Chapter 4 Results and Analysis

4.1 Introduction

This chapter presents the results and analysis described in Chapter 3. It begins by examining the block scale results. Particular attention is given in this section to the interaction between observed yield and vine relevant climate factors. The chapter then proceeds to explore the EM38 data collected at the vineyard scale, focusing in particular on the six blocks with the longest mining history. Finally, the NDVI data collected at the regional scale were analysed. As with the EM38 data, particular attention is given to the same six blocks with the longest mining history.

A note on terminology is required. In order to prevent confusion, particular data sets will be referred to using italicised capital letters and normal type will be used to indicate normal usage. For instance, *PILLAR* will be used when referring to the data set or statistical model, whereas pillar will refer to the areas above the chain pillar, *BEFORE* when referring to the data set or statistical models, and before when talking about mining progression. Terms from the statistical modelling are indicated with the first letter capitalized and the entire word in italics, as in *Vintage, Before-After,* etc.

4.2 Block Results and Analysis

4.2.1 Harvest and Pruning Results

Boxplots of harvest yield data for blocks A4 and B22 are presented in Figures 4.1A and 4.1B respectively. As boxplots (a.k.a. box and whisker plots) are useful for examining the range and variability of data at a glance, they are used extensively throughout this chapter. The box depicts the range between the first and third quartiles, known as the Inter-Quartile Range (IQR), and the solid black line within the box depicts the median point. The 'whiskers' depicted with the dashed line generally represent the minimum and maximum values of the data set. However, in the case where extreme values are present in the data (generally considered outliers), these points are depicted with circles outside the 'whiskers'. Such values are either 1.5 times greater or smaller than the IQR. Boxplots attributing yield to the various zones of blocks A4 and B22 are presented in Figures 4.2A and 4.2B.

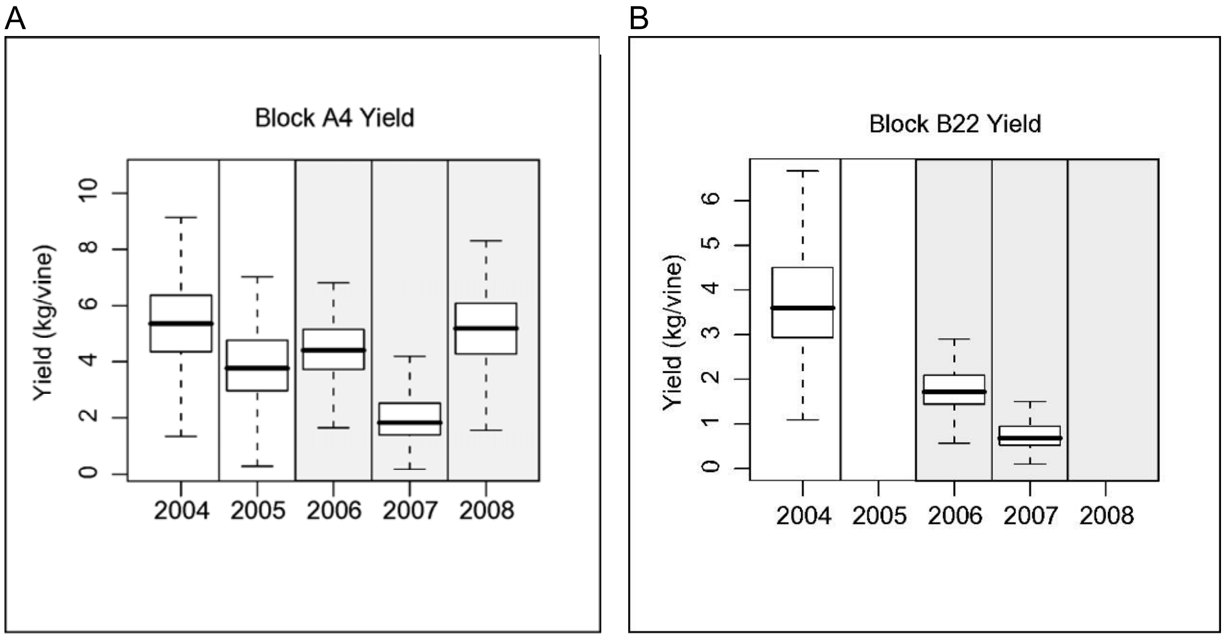


Figure 4.1. **Boxplots of harvest yield data for all years across blocks A4 (A) and B22 (B). Grey highlights mining status (after mining) and outliers were removed.**

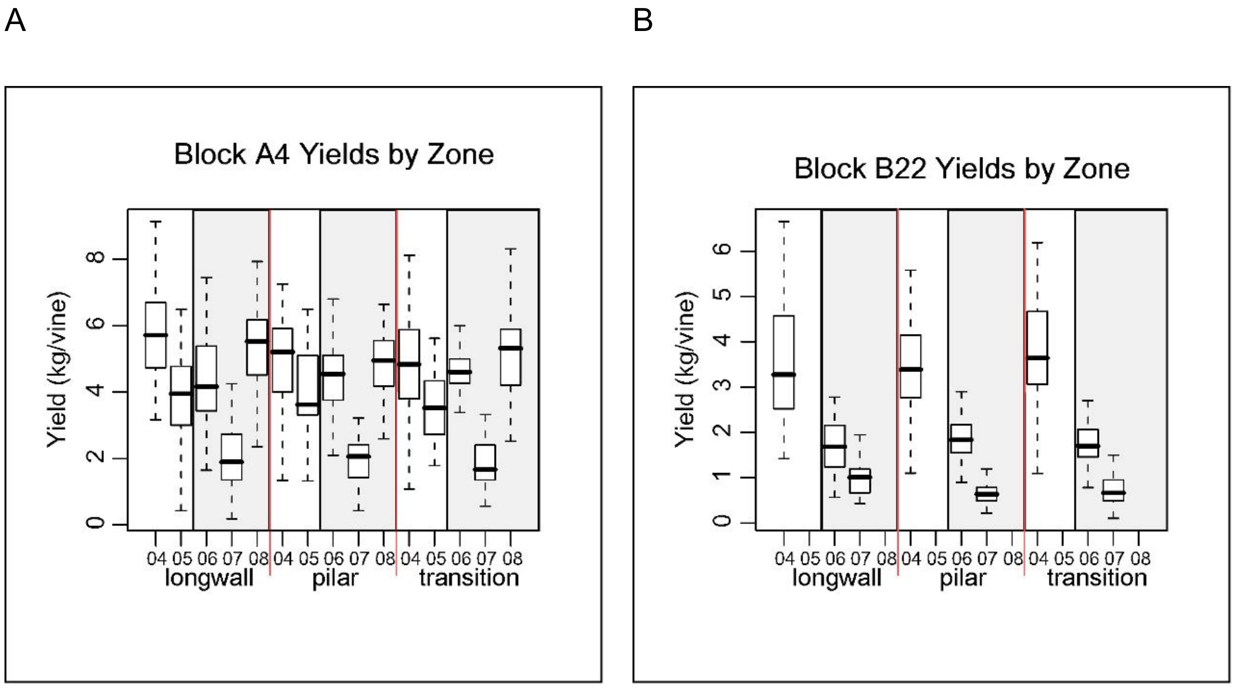


Figure 4.2. **Boxplots of harvest yield by zone by year for block A4 (A) and B22 (B). Grey highlights mining status (after mining), red lines separates zones and outliers were removed.**

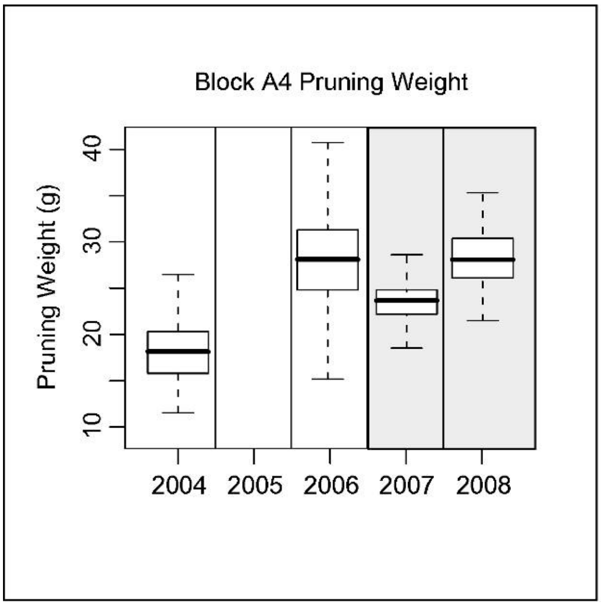
Overall, it is difficult to discern any clear LMS-induced trends within the data presented in Figures 4.1 and 4.2. For both blocks, the year of lowest yield was in 2007, the second year post-mining. An examination of figure 4.2A,B reveals that the each zone follows this same temporal behaviour, and significant differences between the zones are not readily apparent. Unfortunately yield data were not available for 2008 for Block B22 but Block A4 does show the yield recovers the following season.

