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1975 Final Crop Stocking Trials: Assessment of Crown and Wood Properties for Trees from Different Silvicultural Treatments

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EXECUTIVE SUMMARY

Historically tree growth research has been carried out in isolation to tree wood property (quality) research. Consequently, the data available for developing models of radiata pine stem growth is independent of the data available for developing models to predict the variation in wood properties with position in the stem. The variability in wood properties can be better understood by considering wood formation as an integral part of tree growth. This is because the external environment (climate and soil) and the genetic make-up of trees directly influence the functioning of the crown, which in turn influences the structure of wood cells.

An aim of the FFR Radiata Management Theme Objective 1 - Task 1.5 – Integrated Growth and Wood Property Models is to develop an initial version of an integrated empirical individual tree model that predicts stem growth, branch distribution and wood properties.

The logical way to develop such an empirical model is to use datasets where growth variables, branch variables and wood property variables are measured on the same trees. Four such datasets were collected under the auspices of the Stand Growth Modelling Cooperative. Further datasets, covering the range of site conditions, silvicultural treatments and genetic material are required in order to develop robust models applicable throughout New Zealand.

In 2008, FFR supported the collection of growth, branching and wood property data from two of the 1975 Final Crop Stocking (FCS) trials, i.e., AK1056 - Woodhill and NN529/1 - Golden Downs. This was the last opportunity to collect such data as they were scheduled for clearfelling.

The 1975 FCS trials were planted with an initial stocking of 625 stems/ha. Seven different silvicultural treatments were applied, i.e.:

1: thin to 100 stem/ha at age 11 years
2: thin to 200 stem/ha at age 11 years
3: thin to 400 stem/ha at age 11 years
4: unthinned control
5: thin to 100 stem/ha at age 14 years
6: thin to 200 stem/ha at age 14 years
7: thin to 400 stem/ha at age 14 years.

Novel sampling schemes are required to collect growth, branching and wood property data in a cost-effective manner from near-rotation-age trials that cover a large range of silvicultural treatments and genetic material. In this study, some additional new ideas for sampling schemes were tested as methods to provide data for model development.

Data were collected at three levels of intensity:

- A non-destructive "pre-screening" level to provide treatment average values for a number of wood properties. This sample allows the destructively sampled trees to be "benchmarked" against the treatment variability.
- A "low-intensity" destructive sampling to provide details of various traits at a log level, and to determine whether there is a silvicultural influence on wood properties over and above the effect of tree DBH.
- A "high-intensity" destructive sampling to provide details of branching characteristics, within disc variation in compression wood distribution with respect to branching characteristics and wood property variation at selected ages with reference to the silvicultural treatments.

It is recommended that further datasets are collected just prior to harvest age, so that FFR has full rotation growth and wood quality data covering the range of environmental conditions across the country. This is particularly important as data are the "backbone" of empirical models, and extrapolation is not desirable. Determining whether there are statistical differences in specific properties between treatments has previously been shown to require larger sample sizes.

Crown and wood property characteristics
Chapter 1 documents the analysis of crown and wood property characteristics collected "non-destructively" on standing trees. In summary the following results may be drawn from this pre-screening assessment:

Characteristic	Between sites	Woodhill	Golden Downs
Plot mean DBH	For a given treatment, higher values at Golden Downs compared to Woodhill	Higher at lower stockings	Higher at lower stockings
Plot mean outer wood density	For a given treatment, higher at Woodhill compared to Golden Downs	No obvious trends with stocking	Increases with increasing stocking
Standing tree velocity	For a given treatment, higher at Woodhil compared to Golden Downs	Increases with increasing stocking for treatments thinned at 11 years, No trend for the treatments thinned at 14 years	Increases with increasing stocking for both times of thinning
Resin features	For a given treatment, higher at Woodhill compared to Golden Downs	No consistent trends with silvicultural treatment	No consistent trends with silvicultural treatments
Branch diameter	NO DATA	Branches tend to be larger at lower stocking. Larger branches with thinning at 11 years for the lower final crop stockings.	NO DATA

The difference between the two timing of thinning treatments was minor for wood properties measured compared to the difference between the different final crop stocking. For branching, the early time of thinning resulted in more large branches particularly at 100 stems/ha. This may have implications for the internal wood property distributions, particularly compression wood.

The different timing of thinning will result in differences in wind risk to the stand.

It appears that the most appropriate silviculture regime will be site dependent, and a range of factors need to be considered when deciding on a regime for a given site, i.e., taking a holistic view of the forest system. For example, keeping branch size small to reduce the occurrence of compression wood may make trees more vulnerable to wind damage.

Chapter 2 documents the analysis of data from the "low intensity" destructive sample.
This sample consisted of three groups of trees, each containing a minimum of 1 tree from each of the seven silviculture treatments. Within each group, trees were of equal DBH at the time of the last PSP remeasurement. Consequently the trees were of small DBH compared to the plot average for PSPs with a nominal final crop stocking of 100 stems/ha and of large DBH compared to the plot average for PSPs with a nominal final crop stocking of 625 stems/ha.

Branch diameter was assessed using TreeD images collected prior to tree felling, and log velocity was measured using the HM200 for the whole stem and each 5 m logs.

Discs were cut at approximately 0.0 m, 1.4m, and at the small-end of each 5 m log, and the following assessed:

- Stem diameter under bark
- Log volume
- Bark thickness

- Juvenile wood percentage (percentage of disc occupied by 1st 10 growth rings)
- Percentage of disc occupied by heartwood
- Number of heartwood rings
- Disc density
- Spiral grain

One strip was cut from the 1.4 m disc and processed using SilviScan to provide a pith-bark trace for:

- Density
- Microfibril angle
- Modulus of elasticity

There was generally little difference in these variables between trees of the same DBH from the different silvicultural treatments.

It is considered that heartwood percentage showed the most variability between individual trees.

Microfibril angle and modulus of elasticity exhibited the most obvious trends with respect to the different silvicultural treatments with a sharp increase in ring-average microfibril angle and decrease in ring-average modulus of elasticity around the time of thinning (particularly for trees with a final crop stocking of 100 stems/ha). Close to the bark (tree age over 30 years), there was little difference in these properties between the individual trees.

An underlying biological reason for the observed increase in microfibril angle may be the change in wind environment and tree movement as a result of the reduction in stocking.

From the perspective of developing integrated growth, branching and wood property models, an important issue is how to collect empirical data required for model building in a cost-effective manner. The use of trees of equal DBH across a range of silvicultural treatments has provided useful information for model development in a cost-effective manner and it is recommended that this approach be used and further developed in future studies.

For developing integrated growth, branching and wood property models, ring or within ring wood properties are required, so it is recommended that research funding be spent on collecting such wood property data in conjunction with growth and branching data.

SilviScan is an appropriate tool to provide information on wood properties, in particular, microfibril angle which was the variable most influenced by silvicultural treatment over and above the effect of tree size.

Chapter 3 documents the analysis of data from the “high intensity” destructive sample.

The average number of branch clusters in an annual shoot was slightly higher at Woodhill compared to Golden Downs and is consistent with previous studies that indicate that the number of branch clusters in an annual shoot is influenced by latitude.

The length of the internodes between branch clusters varied between Woodhill and Golden Downs with there being more internodes over 30 cm at Golden Downs compared to Woodhill. The number of branches in a cluster varied from 0 to 13 with the median value generally between 5 and 7.

Visible compression wood below branch clusters tended to be more frequent as the diameter of the branches in the cluster increased. This result agrees with previous studies and has implications for the circumferential variability of wood properties within the stem.

There appears to be an influence of silviculture on ring-average values for spiral grain, density, microfibril angle, and modulus of elasticity, particularly for the treatments thinned to 100 stems/ha, and for the wood properties related to tree movement (i.e., microfibril angle and spiral grain). The increases in microfibril angle and spiral grain observed around the time of silviculture are considered to result from more tree movement after thinning.

Selecting sample trees from across a whole trial to cover the range in tree DBH is appropriate in large trials to provide data for model development. In this overall study, the matrix of tree DBH included trees of average DBH from each silvicultural treatment, and trees of the same DBH across the silvicultural treatments. In future studies, it would be useful to include DBH of the extremes, i.e., very large and very small.

Relationship between outerwood density and DBH

Chapter 4 documents the relationships, at an individual tree level, between (1) outerwood density and DBH, and (2) standing tree sonics and DBH. Also, graphical illustrations are provided that show where the destructively-sampled trees sit within these joint-distributions.

The analyses indicate that the selection of sample trees for destructive sampling based on DBH alone generally provided an equally representative sample of wood quality variability, compared with the use of outerwood density and standing tree sonics of a larger sample.

Given that the sample selected in this study were generally representative of the population, it is recommended that future studies trees are selected on the basis of DBH alone, particularly as it avoids the costs of an extra site visit.

INTRODUCTION

Historically tree growth research has been carried out in isolation to tree wood property (quality) research. Consequently the data available for developing models of radiata pine stem growth is independent of the data available for developing models to predict the variation in wood properties with position in the stem.

The variability in wood properties can be better understood by considering wood formation as an integral part of tree growth[1]. This is because the external environment (climate and soil) and the genetic make-up of trees directly influence the functioning of the crown, which in turn influences the structure of wood cells[2]. These underlying processes lead to the observed variations in growth, crown structure and wood properties with site and silvicultural treatments.

An objective of the FFR Radiata Theme Task 1.5 is to develop an initial version of an integrated empirical individual tree model that predicts stem growth, branch distribution and wood properties.

A logical way to develop such an empirical model is to use datasets where growth variables, branch variables and wood property variables are measured on the same trees.

Four datasets, to support the development of such models, were collected previously by the Stand Growth Modelling Cooperative:

- A pilot study to determine data collection methodology was carried out by sampling 1 or 2 trees from several seedlots, and 1 silvicultural treatment in the Special Purpose Breed Trial, FR172/3 in Kaingaroa[15,16,25].
- Datasets were collected from the GF14 seedlot in the 1978 Genetic Gain Trials at Golden Downs NN530/2 and Mokaka WN377, providing a contrast in site conditions for the same seedlot and silvicultural treatment[26,17,18].
- A dataset was collected from the 1991 Silviculture-Breed Trial FR121/11 Canterbury. This data set considered a two seedlots (GF25 and a Long Internode Seedlot LI25/GF13)[19].

The 1975 final crop stocking trials were planted at Woodhill, Kaingaroa, Golden Downs and Eyrewell, and represent one of the earliest silviculture trials planted with improved radiata pine from the “850” breed. The trials have been regularly measured for growth and branching data collected. The Woodhill and Golden Downs replicates were both scheduled to be clearfelled in 2008/9, consequently it was considered essential to collect branching and wood property data to complement the growth data in order to determine how this seedlot responded to the seven different silvicultural treatments (Table 1) in terms of growth, branching and wood properties, and also provide data for model development.

Table 1.
Silviculture treatments in the 1975 final crop stocking trials.

Number of Permanent Sample Plots established	Initial Stocking (stems/ha)	Final Stocking (stems/ha)	Nominal mean crop height at time of thinning (m)	Age at thinning (years)	Treatment Number
3	625	100	12	11	1
3	625	200	12	11	2
3	625	400	12	11	3
6	625	625	-	Unthinned	4
3	625	100	20	14	5
3	625	200	20	14	6
3	625	400	20	14	7

Data were collected at three levels of intensity:

- A non-destructive “pre-screening” level to provide treatment average values for a number of wood properties. This sample allows the destructively sampled trees to be “benchmarked” against the treatment variability.
- A “low-intensity” destructive sampling to provide details of various traits at a log level, and to determine whether there is a silvicultural influence on wood properties over and above the effect of tree DBH.
- A “high-intensity” destructive sampling to provide details of branching characteristics, within disc variation in compression wood distribution with respect to branching characteristics and wood property variation at selected ages with reference to the silvicultural treatments.

This report is presented in chapter form:

- Chapter 1 only discusses the non-destructive assessment.
- Chapter 2 presents the crown and wood properties for trees of the same DBH from different silvicultural treatments.
- Chapter 3 presents the crown and wood properties for trees of the average DBH from different silvicultural treatments.
- Chapter 4 presents the relationship between destructively and non-destructively assessed trees.

CHAPTER 1: NON-DESTRUCTIVE ASSESSMENT OF CROWN AND WOOD PROPERTIES FOR TREES FROM DIFFERENT SILVICULTURAL TREATMENTS

INTRODUCTION

Chapter 1 describes the non-destructive “pre-screening” level to provide treatment average values for a number of wood properties. This sample allows the destructively sampled trees to be “benchmarked” against the treatment variability.

METHODS

For the non-destructive assessment, the inner 10 trees were selected from each of the 3 replicates of the 6 silvicultural treatments. For the unthinned control, there were only two replicates with a current stocking close to the planting stocking of 625 stems/ha. For this treatment, the inner 15 trees were selected from these two plots.

At Golden Downs the recent windthrow had destroyed 4 plots consisting of:

- 1 replicate 100 spha early thin
- 1 replicate 200 spha late thin
- 2 replicates 400spha late thin

Extra trees were sampled from the remaining replicates to provide approximately 30 trees, however only 18 were available from the one remaining replicate of the 400 spha late thinning treatment.

Overall sample numbers are given in Table 1.1.

Table 1.1: Trial information and sample size

Location	Woodhill	Golden Downs
Trial	AK1056	NN529/1
Age (years)	33	33
No. of treatments	7	7
No. of sample trees	215	199

The following variables were measured for the trees selected:

- tree DBH
- outerwood density (using a 5mm increment core, selecting the outer 50mm, and then using the maximum moisture method[3]
- acoustic velocity (using the ST300)
- external resin bleeding[4]

At Woodhill, a non-destructive assessment of branching characteristics was carried out using the Cruiser methodology. Branch diameters were visually assessed along the length of the stem, and a branch diameter class assigned to sections of the stem. For this study, the branch diameter classes used were: 4cm, 8 cm, 10 cm, 12 cm, 14 cm, 16 cm, 20 cm.

RESULTS

Site Level
Appendix 1 details the standing tree properties by forest, stocking and thinning treatment for the 416 trees assessed for the DBH, outerwood density, standing tree sonics and external resin. Where available, distances from the centre of the plot are given.

Table 1.2 presents the average and standard deviation for these four properties measured by forest and Fig. 1.1 provides the frequency distributions. Given the contrasting site types the average standing tree properties are as expected i.e. Woodhill with reduced DBHOB, higher resin score, higher ST300 velocity and higher outerwood density.

Table 1.2. Standing tree properties by forest.

	DBHOB (cm)		**Outerwood density (kg/m^3)**	
	Woodhill	**G. Downs**	**Woodhill**	**G. Downs**
Mean	45.2	53.8	504	411
SD	9.8	11.7	34.5	31.8
n	215	199	215	198
	ST300 (km/s)		**Resin Score***	
	Woodhill	G. Downs	**Woodhill**	**G. Downs**
Mean	5.02	4.29	0.9	0.5
SD	0.29	0.32	0.8	0.5
n	207	191	207	195

*visually assessed

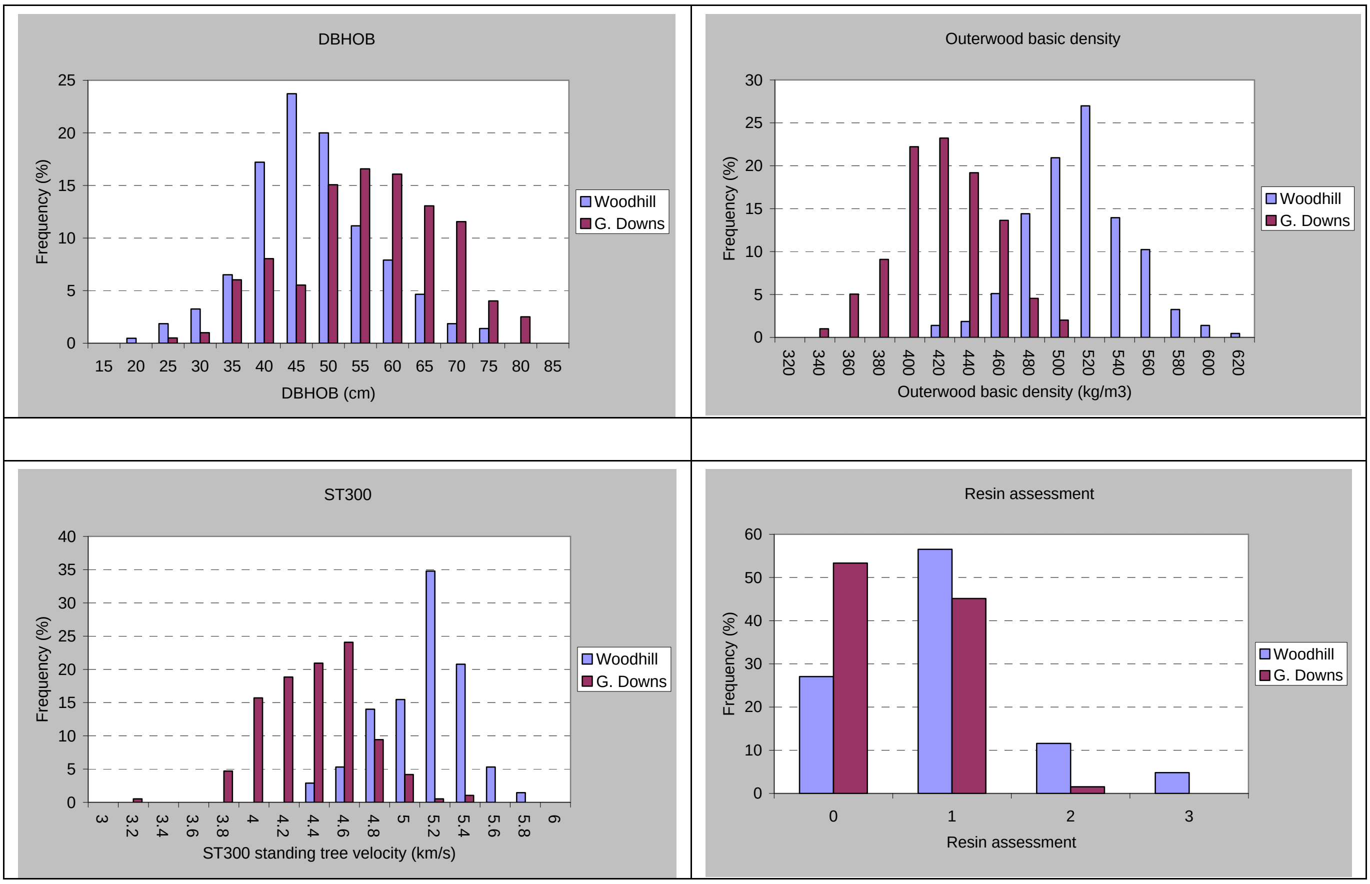


Figure 1.1: Standing tree parameter frequency distributions by forest.

The diameter distributions are approximately normal for both sites, as might be expected, and the range is wide, spanning about 50cm.

The density differences between sites (107 kg/m^3) and within sites (>200 kg/m^3) are very large, due to the wide range of nominal final crop stocking ranging from 100 stems/ha to 625 stems/ha. However the values are comparable to other studies[5,6,7].

Interestingly, the Woodhill sample corresponds well to the average values published for High Density sites[6], but the Golden Downs data is more related to the Low Density zone. This logical given that the trial was at 670 m, and the Nelson area is renowned for wood density variation related to altitude with inland high altitude sites having low density.

The acoustic values from the ST300 reflect the wood density trends, with Woodhill having significantly higher acoustic values overall than Golden Downs. The assessment of standing tree acoustic velocity is relatively new, and limited regional data is available.

Resin data indicated that visible resin was more apparent at Woodhill. The assessment of external resin bleeding is relatively new, and limited regional data is available.

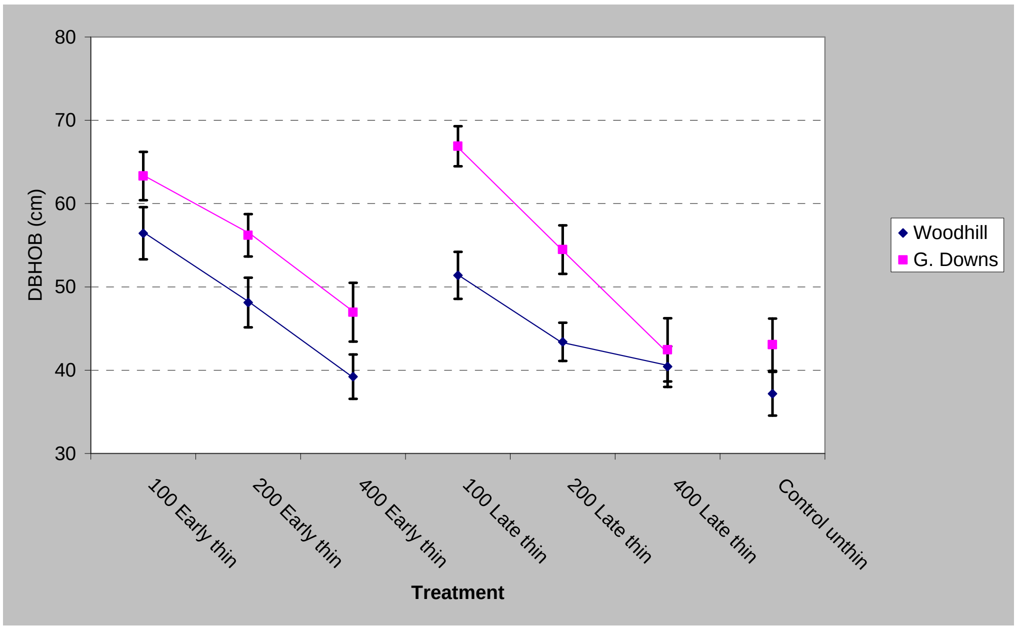
Silvicultural treatment level
Table 1.3 documents the average standing tree properties by forest, final crop stocking stocking and time of thinning. Figures 1.2, 1.3, 1.5 and 1.8 show the means and 95% confidence intervals by forest and treatment for DBHOB, outerwood density, ST300 standing tree velocity and resin score respectively.

Table 1.3: Average standing tree properties by forest, stocking and time of thinning

Forest/ Stocking (s/ha)	DBHOB (cm)		Outerwood density (kg/m^3)		ST300 (km/s)		Resin score *	
	Early thin	Late thin	Early thin	Late thin	Early thin	Late thin	Early thin	Late thin
100	56.4	51.4	495	507	4.82	4.97	1.4	1.1
200	48.1	43.4	495	517	4.95	5.12	1.2	0.8
400	39.2	40.4	498	507	5.18	5.09	0.6	0.9
Control	37.2		511		5.02		0.6	
Golden Downs								
100	63.3	66.9	399	394	4.04	4.04	0.4	0.6
200	56.2	54.5	404	407	4.29	4.33	0.5	0.7
400	47	42.4	419	417	4.38	4.44	0.4	0.3
Control	43.1		434		4.49		0.3	

* Visually assessed

DBHOB
Stocking effects were clearly apparent for both Woodhill and Golden Downs forests (Fig. 1.2). Both thinning treatments showed significant differences in DBHOB for the range of stockings. DBHOB was highest for the 100 sph treatment, less for the 200 sph treatment and similar for the 400 sph and control treatment. For a given stocking, differences in DBHOB between early and late thinning treatments were small and probably not significant. Generally speaking, the early thinned trees had slightly greater diameter growth, with the main exception of Golden Downs 100 spha where the late thinned trees averaged 66.9 cm compared to 63.3 cm for the early thinned trees.

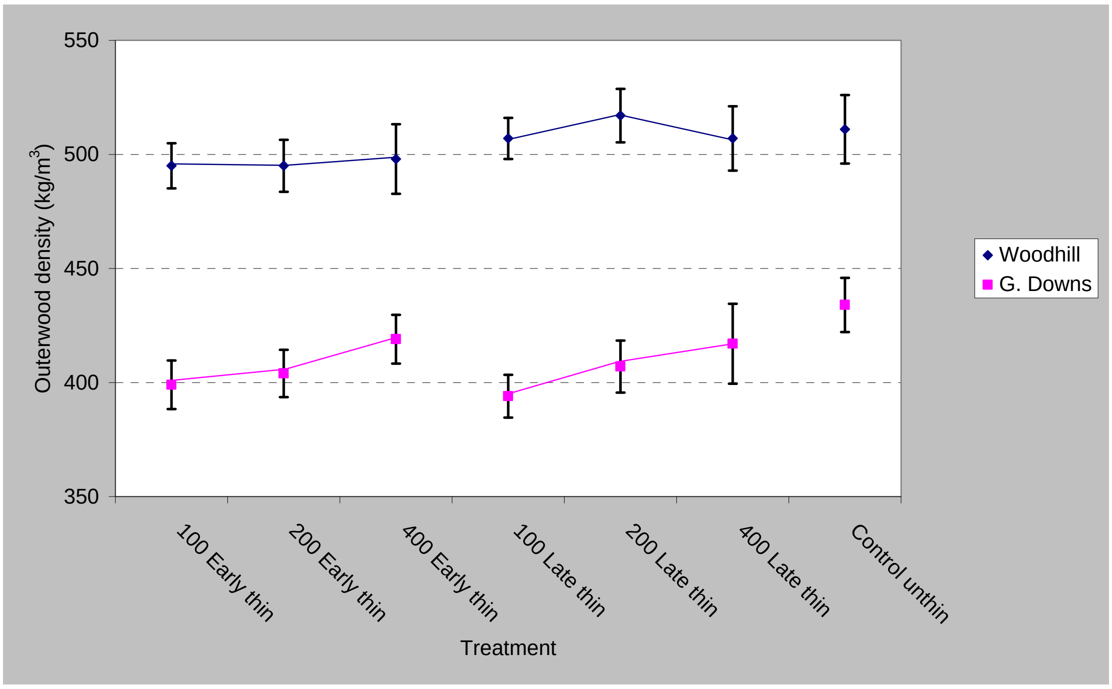


Note: Error bars are the 95%confidence limits of the means, sample size approx. 30 trees per treatment

Figure 1.2: DBHOB by forest and treatment.

Outerwood Density
The clear forest differences in average outerwood density (Fig.1.1) were apparent across all treatments (Fig. 1.3).

Numerous studies have indicated a negative relationship between DBH and wood density [5,8,9,10,11]. At Golden Downs, the density values trend downwards as the stocking decreases – in this case from 434 kg/m^3 for the Control unthinned plots to just under 400 kg/m^3 for both the 100 spha thinning treatments. At Woodhill, treatment differences in terms of outerwood density were less obvious and the range in plot average densities was much reduced.



Note: Error bars are the 95%confidence limits of the means based on a sample size of approximately 30 trees

Figure 1.3: Outerwood density by forest and treatment.

Relationship between DBHOB and outerwood density
Treatment average outerwood density and treatment average DBHOB were weakly and negatively correlated at both locations (Fig. 1.4). This result is not unexpected, as increasing spacing has often been shown to cause a drop in wood density[8,9,11].

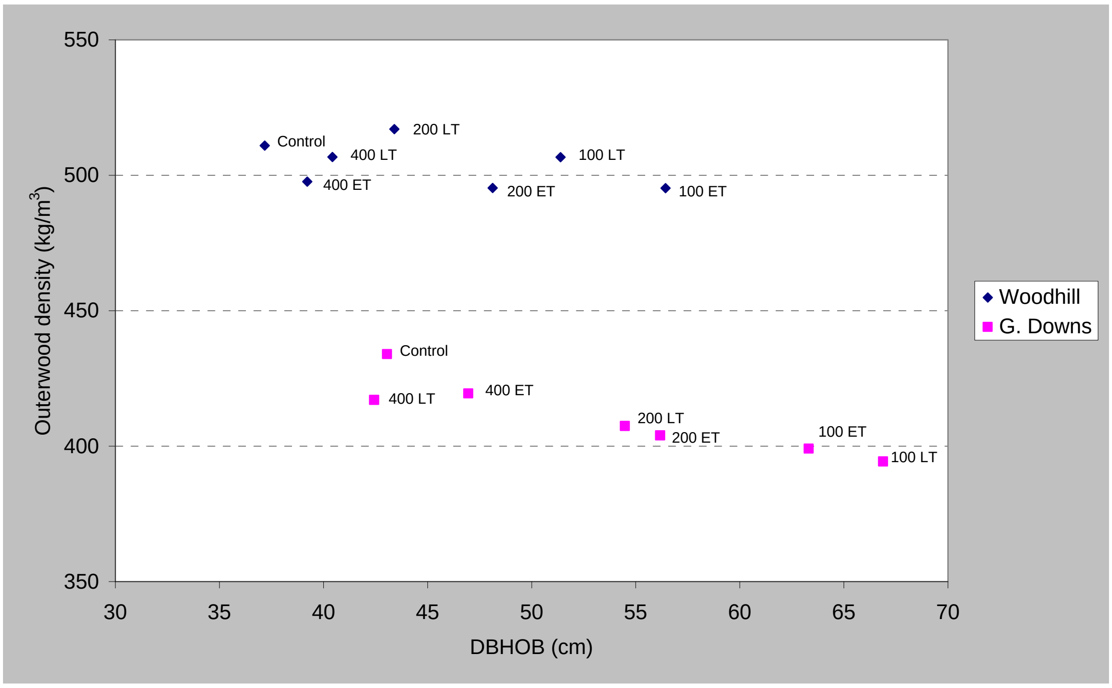
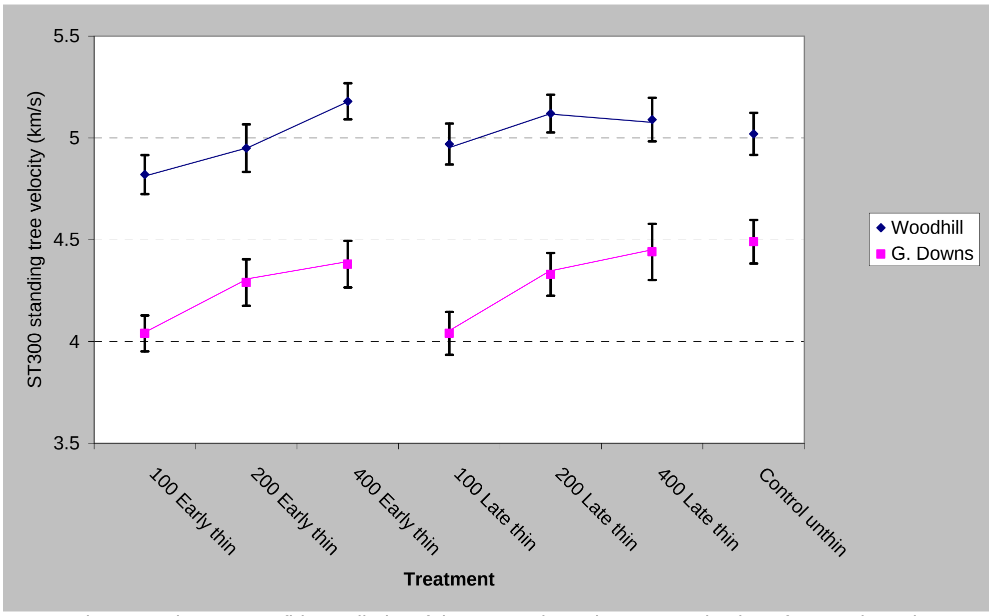


Figure 1.4: Relationship between treatment average values of outerwood density and breast height diameter (DBHOB).

