INTERPINE

Forestry Innovation

Investigation of Measurement Variability in FCM indicators

Task 3

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Prepared for **NZFOA**

Print Date: Thursday, 31 March 2011

Ref. No: NZFOA170111

37 pages (including cover)

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1 EXECUTIVE SUMMARY

Abstract

Interpine were commissioned to carry out an experimental field trial with the aim of understanding the sources of variability in visual assessment of crown condition indicators by Interpine's field teams. 755 tree assessments were made across 18 plots by three operators following an experimental design aimed to control sources of variability wherever possible. Analysis of the results showed that significant between operator variability remained in the dataset which suggests that significantly more effort and funding is required for training and calibration of field teams. A comparison of the sources of variation for the key crown indicators when assessed from a common or unique assessment position was carried out which suggested that the assessment position was important for the transparency indicators. A graphical and statistical analysis of the additional crown indicators is also provided.

Objectives

The objective of this study was to quantify the sources of variation in the visual assessment of crown condition as undertaken by trained assessors from the 2010 survey. The between operator variability was of particular importance.

Key results

A field experiment was designed where experienced operators carried out assessment on plots in Kaingaroa forest which were part of the 2010 FCM survey. The results were analysed through the development of a mixed effect model which partitioned the variation in the data set. The model output indicated that the between operator variation remains significant for both transparency measures and for defoliation. This suggests that significant effort must be spent on training and quality assurance in future measurement periods to reduce the between operator variability. The defoliation indicator was found to be more variable than the measures of crown transparency assessed, this indicates that defoliation is more difficult to assess consistently and that the communication of effective assessment of defoliation is a difficult process. Both transparency measures were less variable but the model indicated these indicators are highly correlated with tree age and this must be taken into account when interpreting the FCM dataset. The results of the model analysis also indicated that assessment of crown condition from a known position reduces between operator variability.

Application of Results

The results of this research mean that we have an understanding of the nature of the variability which exists in the assessment of crown condition and we can utilise this in the interpretation of data with relation to changes in forest condition. The between operator variability provides a measure of the consistency of assessment between individuals and through training and documentation we should endeavour to reduce this where possible. Continuation of similar projects in the future will facilitate monitoring of the between operator differences in the crown condition assessments.

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3 INTRODUCTION

3.1 BACKGROUND

During winter 2010 Interpine Forestry Limited (Interpine) were commissioned by the New Zealand Forest Owners Association (NZFOA) to design and carry out the first measurement of a national forest condition monitoring (FCM) survey for New Zealand. With data collection complete Interpine were contracted by NZFOA to carry out a trial aimed at understanding the variability within the FCM indicators used during the 2010 measurement. The methodology followed and the results obtained along with a summary of the analysis undertaken on the data collected are contained in this document.

3.2 OBJECTIVES

Interpine's objective in carrying out this study was to quantify and understand the variability between operators making visual crown condition assessments as part of the FCM programme. Information on the variability of the dataset is a vital component in its analysis and interpretation and trials of this type have become standard practice in FCM programmes around the world. The results should provide insight into the interpretation of measurement procedures by the technicians involved and therefore help guide the manual update which currently being undertaken by Interpine.

4 METHODOLOGY

Significant emphasis was placed on experimental design for the current study and the approach followed is detailed in the following sections.

4.1 FIELD PERSONNEL

Interpine employed experienced team leaders from the 2010 FCM measurement programme for this trial. All technicians received training prior to the start of the 2010 measurement and are familiar with the procedures manual for the collection of FCM indicators in New Zealand[1]. Three operators, working alone to increase the sample size collected, were used during this trial and it was assumed that all operators had similar levels of ability and experience at measuring FCM indicators.

4.2 TRIAL LOCATION

The trial was conducted in plots measured as part of the 2010 FCM programme in the Central North Island of New Zealand. It was decided to use this plot network for the following reasons:

- The plots are part of a pre-existing sampling design across New Zealand based around a grid with a randomly generated start point;
- The plots are already marked leading to efficiencies in tree location
- Survey meta data including ownership information is already available for this plot network;
- Little additional effort is required for mapping;
- A comparison can be made with the 2010 FCM programme measurement if required; although this will not be part of this study;
- The plots are sufficiently distant (at least 4km) to remove any bias caused by proximity.

All trial plots were located in Kaingaroa forest to reduce travel distances for data collection teams. Eighteen plots were located within Kaingaroa for use in the experiment; six plots were selected using a random number generator from each of the three age classes used in the FCM methodology. This approach eliminated bias whilst ensuring that the entire range of plot ages was sampled.

Table 1. The plots included in the experiment and corresponding age classes

Plot	Age class
CY68	3
CZ65	3
CZ66	3
CZ67	3
DA65	1
DA66	1
DB65	2

1 Forest Condition Monitoring (FCM) of Pinus radiata in New Zealand, File Data Collection Procedures. Version 1.2.1 Prepared by Interpine Forestry Ltd. On behalf of the NZFOA

DB66	2
DC65	1
DA64	1
DC61	1
DD60	1
DC63	2
DD61	2
DD62	2
DA62	3
DB62	3
DC64	3

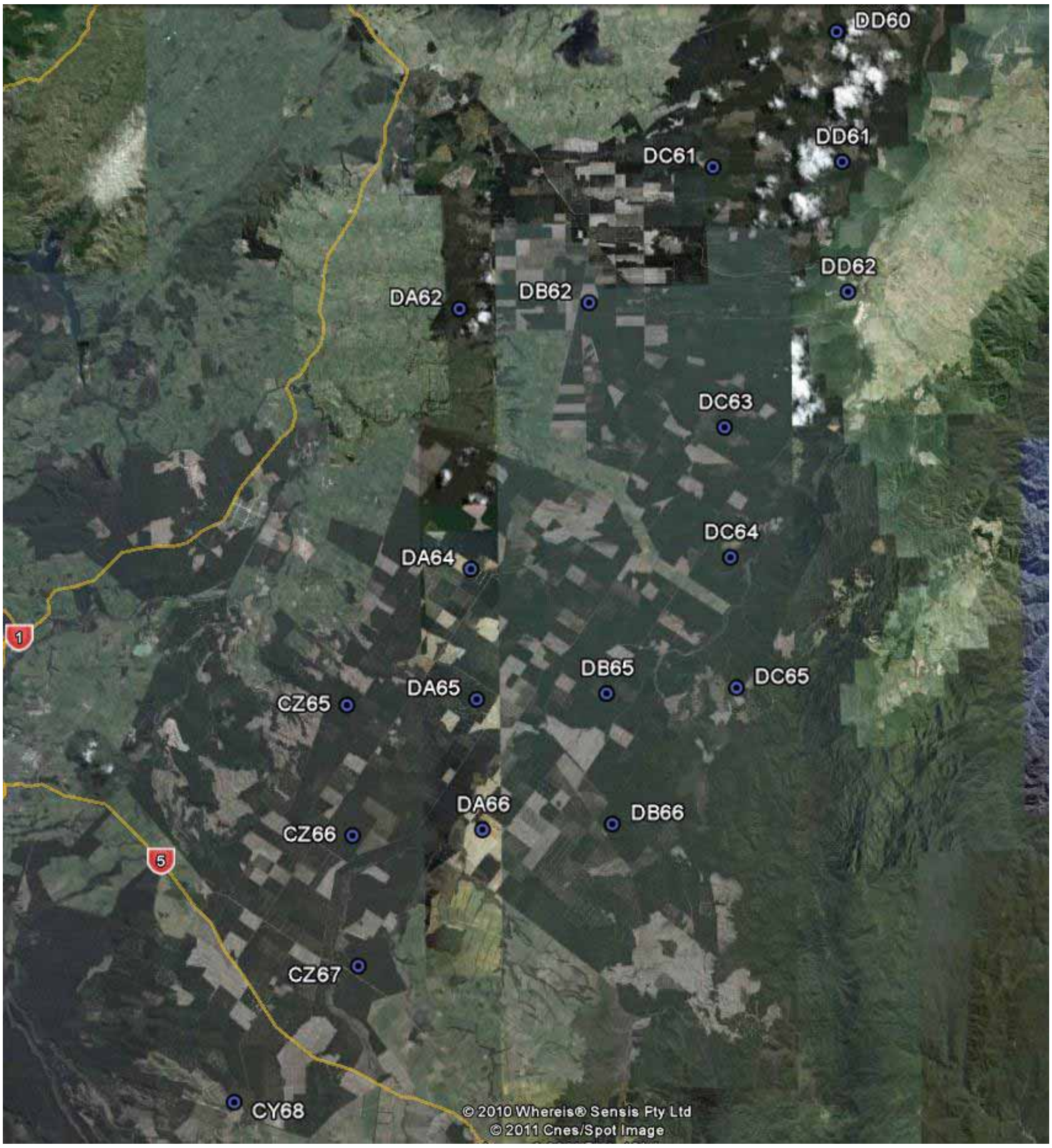

Figure 1 . The locations of the plots used in the experiment.

4.3 TIMING OF MEASUREMENT

The experiment took place over three days in January 2011, all operators were in the same forest region on the same day in order to control the effect of variation associated with specific conditions on any measurement day. The operators start point in the forest was randomly assigned to remove bias and each operator's course through the forest was controlled to prevent operators being in the same plot at the same time. Operators were instructed not to talk to each other should they see each other during data collection to prevent interaction between the field crews. The operators involved in the trial were randomly assigned as operators one, two or three prior to the beginning of the trial and maintained this identity throughout. The operator's identity defined their start point and plot measurement sequence.

4.4 TREE MEASUREMENT

All visual crown condition assessments recorded as part of the 2010 FCM measurement programme were assessed by all operators as part of this study. The operators were given the bearing from where the crown characteristics were assessed in the 2010 measurement for each tree. This is appropriate as this will be standard re-measurement procedure during the repeat measures of the FCM programme. When a situation arose where operators were unable to assess the tree from the assigned position they selected a new suitable assessment position and record the new bearing and distance to the subject tree. All data collection took take place in a specifically designed template using Plotsafe forest data capture software.

4.5 SOURCES OF VARIATION FOR CONSIDERATION

The following section documents the variables which Interpine have attempted to control through the experimental design.

4.5.1 Tree age

It is widely documented that age has a significant impact on FCM indicator assessment. To account for the variability caused by tree age an approach known as blocking has been employed to reduce experimental error. The study plots have been split into three groups according to their age. Grouping plots into homogenous age units decreases the overall variance resulting from the effect of tree age. In concurrence with the segregation in the FCM procedures manual the age classes used in this trial will be:

- 0 – 9 years old -class one;
- 10 – 18 years old –class two;
- Older than 18 years old –class three.

To provide a balanced experiment three plots from each age class are included in the trial plots in each forest region where practicable.

4.5.2 Environmental conditions

To control for the variation associated with the environmental conditions (weather, undergrowth hindrance, tree form) all operators will be in the same forest region on the same day.

4.5.3 Time of day

The time of day of assessment will introduce variability into the crown condition assessment because of the position of the sun in the sky and shifting weather conditions. For the purposes of this trial it is not possible to control this variable. To mitigate any bias which may be introduced as a result of measurement time the start point of each operator in the plot network and direction of travel will be will be randomly assigned. This is appropriate as in the FCM methodology the timing of assessment through the day is not controlled.

4.5.4 Other sources of variation

Other sources of variation include within operator variation and between operator variation and we hope to be able to characterise these in the analysis phase.

4.6 Analysis

All analysis reported on in this report was carried out in the R statistical computing package[2]; where appropriate relevant citations will be made to the specific R packages used.

2 R Development Core Team (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

5 Results

The results obtained during the field trial are presented in the following sections. During the field trial 755 assessments were made by three operators in 18 separate plots over three days. Inevitably some issues were encountered relating to access difficulties due to trees fallen over roads etc. which resulted in fewer than planned plots being sampled during the first day of measurement. As a result the operators were instructed to assess only the first fifteen trees per plot strating from magnetic North for the second and third days of the study which led to an increased plot rate. The number of plots per day assessed during the trial is presented in Table 2. To maintain a balance in the experiment only plots where all three operators made assessments were included in the analysis presented in the following sections.

Table 2. The number of plots per day assessed by the three operators in the trial

	Number of plots		
Day	**Operator 1**	**Operator 2**	**Operator 3**
1	2	2	4
2	7	7	6
3	4	5	5
TOTAL	**13**	**14**	**15**

5.1 Key Crown condition Indictors

The following sections report on a statistical and graphical analysis of the key crown condition indicators of defoliation and crown transparency.

5.1.1 Defoliation

The defoliation assessment of all three operators was matched up on 159 trees which were available for analysis. A graphical summary of the defoliation data collected is presented in Figures 2 – 5.