It is possible that root shearing resulting from subsidence may have affected vine yield in both blocks, especially given subsidence occurred during the latter stages of the 2006 growing season hence requiring a full 2007 growing season for the effects to appear. Were this the case however, it would be expected that the effects would have been dominant in the pillar zone relative to the longwall and transition zones as it is this zone that experiences most soil cracking (Carpenter 1997). The fact that the yield penalty was observed in all zones in 2007 makes this less plausible. Boxplots of pruning related data are presented in Figures 4.6 and 4.7. Like the *HARVEST* data, no clear trends are readily discernable. For block A4, the lowest average pruning weight was observed in 2004, prior to mining. In both 2006 and 2008, similar average pruning weights were observed although their mining status differed. As with the *HARVEST* zone data, the zonal data for block A4 presented in Figure 4.4B mirrors that of the block averages with no zonal effects readily apparent.

For block B22, the lowest average pruning weight was observed in 2007, two years after mining had progressed underneath the block. Observations for 2004 and 2007 appeared to be similar in spite of their differing mining status. As with block A4 and the *HARVEST* data, the zonal representation of the data in Figure 4.7B also mirrors the overall average pruning weight for the entire block. As such, there is no readily discernable difference associated with mining evident in the various zones.

Although no trends are readily observed in either the *HARVEST* or *PRUNING* data, this does not imply the absence of mining impacts. Rather, it merely highlights the need for the further statistical modelling as presented in Section 4.2.2.

A



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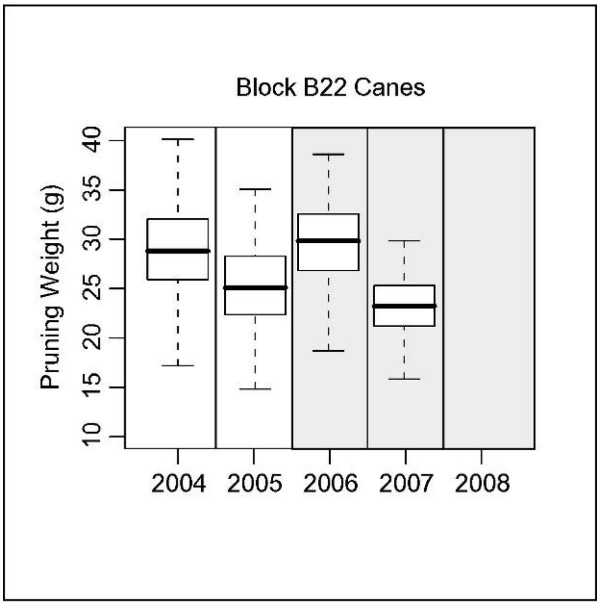
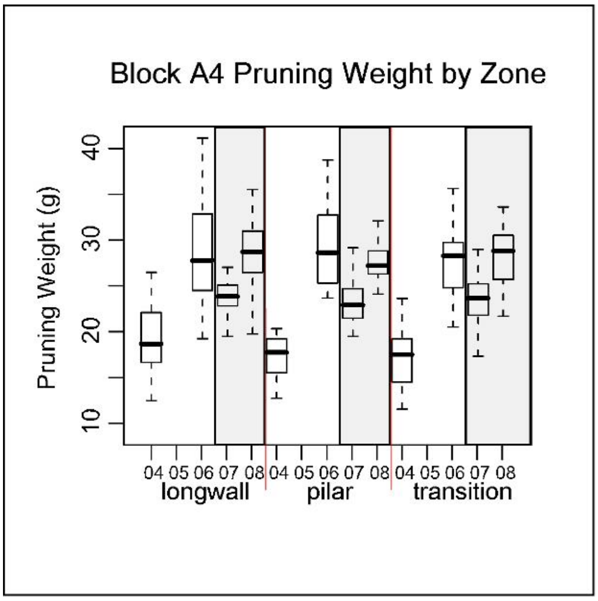


Figure 4.3. **Boxplots of pruning weight data for all years across blocks A4 (A) and B22 (B). Grey highlights mining status (after mining) and outliers were removed.**

A



B

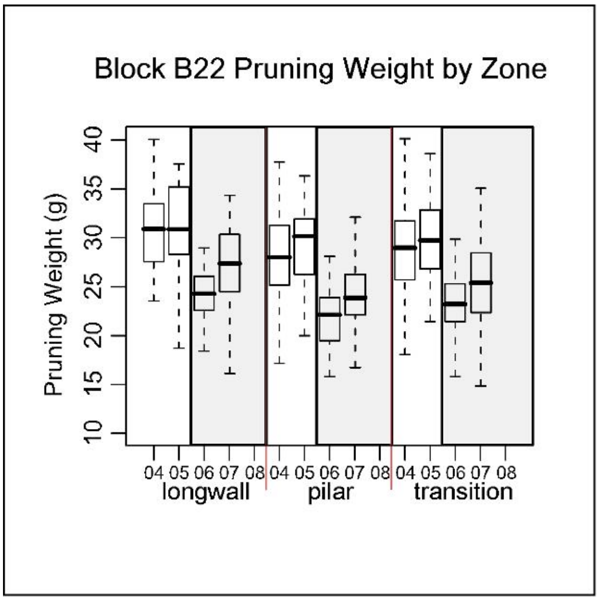


Figure 4.4. **Boxplot of pruning weight by zone by year for block A4 (A) and B22 (B). Grey highlights mining status (after mining), redlines separates zones and outliers were removed.**

4.2.2 Block Scale Statistical Modelling

The results of the statistical modelling of the block *HARVEST* data are presented in Table 4.1. Overall, both the *ZONE* and *ELEVATION* models performed similarly in that they accounted for 68 percent of the overall variability in the data and neither showed any statistical differences that could be attributed to either the mining and zone interaction or to elevation changes resulting from mining. The model indicated that yearly seasonal variation (*Vintage*) accounted for 35 percent of this variability, the difference in grape varietals (*Varieties*) between the blocks accounted for 19 percent and 14 percent is explained by time periods corresponding with before versus after mining (*Before/After*). Each of these terms was statistically significant. That 14 percent of the variability is accounted for by the time periods corresponding with mining activity is particularly important, as it suggests the possibility that mining activities might have impacted vine yield.

Table 4.1. Comparison of statistical modelling results for block yields. Interaction term was removed, as they were not significant. Explanatory variables coded for statistical significance.

	Zone Model (R^2 = 0.677)		**Elevation Model (R^2 = 0.677)**	
Variable	R^2	*Significance*	R^2	*Significance*
Before/After	0.140	***	0.140	***
Vintage	0.346	***	0.346	***
Varieties	0.191	***	0.191	***

Significance codes: '***' $p \leq 0.001$; '**' $p \leq 0.01$; '*' $p \leq 0.05$; ns = Not Significant

Unfortunately, due to the timing of mining progression, a similar model could not be developed for the *PRUNING* data, as indicated in Chapter 3. Hence, the blocks were analysed separately. The results for block A4 are presented in Table 4.2 and the results for B22 are presented in Table 4.3. For block A4, only the *Vintage* term was statistically significant in the *PRUNING* data whilst *Vintage* and both of the interaction terms (*BA:Zone* and *Elevation*) were statistically significant for block B22. The difference in the *PRUNING* responses suggests that mining may have impacted these blocks differently.

Closer examination of the statistical models for B22 indicates significant difference between the *PILLAR* and *LONGWALL*, and between the *PILLAR* and *TRANSITION* zone data. However, these differences were significant both pre- and post-mining. A graphical representation of these differences is presented in the interaction plot of zone means *Before* and *After* mining (Figure 4.5). Section 4.2.3 presents an analysis of the block data.