ST300
At Woodhill, average ST300 values ranged from 4.82 km/s (early thinned 100 sph treatment) to 5.18 km/s (early thinned 400 sph treatment) (Fig. 1.5). At Golden Downs standing tree velocities were considerably lower. Average values per treatment ranged from 4.04 km/s (both early and late thinned 100 sph plots) to 4.49 km/s (Control treatment). As a general rule ST300 velocities increased with stocking level across both sites for early and late thinning treatments.



Note: Error bars are the 95%confidence limits of the means based on a sample size of approximately 30 trees.

Figure 1.5: ST300 standing tree velocity by forest and treatment.

Relationship between DBHOB and ST300
As with outerwood density, treatment average acoustic values were negatively correlated with treatment average DBH (Fig. 1.6).

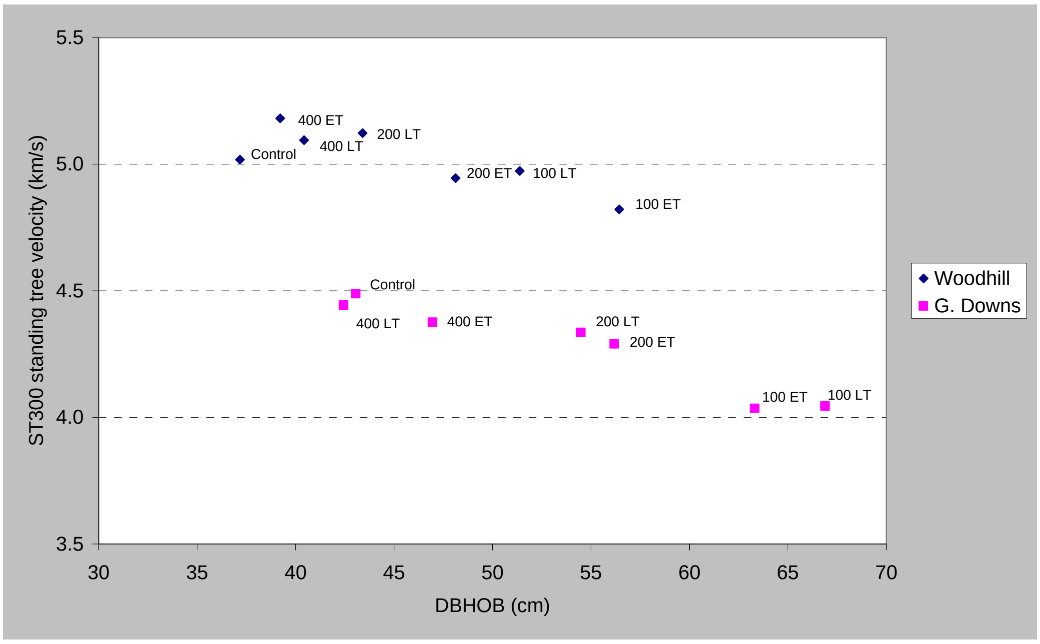


Figure 1.6: DBHOB vs. ST300 velocity – treatment averages.

Relationship between outerwood density and ST300
At Golden Downs, there was a positive correlation between treatment average outerwood density and treatment average ST300. The relationship was weaker at Woodhill. Both sites combined gave a strong positive correlation (Fig. 1.7). This relationship has been observed in several other unpublished studies.

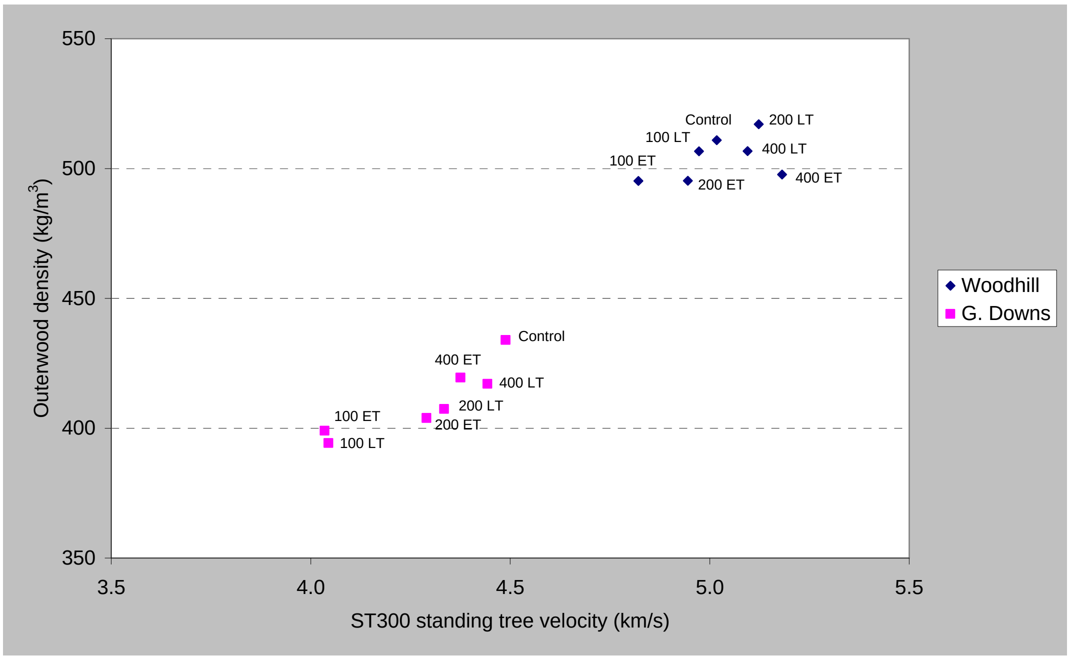
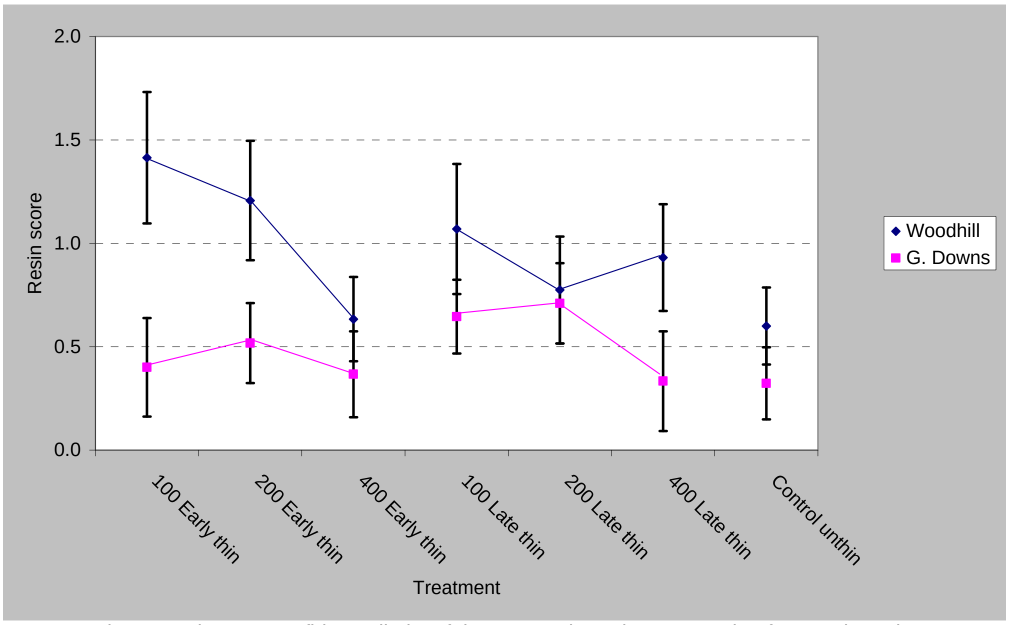


Figure 1.7: ST300 vs. Outerwood density – treatment averages.

Resin
A higher level of resin bleeding and lesions was observed at Woodhill compared to Golden Downs (Fig. 1.8).

At Woodhill, a stocking effect was apparent particularly in the early thinned plots where a significant trend was shown between the 100 sph and 400 sph trees with resin scores of 1.4 and 0.6 respectively (Fig. 1.8). In this case early thinning clearly appears to exacerbate visible resin features.

At Golden Downs, there was no obvious effect of stocking.



Error bars are the 95%confidence limits of the means, based on a sample of approximately 30 trees

Figure 1.8: Resin assessment by forest and treatment.

Branching Characteristics
In Cruiser, branching characteristics are assigned by zones. Cruiser data does not generally record the decrease in branch diameter in the growing part of the crown as this is difficult to observe due the stem being less visible within the green crown. For analysis the stem was divided into 4 zones:

- 8 m – 12.0 m: below mean crop height for early and late thinning
- 12.0 m – 16.0 m: between mean crop height of early and late thinning
- 16.0 m – 20 m: between mean cop height of early and late thinning
- 20.0 – 24 m: above mean crop height of early and late thinning

Figure 1.9 illustrates the assigned length of stem assigned to each branch diameter class (given by branchclass_mm) for each silvicultural treatment. There was a clear effect of silvicultural treatment.

For the 100 stems/ha treatments over 50% of the stem length contained branches 8 cm and over.

For the 400 stems/ha treatments over 70% of the stem contained branches 4 cm or less.

The 200 stems/ha treatments were intermediate between these two treatments.

The control treatment (treatment 4) contained few branches over 4 cm.

At 100 stems/ha and and 200 stems/ha the early thinning resulted in larger branches compared to the late thinning.

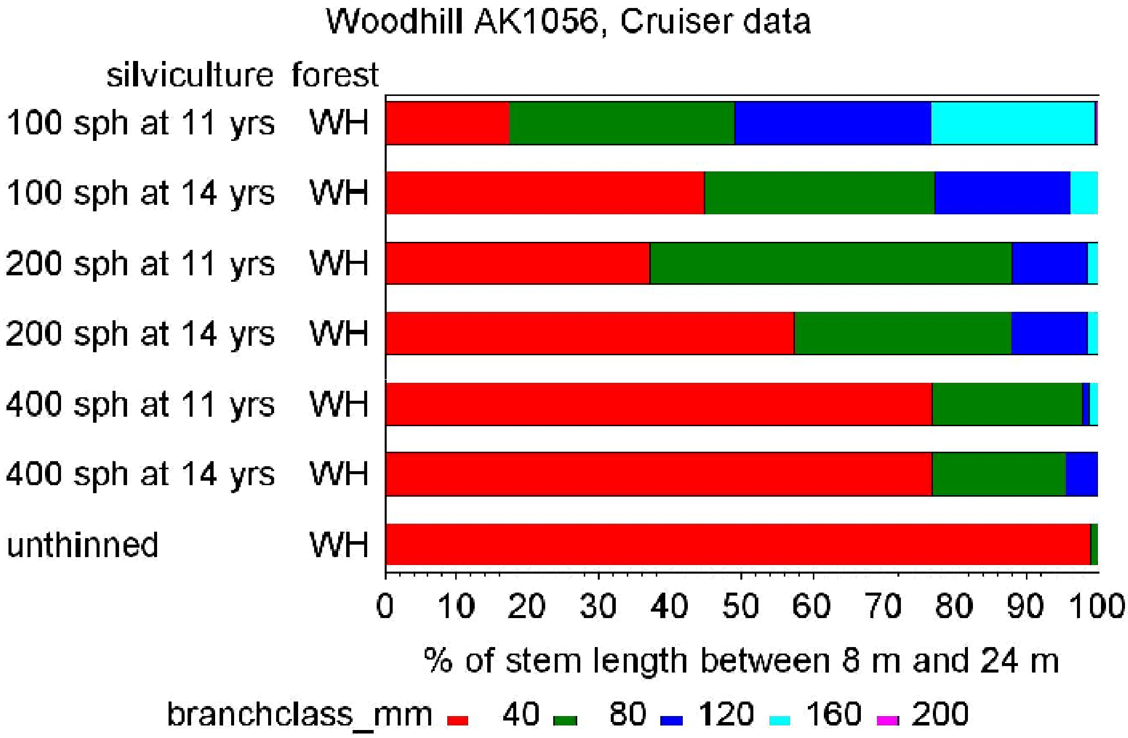


Figure 1.9. Length of stem where assessed branch diameter is given by newmaxd_mm.

Figure 1.10 illustrates how the plot mean branch diameter varies across the different stem zones and allows the effect of the two timings of thinning to be investigated.

For the 100 stems/ha treatments, the early treatment tends to have larger branches. The difference is particularly apparent in the two middle zones. This is the section of stem formed after the height of the early thinning and before the height of the late thinning. For the 200 stems/ha treatments there is little difference due to timing of thinning, but branch diameter is larger after thinning. For the 400 stems/ha treatments, there is little difference due to time of thinning and little increase in branch diameter with height in the tree.

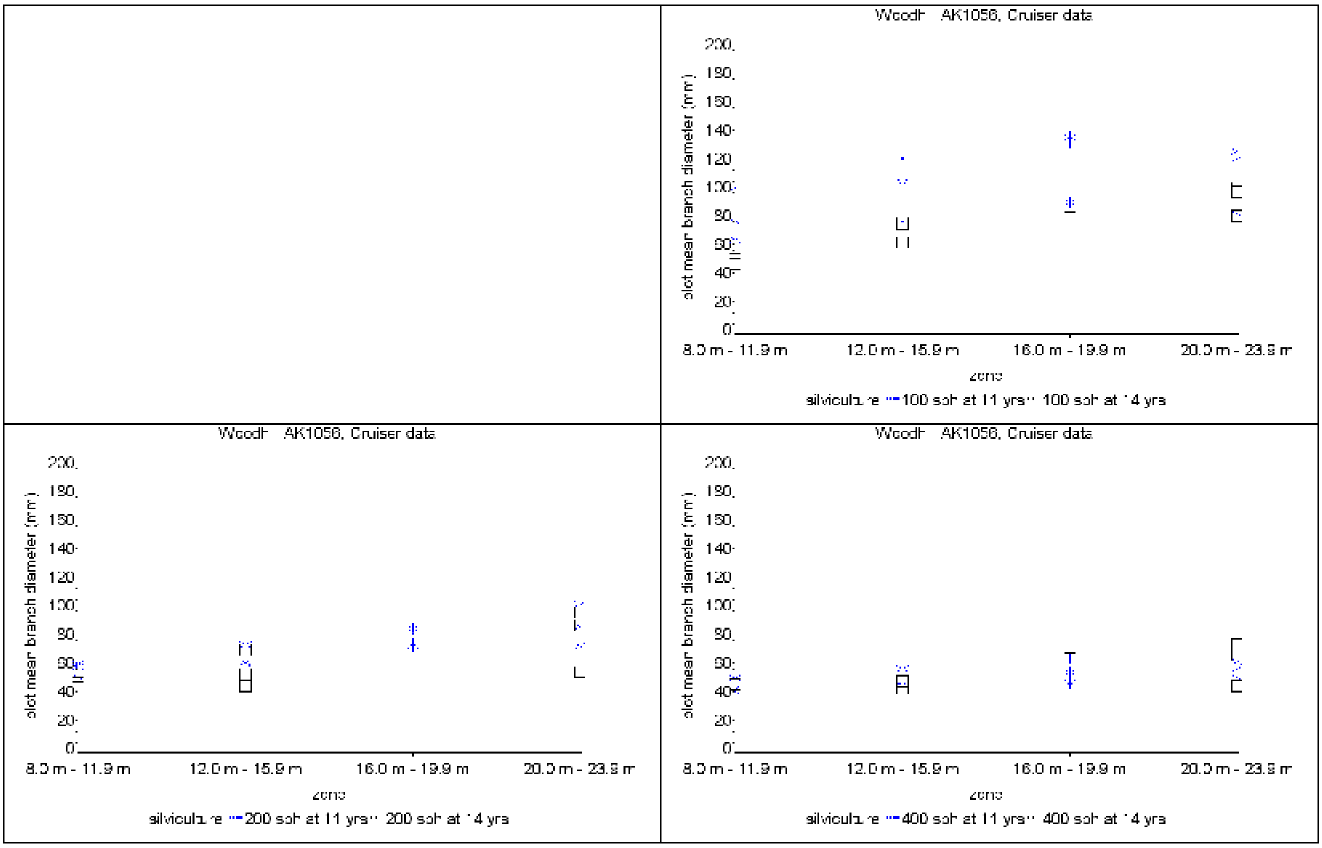


Figure 1.10. Plot mean branch diameter for each stem zone by final crop stocking.

CONCLUSION

The non-destructive sampling provides an overview of the influence of site and silvicultural treatment on treatment mean values for DBH, outerwood density, standing tree sonics, external resin features, and branching (Woodhill only).

Plot mean DBH was less at Woodhill compared to Golden Downs. There was a clear influence of silvicultural treatment at both sites with plot mean DBH being higher at lower stockings.

Plot mean outerwood density was higher at Woodhill than Golden Downs. At Golden Downs, plot mean outerwood density tended to increase with stocking. At Woodhill there was no obvious trend with increasing stocking.

Plot mean standing tree velocities from the ST300, were lower at Golden Downs compared with Woodhill. Standing tree velocities increased with increasing stocking at Golden Downs. At Woodhill this trend was applicable to the early but not the late thinning treatments.

Resin features were more common at Woodhill compared to Golden Downs. There was no consistent response to the different final crop stockings.

The differences between the two timing of thinning treatments were minor for the non-destructive wood properties measured.

Branch diameters were clearly influenced by silvicultural treatment with more large branches occurring at lower stockings; and at the very low stockings more large branches with the earlier time of thinning. This is likely to affect the compression wood distribution within the stem as branch diameter has been shown to impact on compression wood distribution[13].

These results will complement those from more detailed assessment of a fewer number of trees, and the previous growth and branching data collected and analysed under the auspices of the Stand Growth Modelling Cooperative[13,14].

CHAPTER 2: DESTRUCTIVE ASSESSMENT OF CROWN AND WOOD PROPERTIES FOR TREES OF THE SAME DBH FROM DIFFERENT SILVICULTURAL TREATMENTS

INTRODUCTION

Data were collected from three groups of trees of equal DBH (2 groups from Woodhill and 1 group from Golden Downs) and were destructively sampled to determine whether there was a treatment response over and above the tree size response.

This chapter documents the data analysis for trees of equal DBH.

METHODS

Trees with the same DBH at the time of the last PSP remeasurement (Woodhill, 2006; Golden Downs, 2007) were selected from the seven different silvicultural treatments to quantify the influence of silviculture on wood properties over and above the influence of tree DBH alone. Given the wide range of silvicultural treatments in these trials it was difficult to find a DBH that was represented in all 7 treatments. Originally two groups were selected from each site. However many of the trees in the second group at Golden Downs had been windthrown so that group was removed from the study.

The DBH range of each of the three remaining groups was:

- Woodhill Group A, DBH: 47.5 to 48.5 cm
- Woodhill Group B, DBH: 43.5 to 44.5 cm
- Golden Downs, Group C, DBH: 55.5 to 56.5 cm

Prior to felling, TreeD[20] images were collected to provide a record of the standing tree, and provide quantitative information on stem form and branching characteristics as required. External resin bleeding was also recorded.

After the sample trees were felled, the full stem velocity was measured using the HM200. The tree was then cut into 5 m sections up to a SED of approximately 100 mm, and log velocity measured using the HM200.

Wood discs, 50 mm in depth, were cut from the stem at approximately 0 m, 1.4 m, 5 m, 10 m, 15 m, and then every 5 m to a small end diameter of approximately 100 mm. The following properties were measured/ calculated:

- Stem diameter under bark
- Juvenile wood percentage (percentage of disc occupied by 1st 10 growth rings)
- Percentage of disc occupied by heartwood
- Number of heartwood rings
- Disc density (by selecting two opposite sectors that avoided compression wood, and determining density by water immersion for volume and then oven-drying.
- Spiral grain at every second annual growth ring by scribing wood blocks removed from opposite radii.

A single pith-bark strip from the 1.4 m disc was analysed using SilviScan to provide a pith to bark trace of:

- Density (at 12% moisture content)
- Microfibril angle
- Modulus of elasticity

The traces were analysed to give ring-average values for these properties.

RESULTS

Stem diameter under bark (Appendix 2 - Figure 1)
A TreeD images provides a scaled image of a sample tree from which observable features may be measured. For this study the variables extracted were:

- Height to each branch cluster.
- Diameter of the largest branch visible in that cluster (branches immediately behind the stem in the direction the image was taken will not be visible).

The length of stem for which it is practical to measure branch clusters varies between trees due to crown structure. The common length of stem visible across trees on a given site was:

- Woodhill: 6.9 m to 13.8 m.
- Golden Downs: 6.8 m to 12.3 m.

The common stem length does not permit a full examination of branch response to thinning as the early thinning occurred at a nominal mean crop height of 12 m, and the late thinning occurred at a mean crop height of 20 m **(Introduction - Table 1)**.

For each tree, the maximum, minimum and mean branch diameter were calculated over the common stem length for each group of trees (Appendix 2 - Figure 1). For the three individual groups:

- The minimum branch diameter is generally around 10 mm to 20 mm.
- The mean branch diameter is more variable, around 30 mm to 50 mm.
- The maximum branch diameter is even more variable with two trees at Woodhill having branches over 100 mm.
- For all three measures, there was no obvious relationship with respect to silvicultural treatment.

Previous studies of radiata pine branching for the SGMC have indicated that very large diameter branches tend to be the result of stem damage.

Stem diameter under bark (Appendix 2 - Figure 2)

- At Golden Downs (Group C), the stem taper is similar regardless of silvicultural treatment.
- At Woodhill (Groups A and B), the trees at 100 stems/ha are more tapered than the stems at higher stockings. (A possible reason is the fact that height growth tends to be reduced at very low stockings[21].

Log volume inside bark (Appendix 2 - Figure 3)

- Log volumes are very similar across trees for a given log height class for all three groups of trees. This is not unexpected given that the trees were of a similar DBH.
- Observed differences are influenced by differences in stem taper.

Bark thickness (Appendix 2 - Figure 4)

- Bark thickness decreases exponentially with increasing height in the tree.
- There was no obvious variation in bark thickness with silvicultural treatment.

Juvenile wood percentage (% of disc occupied by 1st 10 growth rings) (Append. 2 - Figure 5)

- By definition, the percentage of juvenile wood increases with increasing tree height until it reaches 100%. At the base of the tree, juvenile wood percentage was around 30% at Woodhill and 20% at Golden Downs.
- The juvenile wood percentage is slightly more variable at Woodhill compared to Golden Downs.
- Across the three groups of trees, there are no obvious patterns with respect to the silvicultural treatments.
- Two discs appeared to have a low juvenile wood percentage compared to other discs
    - Woodhill, group A, Tree 1 at 15 m. The image of this disc (below) is interesting. It shows patches of compression wood and eccentric growth that suggest it has been cut very close to a branch cluster.
    - Golden Downs, Group C, Tree 1 at 20 m (no image available).

Heartwood percentage (Figure 6)

- Heartwood percentage increases to approximately 5 m within a tree and then decreases. The lower heartwood percentage near the base of the tree will be due to butt flare.
- Heartwood highly variable between trees.
- No consistent trends with silvicultural treatments across groups.

Heartwood rings (Appendix 2 - Figure 7)

- The number of heartwood rings decreases with increasing height in the tree.
- The number of heartwood rings are highly variable between trees within each group.
- There are no consistent trends with silvicultural treatments across the three groups.

Disc basic density (Figure 8)

- Disc basic density tends to decrease with increasing height in the stem.
- There was no consistent pattern with respect to silvicultural treatment when considering trees of the same DBH. However the tree with the highest density in each group was either from the control treatment or a final crop stocking of 400 stems/ha.

Log velocity (Figure 9)

- Log velocity as measured using the HM200 tends to decrease with increasing log height class within the tree.
- A tree from the control treatment has the highest log velocities for groups B and C. However, there is no consistent pattern with treatment when considering trees of the same

DBH. The selected trees from 100 stems/ha treatments do not have the lowest log velocities.

Spiral grain (Appendix 2 - Figure 10, Figure 11 and Figure 12)
Spiral grain was measured on the latewood band of every second growth ring for two sample directions from discs from 1.4 m, 5 m, 10 m, 15 m, 20 m etc to a small end diameter of approximately 100 mm. The two measures of spiral grain were averaged to give the values shown.

The data for 1.4 m and 10 m are shown in this report. The horizontal axis in this series of figures is the tree age when the ring was formed. This allows one to examine the data for changes in trends around the time of thinning. The two vertical lines at 11 years and 14 years correspond to the time of the early and late thinning respectively. Each individual graph represents a different group / final crop stocking combination.

Woodhill 1.4 m (Appendix 2 - Figure 10)

- There is a trend for spiral grain to start positive and trend negative with time.
- Across each group of trees (group A or Group B), the range of spiral grain values is similar.
- There is a wide variety of patterns between individual trees.
- For some trees, there is a reverse in the trend around the time of silviculture.
- For example, Group B with a final crop stocking of 200 stems/ha. Treatment_tree 2_5 (early thinning) and treatment_tree 6_12 (late thinning) both shows a reversal. This reversal is earlier with the early thinning. The 3rd tree in the group shows no obvious reversal.

Woodhill 10.0 m (Appendix 2 - Figure 11)

- There is a trend for spiral grain to start positive and trend negative with time.
- Across each group of trees (group A or Group B), the range of spiral grain values are similar.
- There is a wide variety of patterns between individual trees.
- For some trees, there is a reverse in the trend around the time of silviculture.
- The reversal appears to be more pronounced for trees with a final crop stocking of 100 stems per hectare (e.g. Group A, Treatment_tree 1_1 and group B Treatment_tree 1_14).

Golden Downs 1.4 m and 10.0 m (Appendix 2 - Figure 12)

- There is a trend for spiral grain to start positive and trend negative.
- The range in spiral grain values is similar across all trees.
- Spiral grain variability appears to be less than at Woodhill.

SilviScan Data (Appendix 2 - Figure 13 to Figure 21)
The horizontal axis in this series of figures is the tree age when the ring was formed. This allows one to examine the data for changes in trends around the time of thinning.

The two vertical lines at 11 years and 14 years correspond to the time of the early and late thinning respectively.

Each column of graphs corresponds to a given group of trees, and the individual graphs are either for a given final crop stocking or timing of thinning.

There is a separate line for each tree given by the variable treatment_tree. The first number is the assigned treatment number:

- 1 = thinned to 100 stems/ha early
- 2 = thinned to 200 stems/ha early
- 3 = thinned to 400 stems/ha early
- 4 = unthinned control
- 5 = thinned to 100 stems/ha late
- 6 = thinned to 200 stems/ha late
- 7 = thinned to 400 stems/ha late

The second number is the assigned tree number.

The data were presented this way to allow differences between individual trees to be more easily distinguished.

Density

- Appendix 2 - Figure 13 presents the data for Woodhill. Each individual graph corresponds to a given final crop stocking and compares trees from the early and late thinning treatments.
- Appendix 2 - Figure 14 presents the data for Woodhill. Each individual graph corresponds to a given timing of thinning and compares trees from the different final crop stocking treatments.
- Appendix 2 - Figure 15 presents the data for Golden Downs. Individual graphs in the left hand column correspond to a given final crop stocking. Individual graphs in the right hand column correspond to a given time of thinning.
- The data correspond to the known general trend for density to increase with increasing with increasing tree age when the ring was formed, and for the more northern site (Woodhill) to exhibit higher values[5].
- Given the year-to-year variability in density, it is difficult to pick out an obvious response to thinning. Density did drop around the time of thinning for treatment_tree 1_1 from Woodhill group A with a final crop stocking of 100 stems/ha.
- Looking each graph, the trend in density with tree age when the ring was formed is very similar for the trees considered, indicating that there are no obvious differences between these trees of the same DBH with respect to either final crop stocking or timing of thinning.
- The lack of obvious differences between silvicultural treatments at a given DBH is mirrored in the outerwood density values from the pre-screening data (Appendix 2 - Figure 22). At the DBH for the selected groups (Woodhill Group A, 47.5 – 48.5 cm; Woodhill Group B, 43.5-44.5 cm; Golden Downs Group C, 55.5-56.5 cm) the treatments are not clearly separated.

