PCA yielded a large, dominant component from each of the spur and cane subscales, with each component accounting for around 40 per cent of observed variance in its respective subscale (Table 5-4). To fully comprehend this finding requires a referral back to the central function of PCA, which is to transform a larger variable set into a smaller number of representative vectors, or components (Hair et al. 2006). In this case, the largest single components accounted for 38.4 % and 43.4 % (Table 5-4) of the variance observed on eleven spur variables and twelve cane variables, respectively. Given the fact that many of the variables were seemingly unrelated to each other, it is surprising that a single component would represent such a considerable proportion of the observed variance. Furthermore, the second component extracted in each of the spur and cane subscales was correlated to the first component at levels of R=0.403 and R=0.493 (output not shown), respectively. Thus, even what might be perceived as unique variance was still shared widely amongst the variables in each subscale. Such an observation adds more support to the notion that participant attitudes were mostly driven by general impressions.

As a refresher, participants were asked to make two overall assessments, one before individual pruning criteria ratings, and one after. Differences (Section 5.3) observed between the two 'overall assessment' linear models provide further confirmation that general impressions, at least at first, heavily influenced criteria ratings for the presented decisions. Note again (*see* Section 4.4) that ratings on the second overall assessment were significantly higher than those for the first overall assessment (t-test, $p<0.001$). In the linear model for the first overall assessment, the 23 individual criteria ratings explained a maximum of 46.1 per cent of the variance observed in the overall assessment. Conversely, in the linear model for the second overall assessment, a maximum of 64.2 per cent of variance was explained by the same 23 individual criteria. The number of significant, positive predictors increased from three (Table 5-2; two spur criteria and one cane criterion) in the first overall assessment model to six (Table 5-2) in the second overall assessment model. All three of these new predictors were related to the quality of the selected canes.

The independent variables entered into each modelling procedure were the same. Such a jump in explanatory power between the two models, thus, can possibly be attributed to participants making a positive adjustment of their second overall rating to account for the positive cane selection attributes of the presented decisions. Also note (Figure 4-2), that several of the assessment criteria that are significant only in the second linear model have relatively high mean values. This supports the conclusion that participants made a positive adjustment on their second overall rating, based on positive attributes of the cane selection decisions. Also implied within this series of arguments is that participants, at first, made an overall assessment based exclusively on position (Table 5-1), and particularly on spur position. An alternative explanation to the jump in explanatory power is that participants simply felt they were too harsh with the first rating.

Regardless of why participants tended to positively adjust their second overall rating, results from both the decision ratings data and the decision indication data suggest that position was the dominant consideration throughout the study of this vine. This was reflected in loadings onto the large first component of Correspondence Analyses (Figure 4-1, Figure 6-3, Figure 6-4), as well as results from Multiple Linear Regression (Table 5-3). These linear models have demonstrated that considerations of position were not only salient at first impression, they also persisted through to the second assessment of overall quality (Table 5-2 and Table 5-3). While these results are relatively unequivocal in the present case, it is unclear whether the pervasive influence of position would carry over into other pruning scenarios.

These results also suggest that attitudes towards position permeated into responses in general, even when the subject matter was not strictly related to position. This conclusion is supported by the confluence of results from Principal Components Analysis (PCA) and multiple linear regression (MLR). PCA, as described several paragraphs previously, demonstrated a considerable amount of widely shared variance (Table 5-4 and Table 5-5), which has been interpreted here as relating to the strength of overall impressions. Linear Modelling has separately established (see previous page) that considerations of position strongly influenced these participant overall impressions, both at first and after recalibration. By continuation, it follows that participant attitudes towards position attributes may have exerted a general influence onto responses-at-large, including those survey items not strictly related to position.

The dominance of general impressions in this study has wide implication for those interested in designing future pruning research. Based on this study, it is plausible to suggest that participants had a very general feeling of satisfaction or dissatisfaction with the overall pruning strategy. In this case, these feelings were demonstrably related to position. A fundamental limitation in the data collection of this study was the time investment required from participants. These findings indicate that a much smaller number of assessments would adequately reflect pruning quality perception. This number of ratings may even be as low as three: one rating of spur selection, one of cane selection, and one assessment of overall pruning quality. However, it is unclear if the presence of a singularly dominant attribute is unique to this vine, or represents a *modus operandi* in conceptualising pruning as a task.

8.5 Region as a driver of pruning preference

A considerable portion of Chapter 6 was dedicated to the reporting of a novel finding, that region influences cane pruning preference and perception. As Figure 6-3 demonstrates, two groups emerged among the four regions. Central Otago tended to exhibit similar preferences to Hawke's Bay, with both demonstrating a tendency towards restructuring the vine by various means. Waipara and Marlborough were also relatively similar, and tended to favour those options corresponding to maintaining the current head width. Over the course of these analyses, however, (Figure 6-1, Figure 6-2, and Figure 6-3), each region displayed particular tendencies that differentiated it from the other three regions. While it is impossible to know how, and to what extent, regions would differ in other vine pruning scenarios, this section will explore potential interfaces between regional conditions and pruning conditions. With that in mind, the purpose of this subchapter is not to make conclusions as to why the four regions differed, but rather to suggest possible explanations that may be appropriate for future investigation.

Before proposing these potential sources of variation, the important issue of scope must be addressed. As made evident throughout this and other chapters, this project focused its investigation onto a single vine, for reasons outlined in Sections 3.3 and 9.2. This observation prompts a questioning of whether the obtained results, which suggest the existence of regional differences in pruning preference, can be generalised into a wider context. While only further investigation can affirm or disaffirm this notion, the fact that these results were obtained on a first attempt suggests promise. As a matter of reason, it is expected that pruning differences between regions would not exist in every circumstance, due to either wide consensus or lack of clear differentiating options. That differences should appear in this, the first such attempt at investigation, suggests that more differences may be found elsewhere, given the appropriate set of circumstances. The following sections are based on the premise that the obtained results are indicative of meaningful differences in regional pruning preference.

8.5.1 Yield and Bud Count

A natural place to begin a discussion of regional differences in pruning preference might be the sizable disparity in average yield per hectare observed between these four regions. Figures obtained from the 2015 New Zealand Winegrowers annual report indicate an average grape yield in Marlborough of 10.0 tonnes per hectare, down from 14.4 tonnes per hectare in 2014. That 2014 figure was close to three times larger than that observed in Central Otago. In 2015, the average tonnage per hectare in Marlborough was over twice that found in both Central Otago and Waipara. In Waipara, the dramatic drop in yield was primarily due to a late spring frost (Gwyn Williams, personal communication, December 2015), which represents an additional layer of complexity that will be deferred from the present investigation.