Table 4.2. Comparison of statistical modelling results for block A4 pruning weight. Zone and elevation interaction terms were removed, as neither was significant for this variable. Explanatory variables coded for statistical significance.

	Zone Model (R^2 = 0. 316)		**Elevation Model (R^2 = 0. 314)**	
Variable	R^2	*Significance*	R^2	*Significance*
Vintage	0.316	***	0.314	***

Significance codes: '***' $p \le 0.001$; '**' $p \le 0.01$; '*' $p \le 0.05$; ns = Not Significant

Table 4.3. Comparison of statistical modelling results for block B22 pruning weight. Explanatory variables coded for statistical significance.

	Zone Model (R^2 = 0. 316)		**Elevation Model (R^2 = 0. 314)**	
Variable	R^2	*Significance*	R^2	*Significance*
Vintage	0.295	***	0.295	***
BA:Zone	0.021	**	-	-
Elevation	-	-	0.019	***

Significance codes: '***' $p \le 0.001$; '**' $p \le 0.01$; '*' $p \le 0.05$; ns = Not Significant

Table 4.4. Mining zone comparisons of pruning weight before, during and after mining. All terms are referenced against the pillar zone, before and after mining. Explanatory variables coded for statistical significance.

	Model Coefficient	*Std. Error*	*Significance*	*Change Direction*
Before: Pillar vs. Longwall	2.5763	0.8389	**	+
After: Pillar vs. Longwall	1.9719	0.8306	*	+
Before: Pillar vs. Transition	1.2751	0.6301	*	+
After: Pillar vs. Transition	1.2474	0.6267	*	+

Significance codes: '***' $p \leq 0.001$; '**' $p \leq 0.01$; '*' $p \leq 0.05$; ns = Not Significant

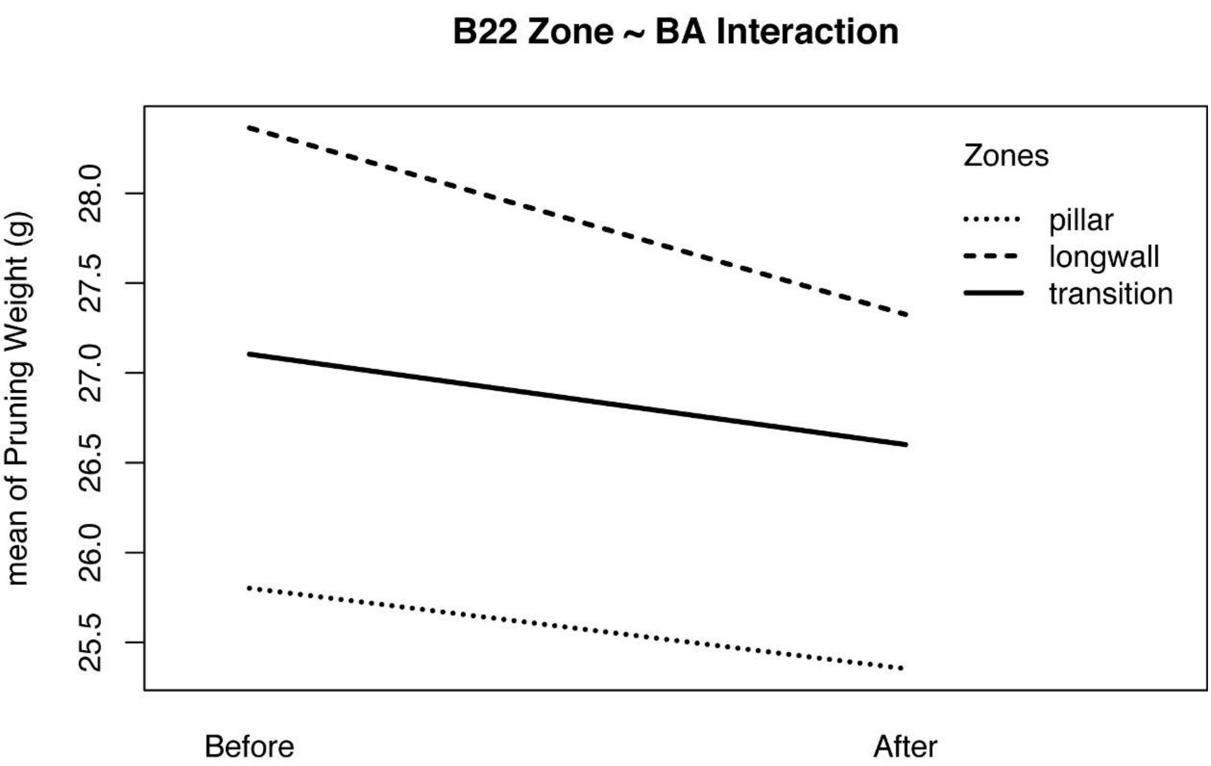


Figure 4.5. Interaction diagram of mean pruning weight for mining zones before and after mining progression.

4.2.3 Block Analysis

The statistical modelling results in the previous section indicated the possibility that mining might have impacted the vines in blocks A4 and B22. The results from the yield modelling indicated that the pre-mining *YIELD* data were significantly different from the post-mining data and that 14 percent (Table 4.1) of the overall variability in these data could be explained by the *Before-After* time periods. Although the statistical model applied to the harvest data in Section 4.2.2 not be used for the pruning data, the pruning data for block B22 in particular indicated significant differences between the pillar and longwall zone, as well as between the pillar and transition zone. As this *PRUNING* model is the easiest to explain, it is examined first.

The mean *Before-After* trend for each zone of block B22 was presented in Figure 4.5. From this interaction plot, the modelled differences in mean pruning weight between the various zones are clearly evident. However, it is also clear that the means for the *LONGWALL* and *TRANSITION* zones were different before mining. As such, these differences cannot be attributed to mining.

Although the *Before-After* mining differences in means weight associated with the individual block were not initially apparent, the differences become apparent when both blocks are considered together. For both blocks, significantly lower yields were observed during the 2007 vintage. During the 2006 vintage, similar low yields were also observed on block B22. Thus, for three of the five surveys conducted post-mining, the overall yields were quite low which explains why the post-mining time period is statistically different from the pre-mining period. Whilst mining could explain these three poor yields, it does not explain block A4's yields in 2006 and 2008, which were higher. Hence, this raises the question as to whether or not there is another, non-mining related explanation for these responses. As block A4 had the most complete set of harvest observations, it is the primary focus of the analysis that follows.

It was noted in Chapter 2 that water could impact overall vine yield in one of two ways. Too much water during flowering negatively impacts berry formation and development. This can lead to either a condition known as poor set or *coulure*, whereby many berries simply fall off when small (Gladstone 2004). Alternatively, excessive water during flowering can also cause *millerandage*, where many small or incompletely formed berries are found on the vine alongside normally seeded berries. If present, either condition will negatively impact overall yield.

However, if berries are properly formed, the lack of water can also negatively impact yield. Sufficient water is required for berries to take up water and swell during their growth phase. As was evident in Figure 2.9 (reproduced below as Figure 4.6 for convenience) most of a grape's mass is acquired during a 60 period day between days 30 and 90 of the berry development cycle. For block A4, this period coincides with the months of October and November. When the total rain for these months leading up to berry ripening (veraison – the transition period between berry development and ripening. Hereafter, the rainfall that during the period leading up to the verasion period is referred to as *Pre-Pre-Veraison Rain*) is plotted for each vintage of the study period, similarities between these totals and block A4's median yields are readily apparent (Figure 4.7).