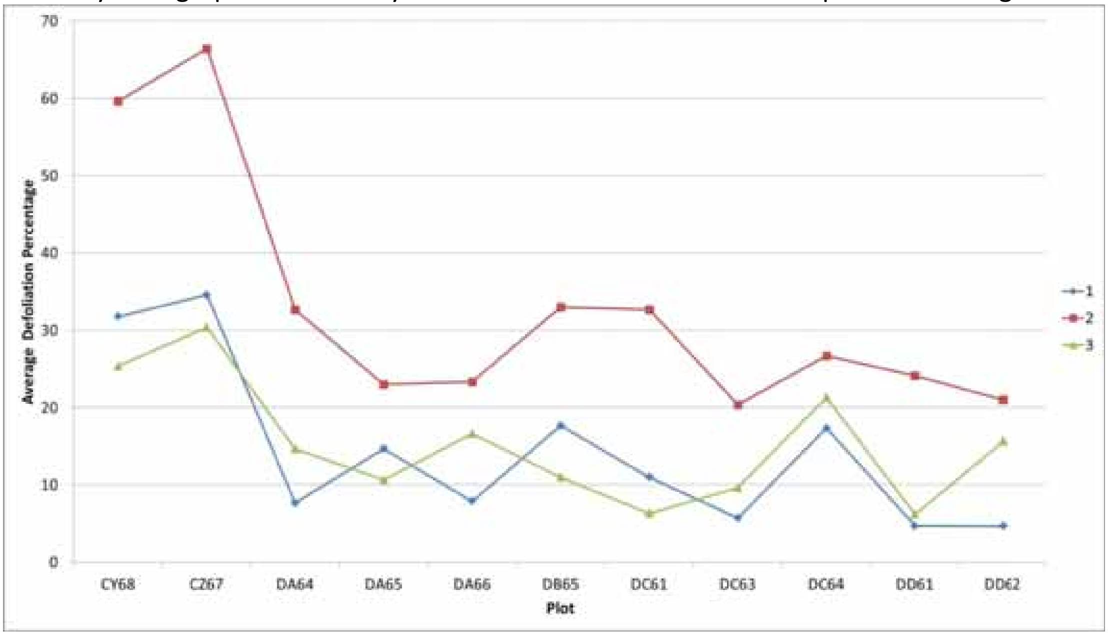

Figure 2. The average defoliation scores by plot for each operator

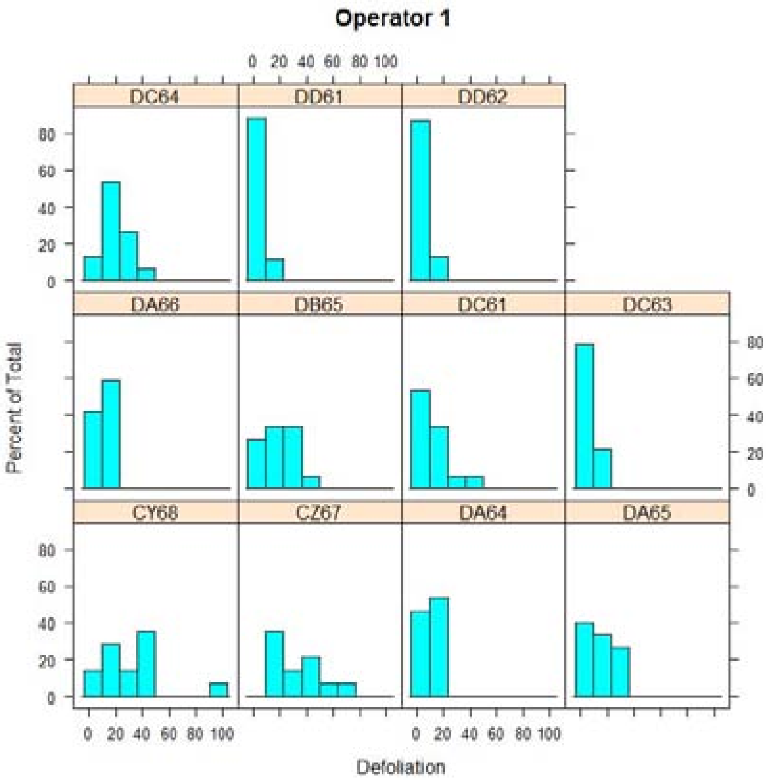

Figure 3. Histograms of the defoliation scores recorded by Operator 1

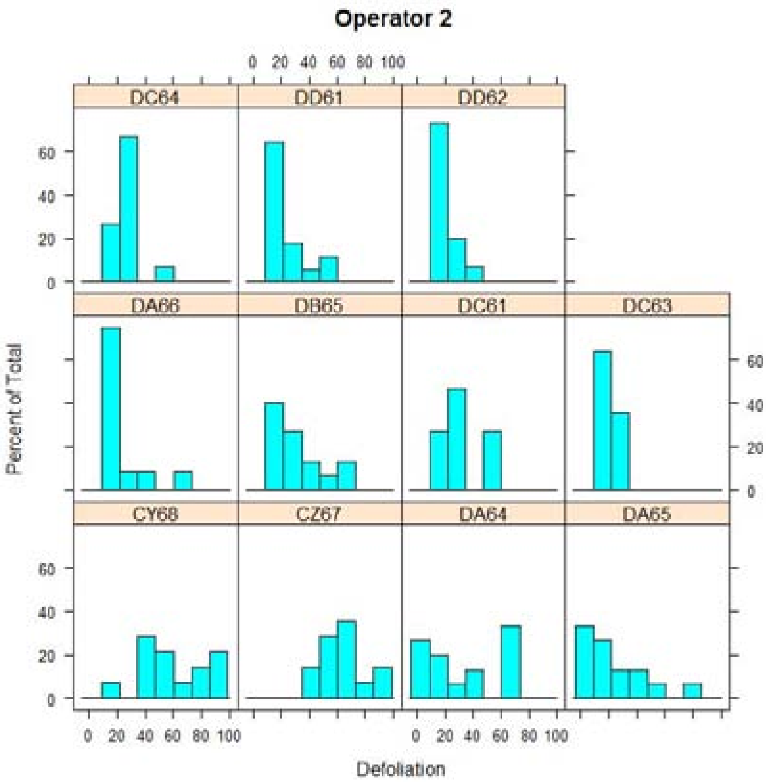

Figure 4. Histograms of the defoliation scores recorded by Operator 2

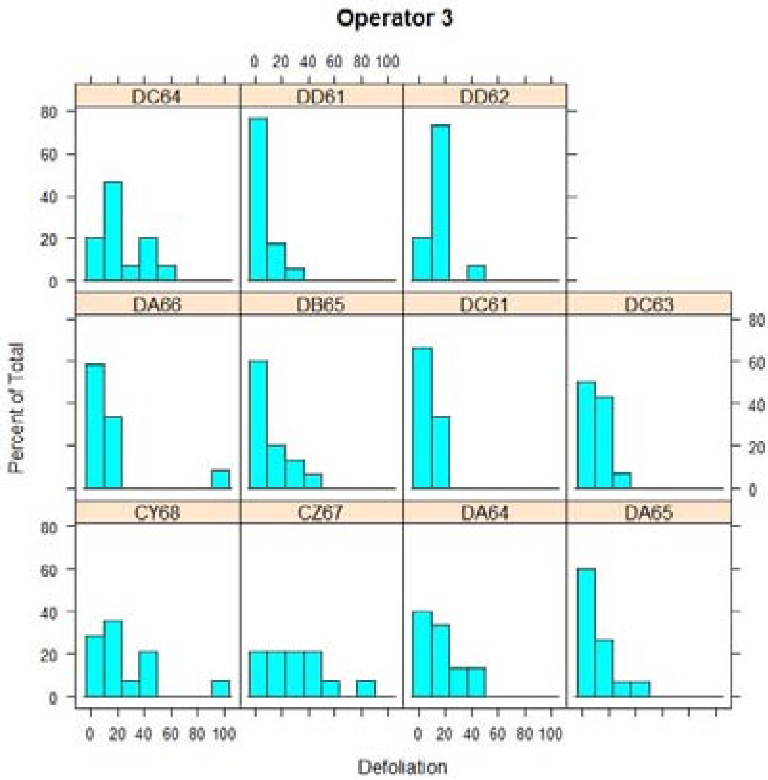

Figure 5. Histograms of the defoliation scores recorded by Operator 3

It seems that there is a systematic difference between the operators with operator 2 consistently scoring defoliation higher than operator 1 or 3. A one way analysis of variance and Tukey's honest significant difference (HSD) test indicate that there is no significant difference between the scores recorded by operator 1 and 3 ($p=0.85$) but there is a statistically significant difference between both operators 1 and 2 ($p<0.01$) and 2 and 3 ($p<0.01$). This suggests that additional training is required to address the systematic differences between the operators for the defoliation indicator.

5.1.2 Crown Transparency of Entire Crown

The assessment of crown transparency for 100% of tree crown, by all three operators was matched on 159 trees which were available for analysis. A graphical summary of the data collected is presented in Figures 7 – 9.

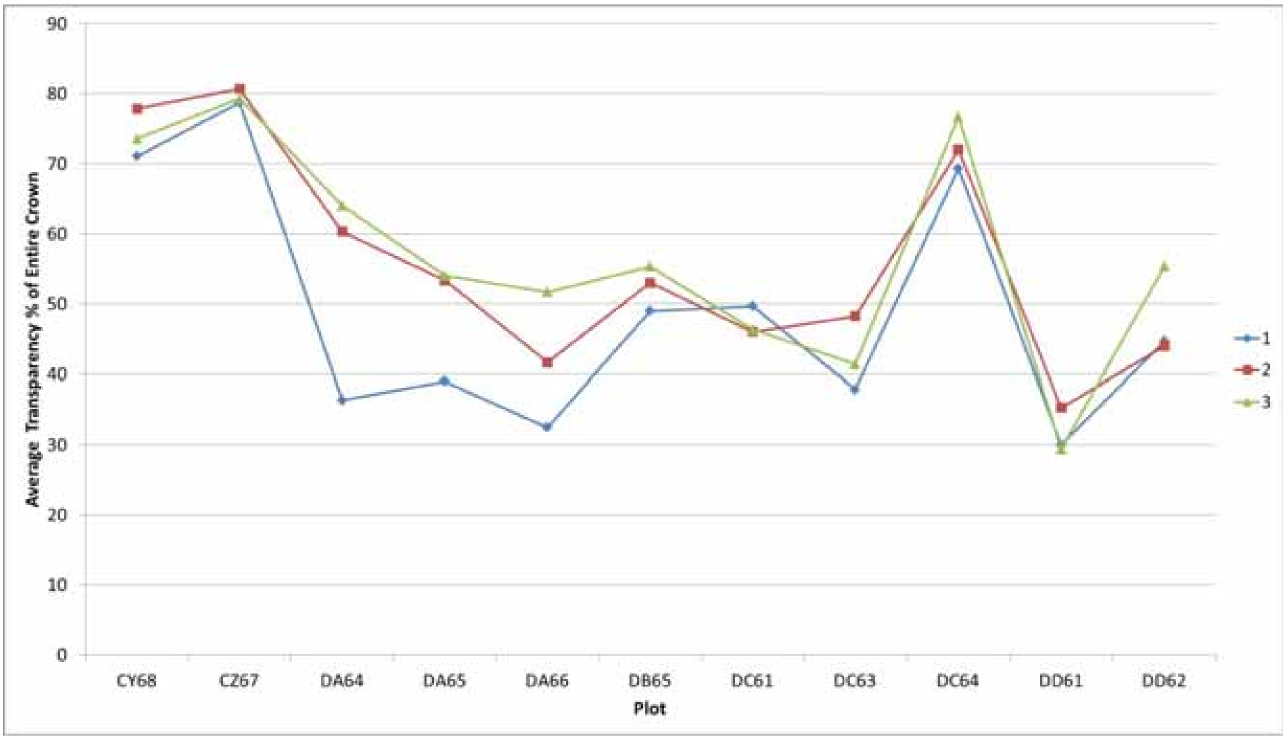

Figure 6. The average crown transparency for the entire crown scores by plot for each operator

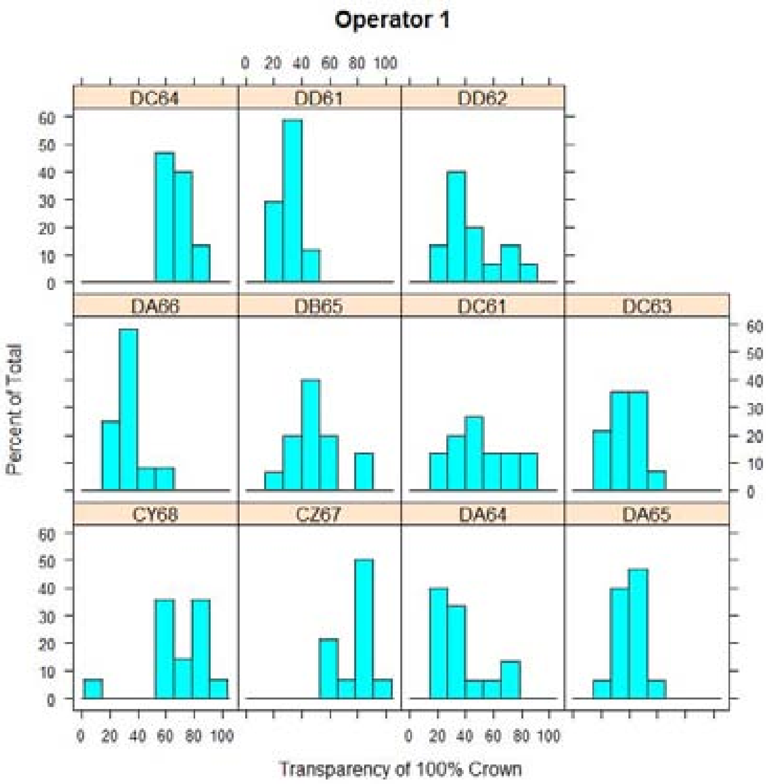

Figure 7. Histograms of the crown transparency of entire crown scores recorded by Operator 1