Before assessing how pruning strategy relates to yield considerations, there is an obvious question as to why these regions average vastly different tonnages per hectare. Some of these differences can be traced back to vine capacity, a concept explored in Section 2.2.2. Compared to Central Otago, the regions of Marlborough and, especially, Hawke's Bay have relatively high accumulations of GDD ((Imre 2011); Table 8-1). Likewise, vineyards in Central Otago will often be subject to naturally drier conditions (Table 8-1), although wide use of irrigation was noted in the data collection for this study. Chapter 3 established that these factors, along with growing season length and sunlight intensity, drive vine capacity (Howell 2001). This suggests that separation will naturally exist as to the yield potential of these four regions. Likewise, site-specific soil holding capacities for nutrients and water have an important part to play in photosynthesis and other cell functions (Creasy and Creasy 2009, Gladstones 2011). The variable nature of these forces within a particular region represents a limitation to the interpretation of regional differences.

Table 8-1: Comparison of the four surveyed wine regions

Region	Mean GDD[a] (°C)	Annual Rainfall[b] (mm)	October through April Rainfall[b] (mm)	Average 9am Relative Humidity[b] % (February)	Mean Annual Solar Radiation[a]	2014 T/Ha.[c]	2015 T/Ha.[c]	February Average High (°C)	February Average Low (°C)
Marlborough (Blenheim)	1165	711	378	74.2	14.1 - 15.3	14.4	10.0	23.8	11.5
Hawke's Bay (Hastings)	1415	724	368	73.9	14.6 - 14.8	9.3	7.5	25.4	14.0
Waipara	1038	637	351	71.5	14.0 - 14.1	7.3[d]	3.7[d]	23.7	11.4
Central Otago (Alexandra)	908	359	238	77.7	13.0 - 13.9	5.5	4.6	24.8	10.1

[a]Data from NIWA, via Imre (2011) [b]NIWA, generated with *CliFlo system (1981-2010)* [c]Regional Data from Winegrowers New Zealand Annual Reports [d]New Zealand Winegrowers data for Canerbury and Waipara combined

Regardless of why a certain crop load is targeted, pruners must subsequently leave the appropriate number of buds to yield the desired amount of fruit. Staying within the example of 2014 in Central Otago and Marlborough, exactly how many extra buds would need to be left in order to achieve a three-fold crop is a fascinating, but complex equation (*see* Bennett et al. (2005), Naylor (2001), Vasconcelos et al. (2009)). What can be said is that some amount of additional buds would have to be retained. Anecdotally, as observed during the data collection for this study and the pilot study (unpublished data, 2014 and 2015), many vineyards in the Marlborough region tie three or four canes down to the fruiting wire, in order to meet these targets. Winkler (1964) recommends one spur for every intended cane position. In practice, having a third or fourth cane does not necessarily require additional spur positions, as additional canes are often selected from the head of the vine (Martin Tillard, personal communication, 2015). However, the necessity of additional canes may shift additional importance onto having a minimum of two quality spur positions.

Participants in this study, as a reminder of context, were instructed that the hypothetical vineyard, from which the vine in question came, was maintained under a two-cane pruning regimen. Participants were given the option to leave more canes if they saw fit, but were also instructed to assume that canes would not break. The results, interpreted with caution, open the possibility that familiarity with a four cane pruning system may have exerted some influence on pruning decisions. Participants from Marlborough, where three and four cane systems are common, were most likely to retain three or more canes in part two of the survey (chi-square analysis, $p<0.05$). They also were more likely to maintain a spur position from the right half of the vine (Figure 6-3) compared to Central Otago, where no four cane systems were encountered in this data collection (unpublished data, 2014 and 2015). To decisively say whether or not this tendency was related to familiarity with four cane pruning will require further investigation.

While this line of reasoning may serve as a potential explanation, it is not without inconsistencies. Waipara, which typically has lower yields than Hawke's Bay or Marlborough, was relatively unlikely to forgo a spur from the right half of the vine (Figure 6-1 and Figure 6-3). In terms of workforce and organisational attributes, however, this region may bear some similarity to Marlborough (Martin Tillard, personal communication, 2015). Results from Hawke's Bay were also relatively inconsistent with the idea that familiarity with three and four-cane pruning influenced participant responses. In this region, where three and four cane pruning were sometimes observed (unpublished data, 2015), participants demonstrated an inclination towards not leaving a spur from the right side (Figure 6-1 and Figure 6-3). In summation, it is unclear whether familiarity with three and four cane pruning affected participant attitudes towards the subject vine. In future investigation, it may be appropriate to design for, or track at the very least, familiarity with these higher yielding systems, in order to facilitate the separation of their effects.

8.5.2 Varietal Familiarity

As noted in Section 3.7.2, participant instructions included information that the vine in question was of the (cv.) *Sauvignon Blanc* variety. It is, however, not out of the realm of possibility that varietal familiarity exhibited some influence on participant responses. This is particularly true in light of regional differences in the percentage of plantings belonging to *Sauvignon Blanc*. Marlborough and Central Otago are at either end of an extreme, in terms of percentage of plantings corresponding to *Sauvignon Blanc*. Central Otago's hectarage is less than 2.5 per cent planted to *Sauvignon Blanc*, meaning that many participants will probably not have had experience pruning this variety. Conversely, more than three-quarters of the vine hectarage in Marlborough is planted to *Sauvignon Blanc*, meaning that participants there likely had extensive experience with that variety.

There are a number of ways in which shoots of a different variety might differ in their attributes. One particular point of difference, which is thought to have wide recognition, is that *Sauvignon Blanc* canes are particularly brittle, and hence prone to breaking (Greg Miller, personal communication, December 2015). A related piece of commonly encountered conventional wisdom holds that canes originating from an old spur have a stronger base juncture, compared to shoots originating from the head of the vine (unpublished data, 2014). Results from this study were consistent with that axiom. Participants from Marlborough, where *Sauvignon Blanc* is prevalent, were particularly likely to select R1 as a cane, which originated from the previous year's spur (Figure 6-1 and Figure 6-3). While this by no means serves as conclusive evidence, the findings do warrant further investigation into whether the shoots of different varieties are more or less prone to breakages. Proof of this attribute would potentially contribute a great deal to the understanding of regional pruning preferences.

Another potential area of discrepancy between varieties is the fruitfulness of basal buds, and the ability to regenerate shoots in the head area of the vine. As described earlier in this chapter, leaving a spur promotes the development of quality shoots in prime renewal positions by effectively shifting the point of apical dominance to the second and third buds of a shoot (Pongracz 1978, Winkler 1962). The buds of *Sauvignon Blanc* are known to be particularly prone to poor basal bud fruitfulness in cane pruning situations (Naylor 2001). It is widely known anecdotally, with modest empirical support (López-Miranda et al. 2002, Rives 2000), that the fertility of basal buds differs between cultivars. Comparing participants from Central Otago and Marlborough directly in a head to head chi-square analysis, those from Central Otago were more likely than those from Marlborough to leave zero or one spurs for the entire vine (chi-square analysis, $p<0.05$). Such a result is consistent with the relative percentages of varietal plantings. This was also despite background instructions that told participants that the vineyard at large was pruned to two spurs.