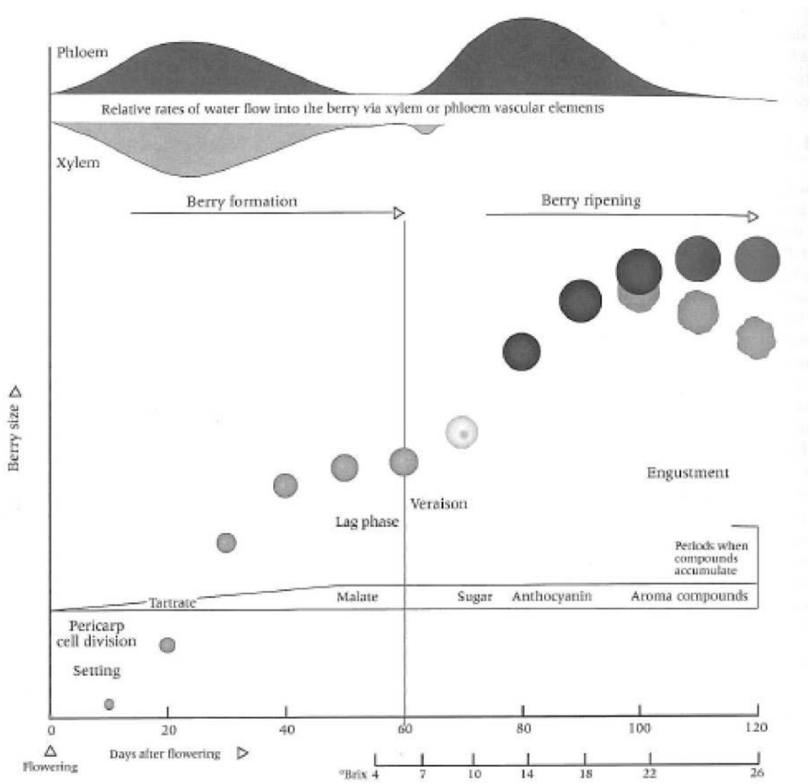


Figure 4.6. Post flowering, the berry development and ripening (Veraison) cycle is completed roughly 120 days later. From Coombe and Iland (2004)

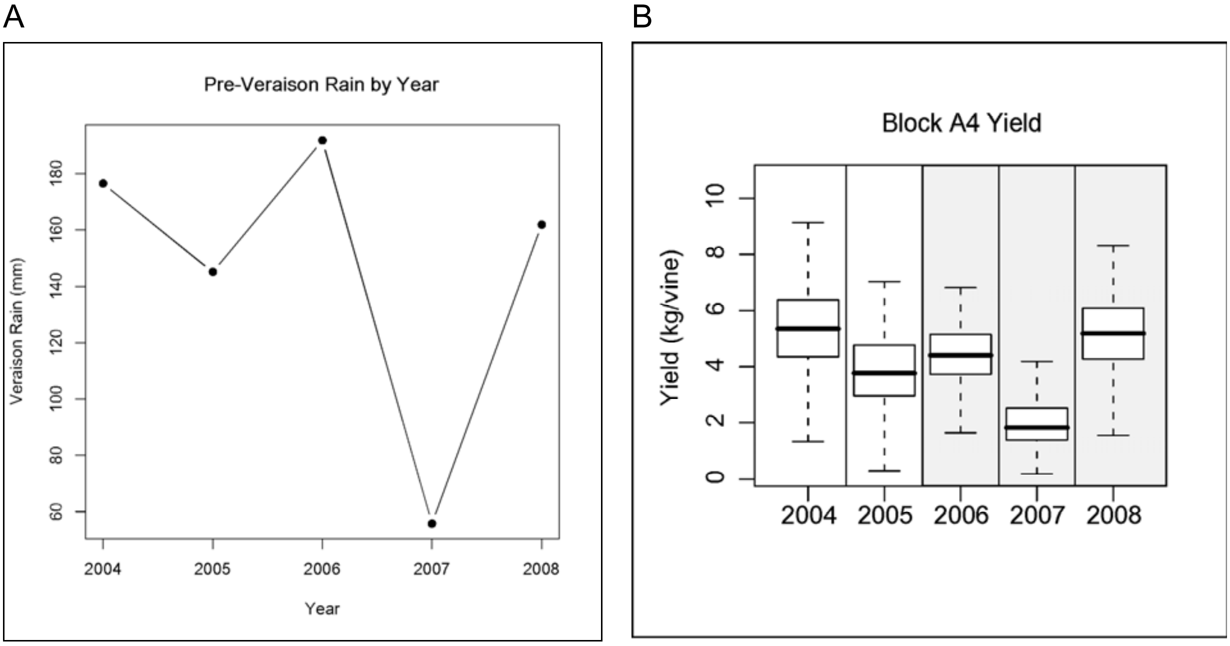
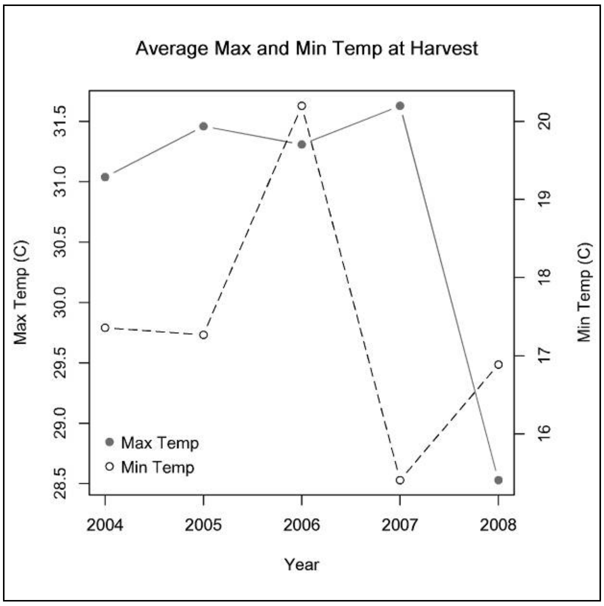


Figure 4.7. A) Plot of the region's total rain during berry development for each year of the study and B) boxplot of block A4's yield for each vintage of the study period.
Source for a: Bureau of Meteorology (2008).

Whilst the similarities between the plots in Figure 4.7A and 4.7B are readily apparent, it is also apparent that even though the 2006 *Vintage* experienced the highest rainfall during the berry development phase, the yield that year was not the highest observed during the study. However, recall from Chapter 2 that hot conditions during the 30 days prior to harvest can also negatively impact yield by causing water to evaporate through the skin of the grape. A plot (Figure 4.8A) of the average maximum and minimum temperatures in the 30 days prior to the harvesting of block A4 indicates that whilst 2006 didn't have the highest average maximum temperature, it did have the highest minimum temperature of the study period. Hence, because it was hotter for longer, vines and berries were likely to have experienced heat stress, and water loss through the berries would be likely.

A



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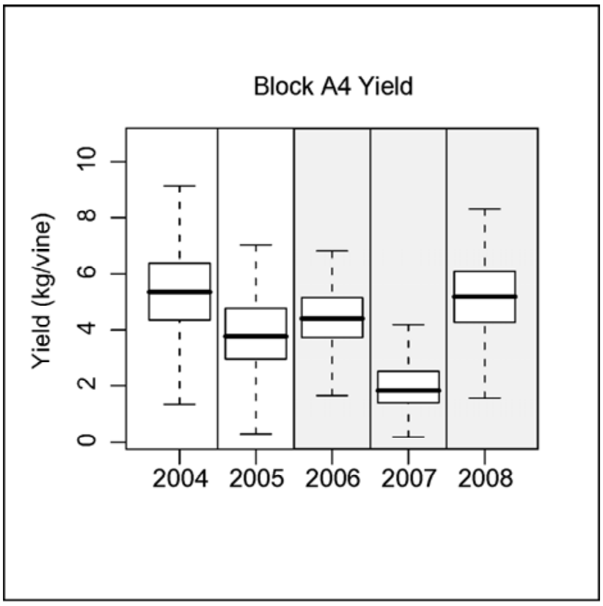

Figure 4.8. **A) Plot of the region's total rain during berry development for each year of the study and B) plot of the average maximum (red) and minimum (blue) temperatures for the region in the 30 days prior to harvest of block A.4. Source: Bureau of Meteorology (2008).**

A simple linear regression model was developed to explore these links between *Pre-Veraison Rain*, average maximum (*MaxTemp*) and minimum temperatures (*MinTemp*) and average block yield for block A4 (Table 4.5). Both *Pre-Veraison Rain* and the interaction between average maximum and average minimum

(*MaxTemp:MinTemp)* temperature were significant, and overall the model accounted for 98 percent of block A4's average yearly yield.

Table 4.5. Performance of multiple regression of block A4 average yield for all years (2004-8). Explanatory variables coded for statistical significance.