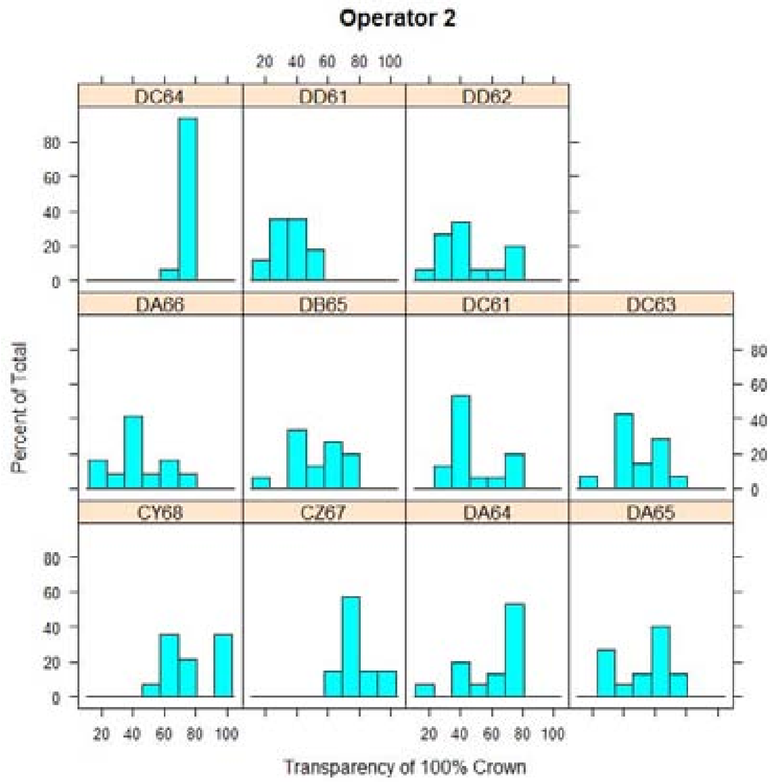

Figure 8. Histograms of the crown transparency of entire crown scores recorded by Operator 2

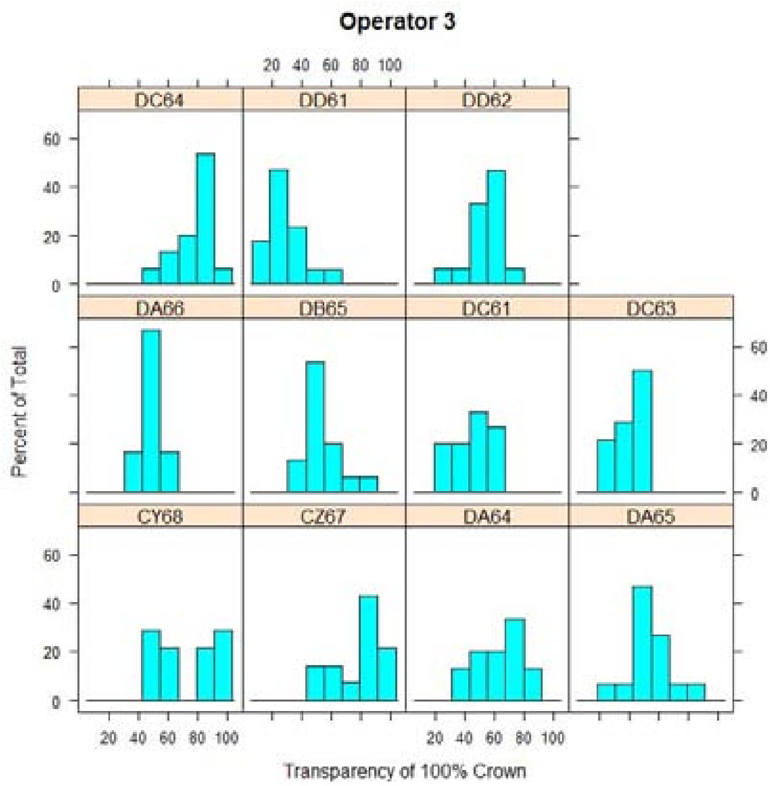

Figure 9. Histograms of the crown transparency of entire crown scores recorded by Operator 3

It seems that there is no systematic difference between the operators with all operators' average scores following the same broad pattern. A one way analysis of variance and Tukey's honest significant difference (HSD) test indicate that there is no statistically significant difference between the scores recorded by operator 2 and 3 (p=0.865) but there was a statistically significant difference between operator 1 and both operator 2 (p=0.006) and 3 (p=0.001). Figure 6 indicates that the difference between operator 1 and the other operators are mainly encompassed in plots DA66 DA64 and DA65 and this is confirmed by an analysis of variance carried out at a plot level the results of which are summarised in Table 3. It is worthy of note that all of the plots where operator one was significantly lower than the other operators are age class one plots and so it seems that operator one assesses this indicator differently to the other operators in younger trees.

Table 3 . The results of a analysis of variance for the entire crown transparency scores recorded by the three operators for each plot

Plot	p	Result
DC64	0.05372	No sig diff
DD61	0.2396	No sig diff
DD62	0.1186	No sig diff
DA66	0.001766	Sig diff
DB65	0.5348	No sig diff
DC61	0.8158	No sig diff
DC63	0.0662	No sig diff
CY68	0.6679	No sig diff
CZ67	0.9282	No sig diff
DA64	0.0001196	Sig diff
DA65	0.006152	Sig diff

5.1.3 Crown Transparency of Top 50% of Crown

The assessment of crown transparency for the top 50% of tree crown, by all three operators was matched on 159 trees which were available for analysis. A graphical summary of the data collected is presented in Figures 10 – 13.

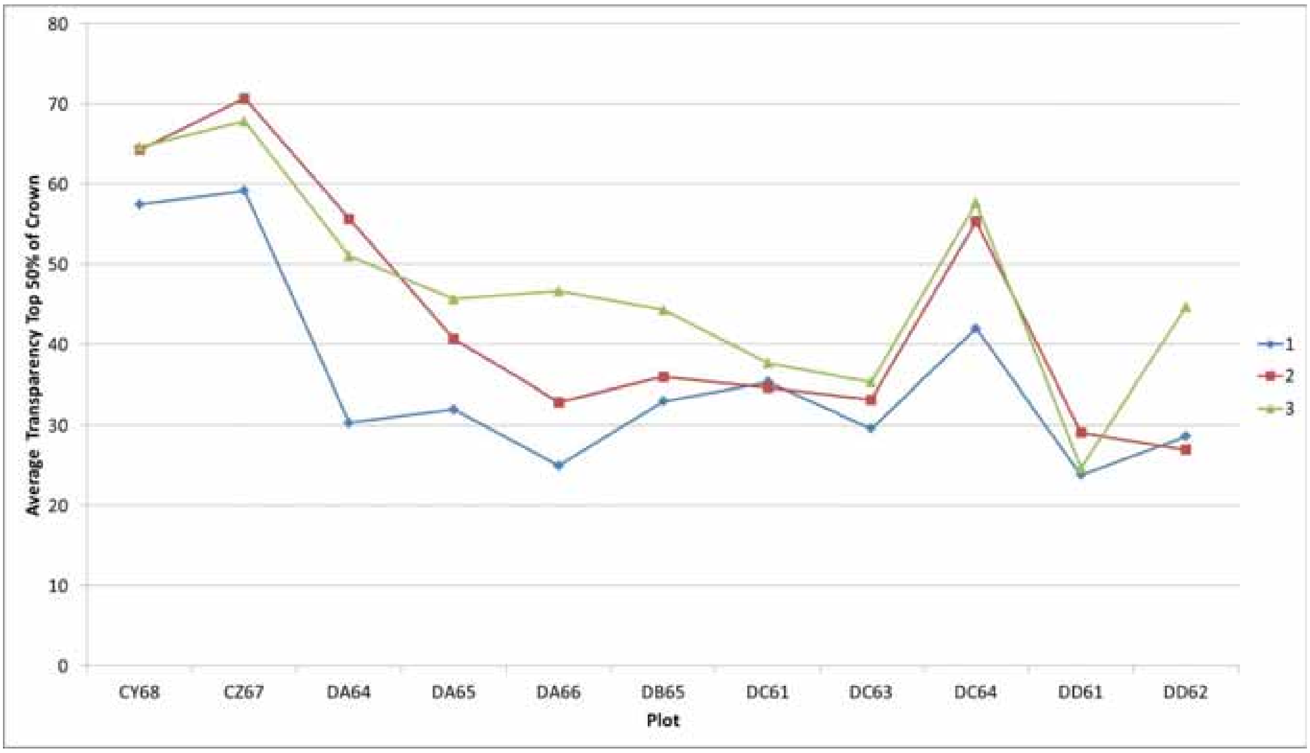

Figure 10. The average crown transparency for the top 50% of the crown scores by plot for each operator

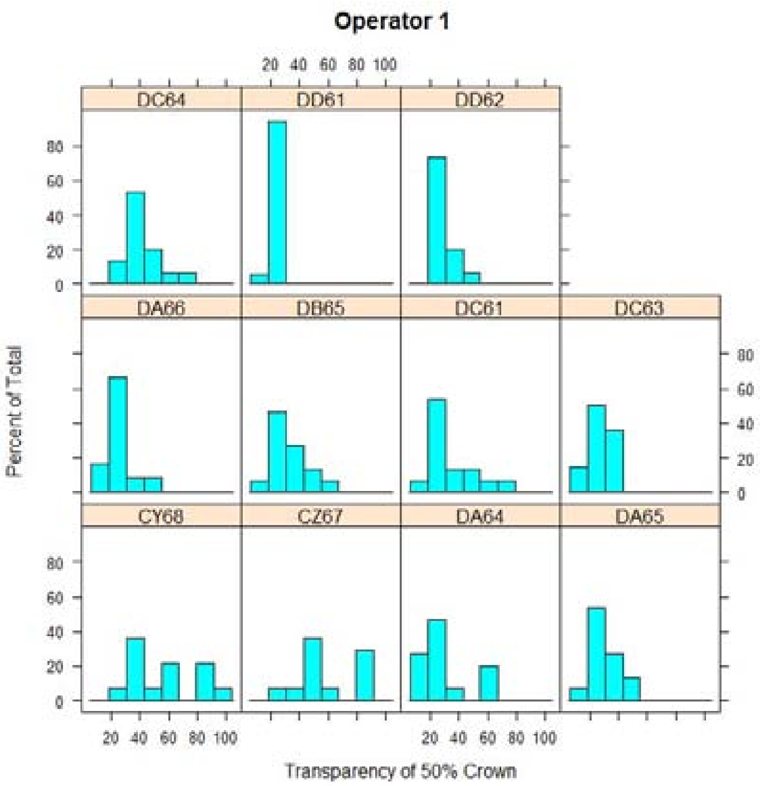

Figure 11. Histograms of the crown transparency of the top 50% of the crown scores recorded by Operator 1

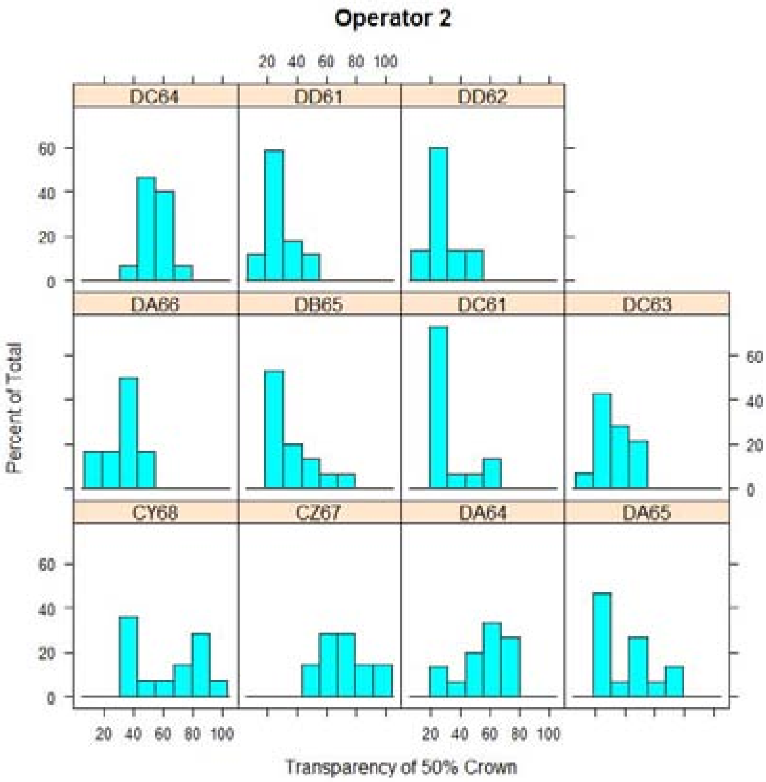

Figure 12. Histograms of the crown transparency of the top 50% of the crown scores recorded by Operator 2