Table 8-2: Regional Plantings by Variety

	Marlborough	Hawke's Bay	Waipara	Central Otago
Sauvignon Blanc	77.4 %	19.6 %	27.3 %	2.3 %
Pinot Noir	10.9 %	6.5 %	27.4 %	76.8 %
Pinot Gris	4.1 %	9.1 %	14.3 %	11.7 %
Riesling	1.3 %	<1.0 %	21.2 %	4.5 %
Chardonnay	4.5 %	21.1 %	5.3 %	2.7 %
Merlot	<1.0 %	22.6 %	<1.0 %	0.0%

Source: 2014 New Zealand Winegrowers Vineyard Register Report

This evidence suggests that it is possible that participants from Central Otago were influenced by experience working predominantly with a variety that is less prone to breakages and basal bud infertility. Within this possibility, at least two areas of experimental confirmation are needed. Firstly, it is relatively unproven that *Pinot Noir* and *Sauvignon Blanc* have different propensities to break. Secondly, a survey design with variety as a controlled variable would more clearly separate the effect of variety from other potential sources of pruning preference variation.

8.5.3 Wine Style Considerations during Pruning

Stylistic considerations relating to wine quality may also prove to be influential on pruning decisions in future research. Central Otago and Marlborough are again an interesting point of contrast here. On a very basic level, three quarters of vineyard output in Marlborough is destined towards white wine production, with the opposite situation present in Central Otago. Elsewhere in the literature, it has been demonstrated that perception of red wine quality is correlated to levels of phenolic compounds, such as anthocyanin and tannin (Jackson et al. 1978, Mercurio et al. 2010). While a full briefing on the dynamics of flavonoid accumulation is out of the scope of this discussion, it is accepted in the literature that, up to certain thresholds, exposure of the fruit and leaf canopy to sunlight promotes the synthesis of flavonoid compounds (Dokoozlian and Kliewer 1996, Downey et al. 2006, Smart et al. 1988). The extent of the promontory effects of sunlight and temperature, as well as their respective thresholds, may be variety dependent (Downey et al. 2006).

In Central Otago, where *Pinot Noir* is most prevalent, flavonoid synthesis dynamics factor into pruning decisions. *Pinot Noir* is known to withstand relatively high daytime temperatures, with little or no decrease in total skin anthocyanin concentration after daytime temperatures between 30 and 35 degrees Celsius (Kliewer and Torres 1972, Mori et al. 2007). Likewise, at least one experiment has demonstrated that diurnal temperature fluctuations promote the synthesis of anthocyanin (Mori et al. 2005). In relation to pruning in Central Otago, these guidelines would seem to encourage a particular emphasis on maintaining well-exposed canopies, both for daytime sunlight and night-time cooling. Curiously, the tendency of participants from Central Otago was to restructure the vine towards a more compact head. It is unclear how, if it all, this practice relates to a desire for sunlight exposure in the vine canopy. As noted above, however, participants from Central Otago were more likely than those from Marlborough to leave less than two spurs, in a head to head comparison. While this does not represent conclusive evidence, by any means, it does leave open the possibility that canopy sunlight exposure influenced participant pruning decisions.

Where Central Otago may hypothetically favour open canopies, there may be incentive, to a limited extent, for pruners in Marlborough to favour more shaded canopies. Several studies have demonstrated that increased canopy density, during the pre-veraison period, encourages the production of various methoxypyrazine compounds (Hashizume and Samuta 1999, Marais et al. 1999). These compounds, specifically 2-methoxy-3-isobutylpyrazine (IbMP) and 2-methoxy-3-Isopropylpyrazine (IpMP), have been positively correlated to consumer perception of *Sauvignon Blanc* quality (Allen et al. 1988).

As was true in the case of Central Otago, it is difficult at best to isolate the effects of such considerations, with respect to the pruning decisions of Marlborough participants. The decisions presented to participants, which Marlborough participants rated higher on key criteria, had spur and cane positions relatively close to each other on either side. Such a configuration may have promoted a dense canopy in the coming season, but it is not possible to make a firm conclusion either way. Likewise, the popular spur configuration of L2 and L3, which was actually less popular in Marlborough, may have led to a high density canopy later in the season.

While such speculation may seem relatively unfruitful, the notion of wine style presents an interesting avenue for future research. With a more time-efficient survey structure, it may also be possible to have participants prune vines under different stylistic assumptions. Integrating variety into design as a treatment level may also provide some baseline information about considerations of wine style. Recommendations for methodological improvements will be further addressed in Chapter 9.

8.6 Attributes of Organisations and Individuals

8.6.1 Individual Role within an Organisation

Sections 6.3 and 7.3 also presented extensive evidence of another novel finding, that role within an organisation is predictive of pruning preference. How, and perhaps whether or not, this finding will be relevant to those working towards artificially intelligent pruning remains to be seen. In a much more immediate sense, though, it may have implications for anyone currently managing a pruning operation. Multiple Correspondence Analysis (Figure 6-4), displayed a clear tendency, among those identifying exclusively as labourers, to favour options relating to the preservation of the current vine shape. The purpose of this discussion section is certainly not to argue whether such tendencies are good or bad, but rather explore how such a disconnect between management and labour may be pertinent to the running of a pruning operation.

One potential interpretation of a tendency to maintain the current shape of a vine, when others would favour more aggressive action, is a conservatism relating to perceived lack of authority. Those identifying as labourers, exclusively, may feel they have less authority to make structurally important changes to the vine architecture. It would be difficult to prove whether or not this interpretation reflects how workers actually feel. Regardless of empirical proof, perhaps there would be little to lose for managers who seek to ensure that their workers feel empowered to make such decisions, when appropriate. Such a delegation of power in the vineyard would likely require a high level of training and trust, however.

Less optimistic interpretations exist to explain the observed disconnect between workers and management. Given the prevalence of piece-rate compensation systems, where workers are paid per vine, some might interpret a reluctance to make structural decisions as a means of working more quickly, and thus earning more money. Working against this notion is the fact that participants were explicitly instructed to assume their choices were not constrained by time. The other side of an expedience-based interpretation would hold that the exuberance of management to make structural decisions may be overzealous and unreflective of the reality that workers face. As in the previous example, it would be difficult to empirically prove whether or any of these interpretations reflect the actual tendency of participants. One place to start would be to obtain more information as to whether or not participants typically work under piece-rate schemes, or better still, to somehow control for compensation schemes within the experiment.