Adjusted R^2 for the multiple regression: 0.976		
Variable	R^2	*Significance*
Verasion Rain	0.759	**
MaxTemp:MinTemp	0.217	*

Significance codes: '***' $p \leq 0.001$; '**' $p \leq 0.01$; '*' $p \leq 0.05$; ns = Not Significant

Clearly, climate factors could be used to explain at least four of the five post-mining yields observed during the study. They could account for all of the post-mining yields for block A4 and the low rainfall during verasion 2007 could also explain the poor yield observed that year in B22. How then to account for the similarly poor 2006 yield for block B22? Whilst pre-harvest heat stress could explain why A4 yield didn't follow the rainfall trend that year, it can also explain why block B22 (Shiraz) exhibited poor yields as well. In response to heat stress, Shiraz vines are prone to a break down of the berry phloem connections (known as "berry shrivel") whereby sugar and water are no longer available to the berries (Coombe & McCarthy 2000; McCarthy 1999) and this response is independent of vine available water. Thus the reduced yields of 2006 may have been associated with berry shrivel.

4.3 EM38 Results and Analysis

4.3.1 EM38 Results

Figure 4.9 presents a series of maps of EM38 measured apparent electrical conductivity (EC_a) for each survey for vineyards in the study area. The original data were interpolated using a standard inverse distance weighting (IDW) algorithm and are displayed with a standard deviation contrast stretch applied individually to each block so as to highlight the variability within each block. Whilst there is evidence of linear patterns within the maps in Figure 4.9 consistent with the direction of mining, similar patterns were evident pre-mining. As such, they cannot be directly linked with mining activities. As with the vineyard block data, this highlights the need for the rigorous statistical modelling detailed in the following section.

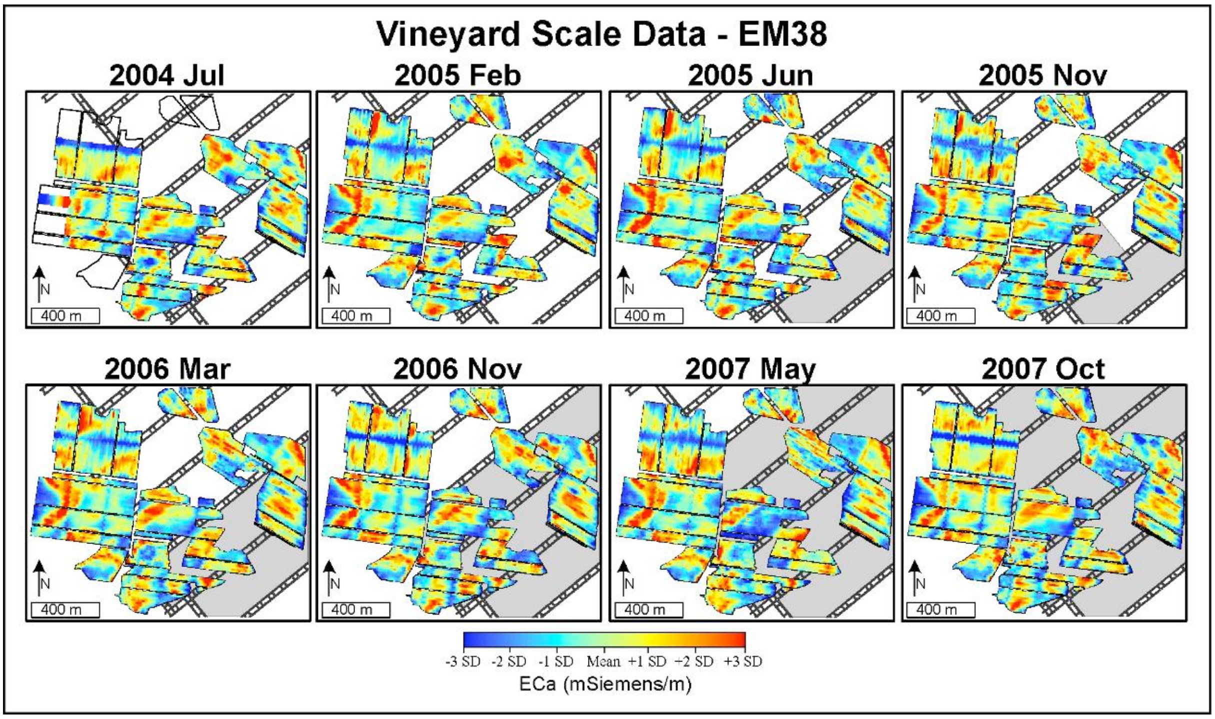

Figure 4.9. Vineyard scale EM38 data for all survey dates. Data were interpolated using a standard inverse distance weighting (IDW) algorithm and are displayed with a standard deviation contrast stretch applied individually to each block so as to highlight the variability within each block. Mining progression highlighted in grey.

Boxplots of apparent electrical conductivity for the analysis blocks (A2-4, B16-17, B22 and the 'control' block as indicated in Figure 3.2) for all survey dates are presented in Figure 4.9. Though differences are evident between blocks, the overall patterns exhibited by the blocks are relatively consistent.

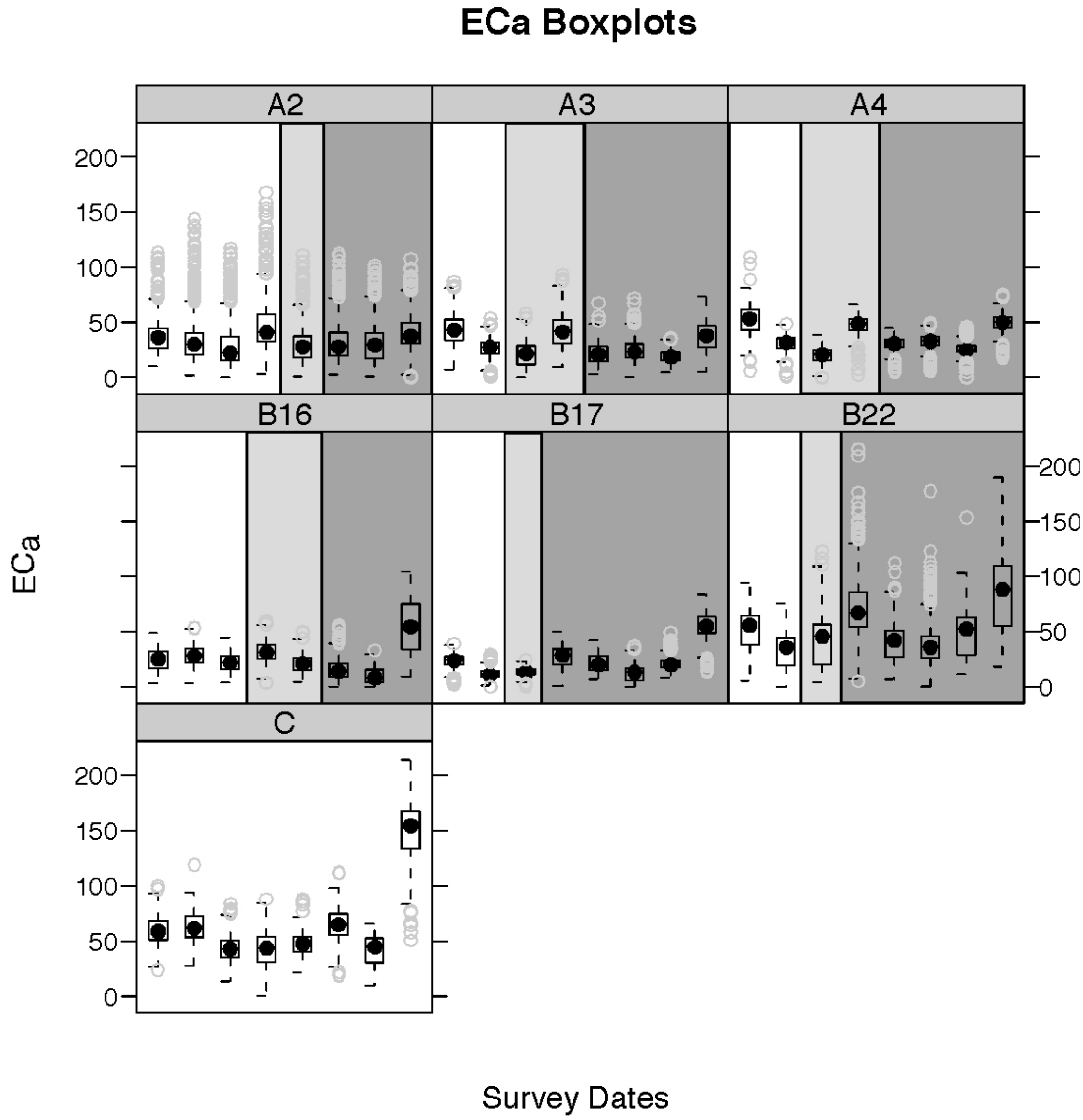

Figure 4.10. Boxplots of EM38 data for selected blocks from vineyards A, B and 'control' block C. Mining progression highlighted as background behind boxplots; white signifying survey data acquired before mining, light grey signifying acquisition during mining, and the dark grey signifying acquisition after mining.