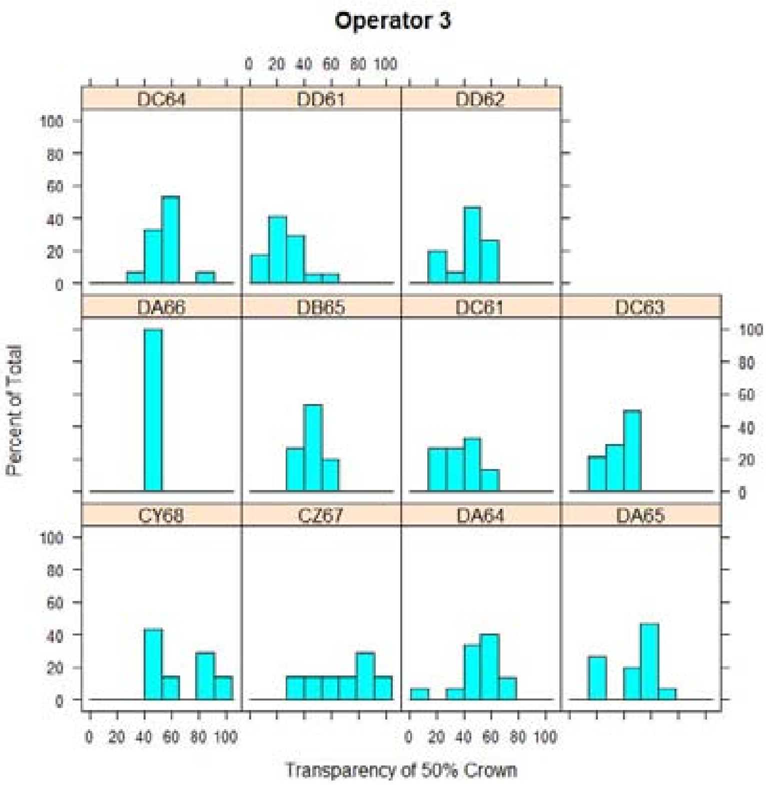

Figure 13. Histograms of the crown transparency of the top 50% of the crown scores recorded by Operator 3

The graphical summaries indicate that there is a systematic bias with operator 1 consistently recording lower scores than the other two operators. A one way analysis of variance and Tukey's honest significant difference (HSD) test confirm showing that there is no significant difference between operator 2 and 3 (p=0.226) but there is a statistically significant difference between operator 1 and both operator 2 (p<0.001) and 3 (p<0.001).

5.2 QUANTIFYING VARIATION IN THE KEY CROWN CONDITION INDICATORS

The experimental dataset was collated and analysed to quantify the sources of variation in the assessment of the crown transparency and defoliation indicators. All tree measurements with assessments carried out by all three operators were included in the dataset used to fit a mixed-effect model. The model was used to partition the variation in the crown transparency of the entire crown, crown transparency of top 50% of the crown, and defoliation variables. The model used was broadly similar to that used by Bulman[3] and in the analysis of variance section of the FCM inventory sampling design document[4]. The model had had the following form:

Equation 1. The random effects model used to partition variation

$$C_{ijk} = A_i + Y + O_k + P_j + T_i + E_{ijk}$$

Where:

C_{ijk} = The FCM indicator of tree i in plot j by operator k
A_i =The fixed effect of the age class of tree i with a variance of V_a
Y = The random effect of measurement day
O_k =The random effect of operator k with a variance V_o
P_j = The random effect of plot j with a variance of V_p
T_i =The random effect of tree i with a variance of V_t
E_{ijk} =The residual error with a variance of V_e

The sources of variation produced by the model fitted using the three crown condition indicators are reported in Table 4 - 6

Table 4 . The sources of variation for the crown transparency of the entire crown indicator

Source of variation	Code	Variance ($\%CT^2$)	Standard deviation (%CT)
Operator	V_o	16.80	4.09
Age Class	A_i	45.78	6.76
Plot	V_p	29.37	5.42
Tree	V_t	138.54	11.77
Residual	V_e	90.40	9.51

3 BUlman 2008 xxx

4 Sampling strategy for a New Zealand Forest Condition Monitoring Programme. Prepared for NZFOA by Interpine Forestry Ltd.

Table 5. The sources of variation for the crown transparency of the top 50% of the crown indicator

Source of variation	Code	Variance ($\%CT^2$)	Standard deviation (%CT)
Operator	V_o	29.50	5.43
Age Class	A_i	39.22	6.26
Plot	V_p	19.01	4.35
Tree	V_t	141.94	11.93
Residual	V_e	81.13	9.00

Table 6. The sources of variation for the defoliation indicator

Source of variation	Code	Variance ($\%Def^2$)	Standard deviation (%Def)
Operator	V_o	103.77	10.96
Age Class	A_i	28.26	5.31
Plot	V_p	23.70	4.86
Tree	V_t	120.22	10.96
Residual	V_e	118.44	10.88

The variance associated with age class, operator, and tree was found to be statistically different from zero for all three indicators $p<0.05$. The variance associated with plot was found to be statistically different from zero for both full crown transparency ($p=0.008$) but insignificant for defoliation ($p=0.06$) and transparency of the upper half of the crown ($p=0.09$). The variance associated with measurement day was not significantly different from zero for all three indicators; however it should be noted that in this study the effects of plot and day were confounded as operators measured the plots on the same days as each other as testing the significance of the effect of measurement day was not the primary objective of this study.

5.2.1 Between operator variability

The between variation reported on in Table 4 – 6 is high indicating that additional effort on training and calibration of operators is required for the three operators involved in this study and is a cause for some concern. The variance associated with the operator is significantly different to zero $p<0.01$ and cannot be considered trivial. The between operator variation is lower for crown transparency than for transparency of the top 50% of the crown or for defoliation. The data suggests that if different operators are used between years then (assuming a normal distribution) there is a 33% probability[5] of observing a 4.09% change in crown transparency of the entire crown, 5.43% change in crown transparency of the top 50% of the crown and 10.96% change in defoliation scores even if the trees had not changed.

The between operator variability for crown transparency of the entire crown is similar to that reported by Bulman and Kimberley[6] in previous studies using novice operators. This suggests that

[5] Outside of one standard deviation from the sample mean
[6] A revised forest health surveillance system, Bulman, L.S., and Kimberley, M.O.

the training undertaken was insufficient to reduce the variability between operators to an acceptable level.

5.2.2 Effect of age class

The data analysis reported here suggests that the variance associated with the age class of the tree assessed is large for both transparency measures but is significantly less for the defoliation indicator. This is consistent with Interpine's understanding of the indicators as crown transparency is greatly affected by the changes in tree architecture that occur with increasing tree age. This must be accounted for in the interpretation of the data sets or predictive modelling approaches based on this indicator.

5.2.3 Effect of known assessment position

Interpine have found that changes in the position of assessment for tree measurements such as height can lead to discrepancies in repeat measurements on the same tree. As a result it was decided during the design of FCM measurement procedures that the bearing to the subject tree from the assessment position should be recorded so that subsequent re-measurements could take place from the same angle. During the current study it was found that some of the plots revisited had not been marked with paint by the original field crews. In this instance the first operator to reach the plot would spray tree numbers onto the trees and these would be used by all operators. This meant that the operators had no knowledge of the prescribed assessment angle for each tree and so were likely to assess them from different positions to each other. A field was included in the data capture software to identify trees recorded without a known assessment angle and this was used to segregate the dataset for analysis using the mixed effect model above (Equation 1). Segregating the data in this manner led to a dataset of 229 observations where the assessment was made from the same position by all three operators and a dataset of 254 observations where the assessment position was not fixed. A two sample t-test revealed that there was a significant difference ($p<0.01$) between trees assessed from a fixed position and trees where the operators' position was variable for all three indicators. The sources of variation outlined by fitting the model with the two data sets are summarised below.

Table 7. The sources of variation for the transparency of the entire crown indicator for trees assessed from a common position

Source of variation	Code	Variance (%CT^2)	Standard deviation (%CT)
Operator	V_o	1.65	1.28
Age Class	A_i	34.10	5.84
Plot	V_p	54.1	7.35
Tree	V_t	108.04	10.39
Residual	V_e	75.88	8.71

Table 8. The sources of variation for the transparency of the entire crown indicator for trees assessed from different positions

Source of variation	Code	Variance (%CT^2)	Standard deviation (%CT)
Operator	V_o	46.34	6.80
Age Class	A_i	29.73	5.45
Plot	V_p	22.01	4.69
Tree	V_t	160.65	12.67
Residual	V_e	90.89	9.54

Table 9. The sources of variation for the transparency of the top 50% of the crown indicator for trees assessed from the same position

Source of variation	Code	Variance (%CT^2)	Standard deviation (%CT)
Operator	V_o	13.69	3.70
Age Class	A_i	26.82	5.27
Plot	V_p	36.87	6.07
Tree	V_t	165.55	12.86
Residual	V_e	55.69	7.46

Table 10. The sources of variation for the transparency of the top 50% of the crown indicator for trees assessed from different positions

Source of variation	Code	Variance (%CT^2)	Standard deviation (%CT)
Operator	V_o	47.08	6.85
Age Class	A_i	27.07	5.20
Plot	V_p	5.54	2.35
Tree	V_t	91.64	9.57
Residual	V_e	102.79	10.14

Table 11. The sources of variation for the defoliation indicator for trees assessed from the same position

Source of variation	Code	Variance (%Def^2)	Standard deviation (%CT)
Operator	V_o	124.14	11.36
Age Class	A_i	23.79	4.88
Plot	V_p	21.55	4.64
Tree	V_t	129.14	11.36
Residual	V_e	140.29	11.84

Table 12. The sources of variation for the defoliation indicator for trees assessed from the different positions

Source of variation	Code	Variance (%Def^2)	Standard deviation (%CT)
Operator	V_o	99.92	9.34
Age Class	A_i	14.26	3.78
Plot	V_p	6.84	2.62
Tree	V_t	87.29	9.34
Residual	V_e	94.35	9.71

The results in summarised in Table 7 and 8 indicate that when trees are assessed from the same angle the between operator variation and residual variation which includes within operator error are reduced significantly for the full crown transparency indicator. The same large decrease in between operator and residual variation is also evident for the crown transparency of the top 50% of crown indicator. The effect is not seen for the defoliation indicator where both the between operator variation and residual are greater for trees assessed from a known angle compared to those where the assessment angle may be different.

5.3 Additional Indicators

There are a number of additional indicators collected as part of the FCM survey which can be used in the analysis of the FCM dataset.

5.3.1 Stem Visibility

The assessment of stem visibility through the tree crown by all three operators was matched on 159 trees which were available for analysis. A graphical summary of the data collected is presented in Figures 14 – 17.