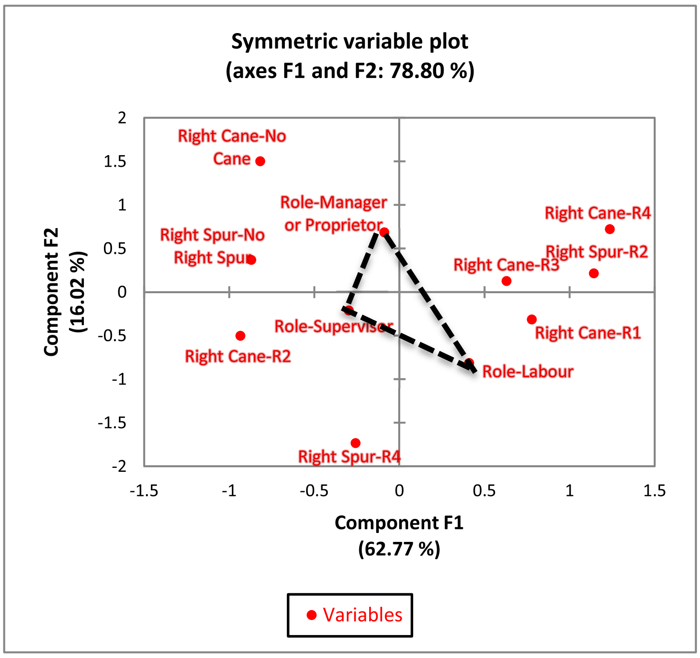


Figure 8-1: Bridging the gap between labourer and Manager

Regardless of why labourers responded differently compared to management, there may be some remedy for those managers and proprietors concerned by the fact that their pruning preferences are not shared by workers. Figure 6-4, reproduced and modified here as Figure 8-1, displays the euclidian distances between the categories of organisational role in two-dimensional space. A hypothetical straight line may be drawn between, the management and labour categories, for the purposes of illustration. Forming a triangle between these two categories is the supervisor category. While, visually, the triangle is not equilateral, it might be said that supervisors represent an ideal bridging point in the gap observed between managers and labourers.

The extension of this point is that managers and proprietors should be able to promote outcomes similar to their own preferred ones by increasing the ratio of supervisors to labourers in their vineyards. While this may seem self-evident, not to mention expensive, it does provide some empirically-based justification for the employment of supervisors. The super-imposition of a relational triangle onto this issue may also seem arbitrary, but the relationships that exist between preferences and organisational role certainly are not. Supervisors, it could be argued from the representation below, were actually more aggressive in their attitudes towards vine re-structuring than managers and proprietors. Having this influence in the vineyard may help alleviate some of the distance between the preferences of management and labour.

With all acknowledgement to a potential bias, the gap between the preferences of management and labourers may also serve as some justification for those wishing to further pursue advances in robotic pruning. The advantage of working with artificial intelligence, hypothetically, is that its decisions may be programmed to closely align with the inclinations of managers. Corbett-Davies et Al. (2012) has demonstrated the potential of an algorithm to produce pruning decisions at a level that may exceed that of a novice human pruner. Given the high level of turnover in the New Zealand pruning workforce (unpublished data, 2014), as assessed by numerous vineyard operators, the impetus to develop and adopt such technology may gain traction over the coming years. In the interim, this section has outlined some strategies that may be helpful for developing the capacity of the present workforce.

8.6.2 Commercial and Organisational Attributes

Although the potential impact of yield on pruning decisions has already been addressed, a number of other considerations are economic in nature. Anecdotally, there is a popular view that the cultural practices of small and large vineyards are drastically different. This study found that vineyard size was insignificant as a predictor, both for ratings of the pruned vine and for decision preferences, themselves. Likewise, the sample pools utilised in this study contained 34 employees of a large company, with operations in Marlborough, Hawke's Bay, and Waipara. This group displayed no significant deviations from the sample at large, indicating a lack of a dominant corporate influence ($p>0.05$).

If these results were at all surprising, they were so only in light of the commercial realities of managing a large pruning operation. Preliminary investigation (unpublished data, 2014 and 2015) revealed that a fundamental challenge, particularly for growers in Marlborough where demand for labour is high, is completing pruning within the necessary time frame. To alleviate labour shortages for horticultural industries, the New Zealand government operates a system of pre-approval for Recognised Seasonal Employers (RSE) to facilitate temporary migration of workers (Ministry of Business, Innovation, and Employment 2010). Undoubtedly, employing temporary workers, whether through RSE or other means, introduces a unique set of challenges. Likewise, it is understandable that speed would be a priority in such a situation. While this study did not track whether workers were part of a temporary labour agreement, nor whether they were compensated in piece-rate agreements, no evidence surfaced to suggest that the views of participants from large vineyards differed from the views of other participants.

Equally interesting was the finding that tertiary viticulture education did not significantly influence pruning preference or perception. This particular result may be unsurprising to many, but perhaps has implications from a labour market perspective. Stated in another way, this finding indicated that there was no measurable difference in performance between those with viticulture qualifications and those without. Hypothetically, if this finding were to hold up in other trials and in other areas of viticulture practice, it would seem fair to question the merits of such training. That said, it would be difficult to find a measure of overall performance with sufficient depth and range to allow for meaningful conclusions. Anecdotally, a number of participants also seemed unsure whether qualifications they completed met the minimum criteria of a one-year viticulture qualification from a tertiary institution. In the event that future quantitative pruning research becomes feasible, a more stringent definition and interpretation of what constitutes a tertiary qualification in viticulture may be necessary.

8.7 Summary of Discussion Points

Although the present chapter has covered much area, a few dominant themes have hopefully emerged. Firstly, this chapter elaborated on the considerable amount of evidence pointing towards a single dominant consideration in the pruning of this vine: whether or not to leave a spur from the right half of the vine. With the popular spur choice L3 as a counter-point, and the support of multivariate analyses, it was argued that this decision related mostly to position. Position not only dominated general impressions and perceptions of overall quality, it also formed the dividing lines for the various stylistic viewpoints that emerged. Upon these decision lines, the four sampled regions varied considerably. Potential origins of these differences were explored in the prospect that future research may be able to better isolate the cause of newly identified tendencies. The implications of another finding, one which identified discrepancies in the preferences of management and labourers, were explored from a managerial perspective. Whereas most of the discussion has focused on those results which were interpretable and significant, the previous section commented on the fact that several supposedly important categorical descriptors were not effective as predictors of pruning preference.

Chapter 9
Discussion of Methodology

9.1 Introduction

This study is, to our knowledge, the first of its kind, which meant that many methodological decisions were characterised by a process of trial and error. Such decisions were subject to a complex mix of considerations, including various timelines, the overall cost of data collection, sample size requirements for multivariate analyses, and theoretical usefulness to viticulture. A review some of these decisions might, offer potentially helpful suggestions for the betterment of future pruning research. Results presented in Chapters 4-8 have provided an opportunity to re-evaluate these methodological issues. Here we discuss and reflect further on those issues.

9.2 Vine Selection: How Many?

This particular decision to use only one vine was the subject of extensive deliberation and feedback, and was based on a mix of practical and theoretical factors. It was thought then that dividing this pool of responses among five to ten vines would reduce the power of the analyses. It is unclear, at present, how many vines would be necessary to approximate a representative sample of vineyard diversity. This approach was roughly comparable to the common practice, within oenological science, of conducting experiments on a model system, where parameters are known and somewhat controlled ((Danilewicz 2007, Dufour and Bayonove 1999).

For all of these positive aspects of studying a single vine, there were considerable drawbacks. Having only vine brought into question how generalizable were the obtained results. On the other hand, there was little or no evidence that the incorporation of five, or even ten vines, would have meaningfully improved the ability to place the findings into wider context. The focus on only one vine also meant that, due to the quite unique properties of the vine in question, many of the ratings criteria seemed superfluous to participants. This led to a noticeable feeling of frustration at times, which may have actually contributed to the observed dominance of general impressions (Section 8.4).