4.3.2 Vineyard Scale BACI Comparisons and Analysis

Figure 4.11 presents a comparison of each block's average apparent electrical conductivity through time with reference to both the 'control' block as well as the total rainfall in the two-week period preceding the EM38 survey. Figure 4.12 shows the same comparison but highlighting the relevant blocks from vineyard A, while Figure 4.13 highlights the comparisons with the blocks from vineyard B. Figure 4.14 depicts the linear relationships between the average block conductivity and total rainfall for the two-week period immediately preceding the survey. Figure 4.15 depicts the average apparent electrical conductivity of the mining zone before, during and after mining while Figure 4.16 provides a block-by-block comparison of the average apparent electrical conductivity for mining zones with that of the control block before, during and after mining.

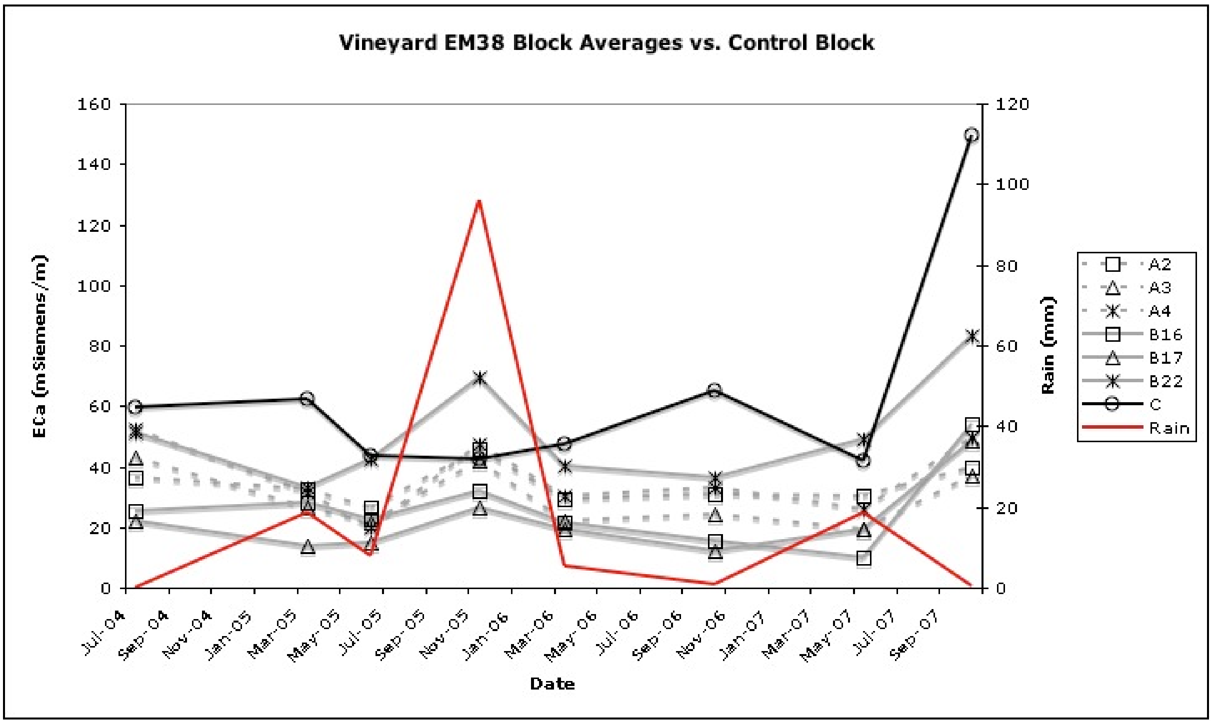

Figure 4.11. Comparison of average apparent electrical conductivity (EC_a) for relevant blocks in vineyards A and B with 'control block' C. Red line indicates total rainfall in the two-week period preceding the survey.

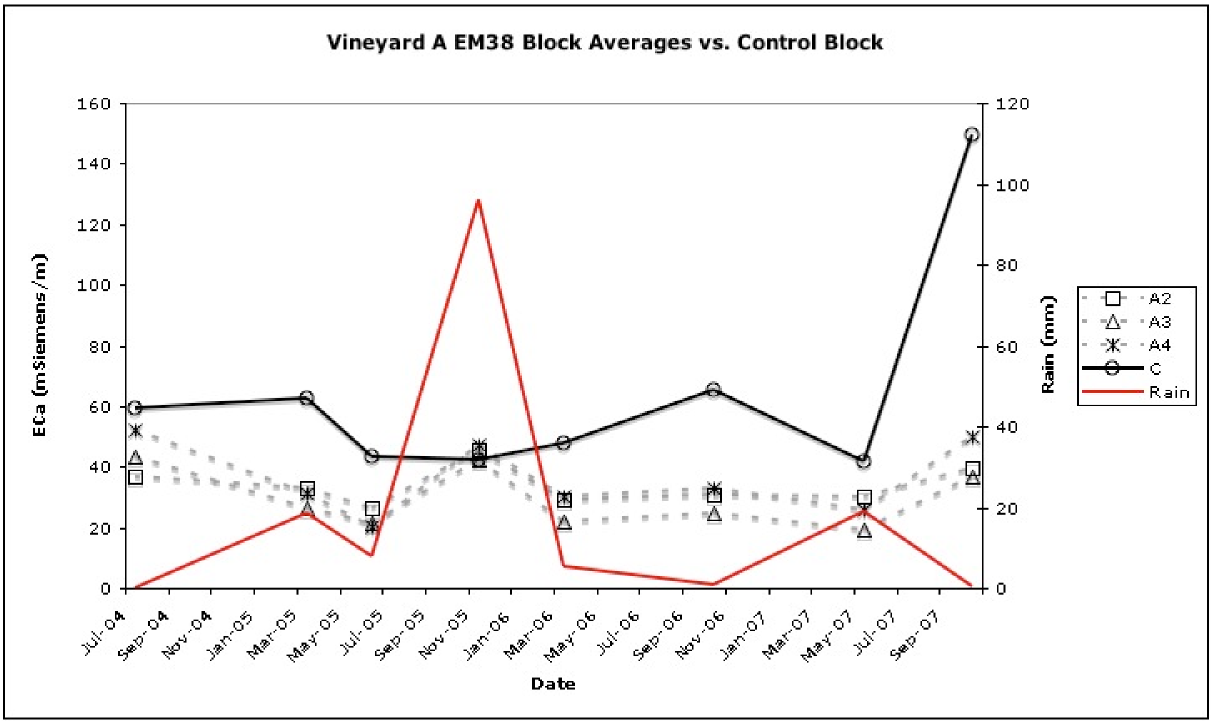

Figure 4.12. Comparison of average apparent electrical conductivity (EC_a) for blocks in vineyard A with 'control block' C. Red line indicates total rainfall in the two-week period preceding the survey.