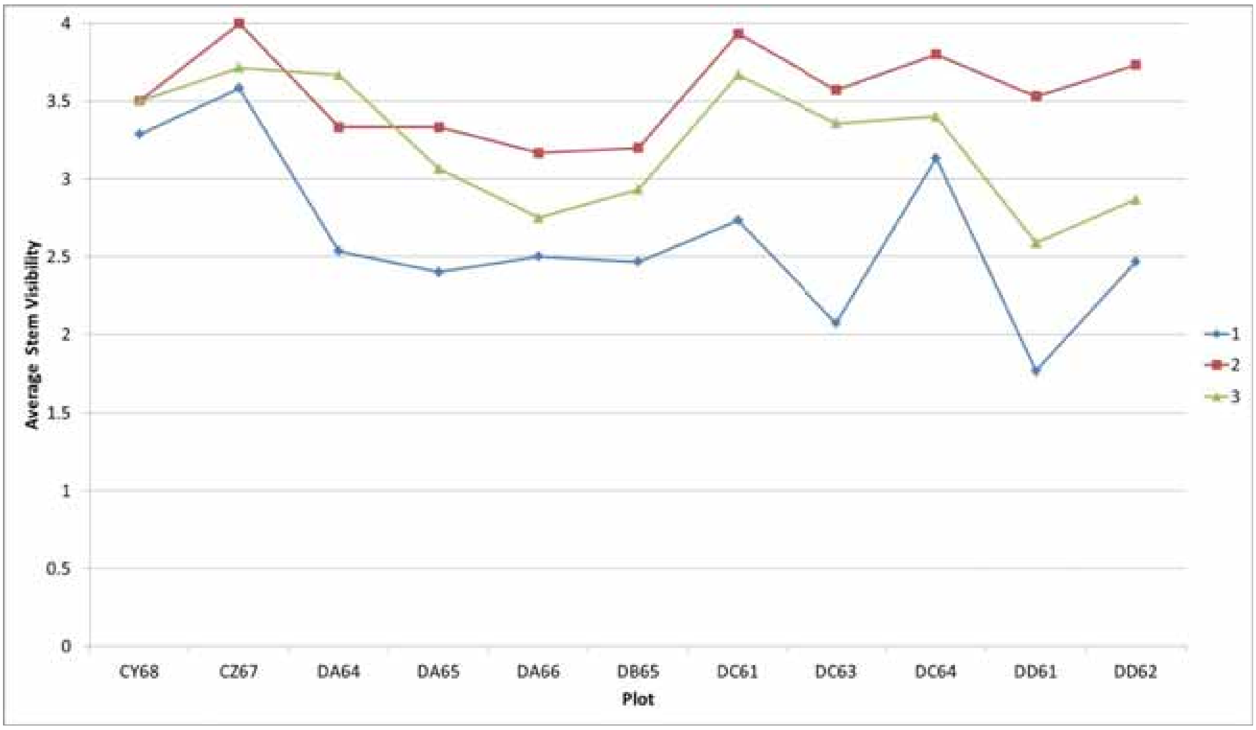

Figure 14. The average stem visibility scores by plot for each operator

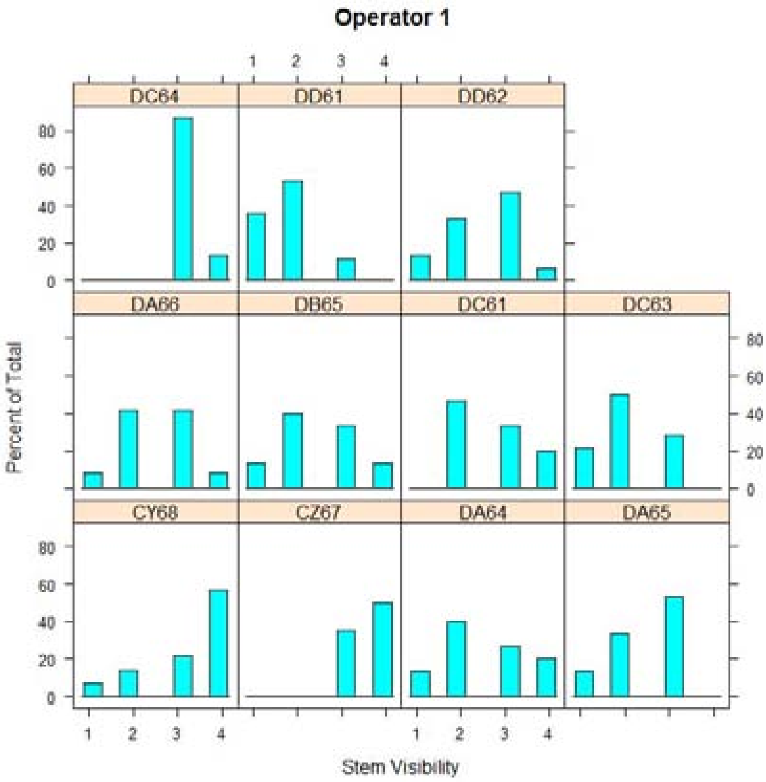

Figure 15. Histograms of the stem visibility scores recorded by Operator 1

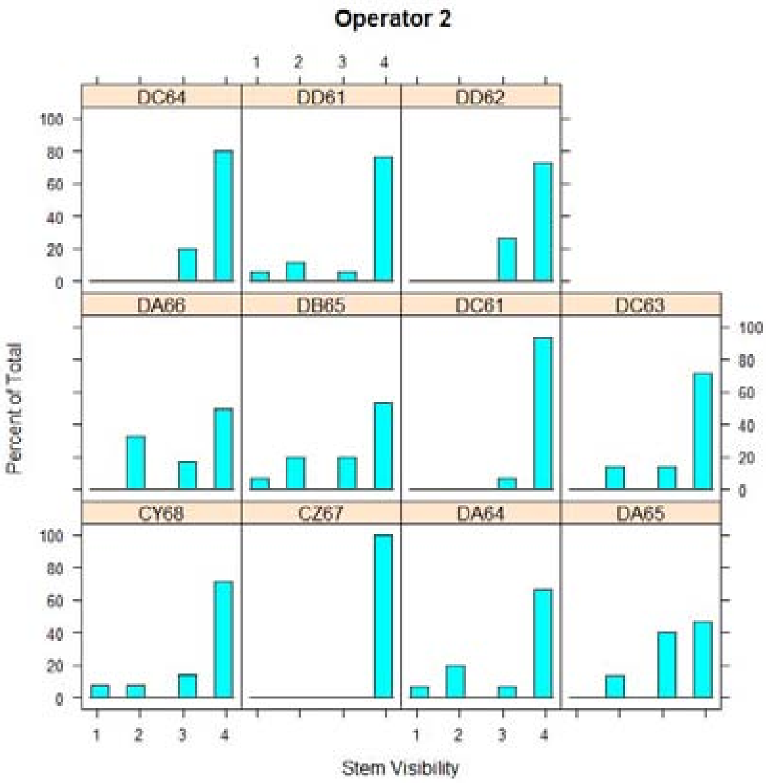

Figure 16. Histograms of the stem visibility scores recorded by Operator 2

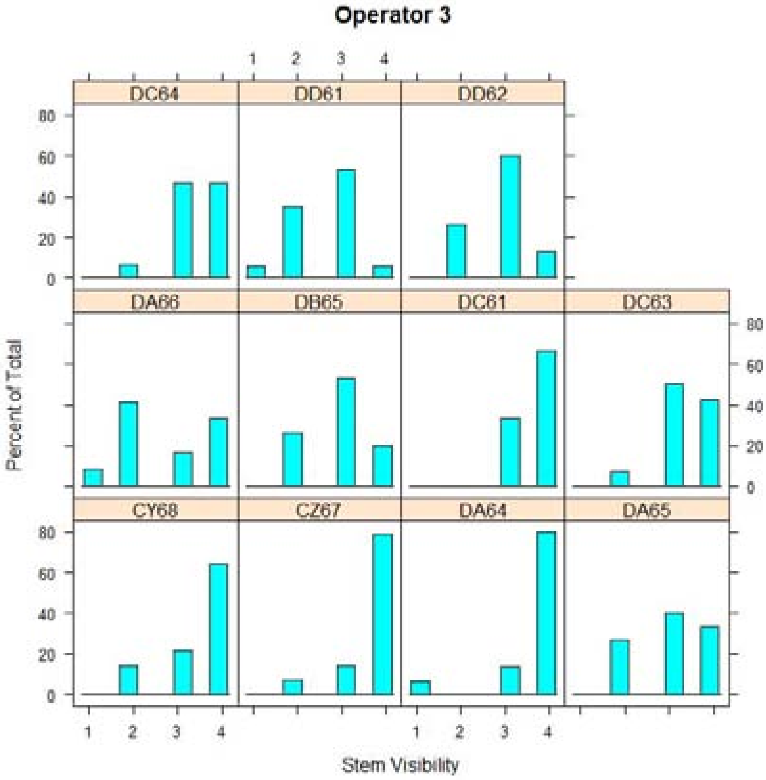

Figure 17. Histograms of the stem visibility scores recorded by Operator 3

A one way analysis of variance and Tukey's honest significant difference (HSD) were carried out on the data which indicate that there is a statistically significant difference ($p<0.001$) between all operators for the measurement of stem visibility. This suggests that there is a requirement for more effort in training and calibration of the operators in this study. Operator one displays a systematic bias consistently recording lower scores for crown transparency.

5.3.2 Needle Retention

The assessment of needle retention for the tree crown by all three operators was matched on 159 trees which were available for analysis. A graphical summary of the defoliation data collected is presented in Figures 18 – 21.