Microfibril Angle (MFA)

- The general trend is for MFA to decrease with increasing tree age when the ring was formed.
- Appendix 2 - Figure 16 presents the data for Woodhill when the individual graphs correspond to a given final crop stocking and compares trees from the early and late thinning treatments.
- With a final crop stocking of 100 stems/ha, 3 of the 4 trees showed a sharp increase in MFA around the time of thinning.
- With a final crop stocking of 200 stems/ha, 2 of the 6 trees showed an increase in MFA around the time of thinning and compares with trees from the different final crop stockings.
- There were no obvious changes to the general trend in MFA for trees with a final crop stocking of 400 stems/ha and for the control trees.
- Appendix 2 - Figure 17 presents the data for Woodhill when the individual graphs correspond to a given time of thinning.
- Examining data for Group A and a late thinning suggests that the response to thinning is more pronounced in the trees with a lower final crop stocking.
- Appendix 2 - Figure 18 presents the data for Golden Downs. Individual graphs in the left hand column correspond to a given final crop stocking. Individual graphs in the right hand column correspond to a given time of thinning.
- Patterns of microfibril angle are quite variable between individual trees.
- Some trees show an increase in microfibril angle around the time of thinning.

Modulus Of Elasticity (MOE)

- SilviScan MOE is estimated from the measurements taken for density and MFA.
- The general trend is for MOE to increase with increasing tree age when the ring was formed.
- Appendix 2 - Figure 19 presents the data for Woodhill where the individual graphs correspond to a given final crop stocking.
- For both Group A and Group B, the trend in MOE values from pith to bark is very similar. However there is more variation in values around the time of thinning.
- For Group A, with a final crop stocking of 100 stems/ha, there are obvious changes in MOE around the time of thinning. The drop in MOE is earlier for treatment_tree1_1 from the early thinning treatment compared to treatment_tree 5_15 from the late thinning treatment.
- Appendix 2 - Figure 20 presents the data for Woodhill when the individual graphs correspond to a given time of thinning.
- For Group A with the late thinning, the drop in MOE is more pronounced with the lower final crop stocking.
- Appendix 2 - Figure 21 presents the data for Golden Downs. Individual graphs in the left hand column correspond to a given final crop stocking. Individual graphs in the right hand column correspond to a given time of thinning.
- MOE decreases slightly around the time of thinning but the change is not as pronounced as at Woodhill.
- The pre-screening, standing tree sonics data (Appendix 2 - Figure 23) shows little differentiation between treatments at the DBH for the selected groups (Woodhill Group A, 47.5 – 48.5 cm; Woodhill Group B, 43.5-44.5 cm; Golden Downs Group C, 55.5-56.5 cm).
- This indicates that measuring standing tree sonics many years after silvicultural treatment does not pick up subtle changes in MOE occurring around the time of thinning.

Discussion

Of the variables measured it is considered that microfibril angle showed a response to silvicultural treatment over and above the effect of tree DBH.

Trees need to be mechanically reliable to grow and survive over a rotation. Trees adjust their mechanical properties through the addition of new cells and through the structure of these new cells[22]. The increased diameter growth achieved at low stocking is attributed to both the increased light availability and the increased exposure to wind which results in more swaying and consequently more diameter growth[23]. Experiments with flexing (swaying) trees[24] have shown that microfibril angle increases with flexing. It is therefore considered that the sharp changes in microfibril angle around the time of thinning are due to increased flexure /sway caused by changes in the wind environment within the PSP due to the reduction in stocking.

CONCLUSION

This chapter documents the variation in branching and wood properties for three groups of trees from the 1975 final crop stocking trials at Woodhill and Golden Downs. Two groups of trees were from Woodhill and one group of trees was from Golden Downs. Within each group, trees were of equal DBH at the time of the last PSP remeasurement, and were selected from each of the seven silvicultural treatments. Consequently the trees were of small DBH compared to the PSP average for PSPs with a nominal final crop stocking of 100 stems/ha and of large DBH compared to the PSP average for PSPs from the control treatment.
The objective was to determine whether there was a treatment response over and above the tree size response.

The characteristics assessed graphically were:

- Branch diameter
- Stem diameter under bark
- Log volume
- Bark thickness
- Juvenile wood percentage (percentage of disc occupied by 1st 10 growth rings)
- Percentage of disc occupied by heartwood
- Number of heartwood rings
- Disc density
- Log acoustics using the HM200
- Spiral grain
- A pith to bark SilviScan profile of density at 1.4 m, summarised to ring average values
- A pith to bark SilviScan profile of microfibril angle at 1.4 m summarised to ring average values
- A pith to bark SilviScan profile of modulus of elasticity at 1.4 m summarised to ring average values

Apart from the spiral grain and SilviScan data, the properties measured can be considered to be tree, log or disc properties rather than a ring property. There was generally little difference in these tree, log or disc property variables between trees of the same DBH from the different silvicultural treatments, indicating that tree size is the primary driver.

Of the “ring” properties, microfibril angle and modulus of elasticity exhibited obvious trends with respect to the different silvicultural treatments with a sharp increase in microfibril angle and a drop in modulus of elasticity around the time of thinning, particularly for trees with a nominal final crop stocking of 100 stems/ha. Close to the bark (tree age over 30 years), there is little difference between the individual trees.

The changes in microfibril angle (and modulus of elasticity as it is a function MFA) are considered to be due to changes in the wind environment as a result of the thinning.

There were also sharp changes in spiral grain around the time of thinning, particularly at Woodhill. This may also be related to changes in the wind environment.

The “ring property” measures are more useful for the purpose of developing integrated growth, branching and wood property models than the log and disc properties. It is recommended that, in future studies, SilviScan data be collected at more heights within the tree in preference to collecting data to estimate high level log characteristics.

The sampling strategy of measuring trees of the same DBH across silvicultural treatments has proved to be a cost –effective way of obtaining data on the response to silviculture treatments. It is recommended that this approach is used in future studies.

CHAPTER 3: DESTRUCTIVE ASSESSMENT OF CROWN AND WOOD PROPERTIES FOR TREES OF AVERAGE DBH FROM DIFFERENT SILVICULTURAL TREATMENTS

INTRODUCTION

Data were collected from trees of average DBH from each of the 7 silvicultural treatment were destructively sampled to determine average responses and explore within-tree variability in wood properties. Eleven trees were sampled at Woodhill and seven trees were sampled at Golden Downs.

This chapter documents the data analysis for trees of average DBH.

METHODS

Trees of average DBH, from the different silvicultural treatments, were selected in the office as ones that were consistently close to plot (PSP) average DBH at the time of each PSP re-measurement[27]. Eleven trees were sampled at Woodhill (Table 2.1) and seven trees at Golden Downs (Table 2.2).

Table 2.1.
Selected sample trees (most average tree) for Woodhill, AK1056.

Treatment Number	Plot	Initial SPH	Final SPH	PSP tree number	DBH-cm	Ht-m	Assigned tree number
1	2/11	515	90	5/4	53.8	29.6	Tree 1
1	23/21	420	95	8/2	61.6	31.5	Tree 2
2	5/12	510	210	2/24	46.5	28.8	Tree 3
3	3/13	480	400	1/ 4	36.7	32.2	Tree 4
3	10/23	600	380	24	36.8	28.5	Tree 5
4	9/14	700	650	1/6	34.6	-	Tree 6
5	11/25	535	90	8/2	51.3	29.7	Tree 7
5	17/35	460	95	20/1	51.9	30.9	Tree 8
6	20/36	350	210	4/27	45.0	32.4	Tree 9
7	1/17	520	360	2/13	38.0	34.2	Tree 10
7	21/37	420	380	1/1	40.5	31.0	Tree 11

Note: Introduction - Table 1 gives the definition of the treatment number

Table 2.2.
Selected sample trees (most average tree) for Golden Downs, NN529/1.

Treatment Number	Plot	Initial SPH	Final SPH	PSP tree number	DBH-cm	Ht-m	Assigned tree number
1	22/21	430	95	5/4	65.2	44.5	Tree 6
2	3/32	560	200	45	59.5	42.0	Tree 3
3	5/33	580	420	22	48.3	-	Tree 4
4	21/24	675	675	16	44.3	38.8	Tree 5
5	11/15	520	95	5/2	68.9	45	Tree 1
6	23/26	450	200	24	57.2	43.1	Tree 7
7	19/27	460	400	8	42.6	39.9	Tree 8

Note: Introduction - Table 1 gives the definition of the treatment number

Data were collected to examine the variability in the following properties with respect to silvicultural treatment[27]:

- Number of branch clusters in an annual shoot
- Internode length
- Number of branches in a cluster
- Number of stem cones in a cluster
- Diameter of the largest branch in a cluster
- Visible compression wood below branch clusters
- Spiral grain for selected positions within the stem
- SilviScan density, microfibril angle, and modulus of elasticity for selected positions within the stem

RESULTS

Number of branch clusters in an annual shoot (Appendix 5 - Figure 24)

- The number of branch clusters in an annual shoot varied between 1 and 10 at Woodhill with a mean value of 3.8.
- The number of branch clusters in an annual shoot varied between 1 and 6 at Golden Downs with a mean value of 3.3.
- At Woodhill, the number of branch clusters in an annual shoot tended to decrease with increasing tree age whereas there was no trend at Golden Downs, provided that ages 6 and 7 (with very few measurements) were ignored.
- A negative trend with tree age has not been recorded previously for radiata pine in New Zealand and highlights the advantage of being able to measure older trials.

Internode length (Appendix 5 - Figure 25)

- This figure shows the distribution of internode lengths in the specified “internodeclass” for each sample tree.
- A few internodes were less than 0 cm. This occurred when two clusters overlapped. In this case the top of one cluster is higher than the base of the following cluster.
- There were more long internodes at Golden Downs compared to Woodhill.
- At Woodhill, approximately 80% of the internodes measured on each tree were less than or equal to 30 cm in length.
- At Golden Downs approximately 60% of the internodes measured were less than or equal to 30 cm.
- At Golden Downs there were a few internodes longer than 90 cm, but none at Woodhill.

Selected common stem length

Branch clusters were not measured in detail above a certain point (approx 10 growth rings).

The common stem length to the nearest metre across all sample trees on a site was selected for displaying branching characteristics of the sample trees.

- For Woodhill, the selected stem length was 7 to 20 m
- For Golden Downs, the selected stem length was 7 to 26 m

Number of branches in a cluster (Appendix 5 - Figure 26)

Woodhill

- The number of branches in a cluster varied between 0 (clusters containing only cones) and 11.
- Less than 10% of the clusters had 10 or more branches.
- Considering the 50% point (median cluster), the number of branches varied between 3 and 7.

- There was no obvious differences between the trees with respect to the different silvicultural treatments.
- Treatment_tree 1_1 stands out as having a low number of branches in a cluster, with 70% of the clusters having 4 or less branches.

Golden Downs

- The number of branches in a cluster varied between 0 (clusters containing only cones) and 13.
- Less than 10% of the clusters had 10 or more branches.
- Considering the 50% point (median cluster), the number of branches varied between 4 and 7.
- There were no obvious differences between trees with respect to the different silvicultural treatments.
- Treatment_tree, 2_3 stands out as having a low number of branches in a cluster, with 60% of the clusters having 4 or less branches.

Number of cones in a cluster (Appendix 5 - Figure 27)

Woodhill

- For all trees at least 70% of the clusters did not contain cones.
- There was no obvious relationship with respect to the silvicultural treatments.

Golden Downs

- There were more clusters containing cones compared to Woodhill.
- For all trees at least 50% of the clusters did not contain cones.
- There was no obvious relationship with respect to the silvicultural treatments.

Diameter of largest branch in a cluster (Appendix 5 - Figure 28)

- The red sections with an undefined “branchclass” correspond to the cone only clusters.

Woodhill

- There is a trend with respect to the silvicultural treatment, with treatments 1 and 5 (final crop stocking of 100 stems/ha) having more clusters where the largest branch is over 6 cm compared to the other treatments.
- The unthinned control has no clusters where the largest branch is over 4 cm.

Golden Downs

- There is a trend with respect to the silvicultural treatment, with the percentage of clusters with branches between 0 -2 cm increasing with increasing final crop stocking
- Treatment_tree, 2_3, stands out as having over 20% of the clusters containing a branch larger than 6 cm. This could be related to the low number of branches in a cluster.

Diameter of largest branch in a cluster – trends with tree age (Appendix 5 - Figure 29)

The graphs show the trends in the diameter of the largest branch formed in a given year with tree age when the annual shoot was formed. There is a separate graph for each final crop stocking/ site combination.

- The diameter of the largest branch is highly variable between years.
- There is more variation between years for trees with a low final crop stocking (100 and 200 stems/ha) compared to a higher final crop stocking (400 and 625 stems/ha). The reason for this is not known and warrants further investigation.

Woodhill

- Trees thinned early to 100 stems/ha and 200 stems/ha (treatments 1 and 2 respectively) appear to have larger branches before age 11 years compared to the trees thinned later (treatments 5 and 6 respectively).

Golden Downs

- There were no obvious differences between timing of thinning.

Disc compression wood (Appendix 5 - Figure 30 to Figure 32)

Compression wood contributes to the circumferential variability in wood properties within a growth ring. Previous studies have indicated that compression wood below branch clusters may be influenced by the size of the branches[12]. Discs were cut immediately below branch clusters and imaged. The images were examined visually and independently by 3 (Golden Downs) or 4 (Woodhill) people. They were asked to score the discs as:

- 0: no visible patches of compression wood
- 1: maybe patches of compression wood
- 2: obvious patches of compression wood

The individual scores were added together (the maximum score being 6 (Golden Downs) or 8 (Woodhill)). A new variable “cwclass” was created based on the sum of the individual scores (Table 2.3).

Table 2.3
Conversion between the sum of the individual scores and the new variable “cwclass”

Value of cwclass	Sum of individual scores Woodhill	Sum of individual scores Golden Downs
0	0, 1, or 2	0 or 1
1	3, 4, or 5	2, 3, or 4
2	6, 7, or 8	5 or 6

Examples of discs with these scores are shown in Appendix 5 - Figure 30.

Woodhill (Appendix 5 - Figure 31)

- For the early thinning, treatments 1 (100 sph), 2 (200 sph) and 3 (400 sph), the percentage of discs classified as 2 tends to decrease while the percentage of discs classified as 0 tends to increase with increasing final crop stocking.
- For the late thinning, treatments 5 (100 sph), 6 (200sph) and 7 (400 sph), the reverse trend seems to hold.

Golden Downs (Appendix 5 - Figure 31)

- For both the early and late thinning, the percentage of discs classified as 2 tends to decrease while the percentage of discs classified as 0 tends to increase with increasing final crop stocking.

At both sites, the compression wood class was influenced by the diameter of the largest branch in the cluster, with a compression wood score of 2 being more frequent for clusters with larger branches (Appendix 5 - Figure 32).

Spiral Grain (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 33).

Discs for spiral grain measurements were selected according to the number of stem growth rings and the diameter of the largest branch in the cluster. Spiral grain was measured in two directions for each growth ring (a bark to bark strip so samples at 180° to each other). The two directions were chosen to cover the observed variation in wood colour (i.e. maximise the variability).

The usual procedure is to average the spiral grain values from the two direction. The averaging approach cancels out any effect of the disc not being perpendicular to the stem direction (if it occurs).

One aim of this study was to gain an idea of the variability in wood properties within a disc. To avoid the issue of the disc not being cut perpendicular to the stem, the following approach was developed which removes the effect of the disc not being perpendicular to the stem direction:

- The difference between the two spiral grain measurements in any one ring
- The maximum difference in any one disc
- The minimum difference in any one disc
- The difference between the maximum and minimum values.

Average spiral grain (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 33).

The ring average spiral grain values with respect to tree age when the ring was formed are shown for one set of sampled labelled “Z1small“. This sample consisted of discs with 24 or 25 stem growth rings (excluding the current year) and branches which were small relative to the other clusters in that zone. Tree age when the ring was formed is used as the horizontal axis as this allows the examination of any response to time of thinning. The two vertical lines at age 11 years and 14 years correspond to the time of the early and late thinning respectively.

These graphs show that spiral grain starts positive but trends negative with tree age when the ring was formed.

Woodhill (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 33, left hand column).

- Trees thinned to 100 stems/ha early have a noticeable increase in spiral grain after thinning and spiral grain remains higher than the treatments with higher stockings.
- Trees thinned to 100 stems/ha late have a slight but not so noticeable increase in spiral grain at this height.
- The control tree also shows an increase in spiral grain around the time of the silvicultural treatments.

Golden Downs (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 33, right hand column).

- The trend in spiral grain with tree age are much smoother than at Woodhill.

Differences in spiral grain within a disc (Appendix 5 - Figure 34)
Woodhill

- Differences in spiral grain, for the selected discs from the trees thinned early, tends to be higher for the trees thinned to 100 stems/ha compared to the trees thinned to 200 or 400 stems/ha
- Differences in spiral grain, for the selected discs from the trees thinned late, is particularly high for one disc from treatment_tree 5_8 (treatment 5: thinned late to 100 sph).

Golden Downs

- The variability is not as high as at Woodhill, and there is no obvious effect of time of thinning or final crop stocking.

Spiral grain - Disc images (Appendix 5 - Figure 35)
Images are shown for 6 discs from Woodhill whose spiral grain data is graphically depicted in Appendix 5 - Figure 34. Images in the left hand column are discs showing a large difference in spiral grain. Images in the right hand column are from the same zone and show a much smaller variation in spiral grain. The arrows show the direction the samples were measured. Two of the three images in the left hand column show significant compression wood while all three images in the right hand column show little compression wood.

Silviscan Data
SilviScan data for density, microfibril angle and modulus of elasticity were available in two directions from disc with a selected number of stem growth rings. The Silviscan data is at a very high resolution and was summarised to give average values for each ring in each direction. These values for the two directions were averaged to give a ring average value. The trends are shown for the discs from breast height (labelled as group_ring = 30).

The horizontal axis is the tree age when the ring was formed. This axis was chosen as it allows the age of the early and late thinning to be depicted by vertical lines at ages 11 and 14 years respectively. This allows the trends to be examined for responses to thinning.

Treatments 1, 2 and 3 were thinned early, whilst treatments 5, 6 and 7 were thinned late.

SilviScan Density (Appendix 5 - Figure 36)
- The trend is for density to increase with increasing tree age when the tree ring was formed (i.e. with increasing ring number from the pith).
- After thinning, the trees thinned to 100 stem/ha (both early and late) tend to have lower density than trees thinned to 400 stem/ha and the control tree.
- There appears to be a slight decrease in density after thinning for some trees.

SilviScan Microfibril angle (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 37 Appendix 5 - Figure 37
- The trend is for microfibril angle to decrease with increasing tree age when the ring was formed (or equivalently with increasing distance from the pith).

Woodhill (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 37, left hand column
- Prior to thinning all treatments are at the same stocking. After thinning trees at 100 stem/ha tend to have higher microfibril angles than trees thinned to 400 stems/ha.
- There is a sharp increase in microfibril angle after thinning for trees thinned to 100 stems/ha. The timing of the response varies between the early and late thinning treatments.

Golden Downs (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 37, right hand column
- Prior to thinning all treatments are at the same stocking. After thinning, microfibril angle is higher at the lower stockings.

- Compared to Woodhill, there is a smaller increase in microfibril angle around the time of thinning.

SilviScan Modulus of Elasticity (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 38
- The trend is for modulus of elasticity to increase with increasing tree age when the ring was formed.
- After thinning modulus of elasticity tends to be lower for the lower final crop stockings.

Woodhill (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 38, left hand column
- There is a decline in modulus of elasticity after thinning. This is particularly obvious for the trees thinned to 100 stems/ha (blue lines). The decrease is not so marked for the trees thinned to 200 stems/ha (red/purple lines). The time of decrease is related to the time of thinning.

Golden Downs (Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 38, right hand column
- The decline in modulus of elasticity is not as marked as at Woodhill.

Variation in average wood properties (from SilviScan) within a growth ring
The difference in the Silviscan properties, between the two directions in each disc, was calculated for each ring. The differences were summarised into classes and displayed in bar charts showing the variation with respect to ring number from the pith (newringfrompith) (Appendix 5 - Figure 39) and with respect to treatment and sample tree (Appendix 5 - Figure 40). Knowledge of the size of these differences is important for understanding and modelling the circumferential variation in wood properties.

Variation in wood properties with respect to ring from pith (Appendix 5 - Figure 39)
- The difference in density (labelled densityrange) between two directions in one disc tends to increase with ring number from the pith at both Woodhill and Golden Downs. i.e. further from the pith, the variation in density within a ring tends to increase.
- The difference in microfibril angle (labelled mfarange) between two directions in one disc is more variable nearer the pith at Woodhill.
- The difference in microfibril angle (labelled mfarange) between two directions in one disc tends to increase with increasing ring from the pith at Golden Downs. This is different from the pattern at Woodhill.
- The difference in modulus of elasticity (labelled moerange) betweens two directions in one disc is reasonably constant with ring from the pith at Woodhill.
- The difference in modulus of elasticity (labelled moerange) between two directions in one disc tends to increase with increasing distance from the pith at Golden Downs.

Variation in wood properties with respect treatment and sample tree (Appendix 5 - Figure 40)
Only a limited number of discs were sampled from each tree, and it is suspected that the following tentative conclusions, may be influenced by the actual discs sampled. Future research will examine the variability with respect to the images of the discs sampled.

- The difference in density (labelled densityrange) between two directions in one disc does not appear to be influenced by silvicultural treatment.
- The difference in microfibril angle (labelled mfarange) between two directions in one disc is more variable for the treatment 1, thinned early to 100 stems/ha.
- The difference in modulus of elasticity (labelled moerange) does not appear to be influenced by silvicultural treatment.

Relationship between SilviScan properties and ring width (Figure 41)

- Density decreases curvilinearly with increasing ring width
- MFA increases approximately linearly with increasing ring width
- MOE decreases curvilinearly with increasing ring width
- There are a number of points that appear to be outliers.

Further analysis of these data are required to examine:

- the reasons for the outliers
- the relationship with other independent variables such as distance from the pith and position within the growth sheath
- the variability in properties compared to visible wood colour and branch diameters within the clusters.

The fact that there is a fairly tight relationship between these SilviScan properties and ring width indicates that it would be practical to develop functions that predicted wood properties from ring width. However growth models currently do not predict variation in ring width around a growth ring, so it is not be feasible to model 3-d variation in wood properties by linking functions that predict wood properties as a function of ring width with current growth models.

CONCLUSION

This report documents the variation in branching and wood properties for trees that represent the treatment average DBH for the seven silvicultural treatments in the 1975 final crop stocking trials. Eleven trees were measured from Woodhill, AK1056 and seven from Golden Downs, NN529/1.

The following characteristics were assessed for each tree and the data examined graphically:

- Number of branch clusters in an annual shoot
- Internode length
- Number of branches in a cluster
- Number of stem cones in a cluster
- Diameter of the largest branch in a cluster
- Visible compression wood below branch clusters
- Spiral grain for selected positions within the stem
- SilviScan density, microfibril angle, and modulus of elasticity for selected positions within the stem

The average number of branch clusters in an annual shoot is consistent with previous SGMC studies, with there being more branch clusters on warmer sites[27].

There were more internodes over 30 cm at Golden Downs compared to Woodhill. This may be explained by differences in number of clusters per years and height growth patterns. At the time of trial establishment (age 11 years), the mean top height was slightly higher at Woodhill compared to Golden Downs, but the height growth was slower at Woodhill compared to Golden Downs[13].

The average number of branches in a cluster is comparable with other SGMC studies[28] and the research of Madgwick[29].

The fact that there are less cones in clusters at Woodhill compared to Golden Downs is also in agreement with previous SGMC studies[27].

The variation in disc compression wood with diameter of the largest branch in a cluster is in agreement with previous studies[12, 18]. Compression wood has different wood properties from "normal" wood, so circumferential variation in wood properties should be reduced by silvicultural treatments that minimise branch diameter growth (i.e. higher stockings). However, small branch diameter growth leads to earlier branch mortality and the formation of bark-encased knots. Higher stocking also increase the height to diameter ratio, which in turn has implications for wind risk[22].

The trend from positive towards negative values of spiral grain with increasing tree age when the ring was formed is consistent with previous studies[31]. There appears to be an increase in spiral grain after silvicultural treatment, particularly for trees thinned to 100 stems/ha at Woodhill. A hypothesis is that this increase is due to the change in canopy structure and more movement of the tree stems until the trees form new wood that allows them to be "stable" in the new environment. Variability in spiral grain within a disc appears to be the result of compression wood within the disc.

The observed trend for density to increase from pith to bark, and the lower density at lower final crop stocking matches previous studies[5, 30].

Of the three SilviScan properties measured, microfibril angle shows the most response to silvicultural treatment with large increases in microfibril angle around the time of silviculture, particularly for trees thinned to 100 stems/ha. Increases in microfibril angle around the time of thinning have previously been noted[18]. Increases in microfibril angle were also noted around the time of wind/snow damage events[18].

Increased exposure to wind results in more swaying and consequently more diameter growth[20]. Experiments with flexing (swaying) trees[23] have shown that microfibril angle increases with flexing. It is therefore considered that the sharp changes in microfibril angle around the time of thinning to in these datasets are due to increased flexure /sway caused by changes in the wind environment within the PSP due to the reduction in stocking.

Minimising the proportion of trees removed in a thinning would avoid the sudden large changes in ring average wood properties in the radial direction, but may have other consequences.

While only one or two trees have been sampled per silvicultural treatment, 7 or 11 trees have been sampled per site and the data collected showed a good relationship between ring width and the wood properties measured by SilviScan at the site level, indicating that the treatment differences are accounted for by ring width.

This suggests selecting sample trees from across a whole trial to cover the range in tree DBH is appropriate in large trials to provide data for model development. In this overall study, the matrix of tree DBH covered trees of average DBH each silvicultural treatment, and trees of the same across the silvicultural treatments. In future studies it would be useful to include a very large and a very small tree.

Determining whether there are statistical differences in specific properties between treatments has previously been shown to require larger sample sizes.

CHAPTER 4: 1975 FINAL CROP STOCKING TRIALS: RELATIONSHIP BETWEEN DESTRUCTIVELY AND NON-DESTRUCTIVELY ASSESSED TREES

INTRODUCTION

Chapter 4 documents the relationships between non-destructive wood property measurements and DBH at the individual tree level, and graphically illustrates where the destructively-sampled trees sit within these joint-distributions.

METHODS

Graphs were produced showing the relationship between (1) outerwood density and DBH and (2) standing tree sonics and DBH, for individual trees within each treatment. Different symbols were used to illustrate the three different samples – the non-destructive sample, the low intensity destructive sample and the high-intensity destructive sample.

RESULTS

Two sets of trees were selected for destructive sampling:

- The "low-intensity" sample, which were trees of the same DBH selected from each silviculture treatment
- The "high-intensity" sample, which were trees of average DBH selected from each silviculture treatment.

The graphs (Appendix 6) show the position of the destructively sampled trees in relation to the larger sample of trees measured non-destructively within the joint-distributions of two variables. Appendix 6 - Figure 42 (Woodhill) and Appendix 6 - Figure 43 (Golden Downs) show the joint-distribution of outerwood density and DBH. Appendix 6 - Figure 45 (Woodhill) and Appendix 6 - Figure 46 (Golden Downs) show the joint-distribution of standing tree sonics and DBH. Note the "high-intensity" trees were generally not measured for standing tree sonics.

The non-destructive trees are labelled "screening" and coloured red. The trees of average DBH are labelled "intensive" and coloured black. The trees of same DBH are labelled "equal DBH" and coloured blue.

Points to note:

Trees of same DBH from each silvicultural treatment:

- The selection criteria of trees of the same DBH meant that the selected trees were small trees in plots a with a nominal final crop stocking of 100 stems/ha and large trees in plots with a nominal final crop stocking of 400 stems/ha, and the control plots with a nominal final crop stocking of 625 stems/ha.
- In terms of outerwood density, the selected trees were representative of the outerwood density for trees of that DBH (Appendix 6 - Figure 42, Woodhill and Appendix 6 - Figure 43, Golden Downs).
- The ratio of tree outerwood density to plot mean outerwood density varied between 0.8 and 1.2 with the ratio for the majority of trees being between 0.9 and 1.1 (Appendix 6 - Figure 44).

- In terms of standing tree sonics, the selected trees were representative of the standing tree sonics for trees of that DBH (Appendix 6 - Figure 45, Woodhill and Appendix 6 - Figure 46 Golden Downs).
- The ratio of tree sonics to plot mean sonics varied between 0.8 and 1.2 with the ratio for the majority of trees being between 0.9 and 1.1 (Appendix 6 - Figure 47).
- Given the difficulty in selecting trees of equal DBH across all seven silvicultural treatments, it is considered that it would have been impossible to select on an additional criterion as well.

Trees of average DBH from each silvicultural treatment:
- The trees of average DBH, were generally representative of trees of the required DBH. Two trees stood out – the tree selected to represent the late thinning to 200 stems/ha, and one of the trees selected to represent the late thinning to 400 stems/ha at Woodhill (Appendix 6 - Figure 42). The ratio of tree outerwood density to plot mean outerwood density was generally between 0.9 and 1.1 (Appendix 6 - Figure 44). For the above two trees it was over 1.1.

CONCLUSION

The trees selected for destructive sampling in this study were selected on the basis of DBH alone. In most cases the selected trees were representative in terms of the relationships (joint-distributions) between outerwood density and DBH and between standing tree sonics and DBH. The question that needs to be resolved for future studies is whether it is sufficient to select on DBH alone, or whether trees should be selected on the basis of DBH and pre-screened data.

An advantage of selecting on DBH alone is that it avoids the need to collect pre-screening data. This study included the novel idea of sampling trees of equal DBH across treatments to determine the impact of treatment over and above DBH. This sample was difficult to select as there were limited choices for sample trees, and definitely not enough choices to use an additional criteria for selection.

It is not known whether sample of trees of average DBH would have been selected any differently if outerwood density and/or sonics were available as well as tree DBH were available prior to felling.

Selecting on the basis of pre-screening data does however require visiting the site twice, once to collect the pre-screening data, and then a second visit to destructively sample the trees.