The findings of this study suggest the possibility of a remedy to this issue. Part of the difficulty in achieving a robust participant number was that participation typically required 20 minutes of participant time. Chapter 8 first noted that participant reactions could have been reasonably well represented with a much smaller number of ratings criteria. A much smaller time-per-vine requirement would make it realistic for participants to rate multiple vines.

To briefly digress, it may be possible to conduct a similar study where participants provide three ratings for a set of pruning decisions, one on overall quality, one on spur decision quality, and one on cane decision quality. This would potentially allow participants to rate ten or more vines in the same amount of time. Implied within this scenario are several assumptions. First, more information is needed as to the typical amount of pre-pruning variability observed from vine to vine. This would allow some estimation of how many vines would constitute a representative sample. Secondly, these behavioural research scenarios are potentially limited by the number of qualified pruners in the New Zealand wine industry. Finally, there is the reality of cost, which may be prohibitive in this scenario, as methods of in-person surveying can be expensive.

9.3 Survey vine Selection: Which One?

While such discussion can be illuminating, it assumes that any vines chosen for a particular study will reveal some meaningful information about industry pruning practice. In this case, considerable time and energy were invested into identifying a suitable vine for further study. Chapter 3 briefly described the vine selection process employed in this study. This process can be summarised by stating that any chosen vine needed to present a clear choice between two or more feasible pruning options. Conversely, it was reasoned that a vine having only one satisfactory choice or none at all was not likely to provide meaningful information about pruning preferences.

As such, a minimum set of requirements had to be met in order to consider a vine for selection. For the purposes of this study, there were three main areas of consideration, based on pilot study research visits to Waipara (unpublished data, 2014). First was that the head of the vine needed to be at least ten centimetres below the wire. Likewise, there needed to be several shoots in this vicinity that would provide options for a spur decision. Otherwise, many participants might have opted against retaining any positions from the current head of the vine, in favour of bringing up a renewal shoot from the base of the vine. Such a scenario would have created further ambiguity around pruning decision responses. Over the course of the conducted survey, no participants indicated a preference for retraining a renewal shoot as a vine trunk. This would indicate that the selection criteria were applied in a way to eliminate this area of complication.

Once a vine met the criterion of having a viable head position, in terms of height, attention turned to whether there were options within a reasonable horizontal distance to the centre of the vine. In the selected vine, there were at least four shoots identified as potential spur options. This facilitated a meaningful choice. Also in relation to spur horizontal position, it was known at the time at selection that some pruners prefer spurs to the inside of cane selections, and vice versa. The selected vine provided a clear choice between the two preferences, at least on the right side of the vine. There also was the potential for cane selections within a reasonable distance from the centre of the head.

As it turned out, horizontal position emerged as one of the central variables in participant responses. This was viewed as a validation of including this criterion in the vine selection process.

An additional criterion was considered in the vine selection process, to ensure that adequate cane selections were available throughout the exercises. The 2014 pilot study (unpublished data) revealed that some pruners have a strong preference for canes that emerge from a spur established during the previous pruning season, rather than a shoot emerging directly from the head of the vine. Initially, it was hoped that the present study would provide insight into the nature and extent of these preferences. The selected vine contained options that arose from previous spurs, as well as options directly from the head. Several factors, however, worked against a clear interpretation of these choices. Each of the options from previous spurs were shoots that left the old spur at an angle unconducive to tying the shoot down to the fruiting wire. Likewise, the previous chapters have suggested that position may have superseded any consideration of other criteria in this study. Both of these factors made it difficult to draw conclusions about the strength of any preference for canes that originate from old spurs.

The vine selection process was actually conducted in 2014, due to the fact that photos must be taken during the dormant season. Otherwise, they are obscured by leaf and shoot growth. Availability of vines was another potential area of restriction. The manipulation of pruning decisions as a research treatment might impact the subsequent performance of the vine. Thus to gain access to vines for such purposes may be difficult. In the present example, the available vines were those that were due to be replaced at the start of the new growing season. Access to suitable vine material may prove an issue in future experimental design.

9.4 Suitability of Presented Pruning Decisions

The set of pruning cuts made by the researcher were an integral part of this study. With these cuts playing such a central role, it is fair to assess how suitable these cuts were for the purpose of revealing participant pruning preferences (Figure 3-3 for view of the cuts). Chapter 8 presented the argument that considerations of position dominated participant responses throughout the present study. In this sense, the cuts presented to participants seem to have served their purpose well. By presenting R2 as a right side spur, this set of pruning decisions highlighted the divide in participants, as to whether the vine should be restructured towards the centre of the head. To an extent, these patterns were consistent between both the Qualtrics ratings and decision-indication data types.

Chapter 8 explained that the presented cuts were influenced by preliminary research visits to Waipara. It is certainly debatable to what extent these cuts reflect general pruning preferences in Waipara. Such a debate, however, seems secondary in importance to the fact that the presented cuts were a suitable fit for the general content themes revealed by the survey. To the inverse of this point, it is possible to envision a future scenario where the decisions presented to participants fail to capture the substantive issue within a particular vine. This possibility reiterates the need to properly conceptualise this aspect of research design. Successful research design in the future will need to consider this balance between theoretical goals and the practical issues associated with a particular vine pruning scenario.

9.5 Background Assumptions

Simulating the contextual background for winter pruning is deceptively complex. Over the course of many vineyard visits for this research, it has become increasingly evident that countless factors bear some, if perhaps minor, influence on the pruning process. The methodology of this study attempted to control for a few of these background variables by asking participants to make assumptions. Most fundamental of these requests was that participants rate the presented set of decisions based on what options were actually available.

This is a subtle distinction that differentiates between the quality of the decision, and the quality of the end result. In some instances, a pruner might make the best possible decision, and still be unsatisfied with the state of the vine. Therefore, participants were asked to consider where the decision, itself, rated in the spectrum between extremely good and extremely bad. To some extent, this ambiguity was also mitigated during the vine selection process, when it was ensured that the chosen vine offered a variety of options. It is unclear to what extent this assumption was effective. An interesting point of contrast is that the decision preference data is not burdened with this ambiguity of whether participants rated the decision or the outcome, due to the fact that they provided their own preferred decisions. This may be a point of support for utilising this data type exclusively in future research.

A second assumption was enacted when participants were asked to indicate their pruning decisions, based on whichever options they would prefer to tie down to the wire. The assumption here was that these preferred decisions would not break, thus eliminating the need to leave additional canes as insurance against breakages. This particular assumption, anecdotally, appeared difficult for participants to accept. It is unclear to what extent, if any, this assumption produced a confounding effect within the participant responses. In future research, it would be advisable, if possible, to avoid this issue altogether by finding a way to incorporate insurance canes into the experimental design. It is clear, from the months of data collection, that insurance canes constitute an important part of pruning protocol for some. Rather than confuse participants, it would seem to be preferable to tailor to their typical mode of thinking.