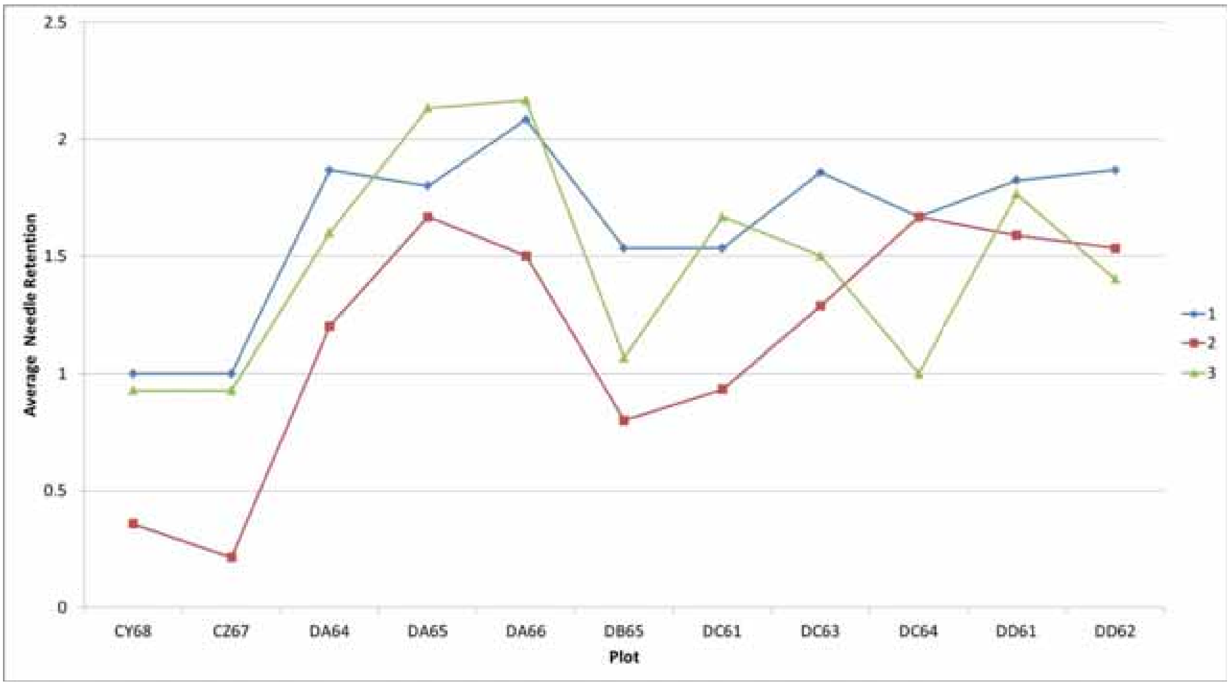

Figure 18. The average needle retention scores by plot for each operator

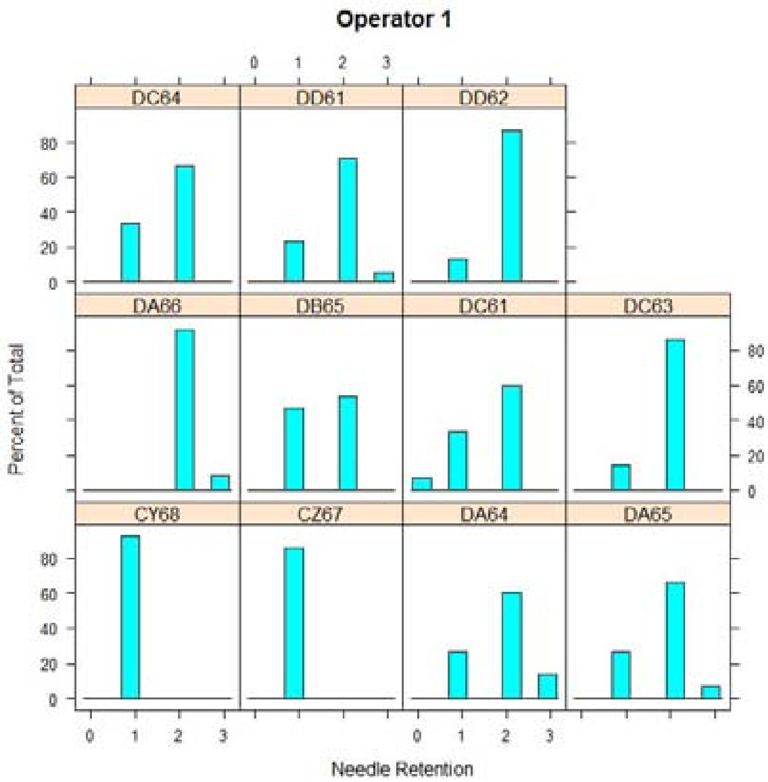

Figure 19. Histograms of the needle retention scores recorded by Operator 1

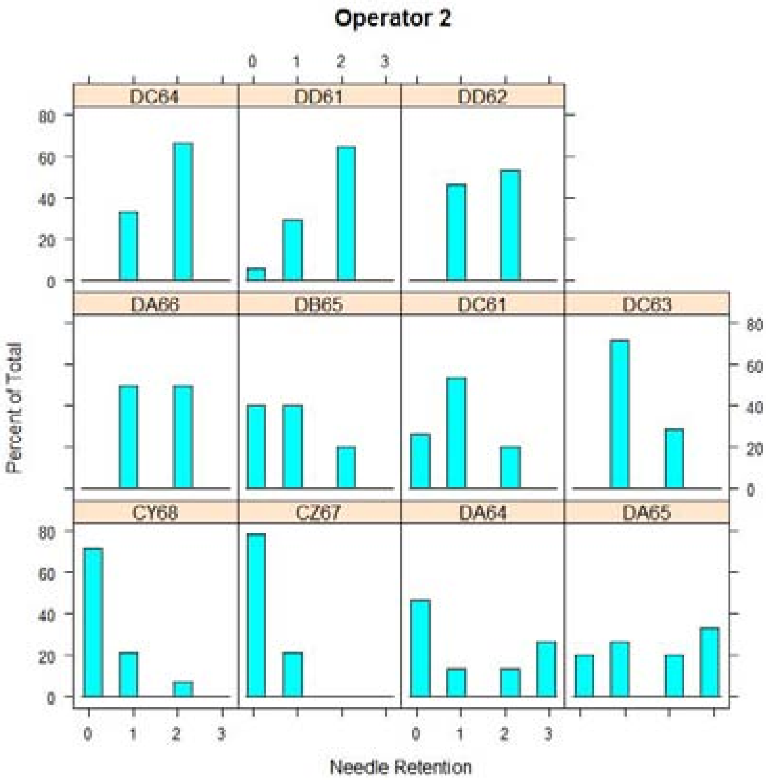

Figure 20. Histograms of the needle retention scores recorded by Operator 2

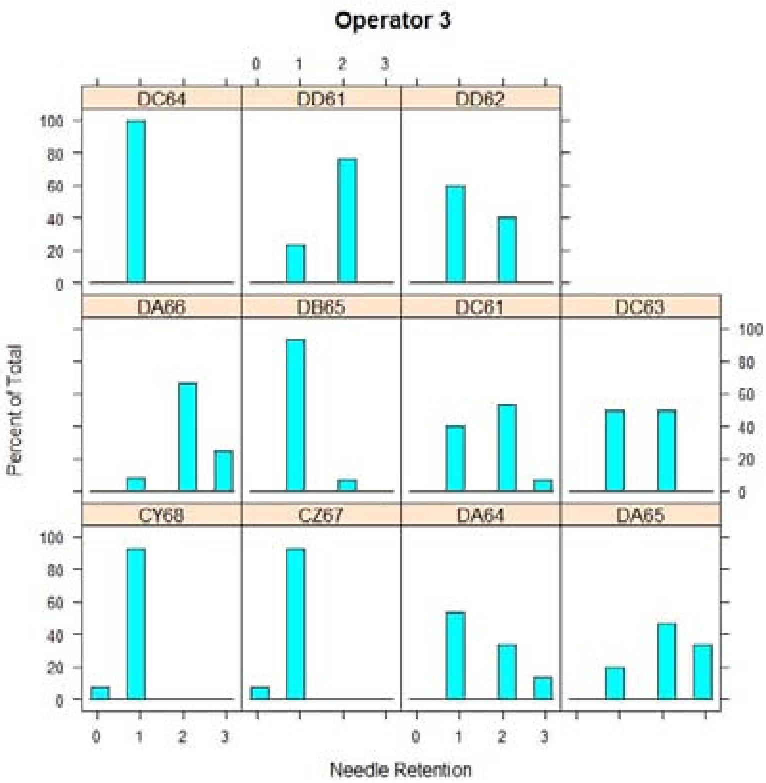

Figure 21. Histograms of the needle retention scores recorded by Operator 3

A one way analysis of variance and Tukey's honest significant difference (HSD) were carried out on the data which indicate that there is no statistically significant difference between the needle retention scores recorded by operator 1 and 3 (p=0.051) but the differences in the needle retention scores between operator 2 and both operator 1 (p<0.001) and 3 (p<0.001) are statistically significant. Figure 18 indicates that there is a systematic negative bias in the needle retention scores recorded by operator 2 compared to those recorded by 1 and 3.

5.3.3 Crown Dieback

The assessment of crown dieback for the top 50% of tree crown, by all three operators was matched on 159 trees which were available for analysis. A graphical summary of the defoliation data collected is presented in Figures 22 – 25.

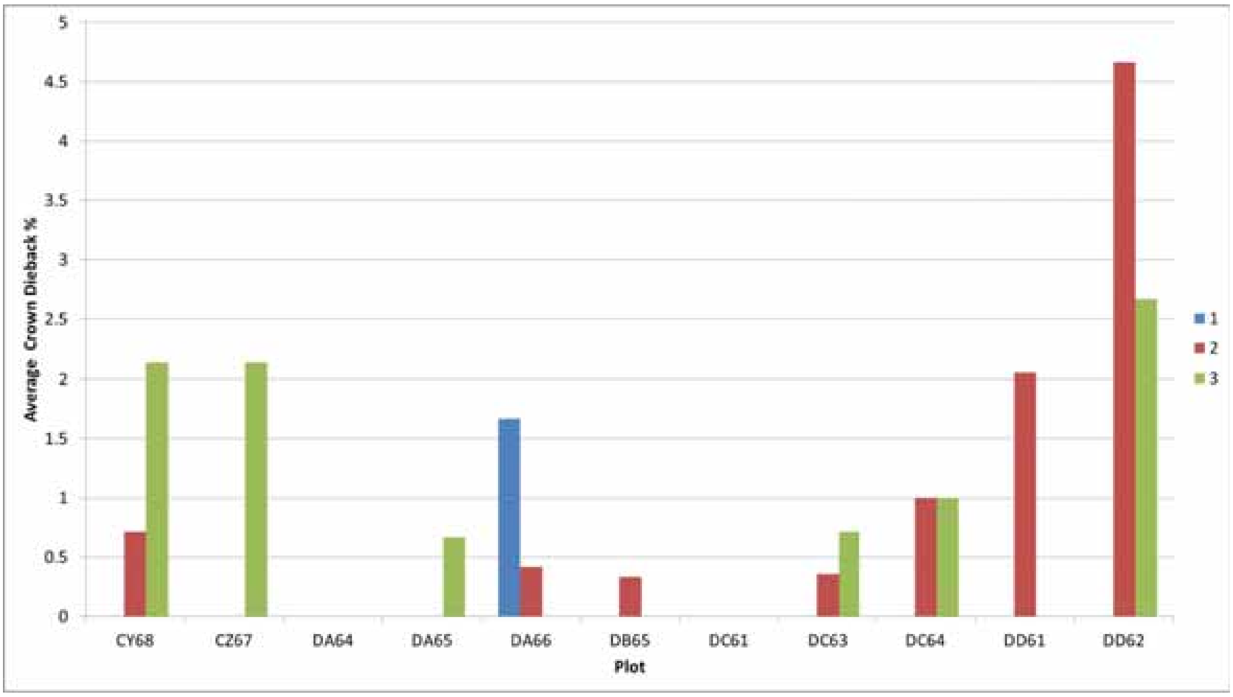

Figure 22. The crown dieback scores by plot for each operator

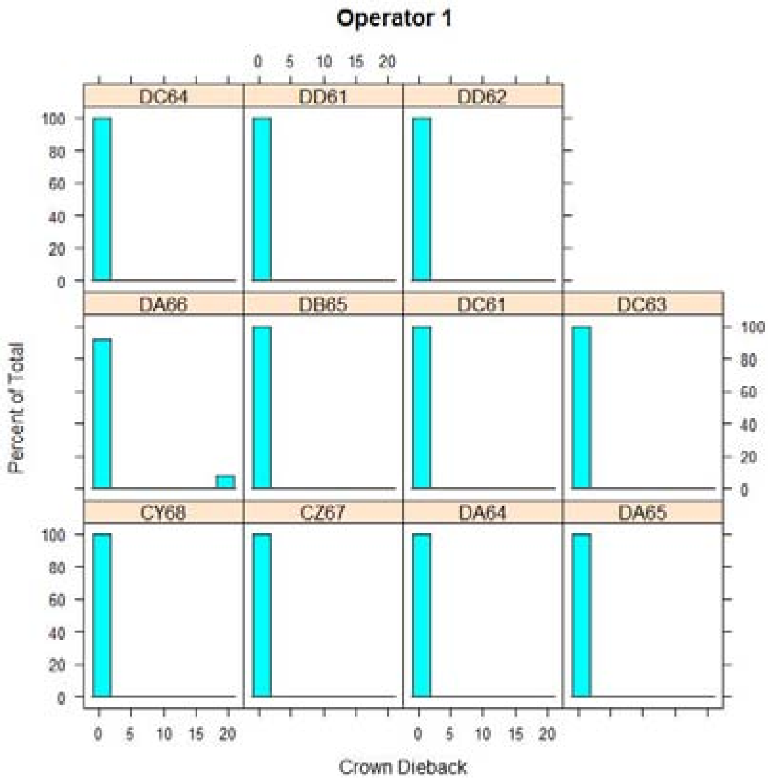

Figure 23. Histograms of the crown dieback scores recorded by Operator 1

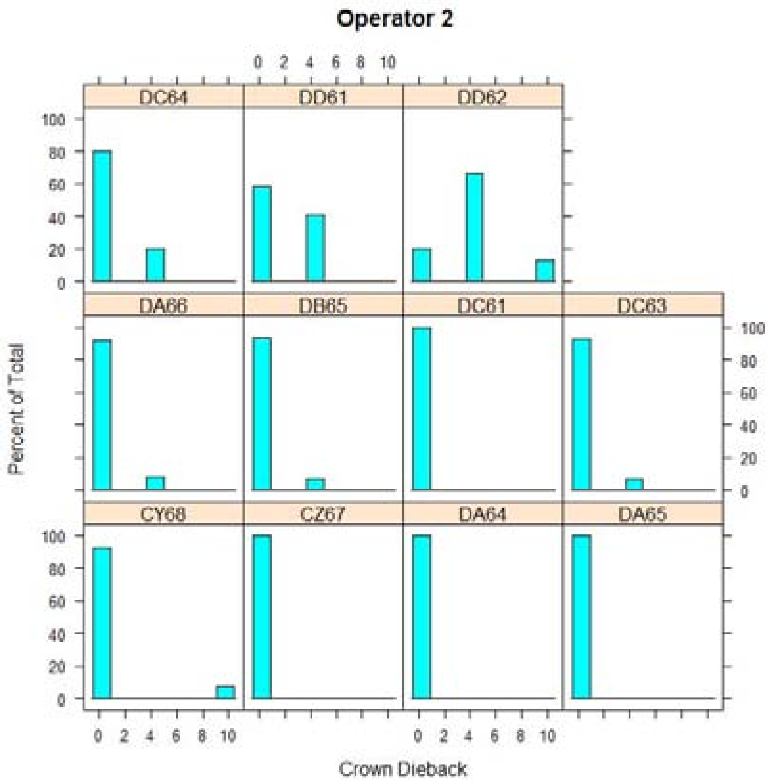

Figure 24. Histograms of the crown dieback scores recorded by Operator 2

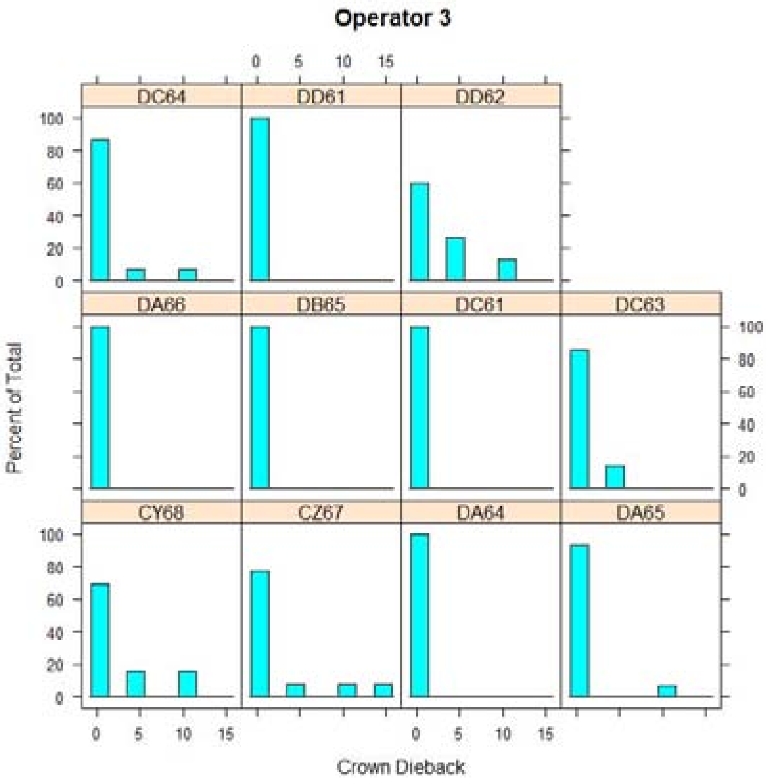

Figure 25. Histograms of the crown dieback scores recorded by Operator 3

A one way analysis of variance and Tukey's honest significant difference (HSD) were carried out on the data which indicate the there is no statistically significant difference between operator 2 and 3 ($p=0.975$) where as operator 1 is statistically significantly different from both operator 2 ($p=0.004$) and 3 ($p=0.008$). In this case there appears to be a methodological difference in the recording procedure for crown die back between the three operators.

5.3.4 Crown Depth

The assessment of crown depth by all three operators was matched on 159 trees which were available for analysis. A graphical summary of the defoliation data collected is presented in Figures 26 – 29.