Given that the sample selected in this study were generally representative of the population, it is recommended that in future studies trees are selected on the basis of DBH alone, particularly as it avoids the costs of an extra site visit.

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APPENDICES

Appendix 1: Chapter 1 - Pre-screening Standing Tree Data

Trial Plot	Distance (m)	PSP Quad Row	PSP Tree No	DBH (cm)	Resin Score	ST300 (km/s)	Basic Density (kg/m^3)	DESC_ Code	Low intensity sample tree	High intensity sample tree
Woodhill	**100**	**Early thin**								
2.11	22.1	5	4	53.8	B		483			1
2.11	20.6	6	1	48	0	5.04	509		1	
2.11	11.7	8	5	60	2	4.63	481			
2.11	2.8	10	3	55.5	2	5.22	532	DT		
2.11	6.3	11	5	66.8	2	4.61	470			
2.11	11.7	13	2	53.2	2	4.94	460			
2.11	14.1	13	6	35.1	1	5.01	485			
2.11	20.6	15	6	58.2	3	4.21	568	DT		
2.11	22.8	16	2	39.3	1	4.88	453			
2.11	22.8	16	5	49.7	1	5.01	506			
14.31	19	6	5	65.1	1	4.64	495			
14.31	14.1	8	1	54.9	1	4.35	463			
14.31	11.7	8	5	54.5	1	4.58	533			
14.31	6.3	9	3	65.8	1	4.43	507			
14.31	11.7	9	6	43.8	1	5.16	505		14	
14.31	10.2	11	1	61.2	1	4.77	459	galls		
14.31	6.3	11	5	54.5	2	4.75	522			
14.31	14.1	13	1	61.2	0	4.69	498			
14.31	14.1	13	6	56.9	1	4.70	483			
14.31	18.1	15	4	54.2	0	5.05	523			
14.31	39.3	20	1	48.5	1	4.99	502		13	
23.21	22.8	5	2	63.5	1	4.98	492			
23.21	11.7	8	2	61.6	B	4.98	476			2
23.21	14.1	8	6	60.1	3	4.66	498			
23.21	6.3	10	5	53.9	3	4.70	510			
23.21	2.8	11	4	52.8	1	5.14	523			
23.21	6.3	12	3	61.1	2	4.96	483			
23.21	14.1	13	1	48.4	1	5.11	518			
23.21	11.7	13	5	70.4	1	5.08	477			
23.21	20.6	15	6	64.3	3	4.51	443	Galls		
23.21	22.1	16	3	73.1	2	4.87	504			
Woodhill	**200**	**Early thin**								
5.12	11.5	0	1	37.1	1		487			
5.12	6.2	1	2	53	1	4.89	417			
5.12	9.8	1	6	54	1	5.12	526			
5.12	2.9	1	11	38.6	1	5.23	570			
5.12	11.4	0	15	42.4	1	5.06	482	CK		
5.12	7.9	2	24	46.5	B		475			3
5.12	5.9	3	28	46	1	4.74	482			
5.12	11.3	3	35	41.8	0	5.27	513			
5.12	3.1	4	38	56.8	2	5.09	518			
5.12	10.5	4	47	44	0	4.60	513		5	
19.32	10.6	1	5	51.5	1	4.79	445	CK		
19.32	10.6	1	6	47.9	2	5.10	495	FK	16	
19.32	6.2	1	7	50.4	1	5.02	504			
19.32	14.3	0	17	51.7	1	5.21	490			

19.32	5.8	3	25	68.2	3	5.07	465			
19.32	14	0	28	41.8	1	5.19	509			
19.32	8.6	4	32	41.2	0	5.17	514			
19.32	3.1	4	33	50.7	1	4.69	516			
19.32	11.9	0	35	41.6	0	5.42	495			
19.32	8.9	4	42	51.3	2	5.14	544			
22.22	6.4	1	3	42.3	1	5.23	510			
22.22	9.8	1	7	44.7	2	5.16	508			
22.22	11.2	2	13	49	1	4.61	473			
22.22	5.9	2	15	37.7	3	4.31	470			
22.22	9.9	2	19	44.9	2	4.65	467			
22.22	2.5	3	23	72.2	2	4.33	451			
22.22	9.7	3	26	53.6	1	4.88	517			
22.22	6.1	3	30	43.4	1	5.23	518			
22.22	10.8	4	37	46.1	1	4.44	502			
22.22	11.1	4	39	53.5	1	4.83	492			
Woodhill	**400**	**Early thin**								
3.13	5.7	1	1	24	0	5.31	462			
3.13	8.4	2	5	34.6	0	5.35	541			
3.13	2.6	2	6	45.2	1	5.33	483			
3.13	6.4	2	7	44.6	1	5.04	493			
3.13	7	2	10	40	0	5.41	540	FK		
3.13	6.5	3	14	36.3	1	5.62	575	FK		
3.13	6.8	3	17	40.8	0	5.31	501			
3.13	6.2	4	20	43.1	1	5.16	454			
3.13	2.5	4	23	43.8	0	5.15	560		2	
3.13	7.7	4	24	34.5	1	4.96	536	OK		
10.23	12	0	24	36.8	B		532			5
10.23	6.4	1	2	38	1	5.26	496			
10.23	5.8	1	5	40.6	1	4.94	505			
10.23	2.4	1	7	25	0	4.97	464			
10.23	6	2	10	27	1	5.18	427	CK		
10.23	5.9	2	13	25.3	1	5.06	463			
10.23	2.3	3	17	44.1	0	5.04	531			
10.23	5.9	3	18	45.8	1	5.19	527			
10.23	3.2	4	23	34.4	1	5.50	560			
10.23	7	4	28	48	0	4.62	550		10	
18.33	6.6	1	1	33.5	1	5.26	502	CK		
18.33	6.2	1	4	45.4	1	5.30	436			
18.33	2.5	1	6	44.1	1	5.40	490	CK		
18.33	11.2	2	8	44.1	0	5.10	480		17	
18.33	5.5	2	11	46.8	1	5.23	485			
18.33	2.2	3	14	41.9	2	5.40	510			
18.33	5.8	3	15	46.7	0	5.07	487			
18.33	6.2	3	17	48.9	0	4.81	446	CK		
18.33	9	4	18	36.2	1	5.55	461			
18.33	3.6	4	19	46.2	1	5.26	525			
18.33	7.5	4	21	30	0	4.66	414			
8.15	18.1	6	3	42.8	0	4.53	481			
Woodhill	**100**	**Late thin**								
8.15	19	6	5	44.2	0	5.33	550		7	
8.15	11.7	9	1	56.5	0	5.30	463			
8.15	6.3	10	2	56.1	1	4.89	508	DT		
8.15	6.3	10	5	39	1	5.18	545			
8.15	11.7	13	2	57.7	2	4.91	491			
8.15	11.7	13	5	45.9	1	5.21	550			
8.15	18.1	15	4	56.2	1	5.08	539			

8.15	20.6	15	6	38.2	1	5.18	482			
8.15	22.8	16	2	56.6	1	4.62	511			
11.25	.	6	5	62.6	1	4.80	467			
11.25	.	8	2	51.3	B		522			7
11.25	.	8	6	58	1	5.08	524			
11.25	.	10	3	52.2	1	5.13	533			
11.25	.	10	6	38.2	0	4.69	521			
11.25	.	11	3	49.5	0	5.05	496			
11.25	.	12	5	61.2	1	5.02	513			
11.25	.	14	1	49.7	2	4.65	507			
11.25	.	14	4	38.6	0	5.19	514			
11.25	.	15	3	55.9	1	5.20	492	DT		
17.35	18.1	6	3	54.3	2	5.21	496			
17.35	17.2	7	1	42.1	2	4.94	512			
17.35	17.2	7	6	59.1	0	5.47	507			
17.35	8.5	9	5	52.9	3	4.75	480			
17.35	10.2	10	1	55.3	1	5.02	516			
17.35	6.3	12	3	55.5	3	4.66	520			
17.35	11.7	12	6	54.5	1	4.63	483			
17.35	17.2	14	1	47.9	1	4.48	502		15	
17.35	17.2	14	6	45.3	1	5.18	519			
17.35	18.1	15	3	64.2	2	4.84	463			
17.35	39.3	20	1	51.9	B		561			8
Woodhill	**200**	**Late thin**								
4.16	10.3	1	5	48.7	3	5.33	542			
4.16	6.3	1	8	35.5	0	5.37	502			
4.16	11.6	0	10	46.2	0	5.20	542			
4.16	11.9	0	15	44.3	2	4.63	493		3	
4.16	10.2	2	19	43.5	1	5.28	520			
4.16	6.5	2	20	43.8	0	5.26	553			
4.16	8.8	2	24	47	1	4.98	549			
4.16	6.4	3	33	48.8	0	5.26	553			
4.16	11.5	0	34	40.3	1	5.32	515	CK		
4.16	10.2	4	41	53.8	0	4.93	515			
4.16	14.2	0	42	48	0	5.19	484		4	
4.16	2.7	4	48	47.7	1	4.93	509			
13.26	9.7	1	4	36.6	0	5.55	567			
13.26	6.1	1	7	48	1	5.17	481		11	
13.26	6.5	2	15	44.2	1	5.15	473			
13.26	10.5	2	16	29.8	1	5.04	517	LN		
13.26	6.2	3	28	44.4	0	4.96	519		12	
13.26	9.7	3	33	35.8	1	5.43	550			
13.26	6.1	4	42	46.4	1	5.03	487			
13.26	9.8	4	43	50.5	1	5.32	521			
13.26	10.1	4	46	39.2	1	4.92	557			
13.26	2.8	4	50	36.3	0	5.40	537			
20.36	6.4	1	1	32.5	1	5.21	502			
20.36	10.2	1	3	31	0	5.29	477			
20.36	6.3	1	4	47.9	1	5.21	491			
20.36	11.8	0	14	48	2	5.11	471			
20.36	2.7	2	15	55.3	1	4.60	464			
20.36	10	3	18	42.6	0	5.28	535			
20.36	11.1	3	22	38.8	1	4.88	500			
20.36	2.7	4	25	48.7	1	4.43	485			
20.36	11.2	4	27	45	B		596			9
20.36	8.7	4	34	40.2	1	5.15	548			

Woodhill	**400**	**Late thin**								
1.17	8.1	2	7	46.2	1	5.20	513	LN		
1.17	2.5	2	8	40.6	2	5.05	493	LN		
1.17	6.7	2	13	38	B		599			10
1.17	3.3	2	14	45.6	0	5.06	551			
1.17	6.9	3	16	46.6	1	4.96	472			
1.17	6.8	3	18	41.1	1	5.11	500	LN		
1.17	3	3	19	41.7	1	5.20	478	LN		
1.17	6.2	4	23	32	0	5.37	501			
1.17	2.5	4	25	38.5	1	4.61	440			
1.17	8	4	26	37.8	1	5.31	495			
21.37	9.3	1	1	40.5	B		538			11
21.37	10.2	1	4	22.8	0	5.17	429	runt		
21.37	6.2	1	5	26.8	0	5.19	442			
21.37	7.8	2	7	36.6	0	5.64	513			
21.37	9.6	2	9	37.7	1	5.44	512			
21.37	2.5	3	12	57.9	1	4.66	491			
21.37	6.2	3	13	37.3	2	4.38	471			
21.37	10.2	3	14	38.3	1	5.22	539			
21.37	9	4	16	42.5	1	5.61	587			
21.37	7.1	4	20	49.4	3	5.10	513			
24.27	2.9	4	1	36.2	2	4.82	464			
24.27	6.1	1	2	43.4	1	5.17	496	TO		
24.27	6.4	1	5	43.8	0	5.31	523		18	
24.27	8.6	2	7	45.3	0	4.89	514			
24.27	3	2	8	43.6	1	4.74	520		19	
24.27	6.8	2	12	37	1	5.31	563			
24.27	3.2	3	14	36	1	5.07	514			
24.27	6.5	3	15	40.9	1	5.19	527			
24.27	8.2	3	18	44.8	1	5.07	515			
24.27	6.2	4	20	35.8	1	4.97	485			
24.27	11.5	0	23	48.5	1	4.93	520		20	
Woodhill	**Cont**	**rol unthin**								
7.24	11.4	0	14	26.8	1	4.65	480			
7.24	2.6	1	1	43.5	1	5.27	524			
7.24	6.1	1	3	40.8	0	5.32	510			
7.24	6	1	6	31.2	1	4.87	517			
7.24	2.8	2	7	37	1	5.12	474			
7.24	6.4	2	8	41.6	0	5.06	603			
7.24	6.4	2	11	37.3	0	5.12	565			
7.24	3	2	12	24.2	1	4.59	540	OK		
7.24	8.5	2	13	30.8	1	5.05	497			
7.24	6.5	3	15	20	0	5.40	541	FK		
7.24	9.9	3	17	44.1	1	5.25	542		6	
7.24	6.3	3	18	41.4	1	4.83	517			
7.24	2.7	3	19	40.4	0	5.06	456	TO		
7.24	8.3	3	20	37.3	1	5.12	521			
7.24	6.7	4	24	40.5	1	5.15	470			
9.14	8.3	1	1	45.6	0	5.17	557			
9.14	6	1	4	43.5	1	4.46	489		8	
9.14	10	1	6	34.6	B		525			6
9.14	6.2	1	7	38.1	1	5.34	562			
9.14	8.2	2	9	34.7	1	5.11	548			
9.14	2.9	2	10	29.2	0	5.12	518			
9.14	9.9	2	13	45.4	1	4.94	467			
9.14	8.4	2	15	31.7	1	5.23	547	SW		
9.14	10.8	3	16	39.5	0	5.29	523			

9.14	5.9	3	17	47.1	1	5.05	509			
9.14	9.5	3	19	32.7	1	4.23	409			
9.14	5.8	3	20	31.8	0	5.04	523	FK		
9.14	11	3	21	36.3	1	4.55	455			
9.14	2.8	4	23	48.4	0	5.10	487		9	
9.14	6.6	4	24	31.8	0	5.00	477			
9.14	6.3	4	27	42.5	0	5.05	504			
G. Downs	**100**	**Early thin**								
10/11	.	1	4	55.9	0	4.33	401		5	
10/11	.	4	4	63.2	0	4.27	407			9
10/11	.	5	6	46.3	2	4.31	436	LN		
10/11	.	7	6	74.2	0	3.88	375			
10/11	.	8	3	59.7	1	4.50	404			
10/11	.	10	3	73.6	1	4.04	380			
10/11	.	11	3	63.3	1	4.04	389	FK		
10/11	.	12	6	64.4	1	3.98	402			
10/11	.	13	3	61.2	0	3.86	376	DT		
10/11	.	13	5	64.4	0	3.97	390			
22/21	.	5	2	67.5	0	4.01	419	SW		
22/21	.	5	4	65.2	0		388			6
22/21	.	7	4	77.6	1	3.85	425			
22/21	.	8	3	59.8	1	4.19	370			
22/21	.	9	5	55.1	0	3.76	362	TO		
22/21	.	10	2	68.8	0	3.83	383			
22/21	.	11	1	69.8	0	4.00	382			
22/21	.	12	6	57.7	0	3.82	420			
22/21	.	13	3	58.4	0	4.40	419	FK		
22/21	.	14	5	61.9	1	3.87	358	FK		
22/21	.	15	3	68.1	0	3.95	365			
22/21	.	16	4	57.3	0	4.17	412			
22/21	.	17	3	67.6	0	3.77	428			
22/21	.	19	2	66.9	0	3.88	443			
22/21	.	20	6	54.9	1	4.17	447		13	
G. Downs	**200**	**Early thin**								
3/32	12	0	5	66.5	0	4.28	405			
3/32	2.6	1	9	47.7	0	4.61	411	SW		
3/32	9.9	2	23	47.9	0	4.57	401			
3/32	3.9	2	24	62.9	0	4.76	411			
3/32	3.7	3	34	56.9	0	4.33	410	LN		
3/32	12.7	0	39	60.8	0	4.53	427			
3/32	6.6	3	40	63.4	1	4.37	384	SW		
3/32	10.6	3	41	52.4	0	4.40	414			
3/32	6.2	4	45	59.5			395			3
3/32	10.7	4	55	55.7		4.75	423		3	
15/12	10.8	1	9	63.9	1	4.16	431			
15/12	2.9	2	13	63	1	4.22	388			
15/12	9.3	2	14	59.4	0	4.26	435	SW		
15/12	12	0	18	48.6	1	4.48	395	FK		
15/12	9.6	3	26	68.5	0	3.67	387			
15/12	6.8	3	30	46.4	1	4.28	444	FK		
15/12	8.5	4	40	67.9	0	4.16	386			
15/12	6.6	4	42	50.5	1	4.23	411			
15/12	14.9	0	44	42.2	0	5.21	461			
15/12	10.9	4	47	57.1	1	4.47	434			
17/22	7.7	1	1	49.2	0	4.17	448	FK		
17/22	3.3	1	3	62.2	1	4.08	385			
17/22	12.6	0	8	55	0	4.11	409	SW	F	

17/22	13	0	12	56.5	1	4.04	354		6	
17/22	11.9	0	14	49.3	1	4.11	328	TO		
17/22	11.5	0	17	61.8	1	4.13	400	SW		
17/22	5.7	3	27	47.9	1	3.85	350	TO		
17/22	9.9	3	28	51.7	1	4.24	403			
17/22	9.7	3	31	55.1	1	4.11	411	SW		
17/22	9.4	4	35	57.9	0	4.33	390			
17/22	12.2	0	39	53.9	1	3.81	398	LN		
G. Downs	**400**	**Early thin**								
5/33	8.7	1	4	51.7	0	4.51	409			
5/33	6.7	1	7	60.4	2	4.23	421			
5/33	7.1	2	12	33.2	1	3.90	381	DT		
5/33	8.4	3	17	50	1	4.59	470			
5/33	2.7	3	18	60.9	1	4.46	377			
5/33	5.8	3	20	45.3	0	4.72	439			
5/33	10.1	4	22	48.3			424			4
5/33	6.1	4	23	30.7	0	4.53	407	FK		
5/33	8.8	4	25	66.7	1	4.67	434			
5/33	2.8	4	26	52.5	1	4.67	405	FK		
5/33	6.7	4	28	42.9	0	3.87	387	TO		
14/13	9.7	1	4	62.2	0	4.08	365			
14/13	5.9	2	6	28.7	0	4.46	423	DT		
14/13	2.3	2	9	43.3	1	4.71	463			
14/13	7.2	3	11	54.3	1	4.07	398		11	
14/13	3.3	3	14	42	0		444			2
14/13	7.7	3	16	52.7	0	4.26	391			
14/13	9.3	4	20	47.3	0	4.43	422			
14/13	6.2	4	21	37.1	0	4.43	446	SW		
14/13	10.5	4	22	48.7	0	4.04	392			
14/13	6.2	4	24	35.1	0	4.91	493	FK		
20/23	5.7	1	1	48.1	1	3.73	388			
20/23	1.8	1	4	29.9	0	4.49	433	DT		
20/23	6.1	2	8	50.1	0	4.50	426			
20/23	8.8	2	10	51	0	4.42	421			
20/23	2.5	2	11	56.4	0	3.85	395		8	
20/23	10.6	2	12	53.2	1	4.24	404			
20/23	9.8	3	14	41.8	0	4.35	421			
20/23	3.6	3	15	45.7	0	4.50	451	SW		
20/23	7.2	3	17	39.5	0	4.77	446			
20/23	5.9	4	19	46	0	4.53	436			
G. Downs	**100**	**Late thin**								
1/35	.	1	2	78.4	0	4.03	363			
1/35	.	2	5	72.7	0	3.95	370	SC		
1/35	.	3	4	66.8	1	3.89	330	DT		
1/35	.	4	1	69.5	1	4.38	417			
1/35	.	5	1	65.9	0	4.31	440			
1/35	.	5	5	79.9	1	4.46	398			
1/35	.	9	5	64.9	0	4.24	372	SW		
1/35	.	10	1	70.6	0	4.05	422	FK		
1/35	.	12	5	64.3	0	4.05	383	SW		
1/35	.	14	2	71.7	0	4.15	399			
11/15	.	4	3	59.5	1	4.33	431	FK		
11/15	.	5	2	68.9			389			1
11/15	.	7	5	73.2	1	4.03	379			
11/15	.	8	2	54.4	0	4.23	382		10	
11/15	.	9	4	56.9	1	4.32	408			
11/15	.	10	3	61.8	1	4.16	408			

11/15	.	11	5	65.8	1	3.88	383			
11/15	.	13	6	75.2	1	4.10	359			
11/15	.	15	6	56.1	1	3.76	385			
11/15	.	17	6	67.8	1	4.18	428			
11/15	.	20	3	56.1	0	4.16	433		4	
24/25	.	4	4	70	1		419			B
24/25	.	6	3	73.3	1	3.74	375			
24/25	.	6	6	63.9	0	3.12	368	ML		
24/25	.	7	2	68.7	0	4.07	384			
24/25	.	8	4	62.7	1	3.83	425	FK		
24/25	.	9	1	69.1	1	3.67	411			
24/25	.	11	1	78.1	1	3.97	358			
24/25	.	12	5	65.8	1	3.67	420			
24/25	.	13	1	57.5	1	4.31	390			
24/25	.	14	4	63.8	1	3.89	401	SW		
24/25	.	15	6	67.1	1	4.41	395			
G. Downs	**200**	**Late thin**								
9/16	10.6	1	1	50.6	1	4.23	388	SW		
9/16	15.6	0	4	52.2	1	5.25	407	SW		
9/16	7.3	1	7	36.3	1	4.09	396	SW		
9/16	15.3	0	9	54.8	0	4.21	361		F	
9/16	10.9	2	10	61.3	0	4.58	465	SW		
9/16	3.1	2	13	50.4	1	4.51	450			
9/16	17.8	0	15	56.9	0	4.13	403			
9/16	16.1	0	17	50.3	1	4.27	365	LN		
9/16	10.8	2	19	47.3	0	4.32	450	SW		
9/16	7	3	21	53.3	1	4.23	428	SW		
9/16	10.6	3	30	74.2	0	4.18	346			
9/16	14.5	0	31	50.7	1	4.46	407			
9/16	14.9	0	35	40.2	1		418			
9/16	7.7	4	38	58	1	4.45	422	SW		
9/16	6	4	42	51.8	0	4.29	399			
23/26	13.5	0	3	68.3	2	3.91	408			
23/26	3.4	1	4	54	1	4.31	424			
23/26	15.8	0	5	57.8	1	4.30	348	SW		
23/26	15.4	0	9	62.2	1	3.94	370			
23/26	15.5	0	10	49.8	0	4.33	440			
23/26	6.9	2	12	59.5	1	4.49	416	FK galls DL		
23/26	11.7	0	13	54.5	0	4.30	401		14	
23/26	14.5	0	16	61	1	3.97	394			
23/26	10.4	2	24	57.2	1		448			7
23/26	8.6	3	27	58.7	1	3.94	387	FK		
23/26	5.9	3	32	52	1	4.42	391	FK		
23/26	8.6	4	37	50.3	1	4.42	467			
23/26	17.5	0	39	63.5	0	4.80	427			
23/26	7.2	4	41	37.8	1	4.64	414	CK		
23/26	16.3	0	42	57.9	1	4.45	402	SW		
23/26	15.5	0	45	56.1	0	4.26	396		7	
G. Downs	**400**	**Late thin**								
19/27	11.2	1	1	46.9	0	4.50	429			
19/27	7.2	1	2	38.2	0	4.59	409			
19/27	3.2	1	3	37.5	0	4.08	463			
19/27	7	1	4	38.9	1	4.30	351			
19/27	6.5	2	6	34.1	0	4.82	478			
19/27	11.6	0	7	45.4	0	4.53	392			
19/27	2.8	2	8	42.6	0	4.66	453			8
19/27	8.6	2	9	52.9	0	4.62	425			

19/27	11.5	0	10	35.1	0	3.94	375	TO		
19/27	7	3	13	52.9	1	4.87	397			
19/27	3.1	3	14	33.7	0	4.26	425			
19/27	6.9	3	16	56.2	1	4.14	351		9	
19/27	10.7	3	17	35.7	1	4.46	432	DT		
19/27	11.8	0	18	50.4	1	4.41	442			
19/27	3.2	4	19	38.7	0	3.96	409			
19/27	8.9	4	20	33.7	0	4.71	428	ML		
19/27	12	0	21	39.2	1	4.64	448			
19/27	6.8	4	22	51.8	0	4.47	405			
G. Downs	**Cont**	**rol unthin**								
4/34	6.4	1	1	39.3	0	4.86	485			
4/34	8.8	1	2	45.4	0	4.54	452			
4/34	3.3	1	3	44.1	1	4.83	470			
4/34	6.8	1	4	48.6	0	4.40	404	CK		
4/34	6.8	2	7	56.6	0	4.65	425	FK		
4/34	3.3	2	8	34.6	0	4.67	488	FK		
4/34	9.2	2	9	34.6	0	3.75	386	DT		
4/34	6.9	2	10	51	1	4.69	466			
4/34	10.2	2	12	36.7	0	3.99	401	CK DL		
4/34	6.4	3	13	55.7	0	4.05	444		1	
4/34	11.4	0	15	54.9	0	4.80	482		2	
4/34	10.1	3	16	47.6	1	4.56	412	CK		
4/34	10.2	3	17	49.9	0	4.44	449	galls		
4/34	6	4	18	47.7	1	4.56	449			
4/34	8	4	20	44.8	1	4.68	442	FK		
4/34	2.7	4	21	35.8	0	4.39	446			
21/24	6	1	2	43.2	0	4.53	386	SW		
21/24	8.3	1	4	35.7	0	4.64	428			
21/24	2.9	1	5	34.5	1	5.01	441			
21/24	6.5	1	6	20.7	1	4.51	441	ML		
21/24	6.7	2	10	34.6	0	4.87	455	DT		
21/24	3.1	2	11	48.8	0	4.10	449			
21/24	8.8	2	12	55	1	4.45	410		12	
21/24	6.6	3	16	44.3	1	4.58	449			5
21/24	2.9	3	17	34.2	0	4.57	382			
21/24	8.7	3	18	49.2	0	4.58	442			
21/24	6.4	3	20	45.5	0	4.45	441			
21/24	6.4	4	23	47.4	0	4.53	436			
21/24	8.3	4	24	49.4	1	4.12				
21/24	2.9	4	25	33.1	0	3.97	404	CK		
21/24	6	4	26	31.9	0	4.40	360			

Appendix 2: Chapter 2 - Figures 1 to 23

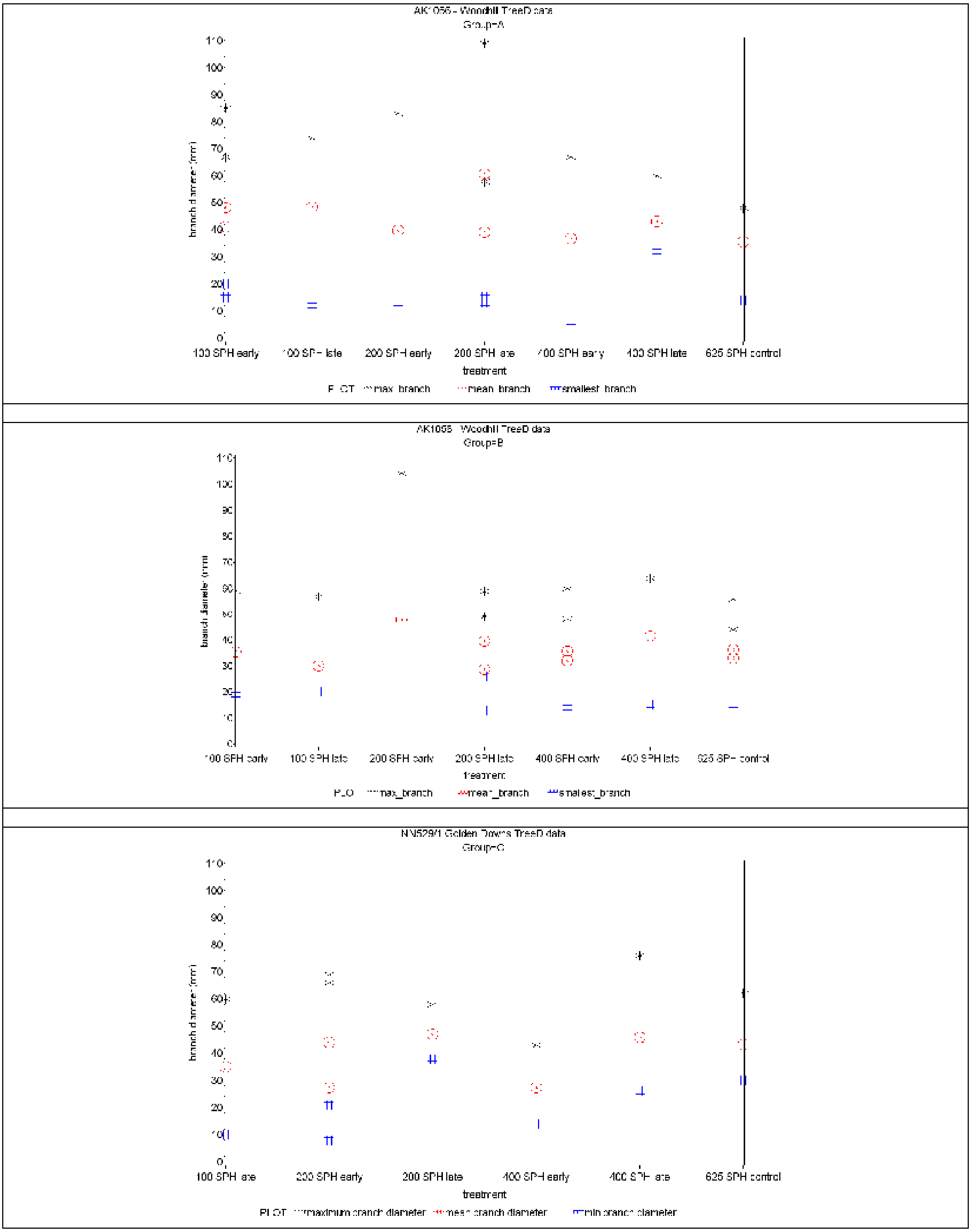


Figure 1. Minimum, mean and maximum branch diameter as measured by TreeD for three groups of trees with the same DBH at last PSP remeasurement.