Thirdly, participants were asked to assume that the vine in question was of the *Sauvignon Blanc* variety. Chapter 8 suggested that familiarity with *Sauvignon Blanc*, or lack thereof, might have been a driver of the observed regional differences. Thus, indirectly, variety may have still somewhat played the part of a variable in this study. However, if a means of achieving a larger sample size is acquired, it would be preferable to integrate variety as a controlled variable in future study. This would be reasonably simple to randomise. Chapter 8 has suggested that a much leaner survey structure would achieve sufficient representation of participant attitudes towards pruning. Such changes could potentially allow for more efficient data collection, and hence for the integration of variety as a variable in future research.

One assumption that was not addressed in this study, and by all accounts should have been, was the effects of vine and row spacing. Even after it was realised that this area should have been accounted for in the survey design, a decision was made to continue on the path of not providing this information. This was due to concerns regarding the introduction of a new assumption after some participants have already completed the survey. It is unclear to what extent this lack of information may have changed participant responses. Only a small number of participants commented on the lack of row spacing information. Nevertheless, future research would profit from addressing this issue in the early stages of experimental design.

9.6 Visual Presentation Format

A number of nuanced issues emerged while arranging the visual format of the survey design. This was true for the Qualtrics ratings portion of the survey, as well as the decision-indication exercise. A basic issue was ensuring that the provided photos, for either part of the survey, contained enough visual information to be sufficient for the purpose of answering a given question. To achieve this goal within the Qualtrics survey, a number of photos from different angles were utilised, depending on the question. Within this task of matching images with question content, the designer of a Qualtrics survey is limited by the constraints imposed by Qualtrics software. In this instance, there were limitations of both size and number. A particular complexity here was that this survey utilised the offline version of Qualtrics, which imposes further graphic restrictions.

As it was, the offline version of the survey, accessible via tablet computers, had a slight visual glitch. This glitch did not affect the actual photos, nor the ratings device. As such, it was not seen to affect participant responses to any meaningful extent. More of concern was whether the presented photos, for both parts of the survey, achieved a sufficient amount of visual information. To alleviate some of this concern, participants were allowed to use supplementary photos if they so desired. These photos included close up views from several angles. Unfortunately, this aid was not available to participants who undertook the survey remotely. This discrepancy would have affected Pool A (Table

4-1) most acutely, as Pool C included 10 participants who completed the survey remotely. In reality, it is unclear to what extent the use of supplementary photos may have influenced participant responses. Future research will hopefully benefit from improved software that will allow for more flexibility in how photos are presented in digital surveys.

As noted in Chapter 3, slight alterations to the supplementary photos were made with Photoshop software. The primary purpose of these alterations was to eliminate tendrils and dead matter that might obscure a clear view of pruning options. It follows that those participants who did not have access to the supplementary photos did not benefit from these alterations. As above, it is unclear to what extent this discrepancy may have influenced participant responses. Among those who had access to the supplementary photos, no participants were able to detect that the photos had been altered. This particular observation suggests that the changes introduced by Photoshop software were indeed minor, as they did not catch the attention of participants who were working with both altered and unaltered photos. In either case, future research would certainly benefit from a more consistent strategy for the application of photo-alteration software. Improvements in capability for presenting photos in general would possibly eliminate some of the need for such alterations.

Another area of concern with regards to the survey operation was due to an idiosyncrasy of the Qualtrics offline survey application. The program had a policy of only recording a response if the participant had touched the dial. Such a nuance potentially could have excluded the responses of some participants who wished to express a middle rating, at the existing position of the dial. Participants were informed about this verbally at the beginning of the survey. As this only affected the offline application, those who participated remotely should not have been affected. An available setting within qualtrics could have restricted participants from leaving a question unanswered, but this was opted against due to ethical concerns. As such, it is unclear how many, if any, participants left a question unanswered when they actually intended a medium-value response. Future improvements to the survey software may eliminate some of this issue, or the issue may be alleviated through continuous reminders.

A final concern with regards to the presentation format of the survey pertained to the wording of questions in the Qualtrics survey. Wordings for these various ratings criteria may be viewed in Table 3-3. Some of the concepts targeted by these questions are reasonably complex, and, therefore, there is often a limit to how simply they can be expressed. While best attempts have been made to achieve clear wordings in this study, it should be a continual focus of future research to simplify and clarify survey wordings. The results of this study seem to indicate that at least some of the criteria wordings were clear enough to be highly correlated with overall quality. However, it is possible that unclear wordings may have contributed some amount to the high level of variance observed in the qualtrics survey.

9.7 Generation of Ratings Criteria

While Chapter 8 argued that a small number of pruning criteria dominated participant attitudes towards the subject vine, it is worthwhile to pause for an examination of the process employed to generate criteria for this study. At first glance, the explanatory power of the various models reported in Section 5.3 and discussed in Chapter 8 provide something of a validation for the criteria generation process. As these models are based on the relationships between pruning criteria and overall satisfaction, a strong model indicates that relevant criteria were operating.

The list of criteria in this study was the product of extensive preliminary vineyard visitation in 2014 and early 2015. Interestingly, at that time, the concern was whether or not the list of 24 criteria provided sufficient coverage, and whether additional criteria would be warranted. To some extent, this concern was based on work done in scale creation literature, where as many as 97 ratings have been sought within a survey (Verdú Jover et al. 2004). It is possible that such a large list may have yielded a clearer dimensional structure, and facilitated further scale validation analyses. Given the difficulty in producing a mere 24 criteria, and also the pervading need to limit the need for participant time expenditure, the criteria generation process was seen as complete at 24.

Results from the study not only validate this decision, they seem to call for an even more compact survey design in the future (Section 8.4). On the other hand, to abandon a more nuanced approach before having conducted this study, in favour of more general ratings, would have been unfounded. The findings, albeit limited in scope, provide some empirical foundation for a future decision to forego detailed ratings on individual criteria. Should another researcher choose to undergo the criteria generation process again, they are referred to the work of Parasuraman (1988), Spector (1992), and Verdu Jover et Al (2004) for example and guidance.

9.8 Missing Values in the Qualtrics Survey

The attention of the reader, in Chapter 4, was directed towards the issue of potentially Missing-Not-At-Random (MNAR) data. As reported then, the criteria relating to the colour of spurs was a particular trigger for these patterns. This variable was deleted, which was seen as a sufficient solution for the purposes of continuing the intended multivariate analyses, based upon the instruction of several texts (Hair et al. 2006, Tabachnick and Fidell 2001). It is unclear, presently, why this particular criteria was missing in a non-random fashion. One hypothetical explanation is that those who felt that other criteria were supremely important to the pruning of this vine tended to find the spur colour criterion to be superfluous and left it unanswered. Its location within the survey, near several key spur position criteria, may have prompted such a reaction. This explanation is speculative, as a number of explanations appear feasible.

In general, to leave MNAR patterns aside for a moment, there were many missing values throughout the ratings dataset (Table 4-5). Of those six criteria which were missing more than ten per cent of responses, one theme does emerge. Whether the question asked about the structural integrity of wood or how well the selections reflect vine capacity, an argument could be made for each of these questions that not enough information was available to offer an informed rating. In some cases, this may have simply meant that the photo was not of sufficient resolution and focus. In the case of the vine capacity question, it may have been difficult for participants to respond without further information regarding vine spacing, row spacing, and health of neighbouring vines. This represents a starkly different motivation, compared to a participant thinking a particular question is irrelevant.