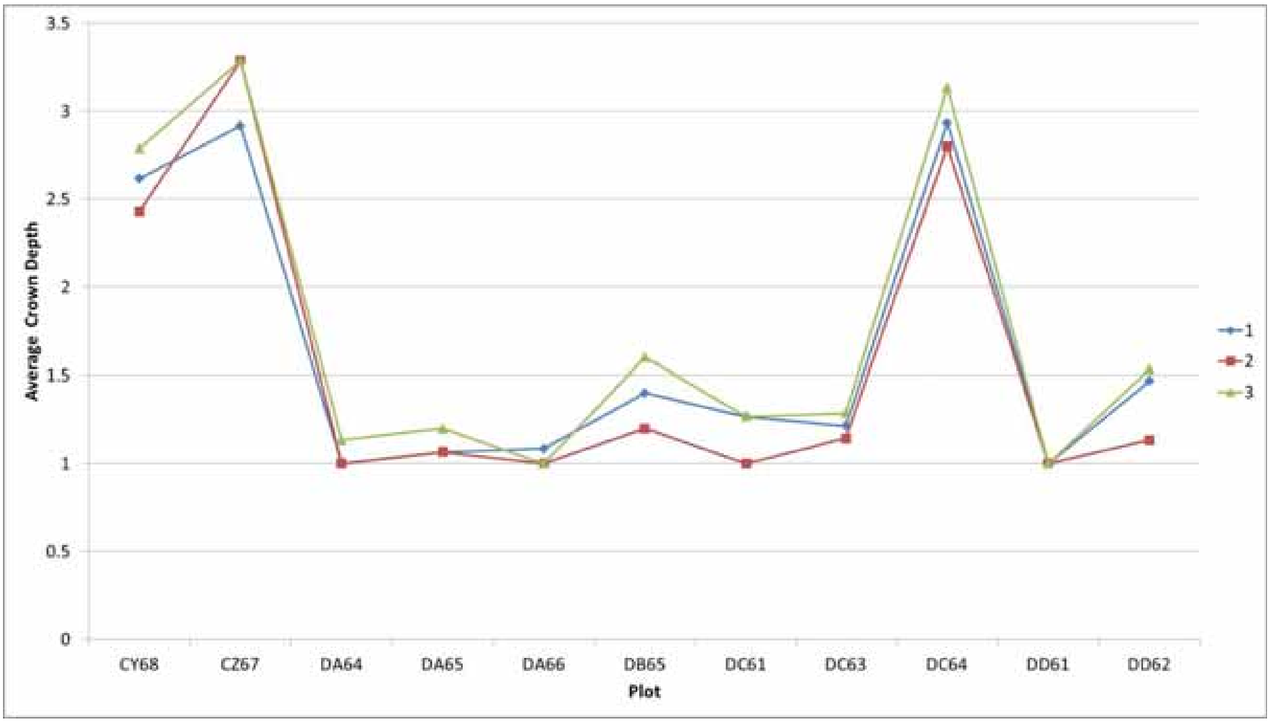

Figure 26. The crown depth scores by plot for each operator

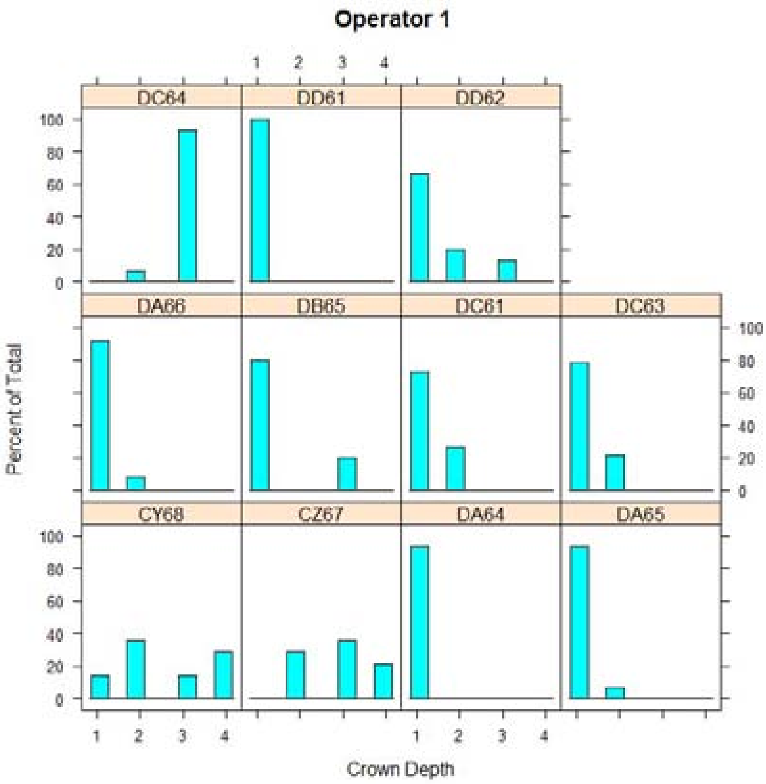

Figure 27. Histograms of the crown dieback scores recorded by Operator 1

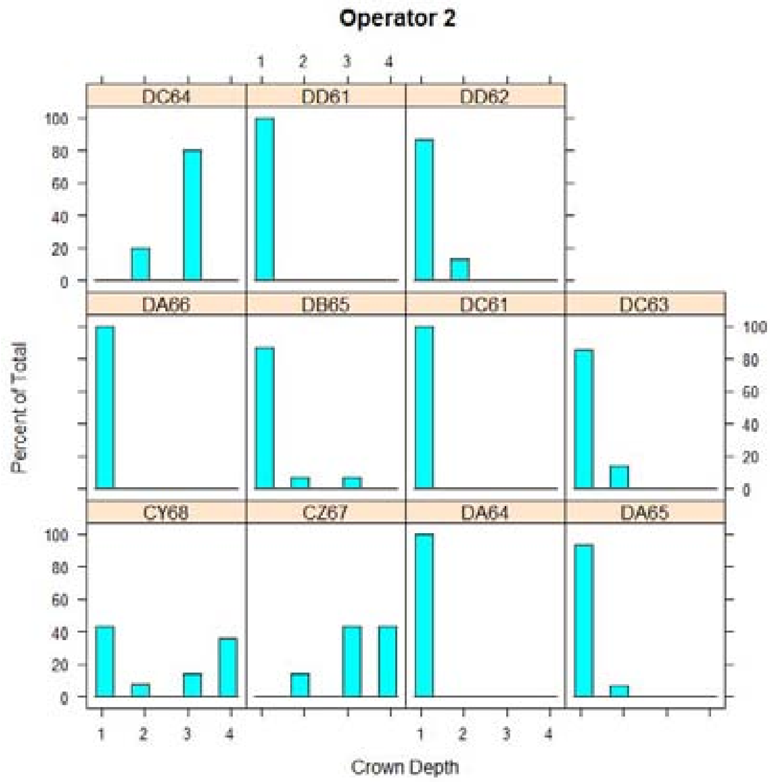

Figure 28. Histograms of the crown dieback scores recorded by Operator 2

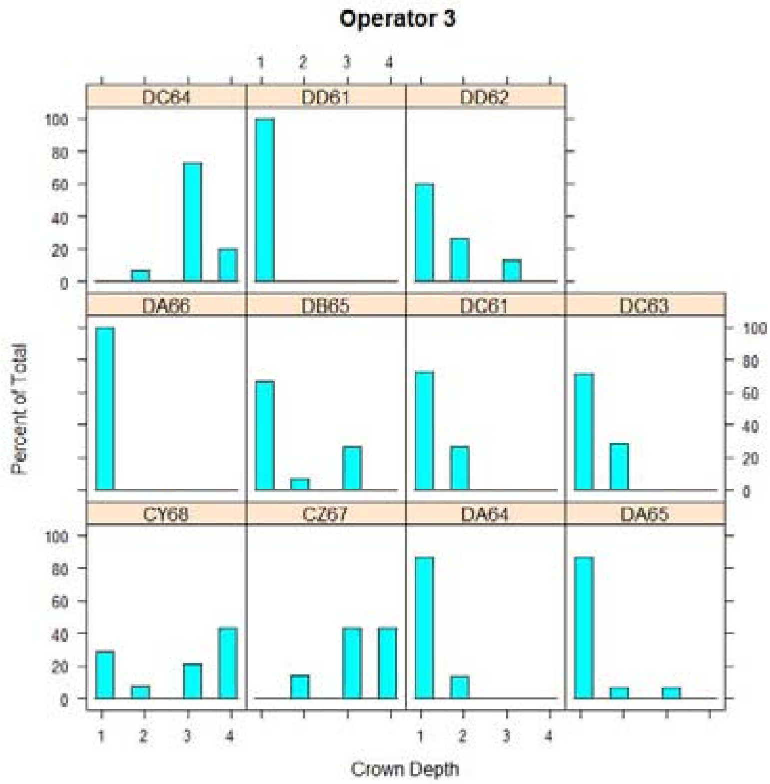

Figure 29. Histograms of the crown dieback scores recorded by Operator 3

A one way analysis of variance test indicates that there is no statistically significant difference between the operators which ($p=0.289$) which suggests that there is a consensus in measurement methodology between the three operators in this study.

5.3.5 Resin Bleeding

The assessment of resin bleeding by all three operators was matched on 159 trees which were available for analysis. A graphical summary of the defoliation data collected is presented in Figure 30 – 33.