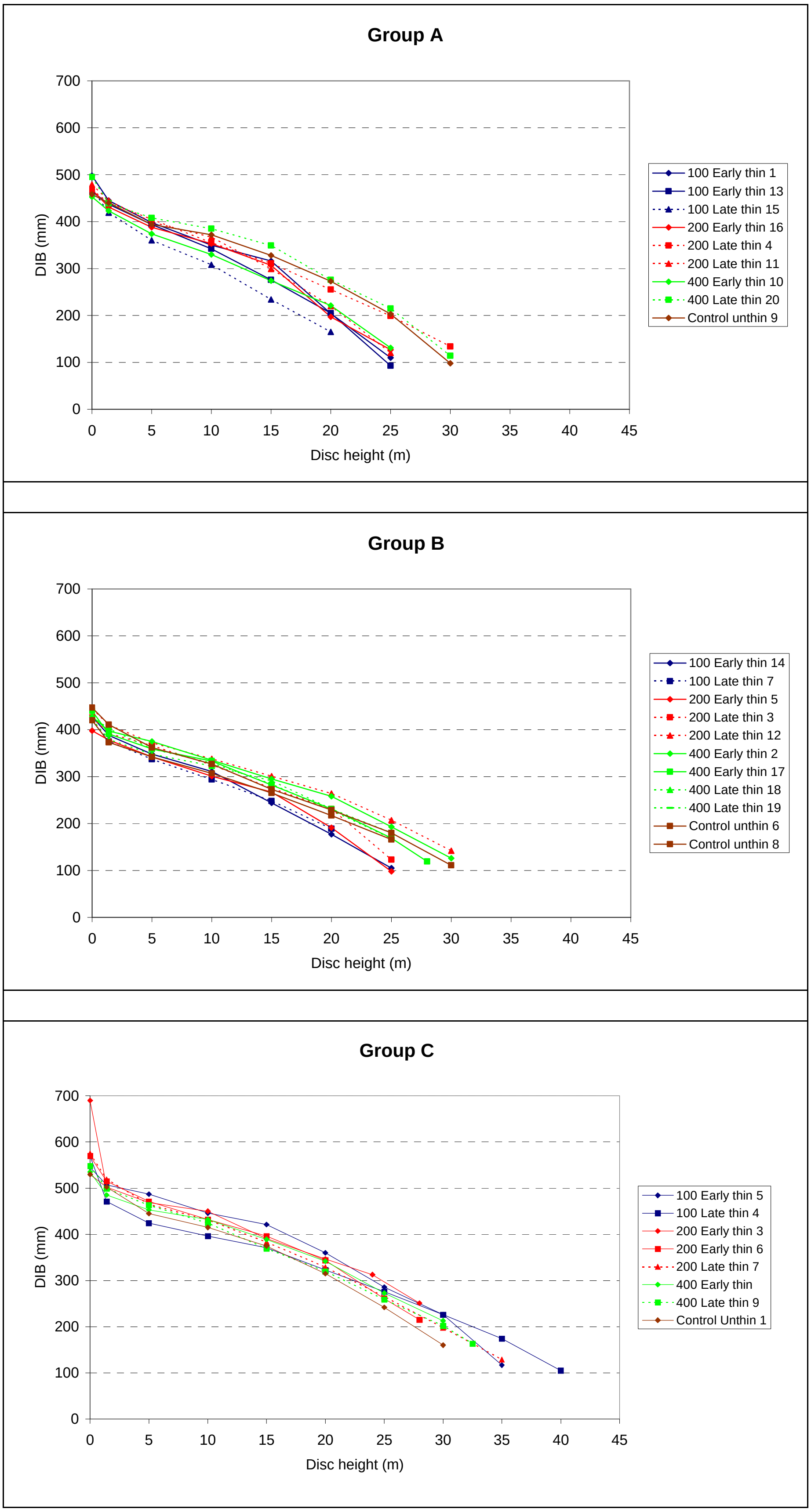
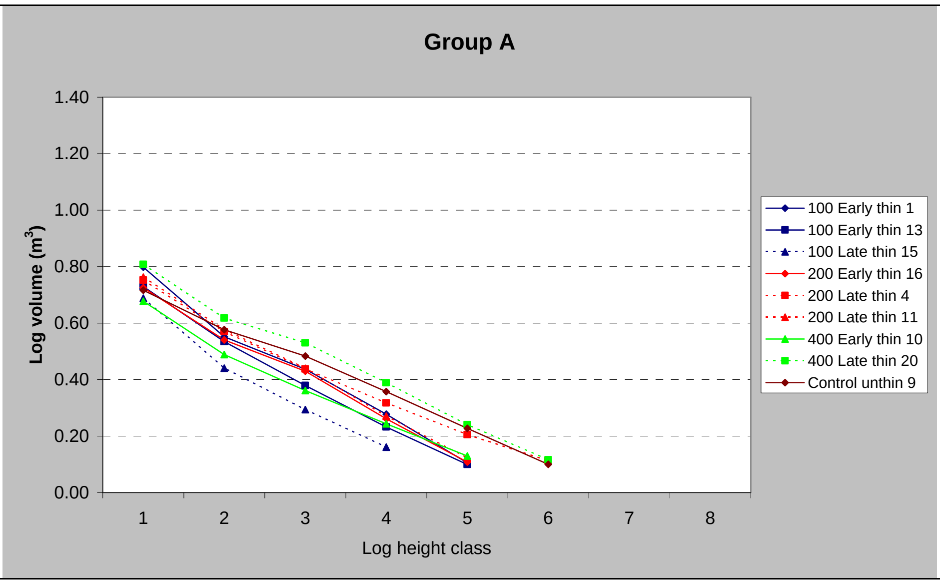
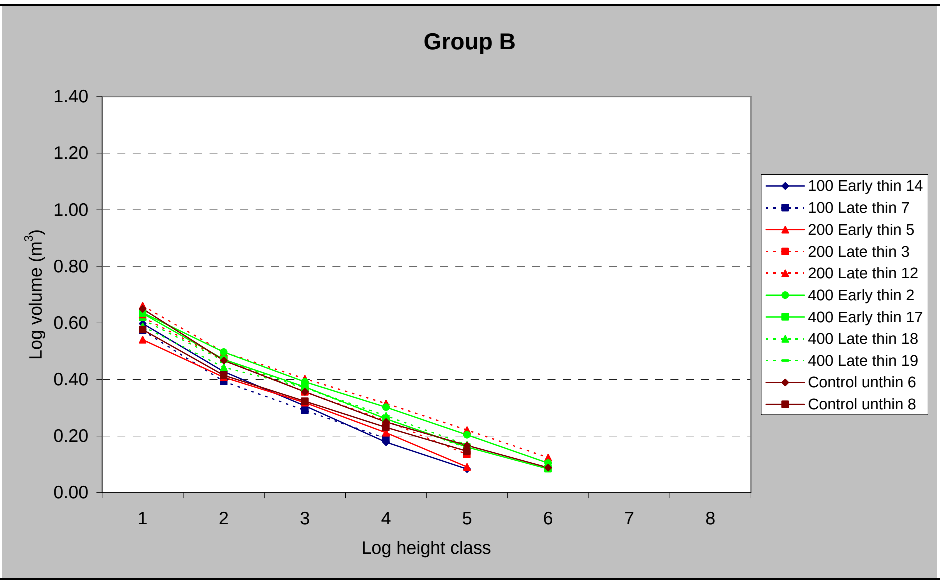


Figure 2. Measured stem diameter under bark for 3 groups of trees with the same DBH at last PSP remeasurement.





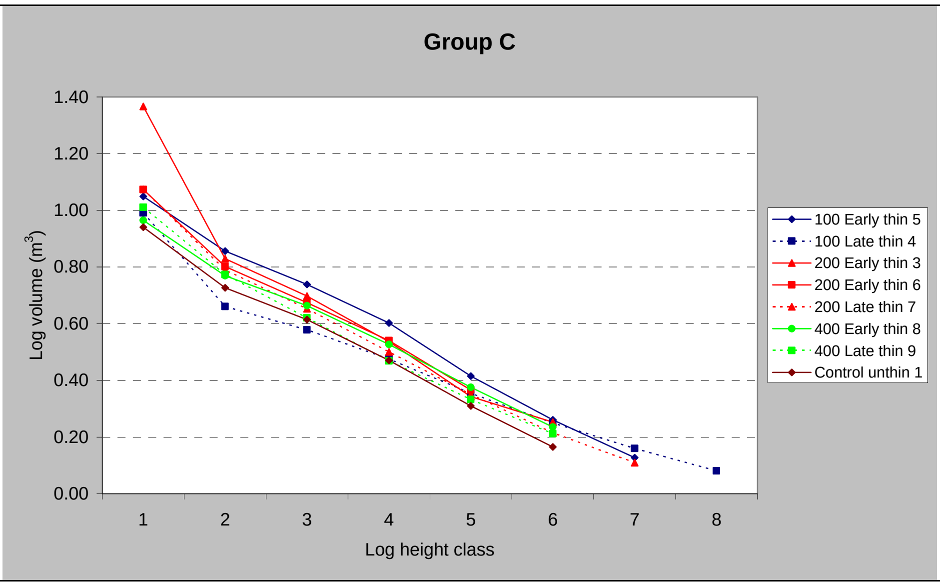
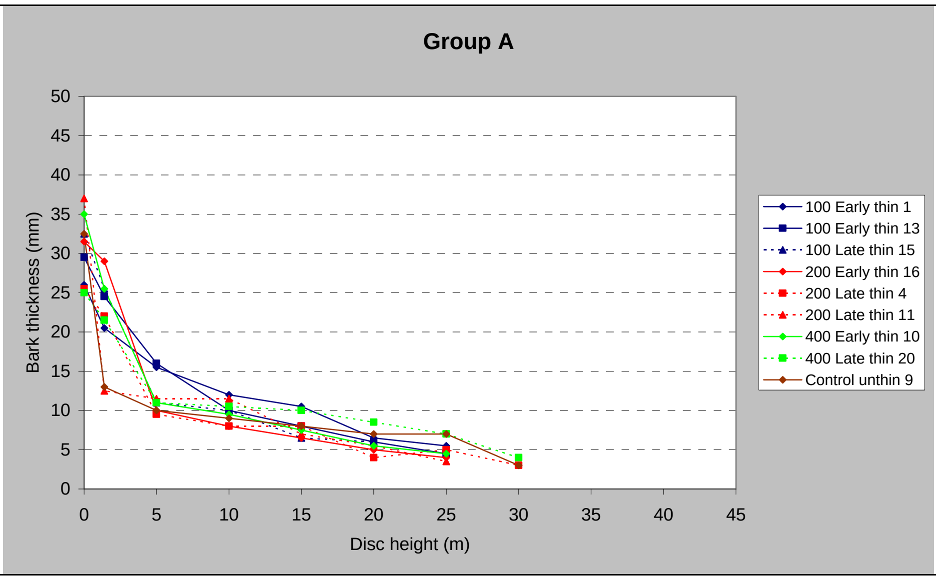
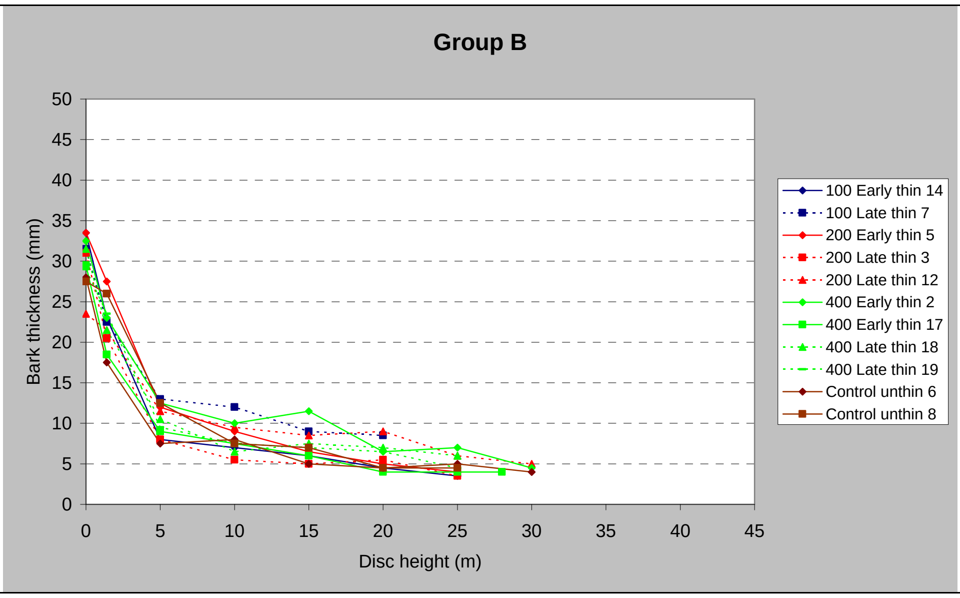


Figure 3. Log volume for three groups of trees with the same DBH at the time of last PSP remeasurement.





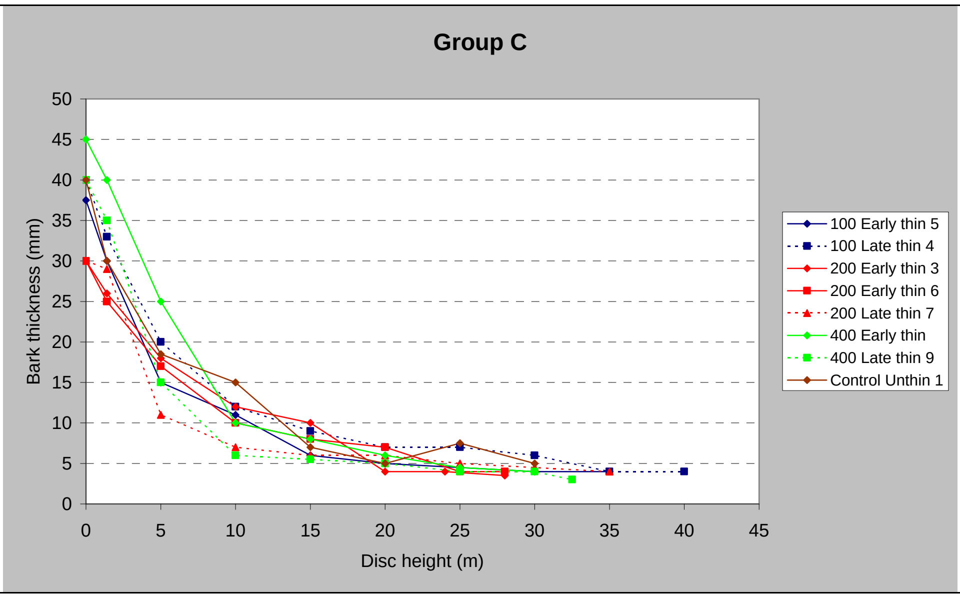
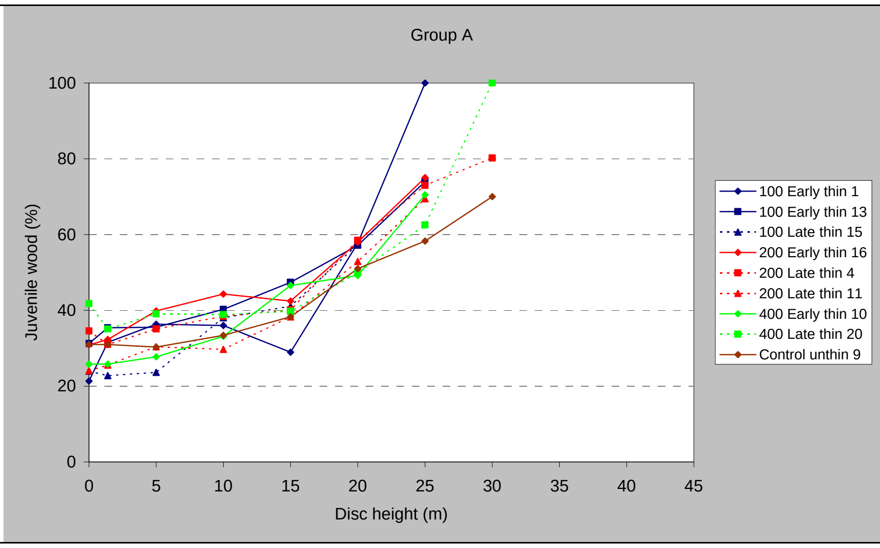
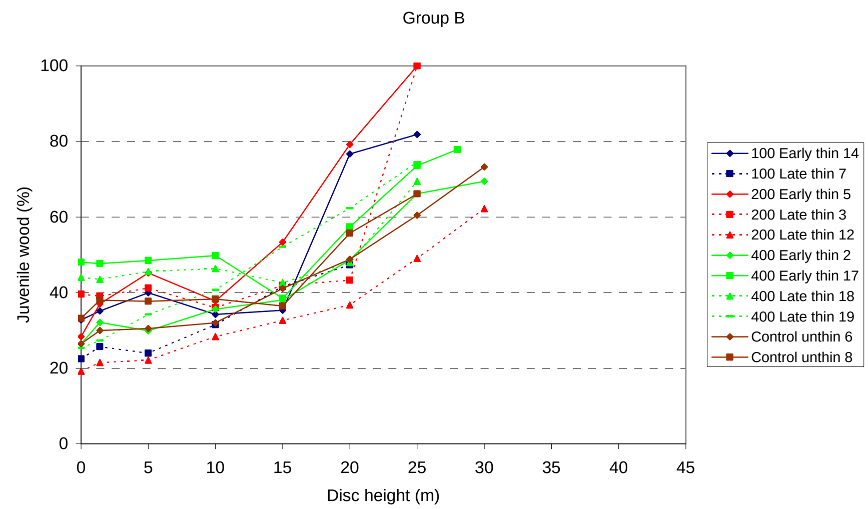


Figure 4. Bark thickness for three groups of trees with the same DBH at the time of last PSP remeasurement.





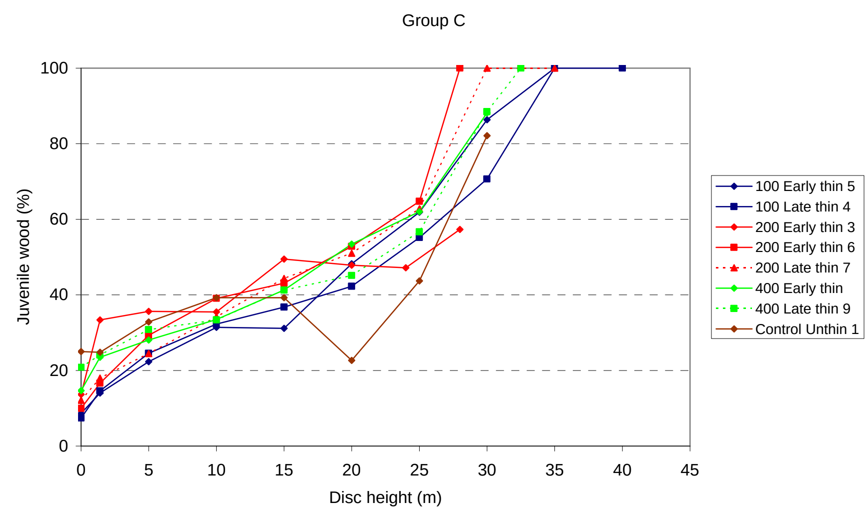
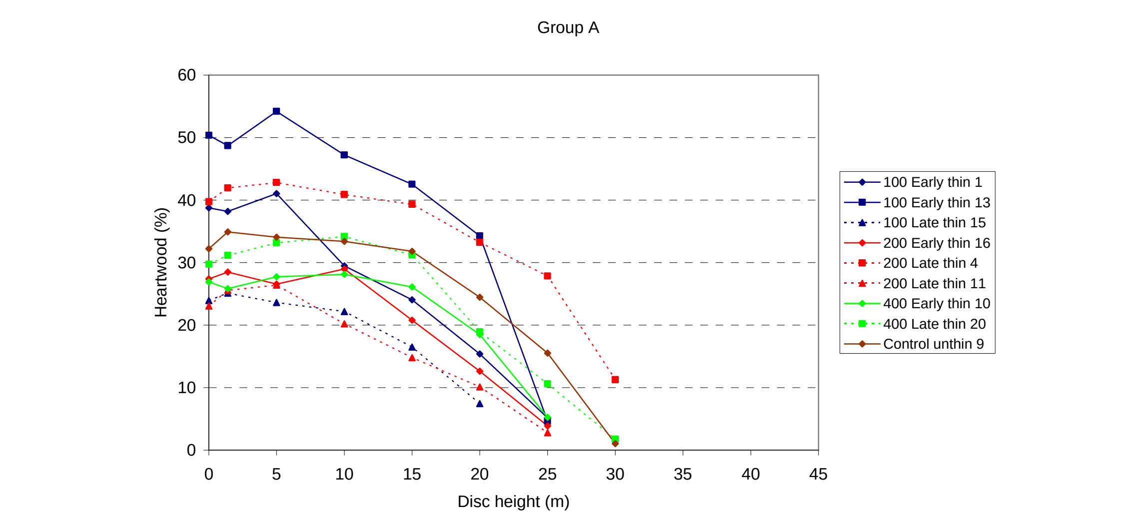
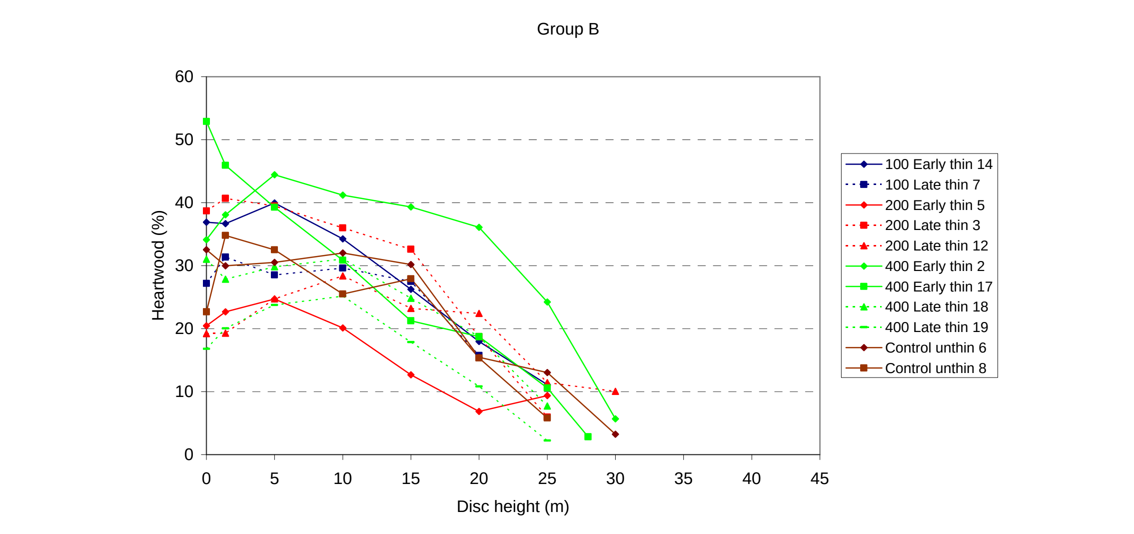


Figure 5. Juvenile wood percentage for three groups of trees with the same DBH at the time of last PSP remeasurement.





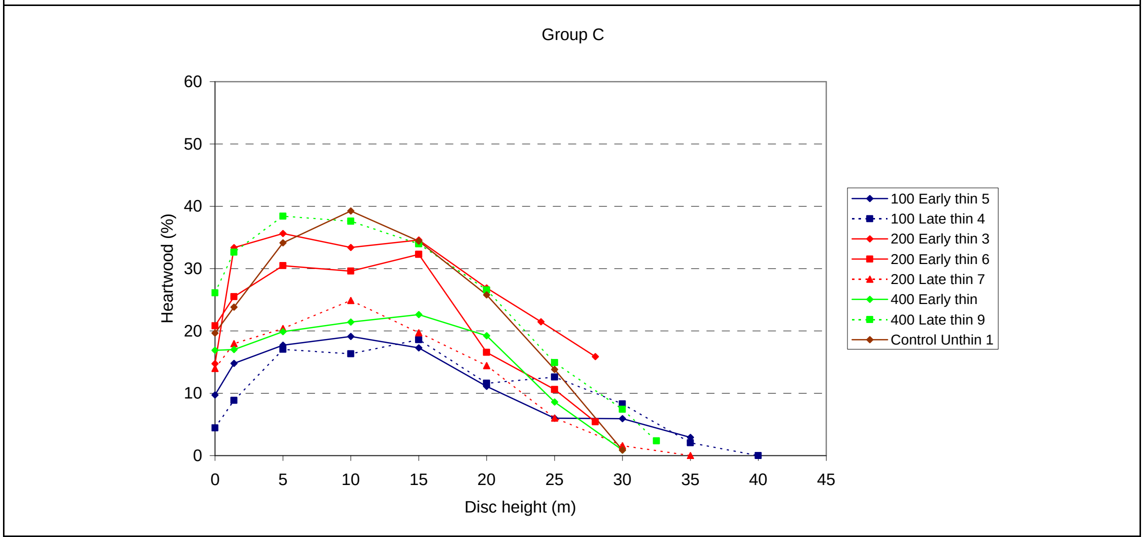
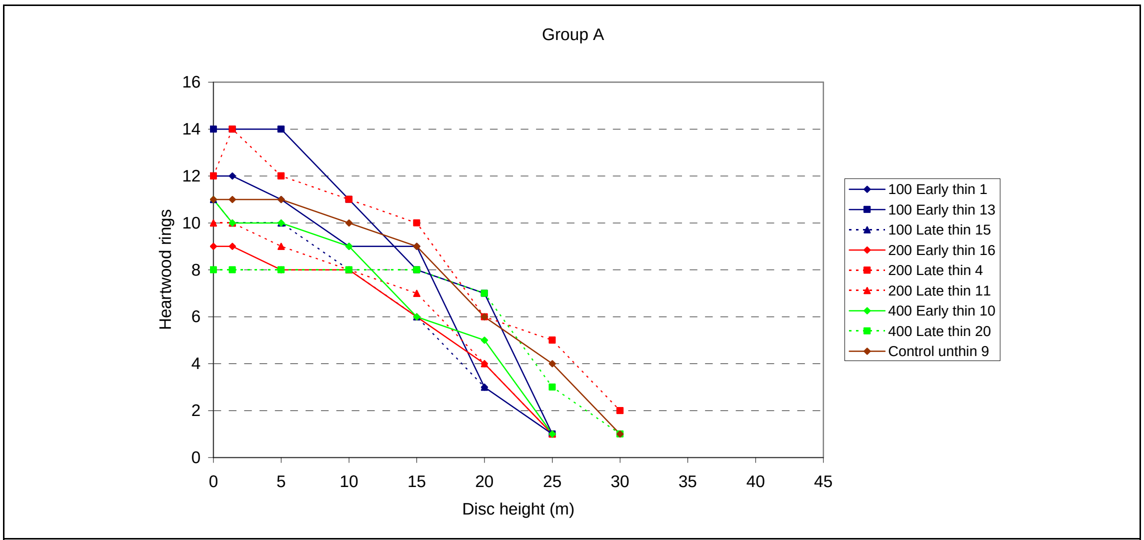
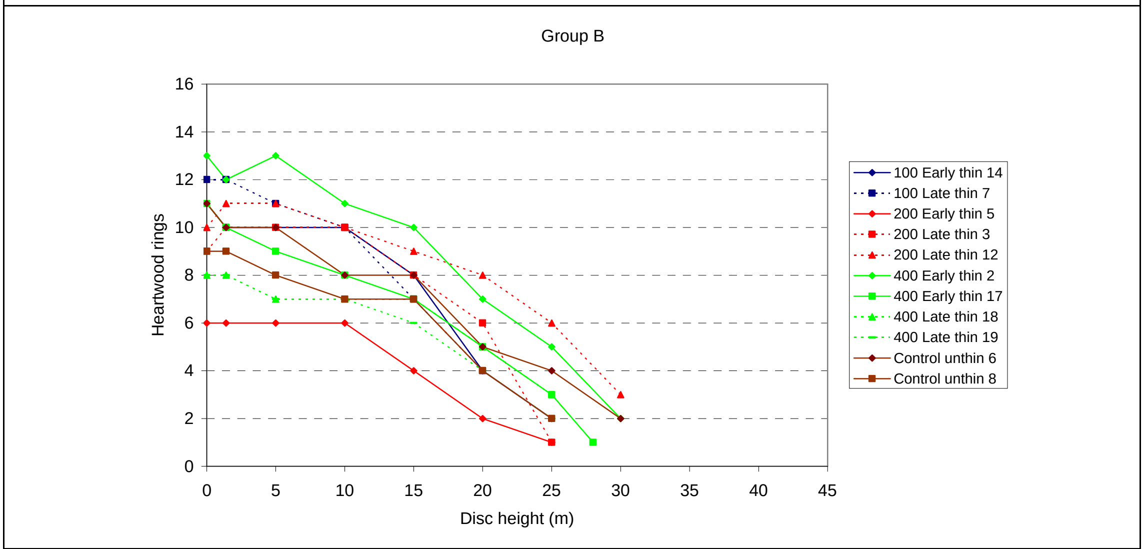


Figure 6. Heartwood Percentage for three groups of trees with the same DBH at the time of last PSP remeasurement.