Such a discrepancy may potentially offer an explanation as to why some criteria with many missing values triggered a failed test for MNAR rating, and some did not. The test for MNAR, to put it simply, involves separately grouping those who did and those who did not answer a particular question. If those who did not answer said question exhibit a significantly higher or lower group mean on other ratings, this will tend to trigger a failed MNAR test (Hair et al. 2006, Tabachnick and Fidell 2001). In this hypothetical scenario, spur colour as a criterion may have matched this description. It follows that participants who felt strongly about other criteria may have been more inclined to leave the spur colour criterion unanswered, thus resulting in a failed MNAR test. On the other hand, if a participant simply felt there was too little information to make a rating, the decision to leave the question unanswered would be unrelated to his or her attitude towards the other criteria in the study. In that situation, a failed MNAR test would be unlikely. This would explain those instances where a criterion was missing a considerable number of responses, but did not contribute to a failed MNAR test.

While this theoretical scenario does offer one potential explanation to the curious patterns of missing data, it is impossible to characterise such patterns definitively at the present time. Fortunately, this issue may be irrelevant to future research. A conclusion of this study is that participant attitudes towards pruning quality could be accurately captured with a small number of more general ratings. This would undoubtedly alleviate much of the incentive to skip questions. Such progress would be a highly positive outcome, as it would eliminate ambiguity in the results, and would also eliminate the need for lengthy hypothetical explanations such as this one.

9.9 Methodological Discussion Summary

One of the most positive outcomes of this study is that it appears to provide a foundation for more efficient pruning research to be conducted in the future. Much of the criticism contained within this chapter could be made somewhat redundant by a simple streamlining of the survey to include a much smaller number of ratings criteria. This chapter has also provided commentary on what vine attributes may be necessary to conduct studies of this kind. Tight control over vine selection parameters, together with a streamlined survey design, could allow for a study with improved scope, both in the number of vines and range of pruning situations. While this concept holds much promise, improvements are needed in the delivery format of such research. These improvements will, hopefully, in turn facilitate positive adjustments to the set of background assumptions that were necessary in this methodology.

Chapter 10

Conclusions

Taken as a whole, this project has yielded a number of notable outcomes, although many are somewhat different than what was originally intended. This chapter will seek to reorganise these outcomes into a more succinct summary. As a means of framing the conclusions of this study, this chapter will look at those core objectives identified at the beginning of this Thesis to highlight where progress has been made, and likewise, where recalibration is needed. Each sub-heading of this chapter will correspond to one of the objectives stated in Chapter 1. A few final remarks at the end of the chapter will conclude this Master's thesis. Referring back to Chapter 1, the four principle objectives of this study were:

- Modelling the relationship between individual pruning criteria and overall pruning quality
- Analysing fit-for-purpose of the criteria set currently in use for pruning evaluation
- Identifying and characterising pruning style groups, based on background variables
- Prediction of pruning decision preferences, with a view to future applications

10.1 Statistical Models for the Importance of Individual Pruning Criteria

A central focus of this report has been to create linear models to portray the effect of various pruning criteria on perception of overall pruning quality. These models were successful in identifying position criteria, particularly spur position criteria, as the main determinants (Table 5-3) of perceived quality in this case study. The results of these linear models were corroborated by participant decision indication data (part two of survey), which identified right side spur placement as a key point of participant division (*see* Section 8.1). Chapter 8 also argued that participant first impressions were formed almost entirely on the basis of position criteria. These first impressions (*see* Section 8.4), it has been argued, were modified by the time of the second overall assessment to reflect additional consideration of positive cane selection attributes.

While there is value in establishing the place of linear modelling techniques in pruning research, the interpretation of this specific set of results warrants some qualification. This report does not conclude that position would be the dominant consideration in all pruning scenarios. Such a universal characteristic would seem unlikely. However, a principle research question that has emerged out of this study is whether the dominance of a single attribute is a typical mode of conceptualising the pruning task, or whether this finding was a unique bi-product of this particular vine pruning scenario.

10.2 Assessing the Set of Pruning Criteria and Survey Structure

Principal Components Analysis revealed a high level of widely-shared variance, and general inter-correlation. This was interpreted (*see* Section 8.4) as a manifestation of the strength of general impressions. Such a condition stands in direct contrast to a highly dimensional structure, where participants are consciously processing detailed aspects of the task. Chapter 8 also posited that the broad nature of participant attitudes towards the presented decisions may have resulted from the salience of positional considerations, which appeared to dominate participant reactions throughout the study. Such arguments jointly suggest a number of possible changes to the structure of future pruning surveys.

These potential changes, as originally noted within Chapter 8, would be a radical departure from the current survey configuration. The suggestion of this report would be for a drastically streamlined set of ratings prompts in future research. Initial indications here suggest that as few as three ratings would provide a sufficient glimpse of participant attitudes. In this scenario, the three ratings would include one rating for spur selection, one for cane selection, and one overall rating. Such a compact structure would not only allow for the collection of data from a larger pool of vines, it would also raise a number of possibilities for the delivery of such a survey. In the view of this researcher, the optimal survey structure should reduce this number of ratings prompts, while still maintaining the decision indication portion of the survey. Such a modification would eliminate a major source of time constraint to pruning research, while continuing to reap the benefits of internal cross-validation.

10.3 Group Identification and Characterisation

Chapter 6 reported a successful identification of pruning preference groups, based primarily on region and organisational role. To the knowledge of the researcher, this is the first reporting of such group tendencies. Compared with those findings regarding the role of pruning decision-making criteria, it seems more realistic to accept the applicability of these findings. Given that this was the first attempt, by all accounts, to isolate such tendencies, it seems probable that they may exist elsewhere as well. The survey modifications proposed above would allow for a full investigation of whether these trends hold up over many vines, some vines, or no other vines.

The observed differences in pruning preference, based on region, were mostly related to differing propensities to restructure the subject vine. Hawke's Bay and Central Otago tended to cluster more closely to those decisions pertaining to vine restructuring. Marlborough and Waipara, on the other hand, tended to favour maintaining the current shape of the vine, by means of an R2 spur selection

(Figure 6-1 and Figure 6-3). Waipara also exhibited an atypical cane selection tendency, in its increased propensity to opt for R4 as right side cane selection. It is unclear, at present, whether regional pruning differences were social in origin, or related to the varying environmental conditions observed in the four selected regions.

As was the case with respect to region, participants of different organisational role differed in their inclination towards aggressive restructuring of the vine. Those identifying as supervisors, managers, or proprietors were significantly more likely to opt against leaving a right side spur selection (Figure 6-4). Those identifying exclusively as labour tended more towards those options associated with maintaining the previous shape of the vine, such as R2 as a spur selection and R1 as a cane selection. While potential social or psychological explanations for such discrepancies are outside the scope of this report, the implications of the finding are relatively clear. Managers of pruning operations must be proactive in bridging the potential disconnect between their strategies and those of their workers.