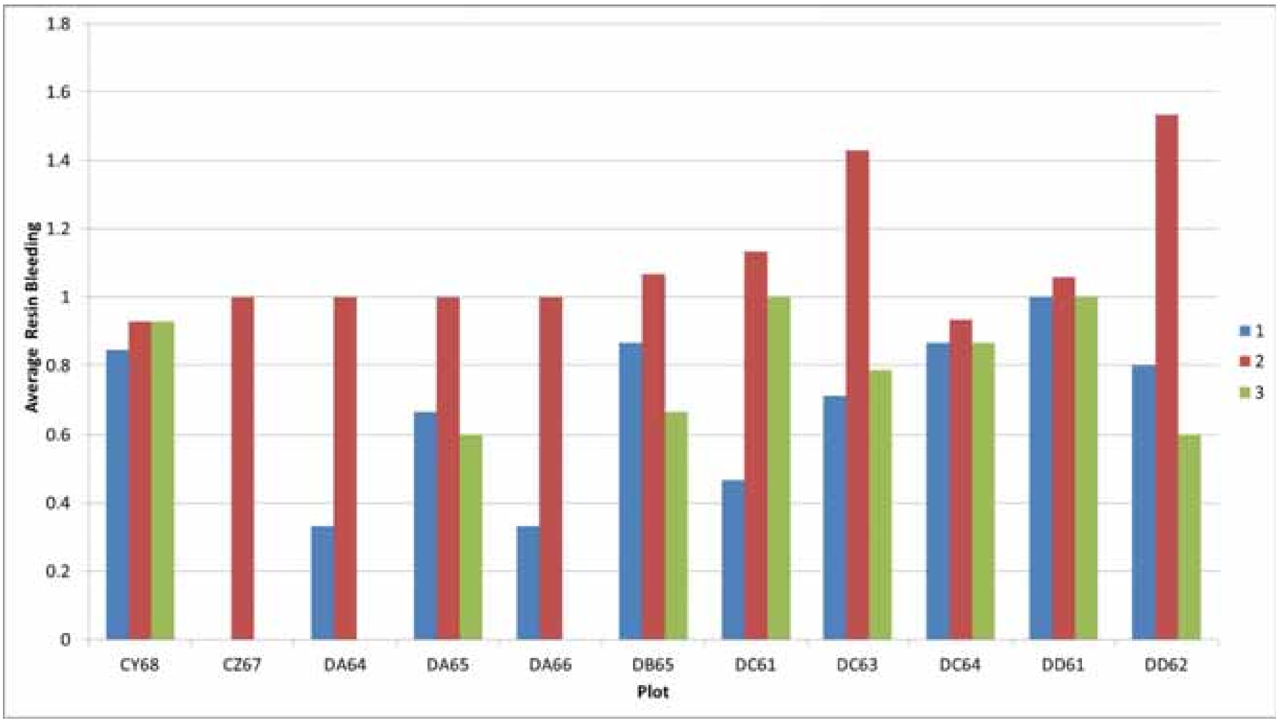

Figure 30. The resin bleeding scores by plot for each operator

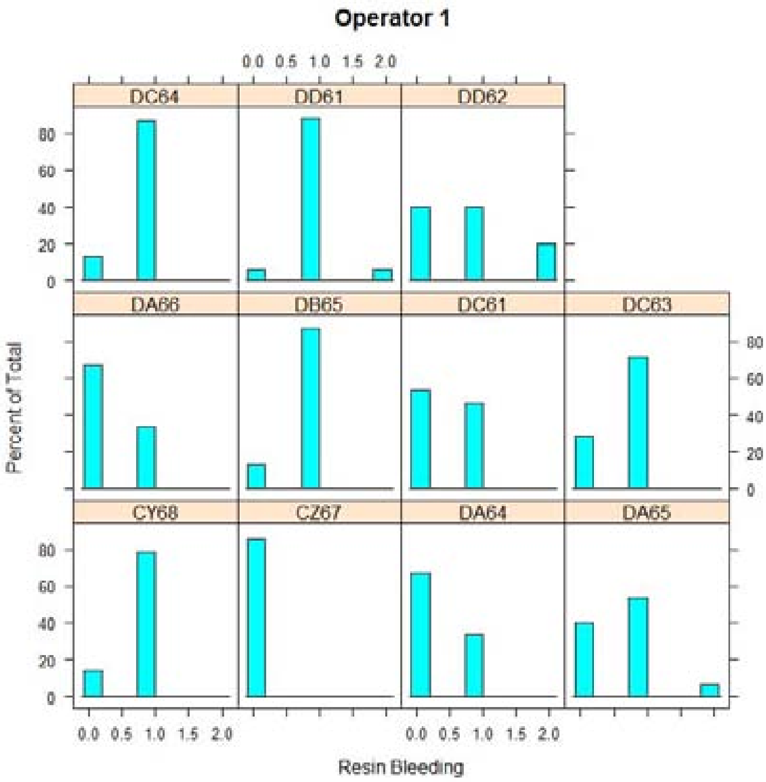

Figure 31. Histograms of the resin bleeding scores recorded by Operator 1

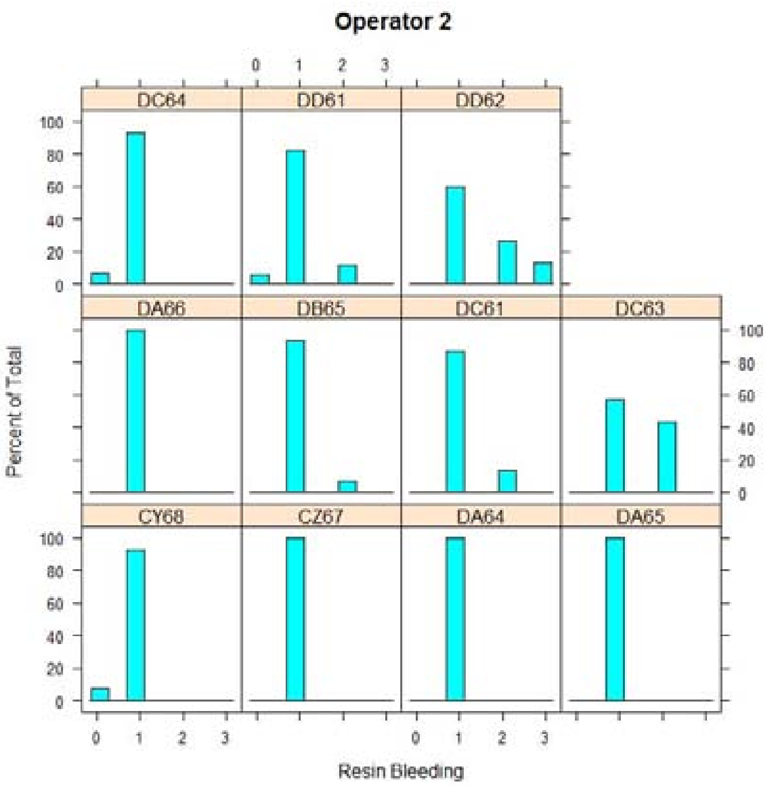

Figure 32. Histograms of the resin bleeding scores recorded by Operator 2

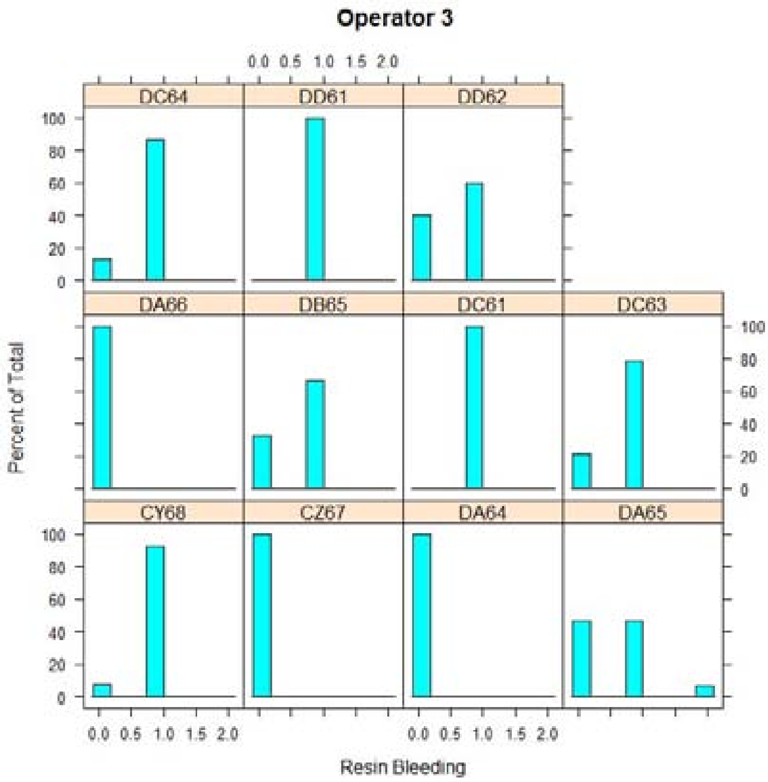

Figure 33. Histograms of the resin bleeding scores recorded by Operator 3

5.3.6 Dothistroma and Cyclaneusma

The assessment of Dothistroma and Cyclaneusma percentage by all three operators was matched on 159 trees which were available for analysis. A graphical summary of the Dothistroma and Cyclaneusma data collected is presented in Figure 34 and 35.

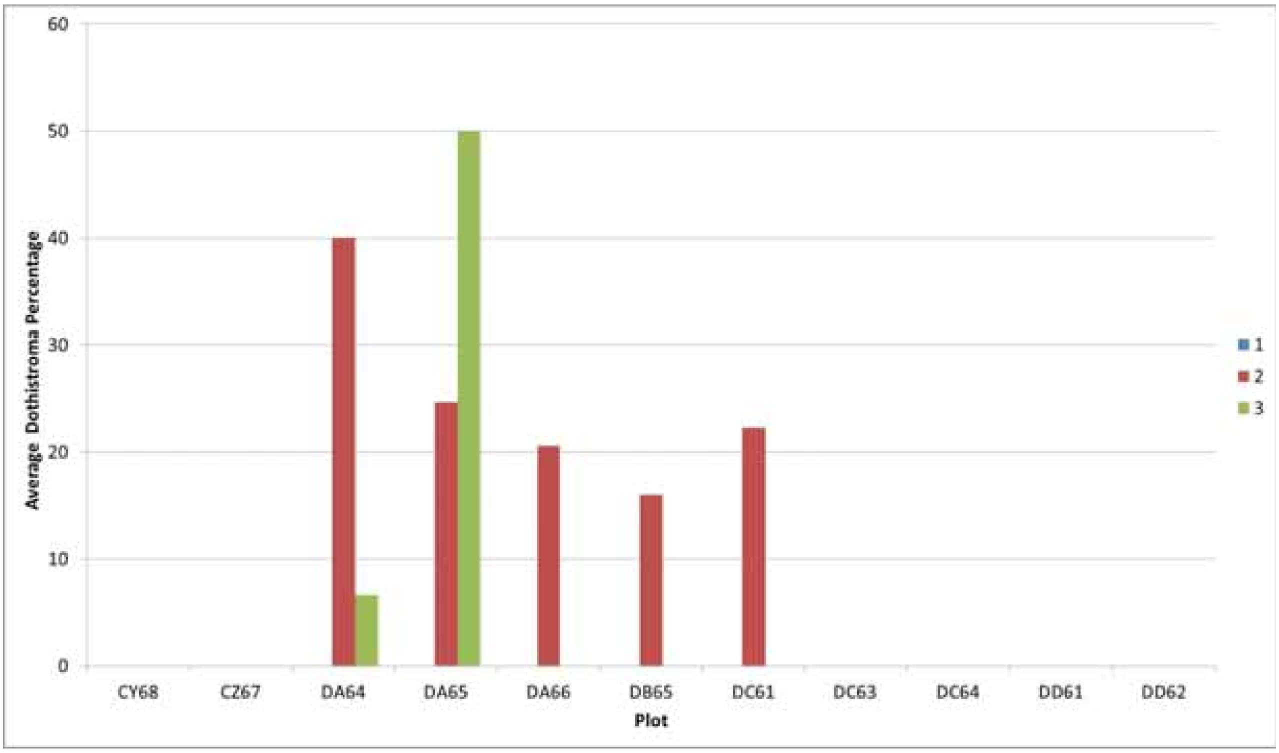

Figure 34. The average Dothistroma score for each plot recorded by operator

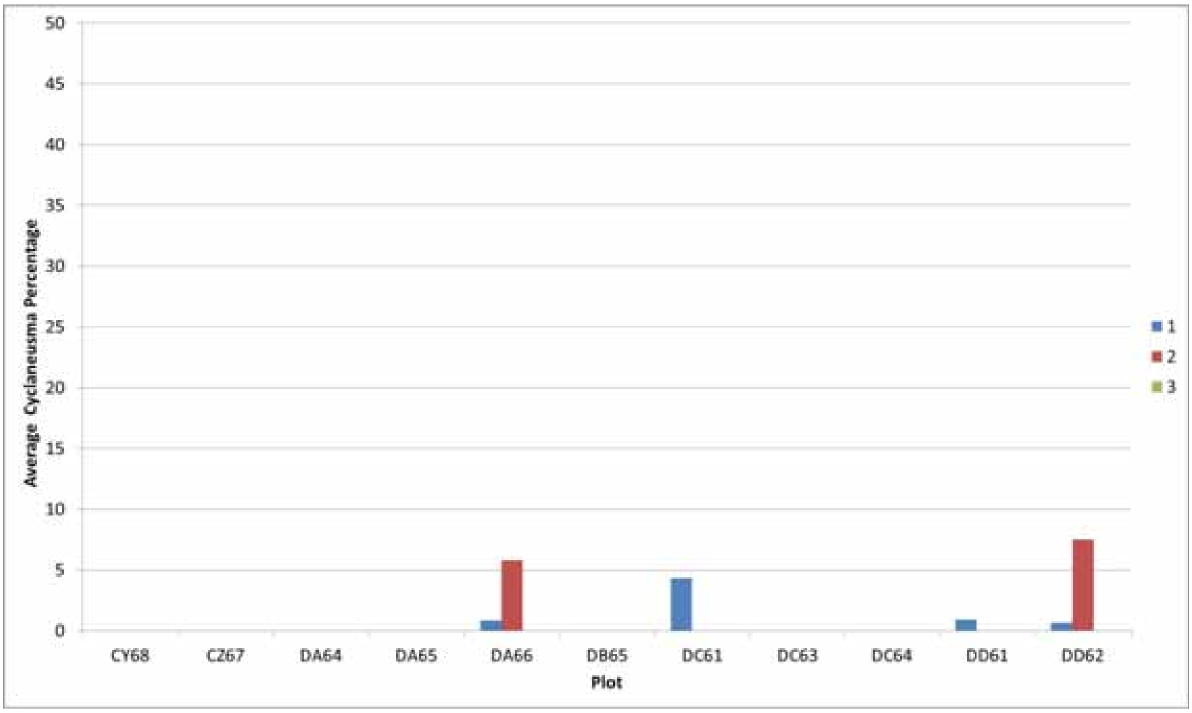

Figure 35. The average Cyclaneusma score for each plot recorded by operator

6 Discussion

The results of this analysis suggest that there remains a significant requirement for training and calibration of the operators involved in the collection of FCM data, differences between the operators in this study remain significant. This is consistent with Interpine's expectations and understandings from more advanced projects around the world. It is important that substantial resources are committed to reducing the sources of variability in the visual assessment of crown condition. The German system, which sees all operators attend a week long calibration course led by trainers skilled to internationally approved standards prior to the commencement of each measurement period, provides a good model for the progression of New Zealand's FCM programme.

Through this analysis and a process of consultation with the field crews' significant insight has been gained into the problems of assessing FCM variables. This has provided a significant benefit to the manual upgrade which constitutes Task 2 in the NZFOA's programme of additional FCM projects.

Of the key crown condition indicators this study has shown that the between operator variation is much greater for the defoliation indicator than for crown transparency. This suggests that defoliation is more difficult to assess and that training efforts should be redoubled for this indicator as the international consensus is that this variable is the most closely associated with tree health and vigour. The pattern of defoliation scores recorded by all three operators was broadly similar but there was significant between operator variability and bias which indicates more, better training is required. A large amount of the variation for the transparency variables is associated with age class. This indicates that the transparency variables are strongly correlated with age and that the crowns of radiata pine become more transparent as the trees gets older regardless of changes in tree condition. The effect of age can be dealt with in the interpretation of results but must be considered carefully with relation to the changing age structure in the sampling population. Of the key crown indicators transparency is easier to measure consistently but defoliation according to the literature on this topic defoliation is more biologically significant. As a result it is recommended that the measurement of both the transparency and defoliation indicators is continued. Transparency of the entire crown appears to be slightly less variable between the operators than upper crown transparency

Measurement assessment position has been shown to have a significant effect on both the between operator variation and the residual variation for transparency indicators. Therefore it is important to continue recording the angle to the assessment tree from the assessment position to reduce variation when measurements are repeated.

Within operator variability could not be assessed in this study due to budget constraints but this can be assessed through repeated measurements with sufficient time elapsed between to negate the effect of memory.

It should be noted that variability is an inevitable part of any dataset particularly one that is subjectively assessed and repeated measurement of plots year on year will enable this to be quantified and used in the interpretation of the survey results.

Of the additional crown condition indicators assessed crown depth and resin bleeding were the least variable and appear to be the easiest to call consistently as they displayed very little between operator variability. Other indicators, notably needle retention, crown dieback and assessment of foliar pathogens, were also highly variable in this experiment. The assessment of foliar diseases and needle retention are commonly used indicators of tree health in New Zealand and the variability in their assessment is of significant concern.

6.1 Conclusions

In conclusion the study reported on here has enable the authors to successfully partition the sources of variation in the crown condition indicators in the experimental dataset collected. The model based analysis reported on here clearly shows that significant between operator variability remains and that this is worse for the defoliation indicator than for transparency. The understanding of variability gained from this exercise will further the interpretation of the 2010 dataset and will help guide the improvement of training materials and methodology. The variability identified in this study underlines the need for significant efforts to be placed on training and calibration of operators in surveys which include the visual assessment of crown condition.

6.2 Acknowledgements

Thanks to Brian Rawley for a very useful review and comments on the statistical methodology used in this paper.

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