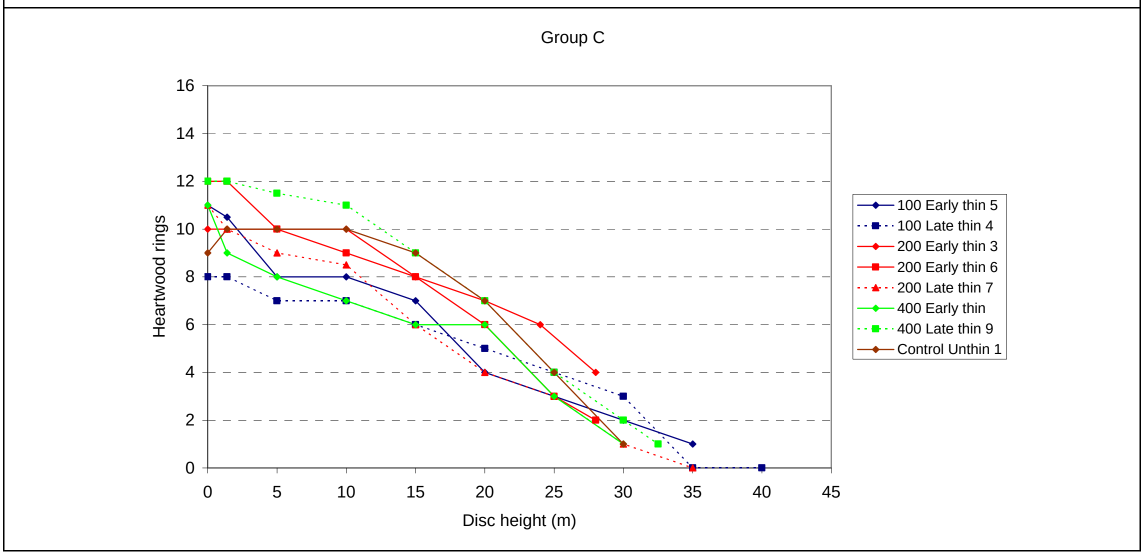
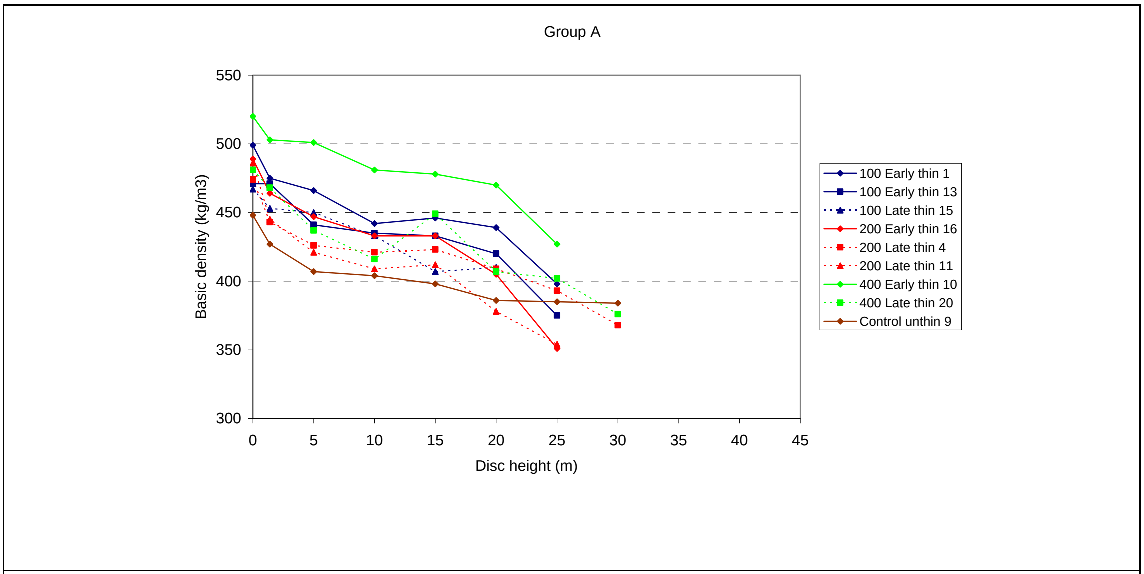
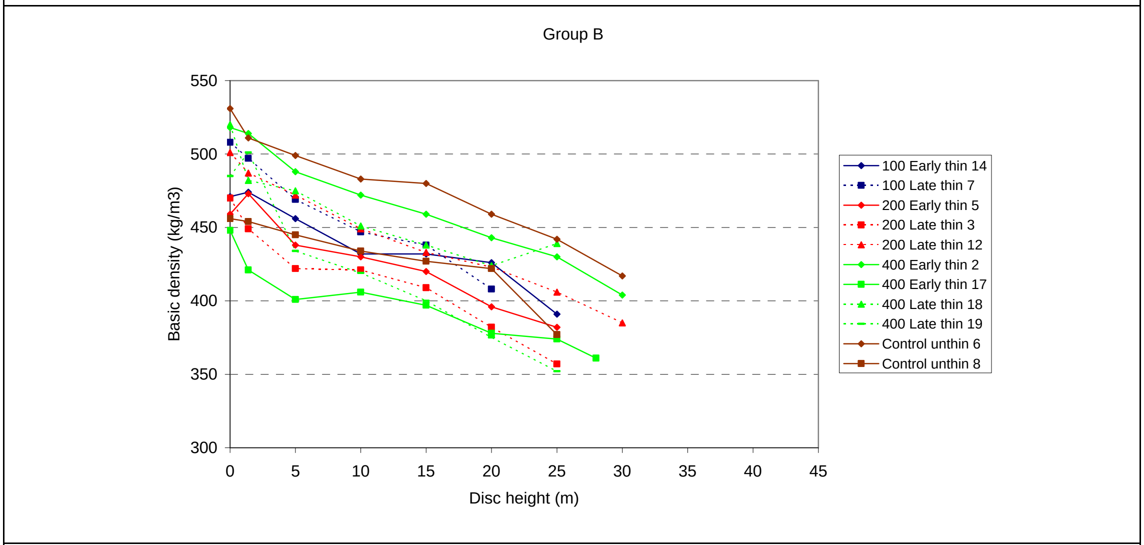


Figure 7. Heartwood Rings for three groups of trees with the same DBH at the time of last PSP remeasurement.





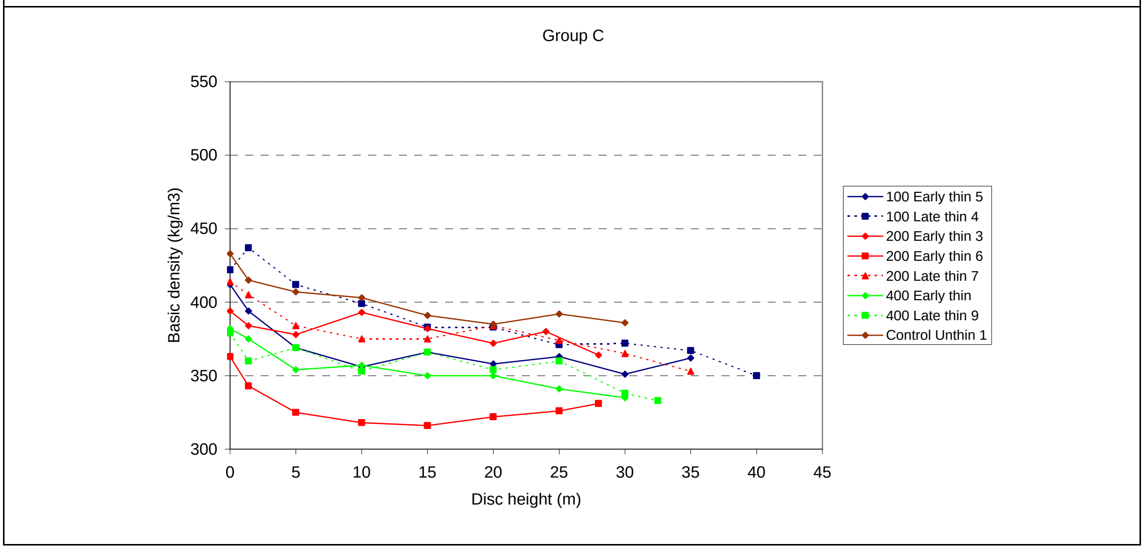


Figure 8. Disc density for three groups of trees with the same DBH at the time of last PSP remeasurement.

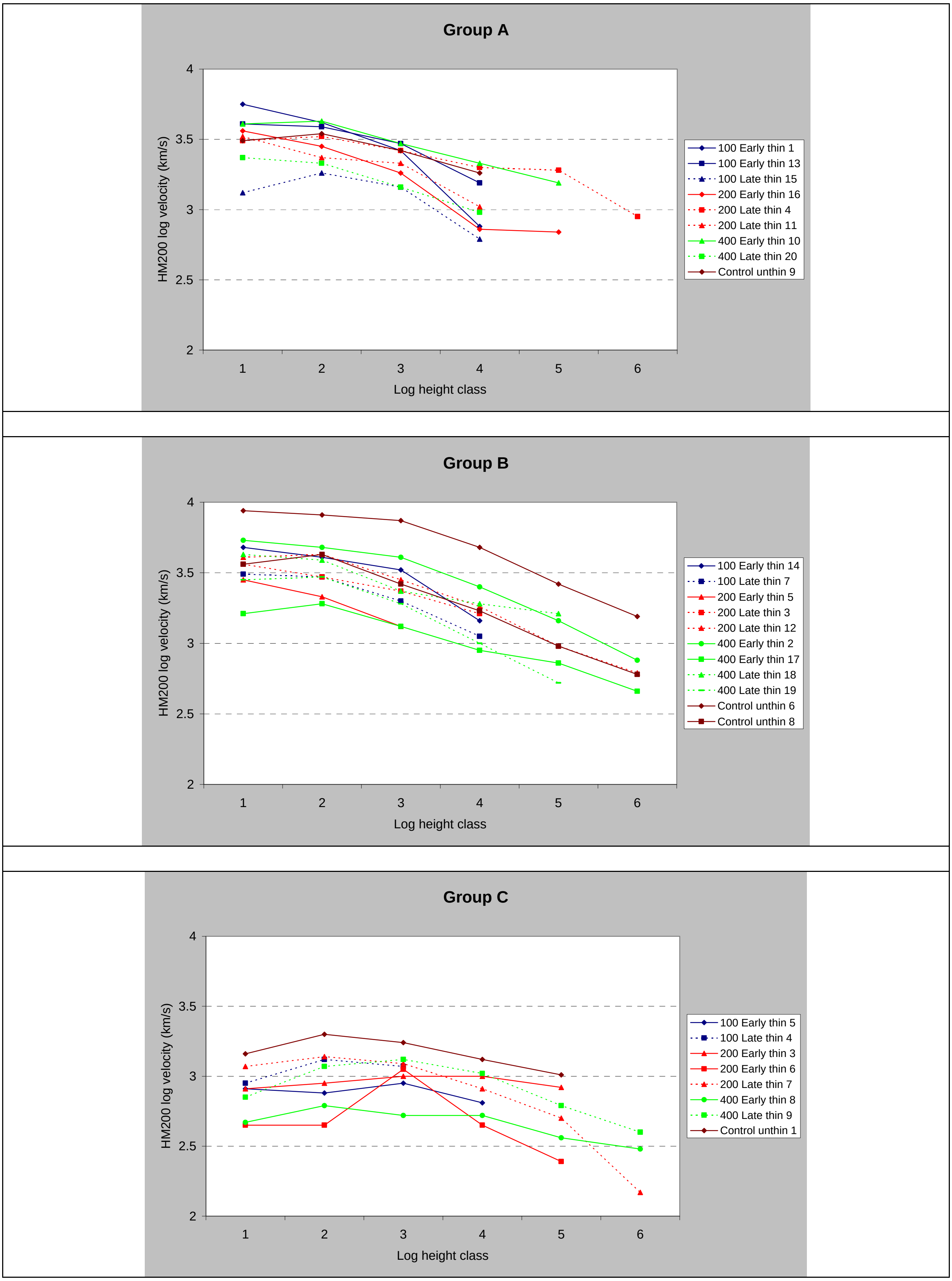
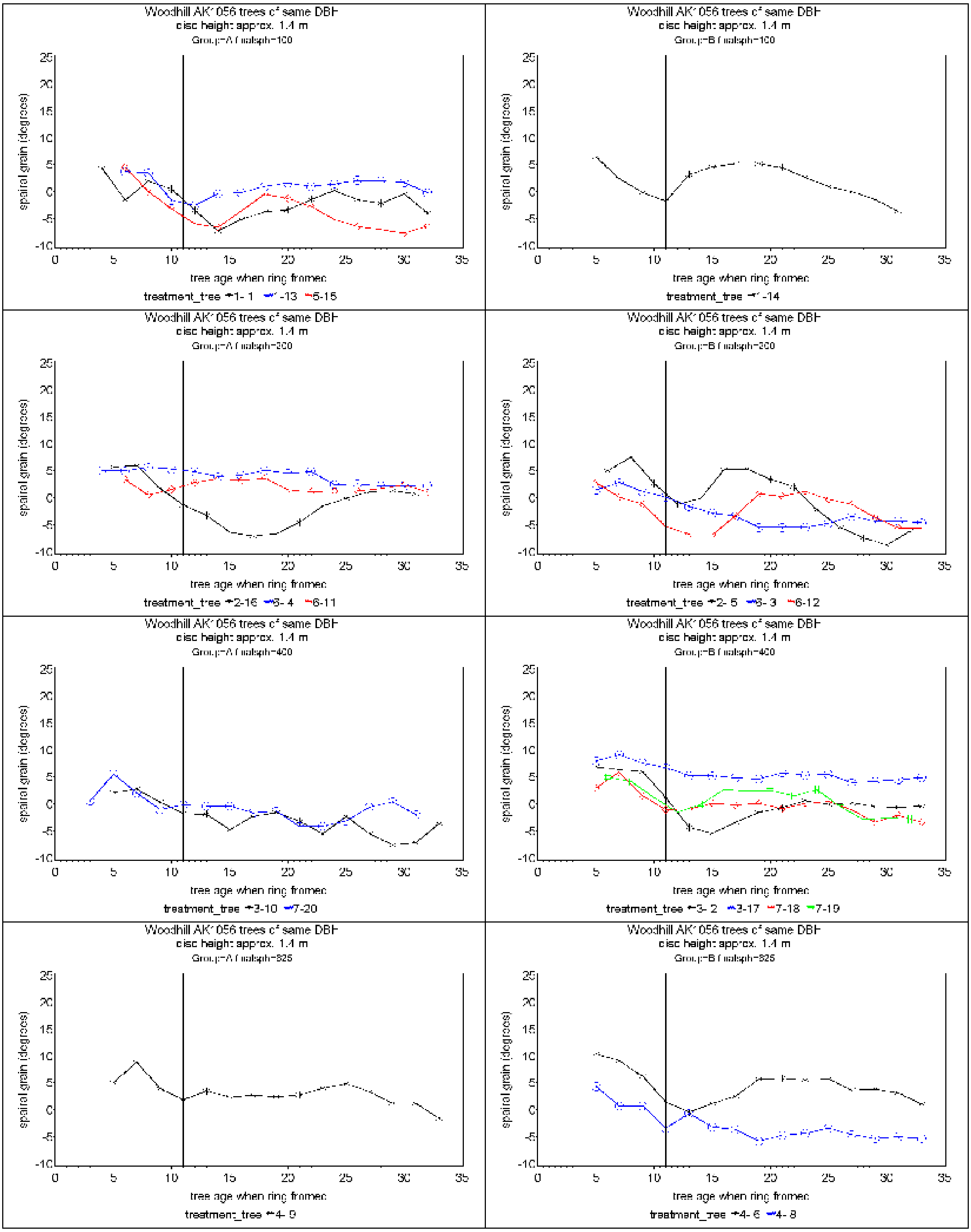
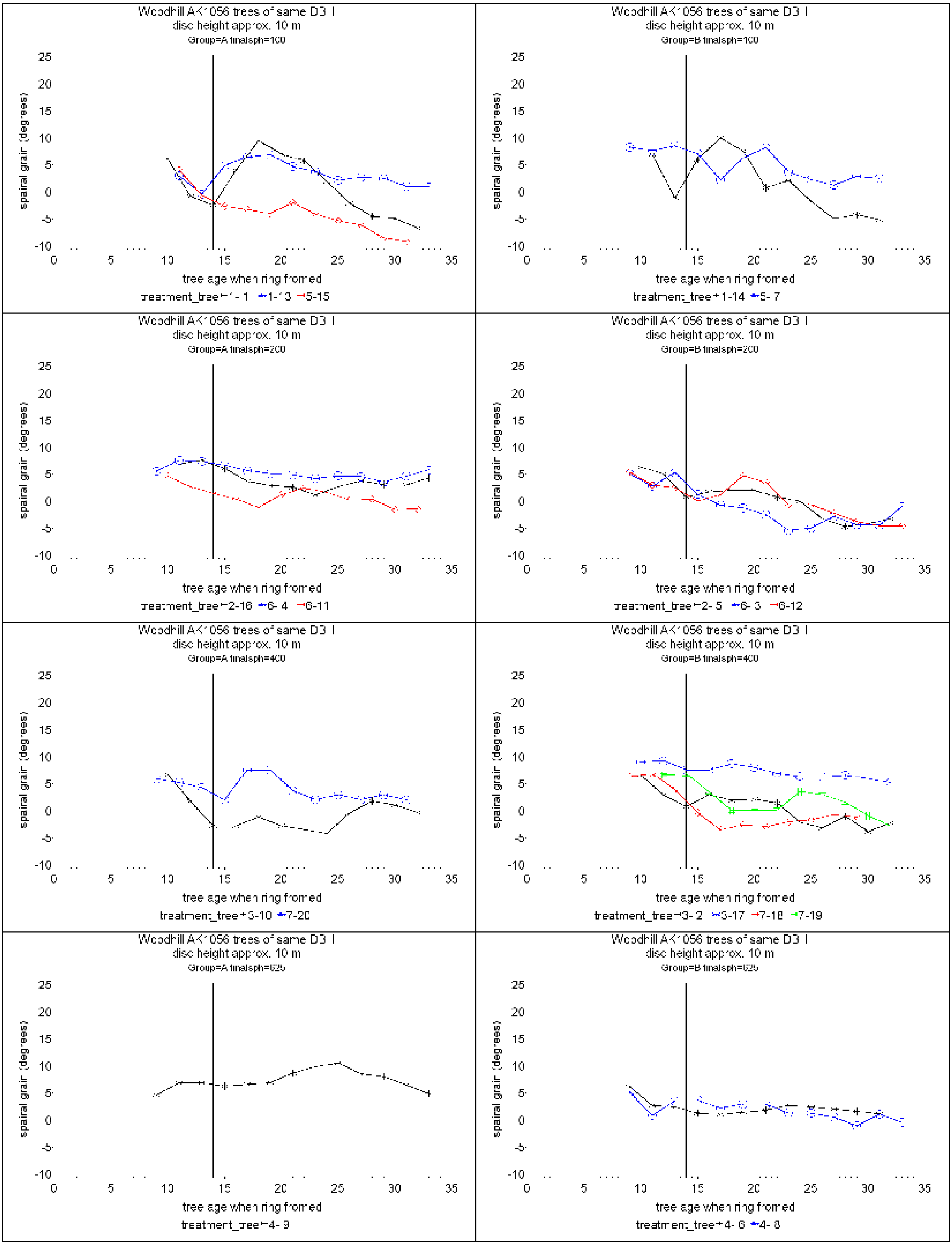


Figure 9. Log velocity as measured using the HM200 for three groups of trees with the same DBH at the time of last PSP remeasurement.



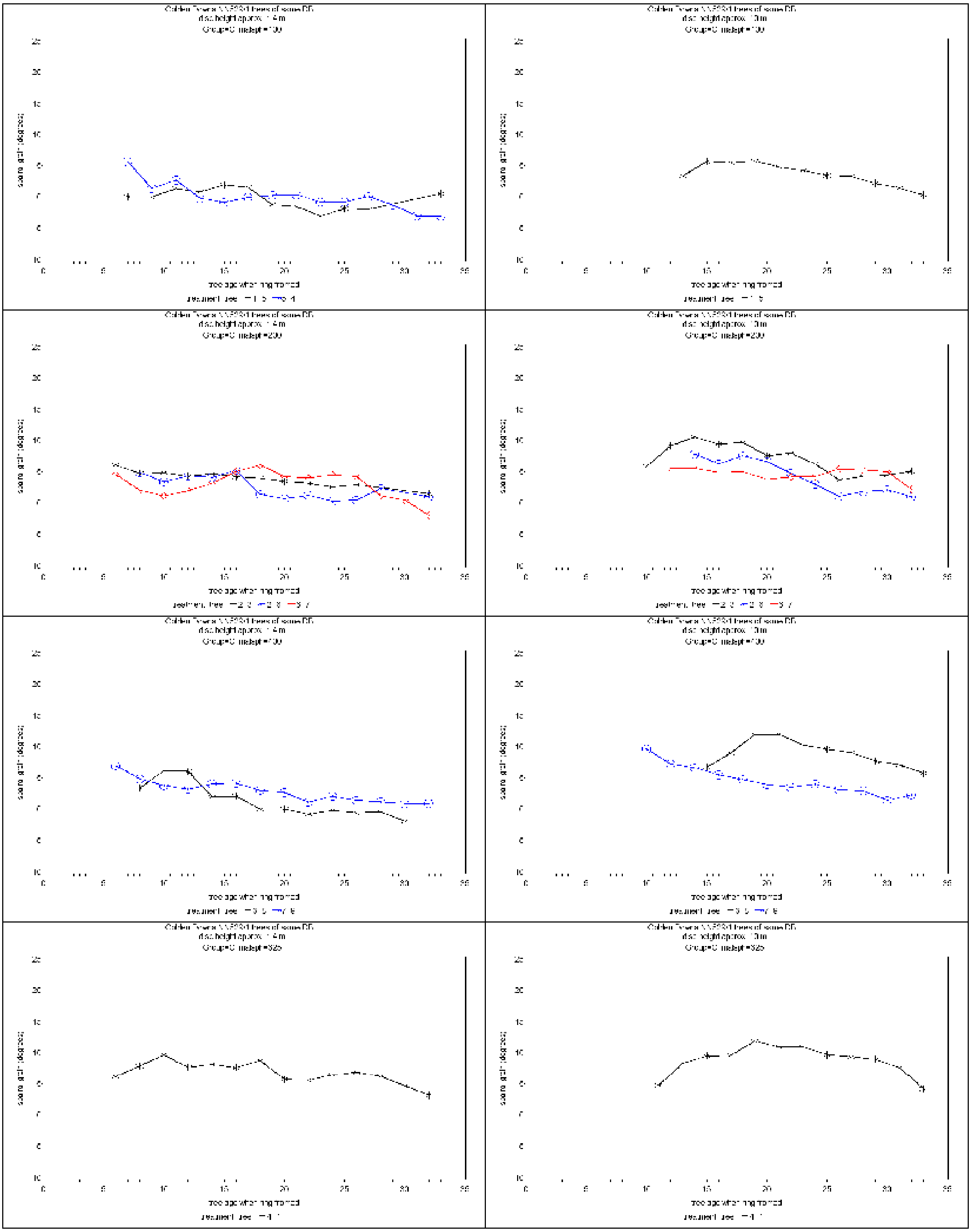
Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 10. Spiral grain at 1.4 m. Individual graphs show individual trees from Woodhill with the same DBH at time of last PSP remeasurement and the same final crop stocking after thinning.



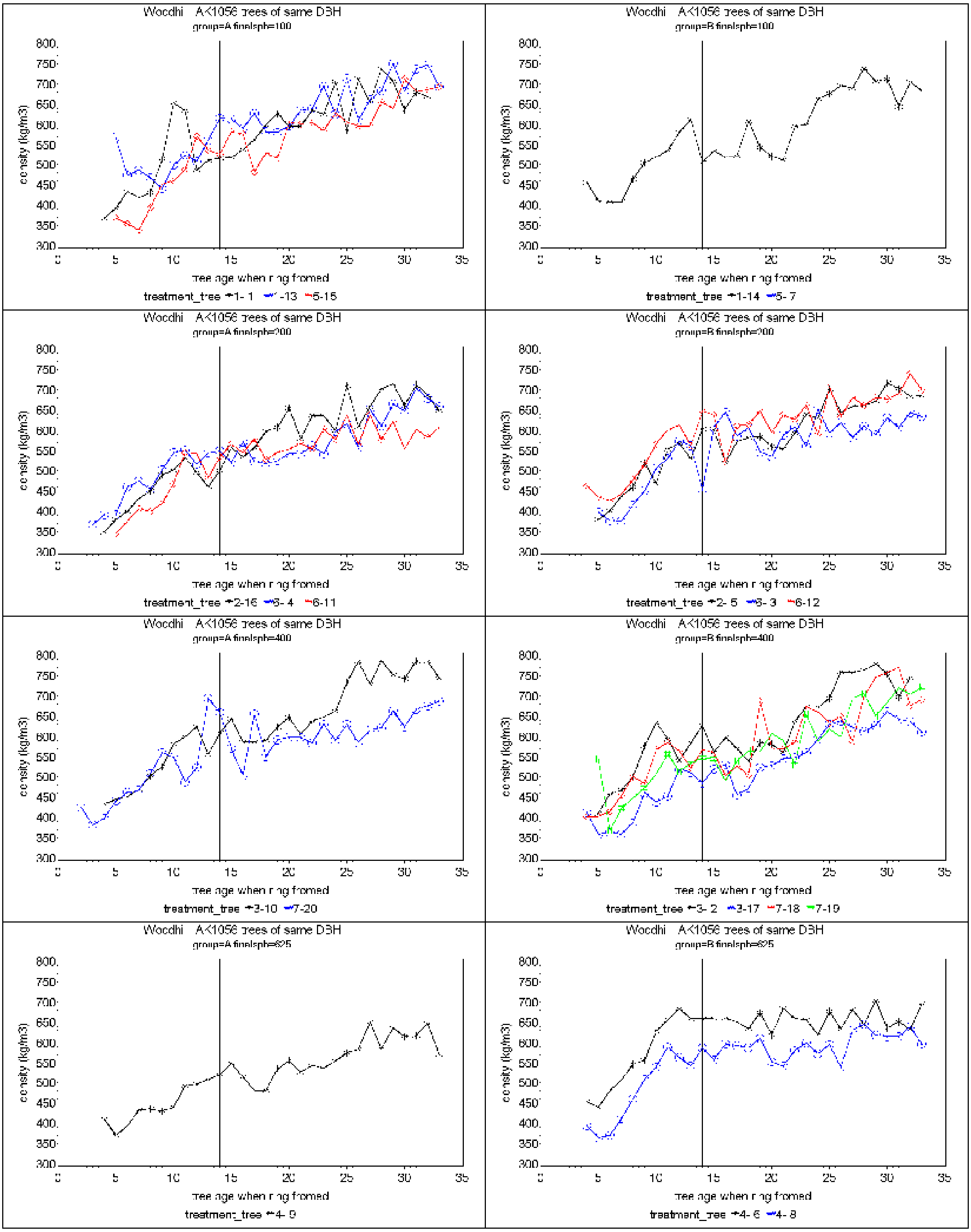
Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 11. Spiral grain at 10 m. Individual graphs show individual trees from Woodhill with the same DBH at time of last PSP remeasurement and the same final crop stocking after thinning.



Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 12. Spiral Grain at approx 1.4 m and 10 m. Individual graphs show individual trees from Golden downs with the same DBH at time of last PSP remeasurement and the same final crop stocking after thinning.

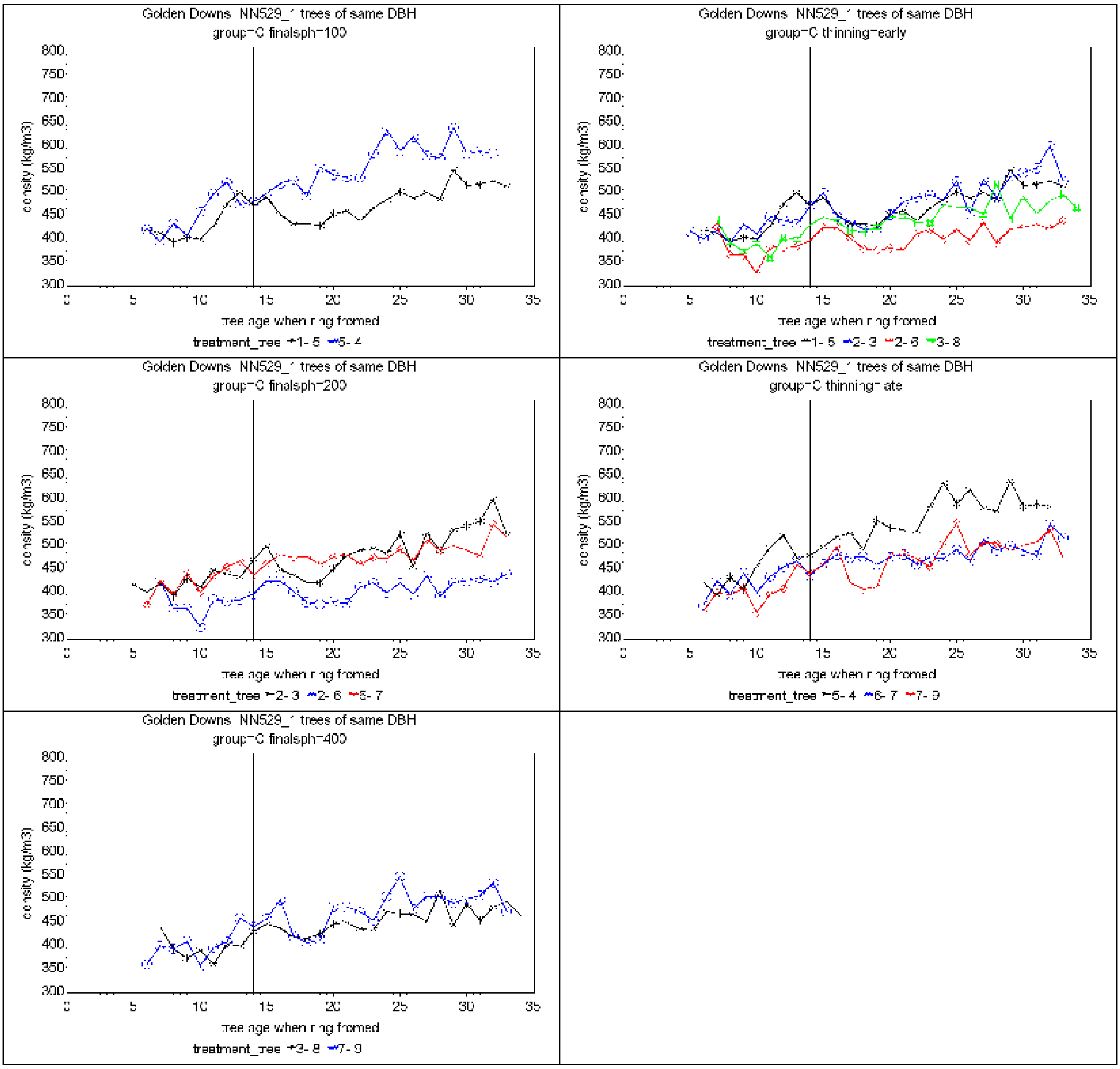


Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 13. SilviScan density at Woodhill from discs at approx. 1.4 m. Each individual graph shows trees of the same DBH at the last PSP remeasurement and the same nominal final crop stocking.