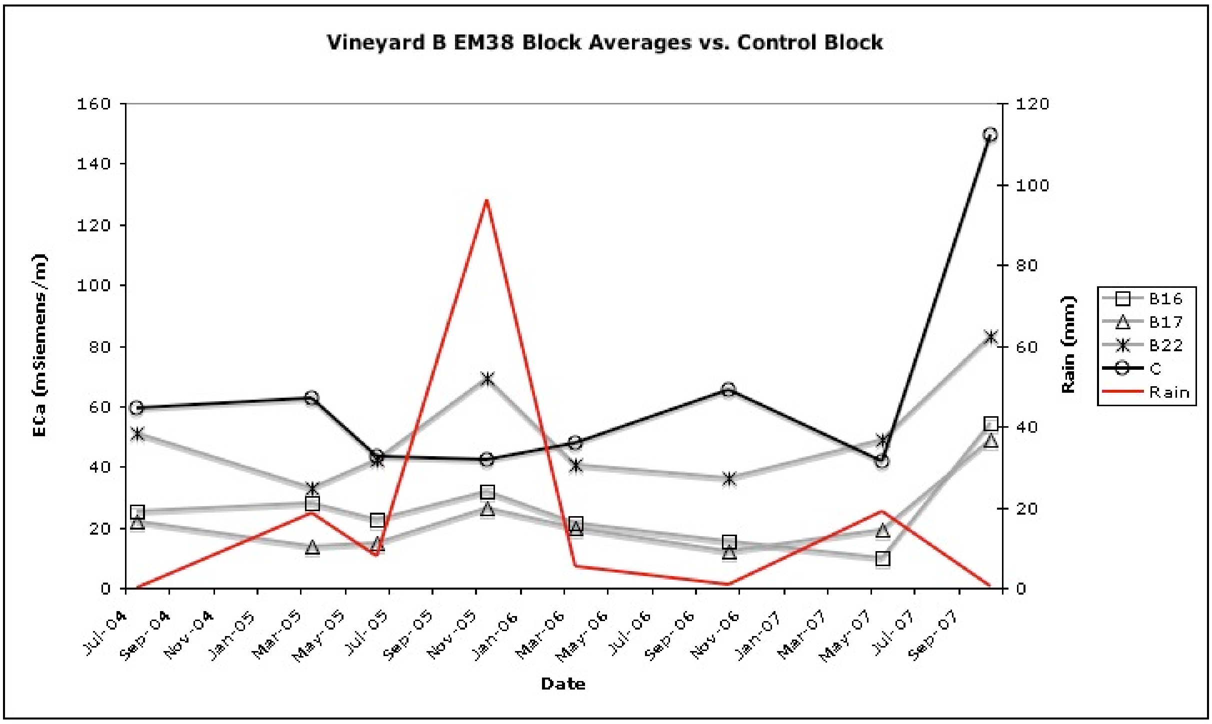

Figure 4.13. Comparison of average apparent electrical conductivity (EC_a) for blocks in vineyard B with 'control block' C. Red line indicates total rainfall in the two-week period preceding the survey.

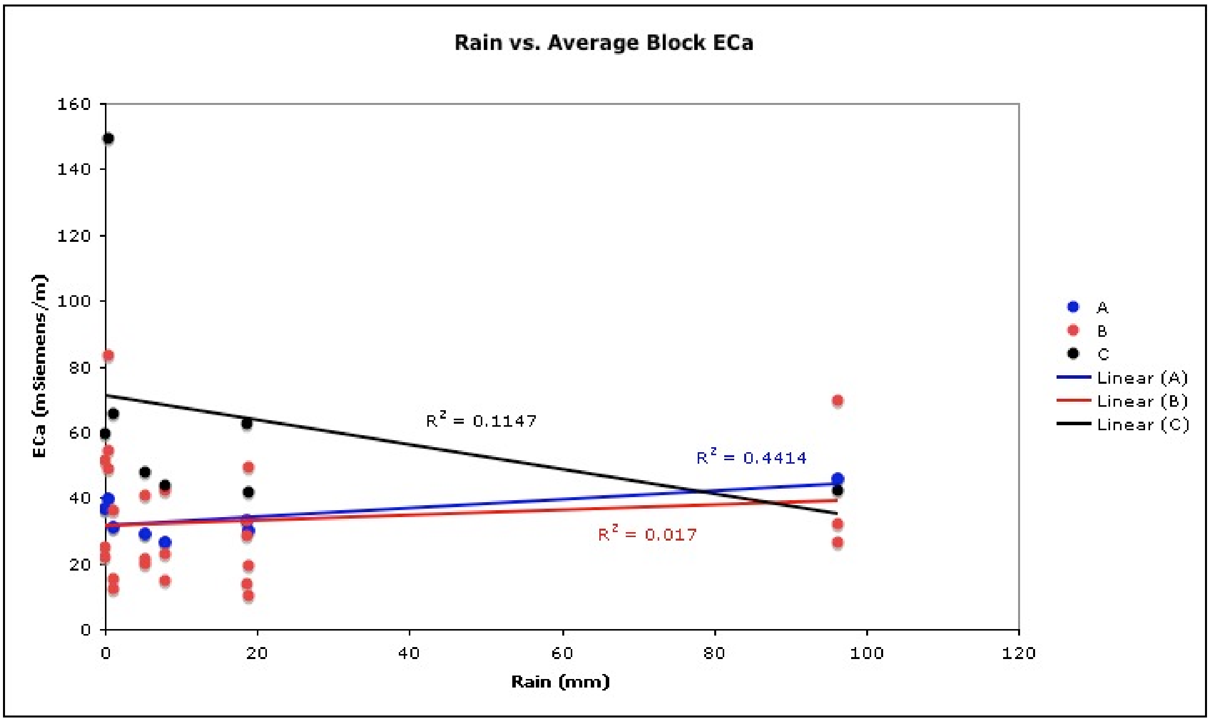

Figure 4.14. Scatter plot of apparent electrical conductivity versus total rainfall for the two weeks preceding the survey. Regression lines indicate the linear relationship between rain and EC_a for each vineyard.

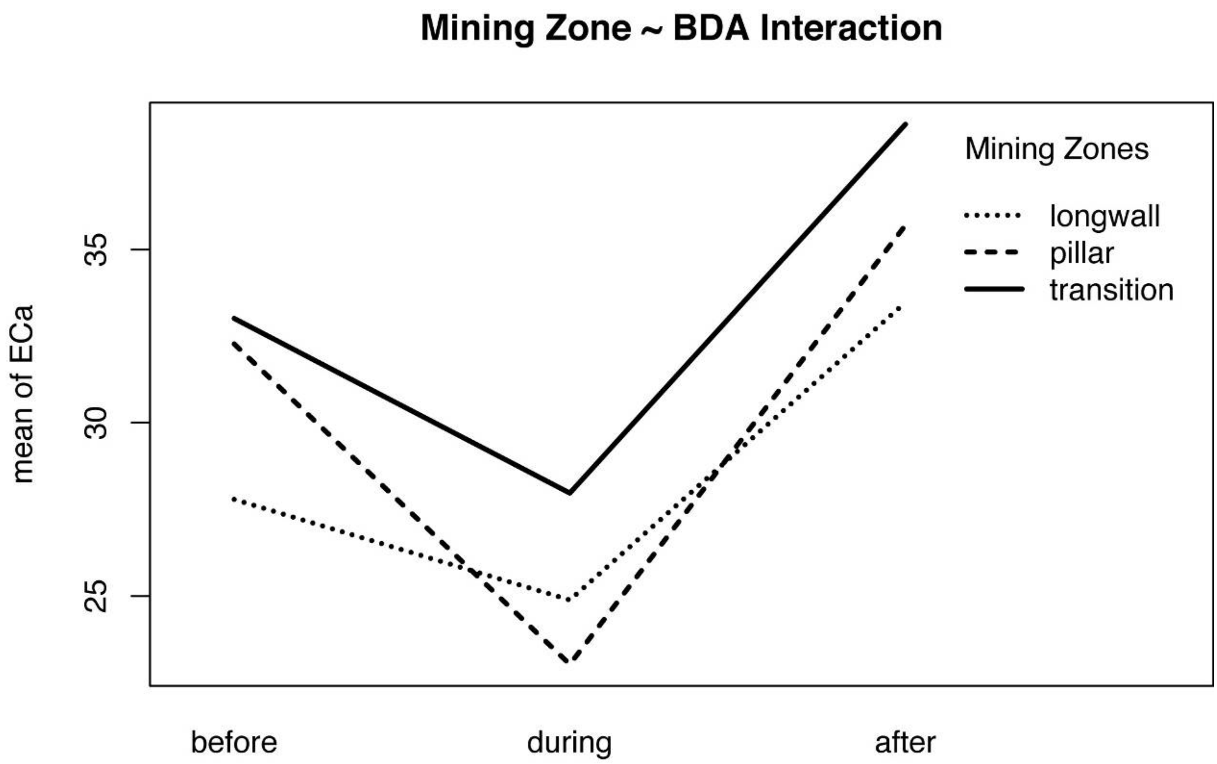

Figure 4.15. Interaction diagram of apparent electrical conductivity for mining zones, before, during and after mining progression.