10.4 Prediction of Pruning Decision Preferences

Chapter 7 centred on the prediction of pruning decision preferences, through logistic regression, mostly for demonstration purposes. These models predicted whether participants would leave a right side spur, and, separately, which right side cane would be preferred. An intriguing feature of these analyses is that they utilised data from both the ratings data, as well as the decision-indication data. As such, these models may prove valuable in the future, not only for their potential application for artificially intelligent pruning, but also in their display of the synergistic effects of incorporating data from different sources and media. For the purposes of this study, the logistic regression models served as an important link between data obtained from the Qualtrics pruning criteria evaluations and the categorical decision-indication exercise.

Within this context, there were several predictors of the decision to leave a right side spur. Of these, region and the rating of horizontal distance away from centre were the most significant predictors. Likewise, a participant that identified exclusively as a labourer was considerably more likely to leave a spur, compared to the rest of participants. A more complex, multinomial model resulted from efforts to predict which right side cane a participant would select. Results from this model highlighted the predictive capacity of the pruned-vine rating of horizontal cane position away from centre. Likewise, this model reinforced the increased proclivity of Waipara participants to retain R4 as a cane selection. While these models were of limited strength, and sometimes difficult to interpret, their potential for application in an A.I. setting offers considerable promise.

10.5 Concluding Remarks

This was an ambitious project that sought to bring quantitative approaches to a millennia-old discipline. The research was moderately successful in that task, but has left much room for improvement. Future possibilities for a highly streamlined pruning survey design are particularly promising, and have been arguably validated within these chapters. Many of the practical constraints that restricted this research related to the time investment required from participants. Any progress on this front would have many positive downstream effects on the research design process.

Despite these limitations, some significant outcomes have been achieved. The identification of pruning style groups has the potential to open this field of research to exciting possibilities. Sensory Science literature has employed similar techniques and contributed a large sum to our understanding of the human element of wine science. This research has also added to our understanding of how human pruners in general are conceptualising their task. As is the case with much research, this endeavour has created more questions than it has answered. With the future of our vines and our industry ultimately resting on pruning decisions, these answers cannot come soon enough.

Appendix I

Contingency Tables for Background Variables and Pruning Decisions

Figure A-1: Contingency table for region and right spur decisions

Right Spur Decisions		**Region**				
	Cell Counts	Marlborough	Hawke's Bay	Waipara	Central Otago	Total
No Right Spur	Observed	24	24	18	24	90
	Expected	30.0	21.4	23.6	15.0	90.0
R2	Observed	31	15	27	7	80
	Expected	26.7	19.0	21.0	13.3	80.0
R4	Observed	11	8	7	2	28
	Expected	9.3	6.6	7.4	4.7	28.0
Total	Observed	66	47	52	33	198
	Expected	66.0	47.0	52.0	33.0	198.0

Figure A-2: Contingency table for region and right cane decisions

Right Cane Decisions		**Region**				
	Cell Counts	Marlborough	Hawke's Bay	Waipara	Central Otago	Total
No Right Cane	Observed	24	24	18	24	90
	Expected	30.0	21.4	23.6	15.0	90.0
R1	Observed	31	15	27	7	80
	Expected	26.7	19.0	21.0	13.3	80.0
R2	Observed	21	16	22	12	71
	Expected	21.8	17.6	19.1	12.6	71.0
R3	Observed	11	8	7	2	28
	Expected	9.3	6.6	7.4	4.7	28.0
R4	Observed	8	3	14	4	29
	Expected	8.9	7.2	7.8	5.1	29.0
Total	Observed	66	47	52	33	198
	Expected	66.0	47.0	52.0	33.0	198.0

Figure A-3: Contingency table for organisational role and right spur decisions

Right Spur Decisions	Organisational Role				
	Cell Counts	Labourer	Supervisor	Manager & Proprietor	Total
No Right Spur	Observed	17	28	42	87
	Expected	27.9	26.6	32.5	87.0
R2	Observed	31	22	25	78
	Expected	25.1	23.8	29.1	78.0
R4	Observed	14	9	5	28
	Expected	9.0	8.6	10.4	28.0
Total	Observed	62	59	72	193
	Expected	62.0	59.0	72.0	193.0

Figure A-4: Contingency table for organisational role and right cane decisions

Right Cane Decisions	Organisational Role				
	Cell Counts	Labourer	Supervisor	Manager & Proprietor	Total
No Right Cane	Observed	3	5	13	21
	Expected	6.2	6.7	8.1	21.0
R1	Observed	22	14	22	58
	Expected	17.2	18.5	22.3	58.0
R2	Observed	21	26	22	69
	Expected	20.5	22.0	26.5	69.0
R3	Observed	1	3	2	6
	Expected	1.8	1.9	2.3	6.0
R4	Observed	7	10	11	28
	Expected	8.3	8.9	10.8	28.0
Total	Observed	54	58	70	182
	Expected	54.0	58.0	70	182.0

Figure A-5: Contingency table for experience level and right spur decisions

Right Spur Decisions	Experience Level						
	Cell Counts	1-2 Years	3-5 Years	5-10 Years	10-20 Years	>20 Years	Total
No Right Spur	Observed	5	13	20	36	10	84
	Expected	7.8	10.5	22.4	32.4	11.0	84.0
R2	Observed	11	9	19	22	13	74
	Expected	6.8	9.3	19.7	28.6	9.7	74.0
R4	Observed	1	1	10	13	1	26
	Expected	2.4	3.3	6.9	10.0	3.4	26.0
Total	Observed	17	23	49	71	24	184
	Expected	17.0	23.0	49.0	71.0	24.0	184.0

Figure A-6: Contingency table for cluster membership and right spur decisions

Right Spur Decisions	Cluster Membership					
	Cell Counts	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
No Right Spur	Observed	13	21	26	8	68
	Expected	21.1	15.2	22.5	9.2	68.0
R2	Observed	30	5	17	8	60
	Expected	18.6	13.4	19.9	8.1	60.0
R4	Observed	3	7	6	4	20
	Expected	6.2	4.5	6.6	2.7	20.0
Total	Observed	46	33	49	20	148
	Expected	46.0	33.0	49.0	20.0	148.0

Figure A-7: Contingency table for cluster membership and right cane decisions

Right Spur Decisions	Cell Counts	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
No Cane from Right	Observed	2	6	8	2	18
	Expected	5.4	4.0	6.2	2.4	18.0
R1	Observed	15	9	14	5	43
	Expected	12.9	9.6	14.7	5.7	43.0
R2	Observed	13	13	19	8	53
	Expected	15.9	11.9	18.2	7.0	53.0
R3	Observed	2	0	2	1	5
	Expected	1.5	1.1	1.7	.7	5
R4	Observed	11	4	6	3	24
	Expected	7.2	5.4	8.2	3.2	24.0
Total	Observed	43	32	49	19	143
	Expected	43.0	32.0	49.0	19.0	148.0

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