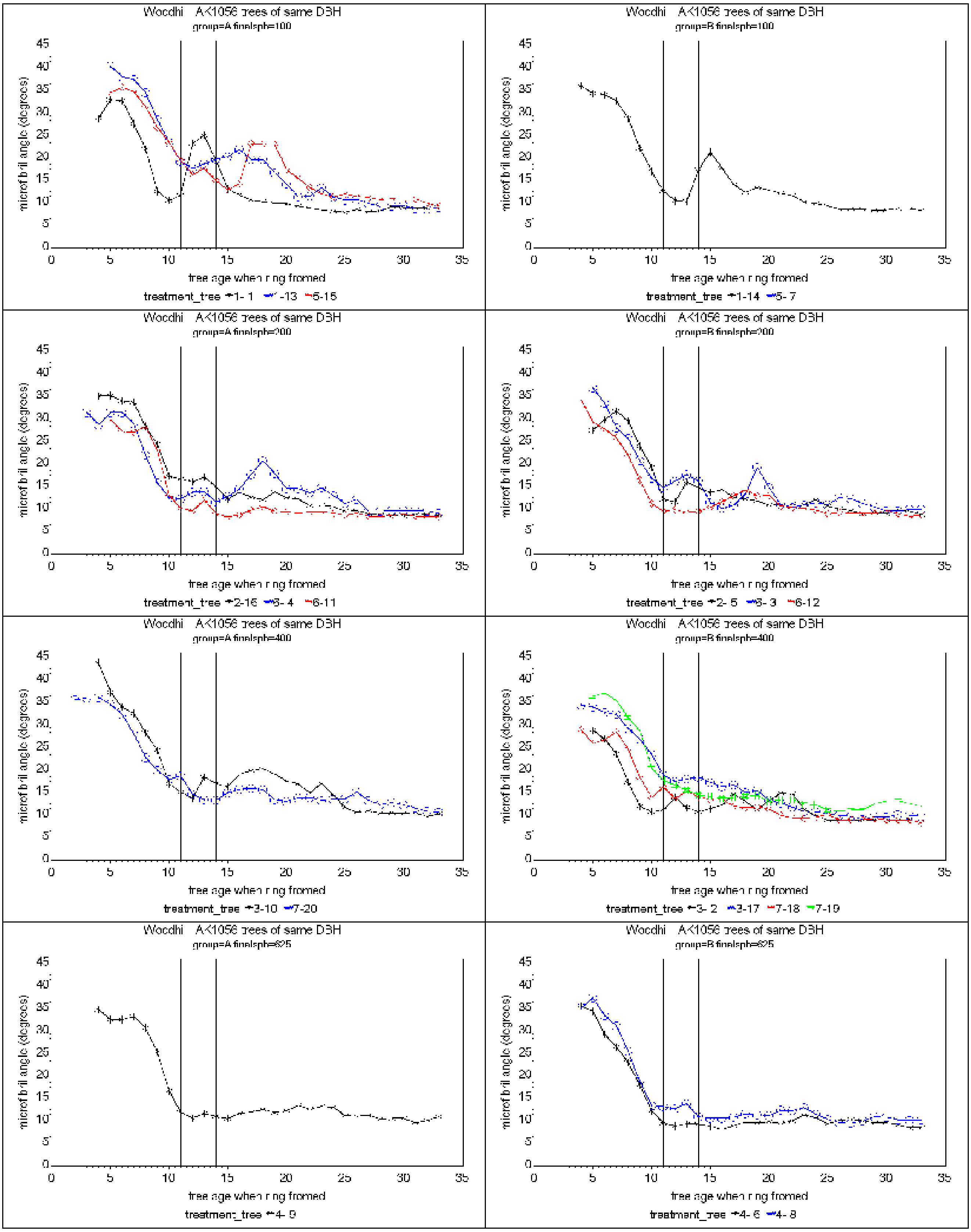
Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 14. SilviScan density at Woodhill from discs at approx. 1.4 m. Each individual graph shows trees of the same DBH at the last PSP remeasurement and the same timing of thinning.



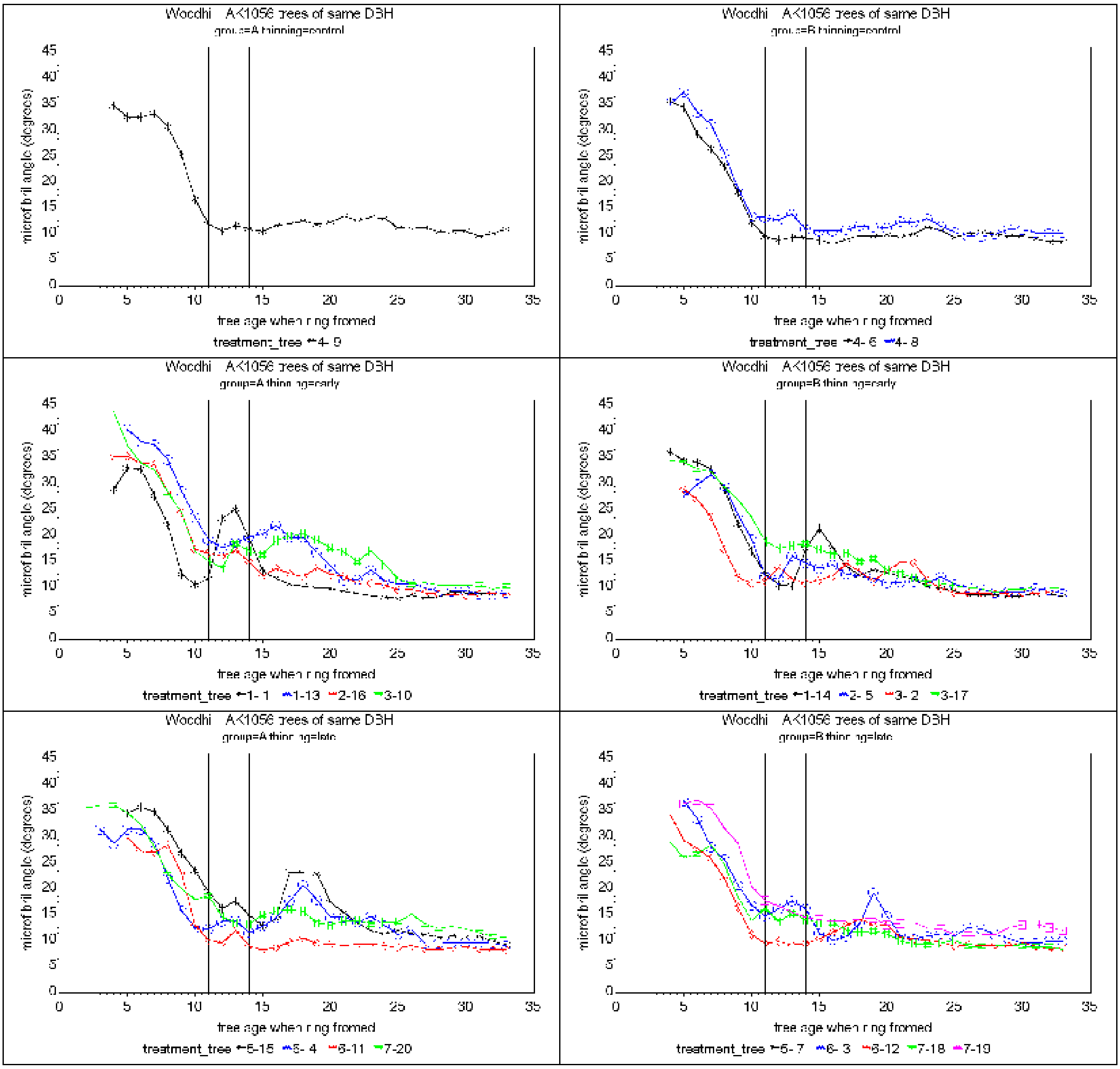
Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 15. SilviScan density at approx. 1.4 m, Golden Downs. Each individual graph shows trees of the same DBH at the last PSP remeasurement. In the left hand column, data are organised by final crop stocking. In the right hand column data are organised by timing of thinning.



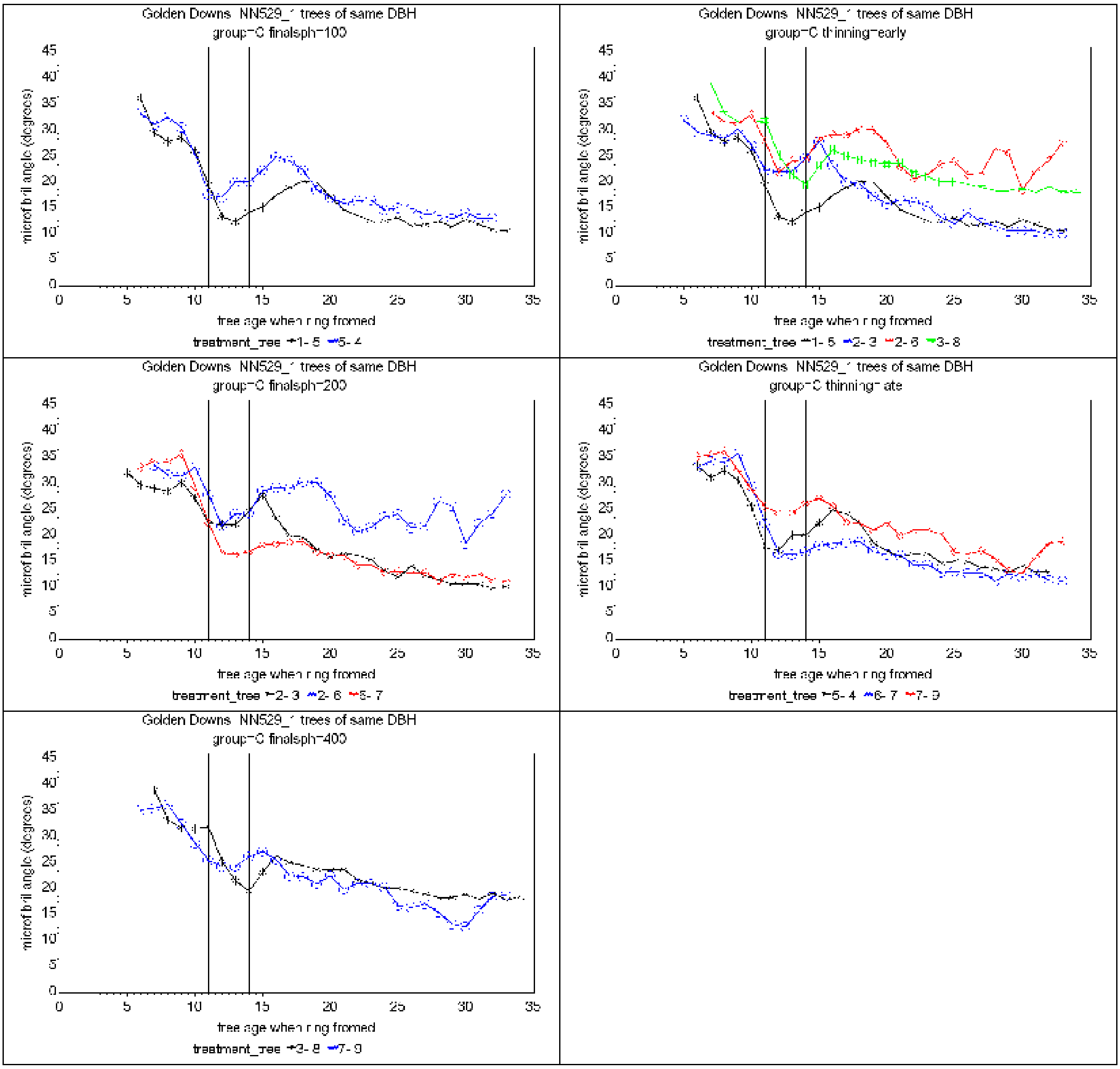
Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 16. SilviScan microfibril angle (MFA) at Woodhill from discs at approx. 1.4 m. Each individual graph shows trees of the same DBH at the last PSP remeasurement and the same nominal final crop stocking.



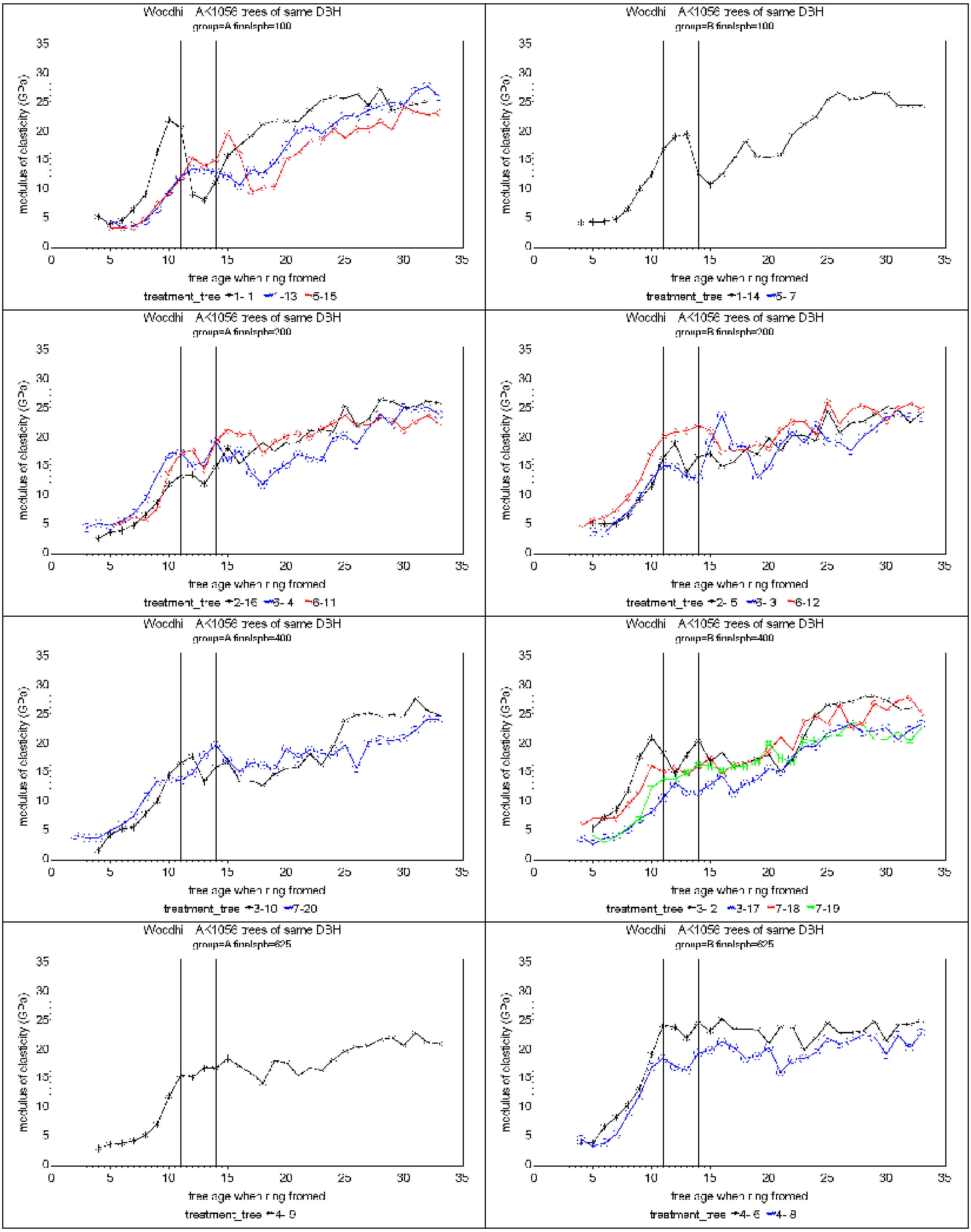
Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 17. SilviScan microfibril angle (MFA) at Woodhill from discs at approx. 1.4 m. Each individual graph shows trees of the same DBH at the last PSP remeasurement and the same timing of thinning.



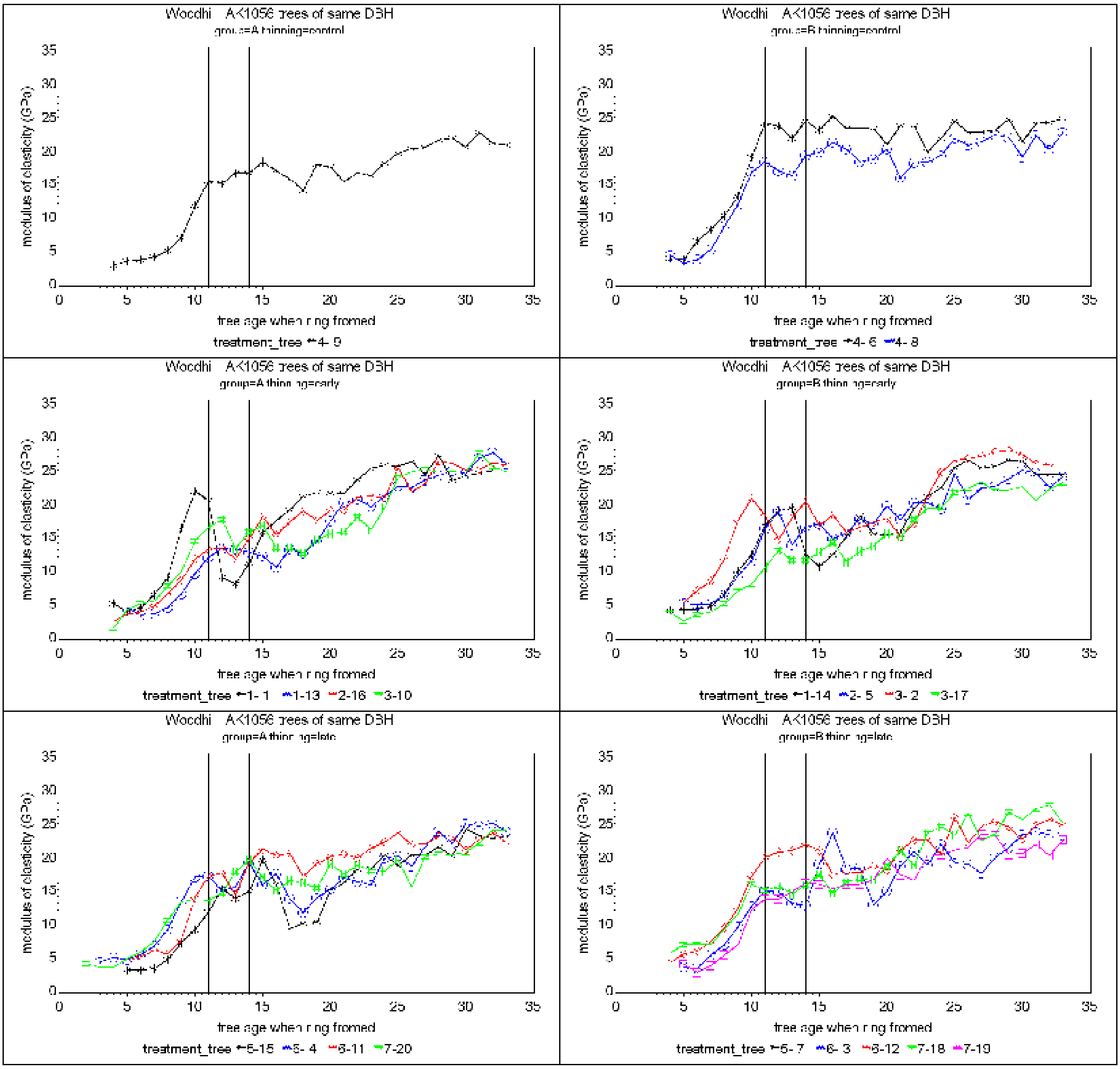
Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 18. SilviScan microfibril angle (MFA) at Golden Downs from discs at approx. 1.4 m. Each individual graph shows trees of the same DBH at the last PSP remeasurement. In the left hand column, data are organised by final crop stocking. In the right hand column data are organised by timing of thinning.



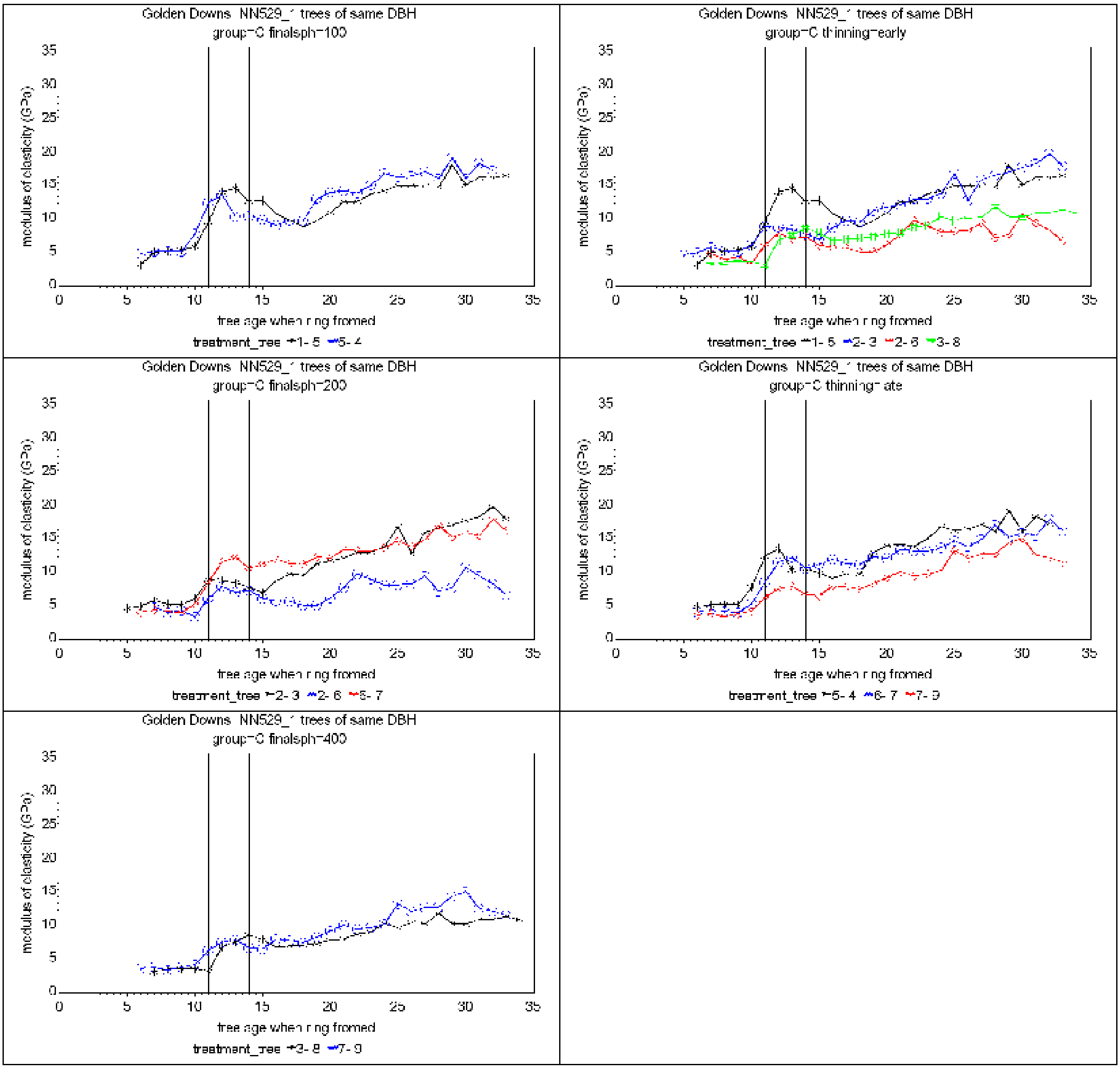
Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 19. SilviScan modulus of elasticity (MOE)at Woodhill from discs at approx. 1.4 m. Each individual graph shows trees of the same DBH at the last PSP remeasurement and the same nominal final crop stocking.



Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 20. SilviScan modulus of elasticity (MOE) at Woodhill from discs at approx. 1.4 m. Each individual graph shows trees of the same DBH at the last PSP remeasurement and the same timing of thinning.



Note: treatment_tree gives the treatment number (Introduction - Table 1) and the individual tree number

Figure 21. SilviScan modulus of elasticity (MOE) at Golden Downs from discs at approx. 1.4 m. Each individual graph shows trees of the same DBH at the last PSP remeasurement. In the left hand column, data are organised by final crop stocking. In the right hand column data are organised by timing of thinning.