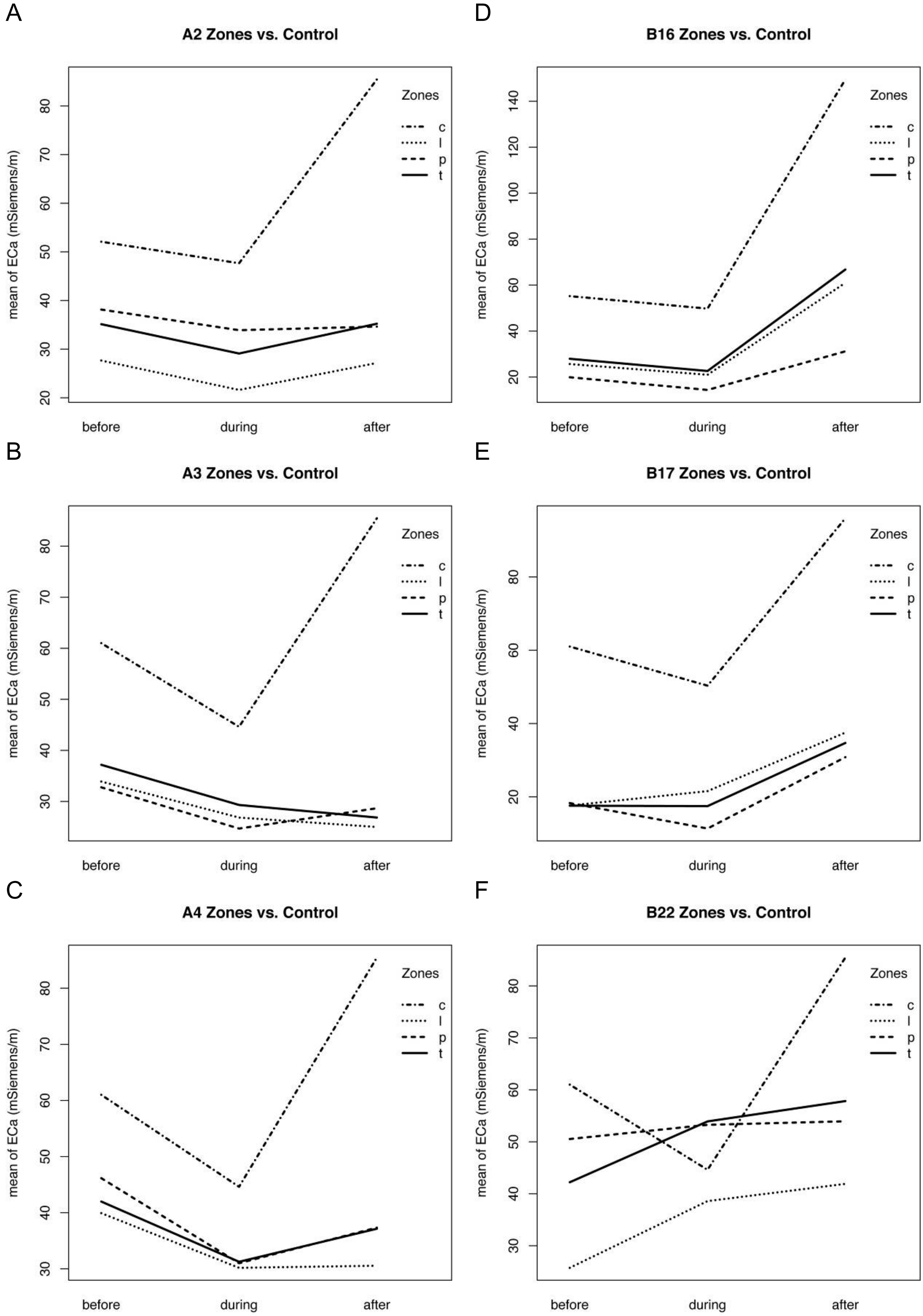

Figure 4.16. Comparison of block zones' mean apparent electrical conductivity (mean EC_a) with 'control' block, before during and after mining for blocks in vineyard A (A-C) and vineyard B (D-F)

Although no statistical BACI comparisons were employed (for reasons discussed in section 5.3) from the plots it is clear from Figures 4.11-13 what such comparisons would indicate. A comparison between each block's apparent average conductivity with that of the 'control' blocks suggests a significant difference between them, occurring after mining. This is primarily a result of the high EC_a observations made in the 'control' block during the final survey; the average from that survey was more than double (~2.5x) that of the next second highest mean. This apparent difference is further magnified by the fact that the second highest EC_a observations for the 'control' block also occur post-mining.

This has the effect of skewing the BACI comparisons, which is apparent in pair-wise comparisons of individual block's mining zone EC_a with that of the 'control' block (Figure 4.16). In each plot in Figure 4.16, the sharply increasing trend in the 'control' block suggests that the magnitude of the difference between it and the various zones is greater in the *After* period than in the *Before* period. Classically, this would be considered the result of the environmental impact. However, it is unclear that these large differences are a result of the mining intervention; the EC_a observations for all of the other blocks were also higher during the final survey, just not quite as high as that of the control block.

These differences in the *Before-After* comparisons are further complicated by the fact that the apparent electrical conductivity of the three vineyards (A, B and C) do not appear to follow similar trends with respect to rainfall (Figure 4.11). Whilst the blocks in vineyard A have a significant positive relationship with total rainfall in the two-weeks leading up to the survey date, the 'control' block as only a weak, negative relationship, and the blocks in vineyard B do not appear to have a significant linear relationship at all. Given the obvious link between EC_a and soil moisture (Corwin &

Lesch 2005) it would be expected that a positive correlation would exist. Also, this is supported by the *in-situ* multi-level capacitance probe data (not presented) that indicated that most moisture had moved below one metre within a week of the rain event. Any deviation from this, certainly a null-response and particularly a negative relationship can largely be attributed to supplementary irrigation during the intervals of zero or less-than-expected rainfall. Irrigation for Block A was managed on the basis of soil moisture sensing Capacitance-probes (C-probes), with irrigation volumes and intervals closely matched to the water requirements of the vines, with little chance of over-watering. By comparison, Blocks B and Control were irrigated using only the traditional 'vigneron's instinct' approach, and the natural tendency is to over-water (Chris Sloane Pers.Comm.) both in terms of frequency and volume.

Overall, there was some evidence of a systematic trend across mining zones through time. As Figure 4.15 indicates, there were significant differences between the EC_a of the *LONGWALL* and *TRANSITION* zone data. However, as both the *LONGWALL* and *TRANSITION* zones followed similar trends both during and after mining these differences cannot be attributed to mining. In contrast, there was very little difference between the apparent electrical conductivity of the *PILLAR* and *TRANSITION* zone prior to mining. During mining, however, the differences in EC_a were readily apparent, although this difference is not so pronounced once mining had been concluded. This suggests that there might have been a systematic impact within the pillar zone caused by the mining process itself. This is supported by Carpenter (1997), who found reported that EC_a decreases in the short term at the boundaries of what are herein considered the boundaries of the pillar and transition zones.

A closer examination of plots in Figure 4.16 suggests that these differences may actually be more localized and site specific than systematic. This is evidenced by the fact that very few of the plots in this Figure exhibit similar trends within the mining zones. For instance, although there were EC_a differences between all the zones in Figure 4.16A (block A3), the differences persisted *During* mining, but *After* mining the *PILLAR* trend was different to those of the *LONGWALL* and *TRANSITION* zones. The zones in block A3 followed a somewhat similar trend to that of block A2. However, whilst the *PILLAR* zone started with higher conductivity than both the *LONGWALL* and *TRANSITION*, and finished with lower average conductivity than the *LONGWALL* in block A2, the *PILLAR* in A3 began with lower average conductivity than both the *LONGWALL* and *TRANSITION* zone before mining, but then it finished with higher conductivity after mining. In fact, although some of the trends appear similar (e.g. between block A4 and B16), a careful examination reveals that this is not the case; for block A4 it is the *LONGWALL* zone that diverges from the other two zones post-mining whilst it is the *PILLAR* zone that diverges in block B16.

4.3.3 EM38 Statistical Modelling Results and Analysis

A map of the slope risk categories calculated for the relevant vineyard blocks (Section 3.2.3.4) is presented in Figure 4.17.