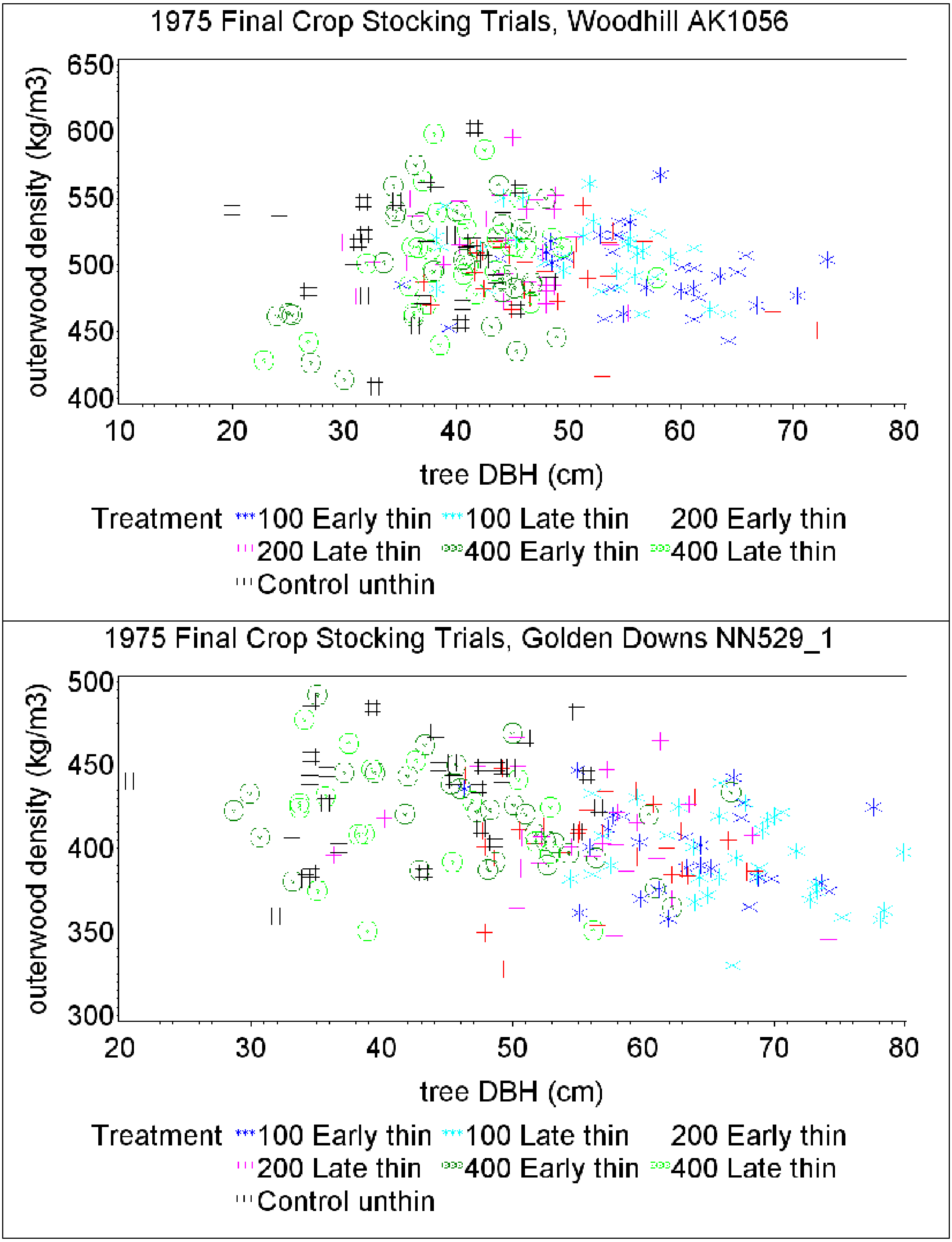


Figure 22. Relation between outerwood density and tree DBH for pre-screening trees

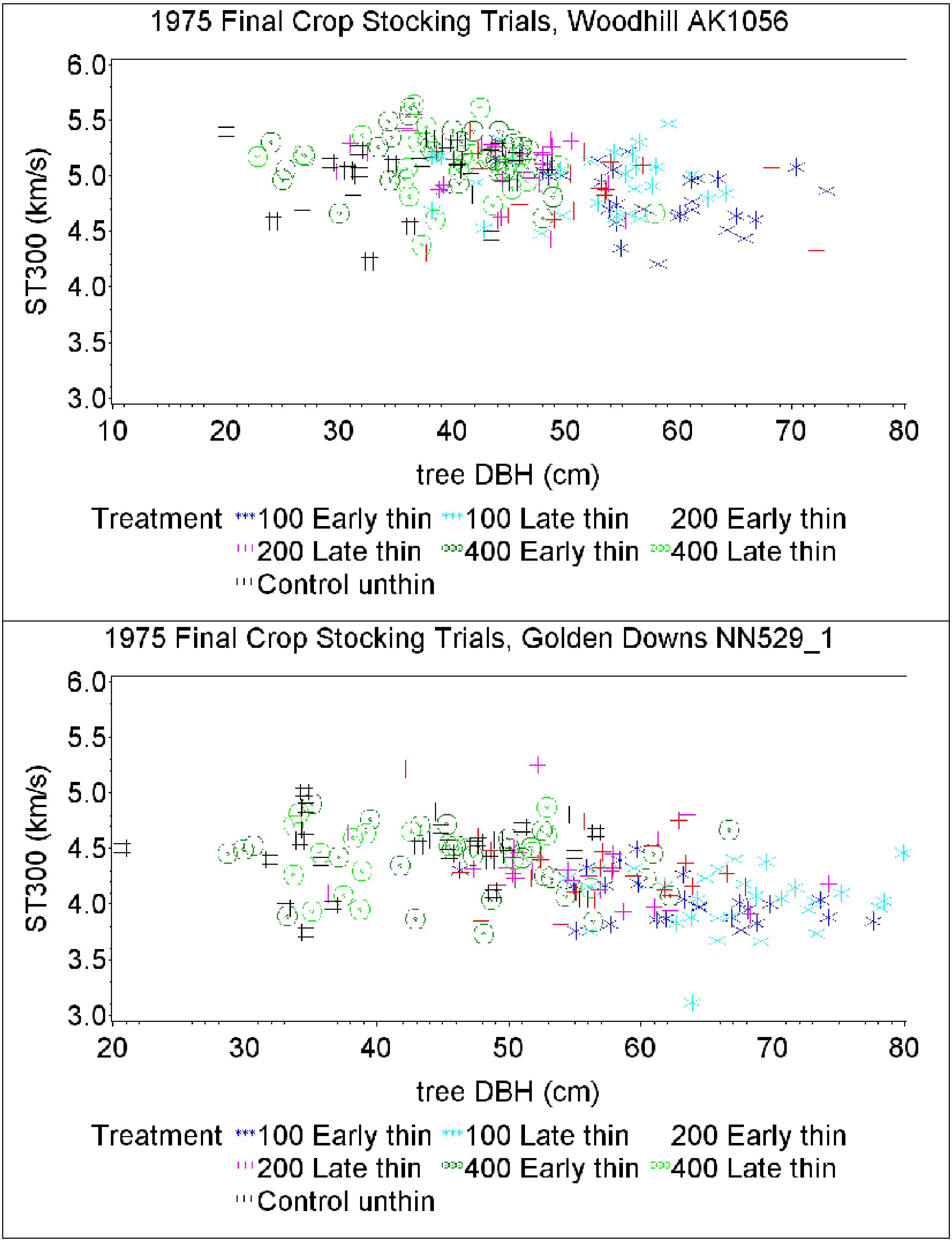


Figure 23. Relationship between standing tree sonics and tree DBH for pre-screening trees.

Appendix 3: Chapter 2 - Sample trees of equal DBH: Standing Tree Properties

Treatment No.	Stocking (spha)	Thinning type	Plot	Quad./ Row	Trial Tree no.	DBHOB# (cm)	Resin Score*	ST300 (km/s)	Density+ (kg/m^3)	Study Tree No.
Group A – Woodhill Forest										
1	100	Early	2.11	6	1	48	0	5.04	509	1
1	100	Early	14.31	20	1	48.5	1	4.99	502	13
2	200	Early	19.32	1	6*	47.9	2	5.10	495	16
3	400	Early	10.23	4	28	48	0	4.62	550	10
4	Control	Unthin	9.14	4	23	48.4	0	5.10	487	9
5	100	Late	17.35	14	1	47.9	1	4.48	502	15
6	200	Late	4.16	0	42	48	0	5.19	484	4
6	200	Late	13.26	1	7	48	1	5.17	481	11
7	400	Late	24.27	0	23	48.5	1	4.93	520	20
Average						**48.1**	**0.7**	**4.96**	**503**	
Group B – Woodhill Forest										
1	100	Early	14.31	9	6	43.8	1	5.16	505	14
2	200	Early	5.12	4	47	44	0	4.60	513	5
3	400	Early	3.13	4	23	43.8	0	5.15	560	2
3	400	Early	18.33	2	8	44.1	0	5.10	480	17
4	Control	Unthin	7.24	3	17	44.1	1	5.25	542	6
4	Control	Unthin	9.14	1	4	43.5	1	4.46	489	8
5	100	Late	8.15	6	5	44.2	0	5.33	550	7
6	200	Late	4.16	0	15	44.3	2	4.63	493	3
6	200	Late	13.26	3	28	44.4	0	4.96	519	12
7	400	Late	24.27	1	5	43.8	0	5.31	523	18
7	400	Late	24.27	2	8	43.6	1	4.74	520	19
Average						**44.0**	**0.5**	**4.97**	**518**	

Treatment No.	Stocking (spha)	Thinning type	Plot	Quad./ Row	Trial Tree no.	DBHOB# (cm)	Resin Score*	ST300 (km/s)	Density+ (kg/m^3)	Study Tree No.
		Group C – Golden Downs Forest								
1	100	Early	10/11	1	4	55.9	0	4.33	401	5
2	200	Early	3/32	4	55	55.7		4.75	423	3
2	200	Early	17/22	0	12	56.5	1	4.04	354	6
3	400	Early	20/23	2	11	56.4	0	3.85	395	8
4	Control	Unthin	4/34	3	13	55.7	0	4.05	444	1
5	100	Late	11/15	20	3	56.1	0	4.16	433	4
6	200	Late	23/26	0	45	56.1	0	4.26	396	7
7	400	Late	19/27	3	16	56.2	1	4.14	351	9
Average						**56.1**	**0.3**	**4.20**	**399**	
		Group D – Golden Downs Forest								
1	100	Early	22/21	20	6	54.9	1	4.17	447	13
3	400	Early	14/13	3	11	54.3	1	4.07	398	11
4	Control	Unthin	4/34	0	15	54.9	0	4.80	482	2
4	Control	Unthin	21/24	2	12	55	1	4.45	410	12
5	100	Late	11/15	8	2	54.4	0	4.23	382	10
6	200	Late	23/26	0	13	54.5	0	4.30	401	14
Average						**54.7**	**0.5**	**4.34**	**420**	

Measured at time of last PSP remeasurement
* Visually assessed
+ Outerwood

Appendix 4: Chapter 2 - Sample trees of equal DBH: HM200 log and stem acoustic measures

Treatment	Stocking	Thinning	Tree	Stem	HM200 acoustic data						
		type	no.	length	Stem	Log 1[+]	Log 2[+]	Log 3[+]	Log 4[+]	Log 5[+]	Log 6[+]
	(spha)			(m)	(km/s)						
Group A – Woodhill Forest											
1	100	Early	1	22.2	3.37	3.75	3.62	3.42	2.88		
1	100	Early	13	25.7	3.26	3.61	3.59	3.47	3.19	2.70	
2	200	Early	16	27.7	3.2	3.56	3.45	3.26	2.86	2.84	
3	400	Early	10	26.7	3.38	3.61	3.63	3.47	3.33	3.19	
4	Control	Unthin	9	30.0	3.23	3.49	3.54	3.42	3.26	3.05	2.77
5	100	Late	15	21.6	3.06	3.12	3.26	3.16	2.79		
6	200	Late	4	30.2	3.31	3.49	3.52	3.42	3.3	3.28	2.95
6	200	Late	11	25.9	3.14	3.52	3.37	3.33	3.02	2.79	
7	400	Late	20	22.2	3.17	3.37	3.33	3.16	2.98		
Average				**25.8**	**3.24**	**3.50**	**3.48**	**3.35**	**3.07**	**2.98**	**2.86**
Group B – Woodhill Forest											
1	100	Early	14	25.2	3.41	3.68	3.61	3.52	3.16	3.56	
2	200	Early	5	17.6	3.26	3.45	3.33	3.12			
3	400	Early	2	30.0	3.36	3.73	3.68	3.61	3.40	3.16	2.88
3	400	Early	17	28.3	3.01	3.21	3.28	3.12	2.95	2.86	2.66
4	Control	Unthin	6	30.0	3.68	3.94	3.91	3.87	3.68	3.42	3.19
4	Control	Unthin	8	27.3	3.26	3.56	3.63	3.42	3.23	2.98	2.78
5	100	Late	7	21.5	3.24	3.49	3.47	3.3	3.05	#	
6	200	Late	3	25.4	3.15	3.56	3.47	3.37	3.21		
6	200	Late	12	32.4	3.17	3.61	3.63	3.45	3.26	2.98	2.79
7	400	Late	18	25.0	3.42	3.63	3.59	3.37	3.28	3.21	
7	400	Late	19	25.5	3.08	3.45	3.47	3.28	3.00	2.72	
Average				**26.2**	**3.28**	**3.57**	**3.55**	**3.40**	**3.22**	**3.11**	**2.86**

Treatment	Stocking (spha)	Thinning type	Tree no.	Stem length (m)	HM200 acoustic data (km/s)						
					Stem	Log 1$^+$	Log 2$^+$	Log 3$^+$	Log 4$^+$	Log 5$^+$	Log 6$^+$
Group C – Golden Downs Forest											
1	100	Early	5	22.2	2.87	2.91	2.88	2.95	2.81	#	#
2	200	Early	3	24.5	2.95	2.91	2.95	3.00	3.00	2.92	
2	200	Early	6	22.9	2.66	2.65	2.65	3.05	2.65	2.39	
3	400	Early	8	31.1	2.59	2.67	2.79	2.72	2.72	2.56	2.48
4	Control	Unthin	1	23.0	3.2	3.16	3.3	3.24	3.12	3.01	
5	100	Late	4	17.7	3.01	2.95	3.12	3.07	#	#	#
6	200	Late	7	22.3	2.99	3.07	3.14	3.09	2.91	2.7	2.17
7	400	Late	9	32.8	2.86	2.85	3.07	3.12	3.02	2.79	2.6
Average				**24.6**	**2.89**	**2.90**	**2.99**	**3.03**	**2.89**	**2.73**	**2.42**
Group D – Golden Downs Forest											
4	Control	Unthin	2	35.2	3.01	3.12	3.19	3.19	3.00	2.88	2.56
Average				**35.2**	**3.01**	**3.12**	**3.19**	**3.19**	**3.00**	**2.88**	**2.56**

$^+$ 5m length
shattered

Appendix 5: Chapter 3 - Figures 24 to 41

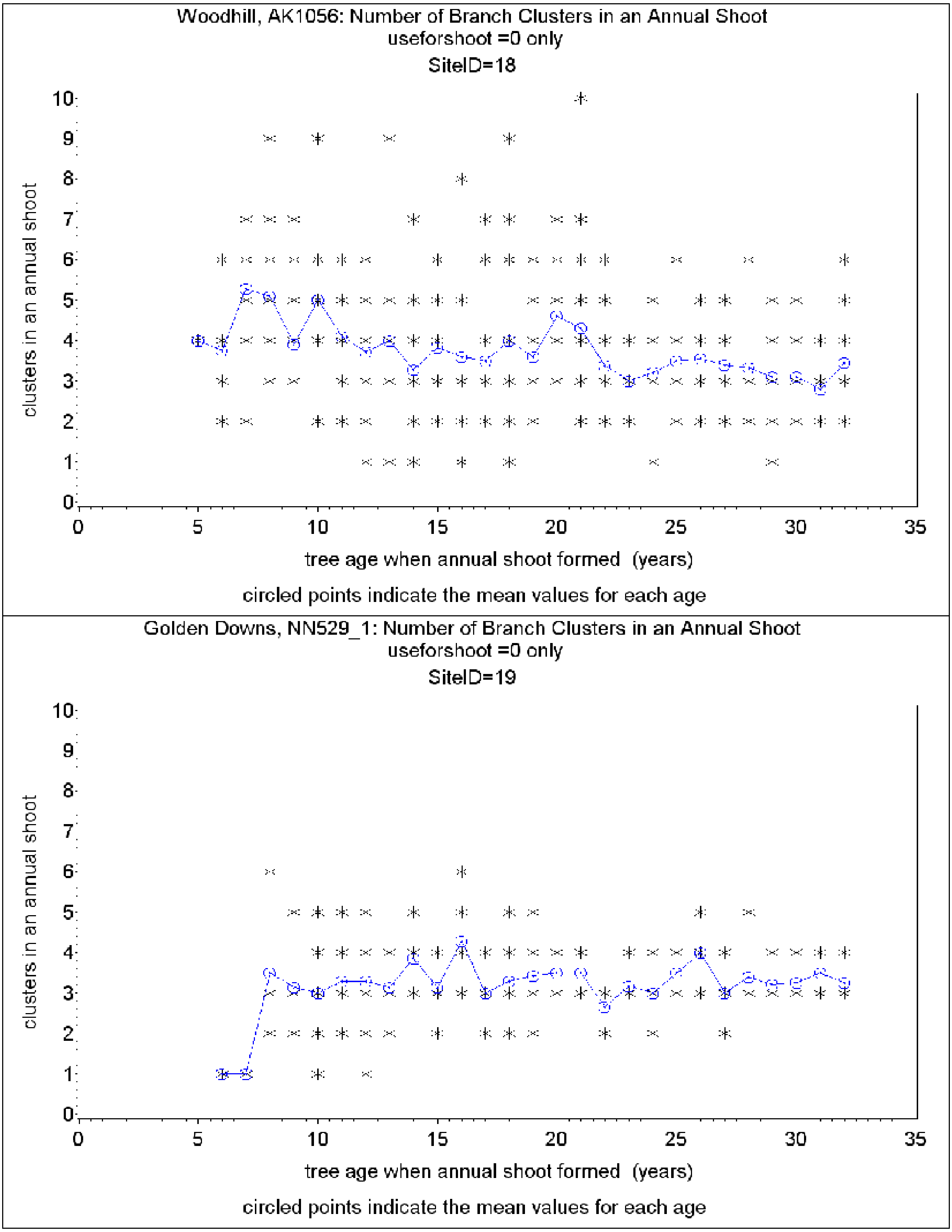


Figure 24. Number of branch clusters in an annual shoot.

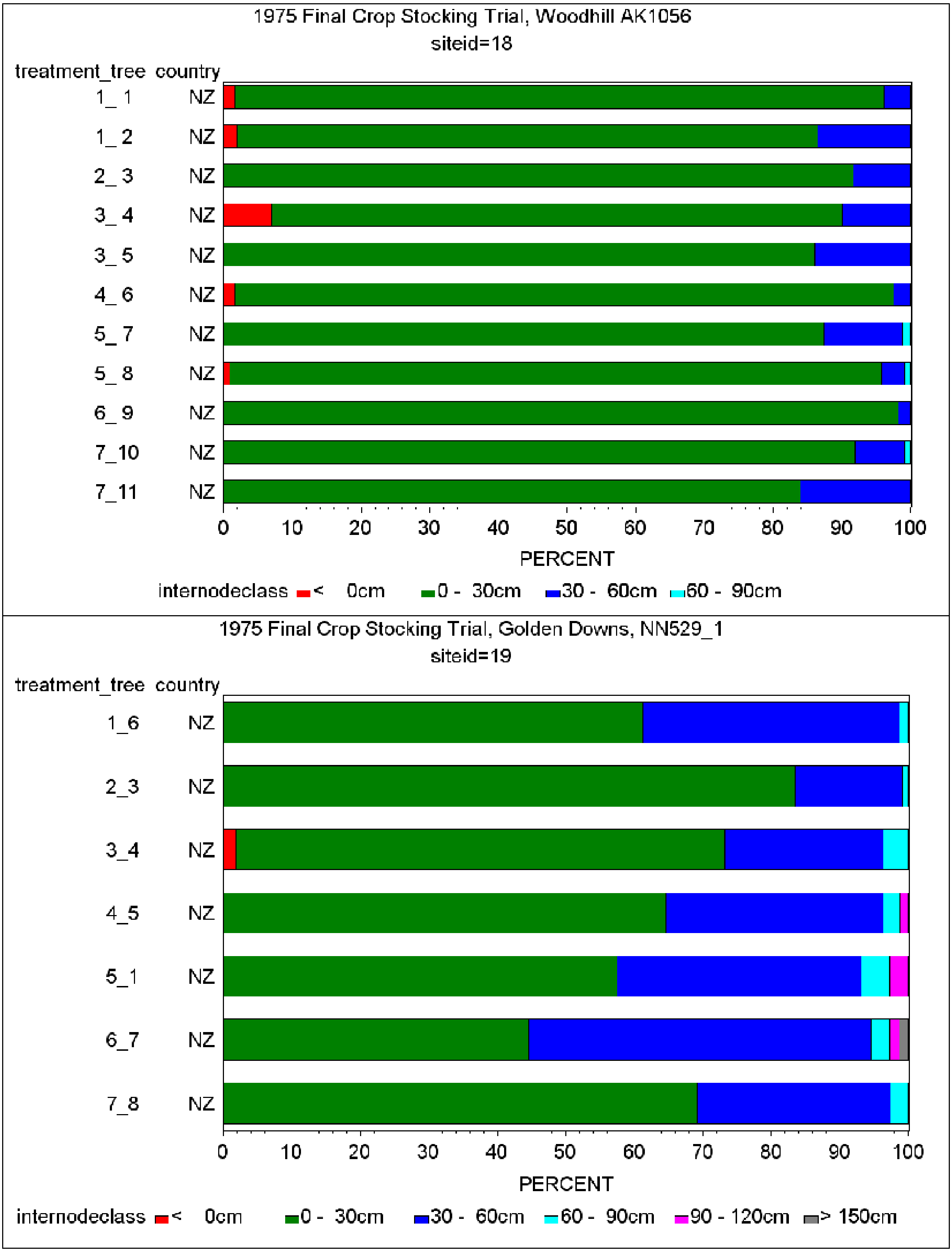
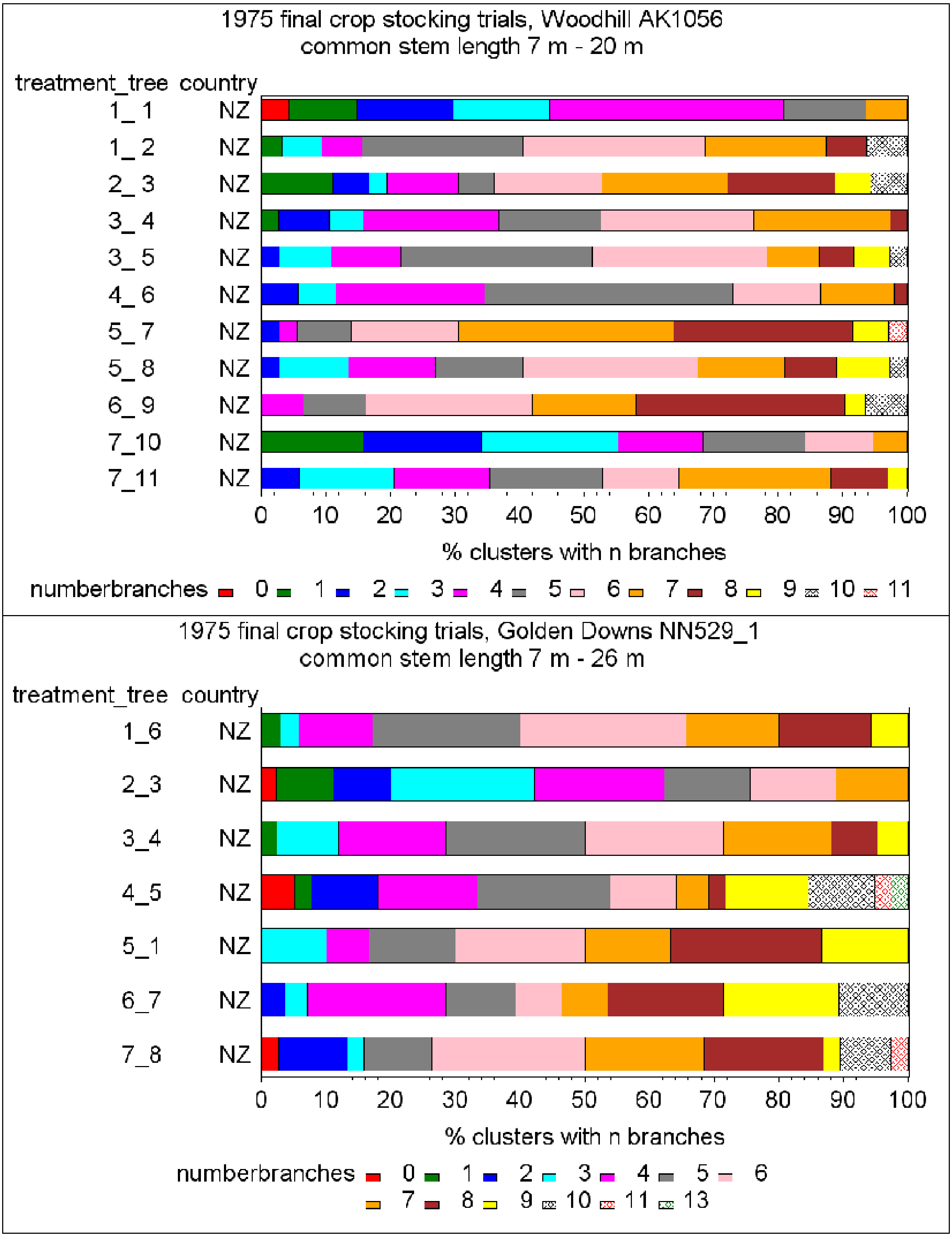
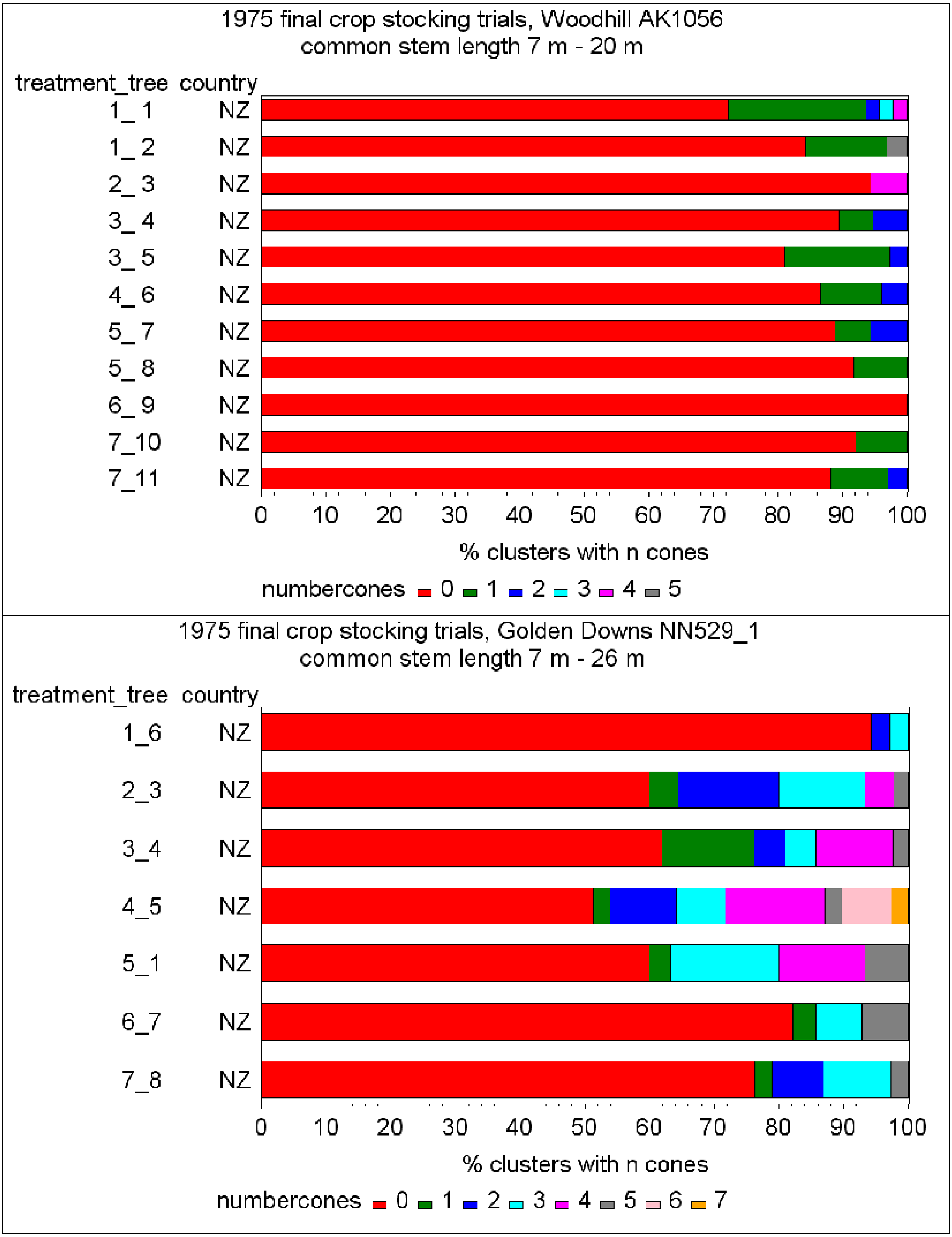


Figure 25. Internode length distribution.



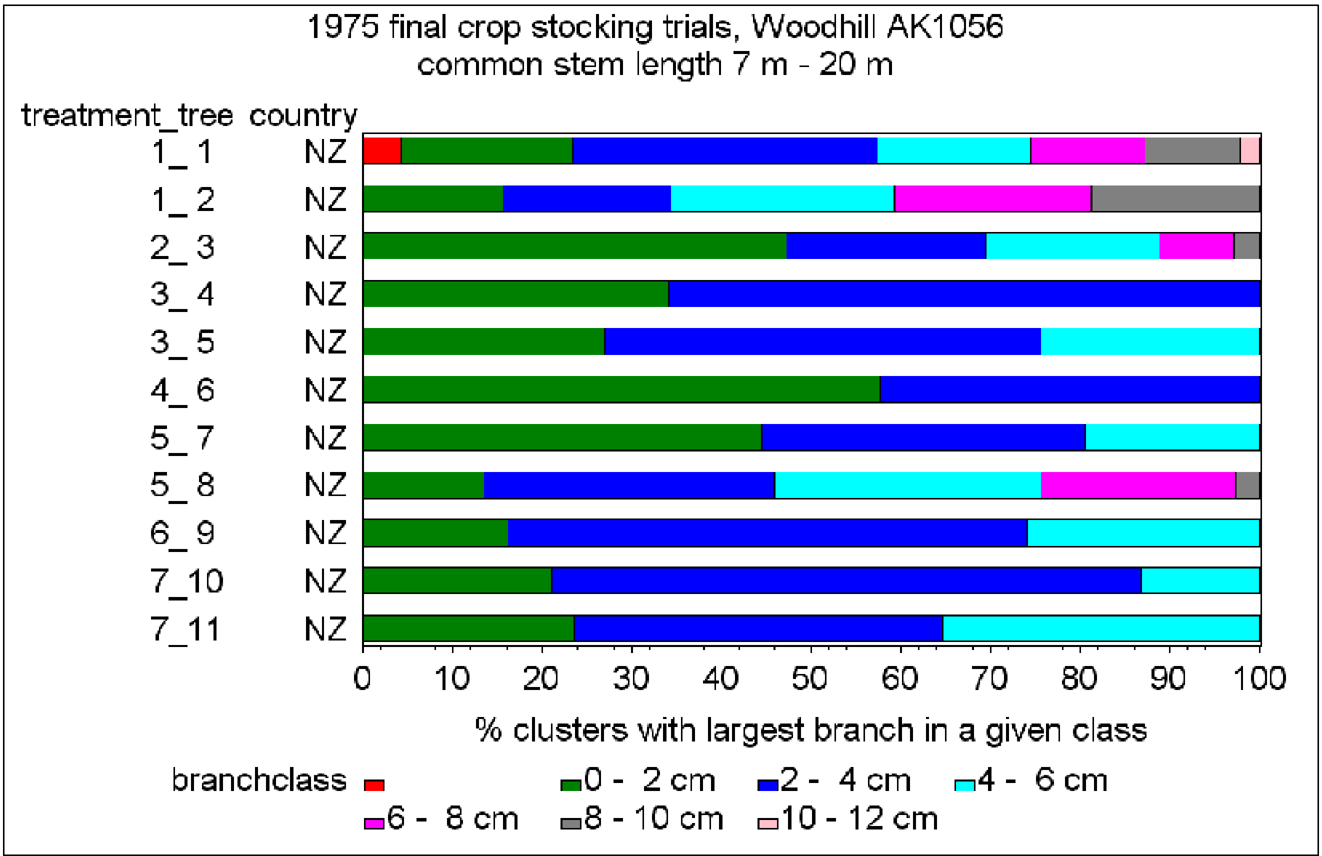
Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph.

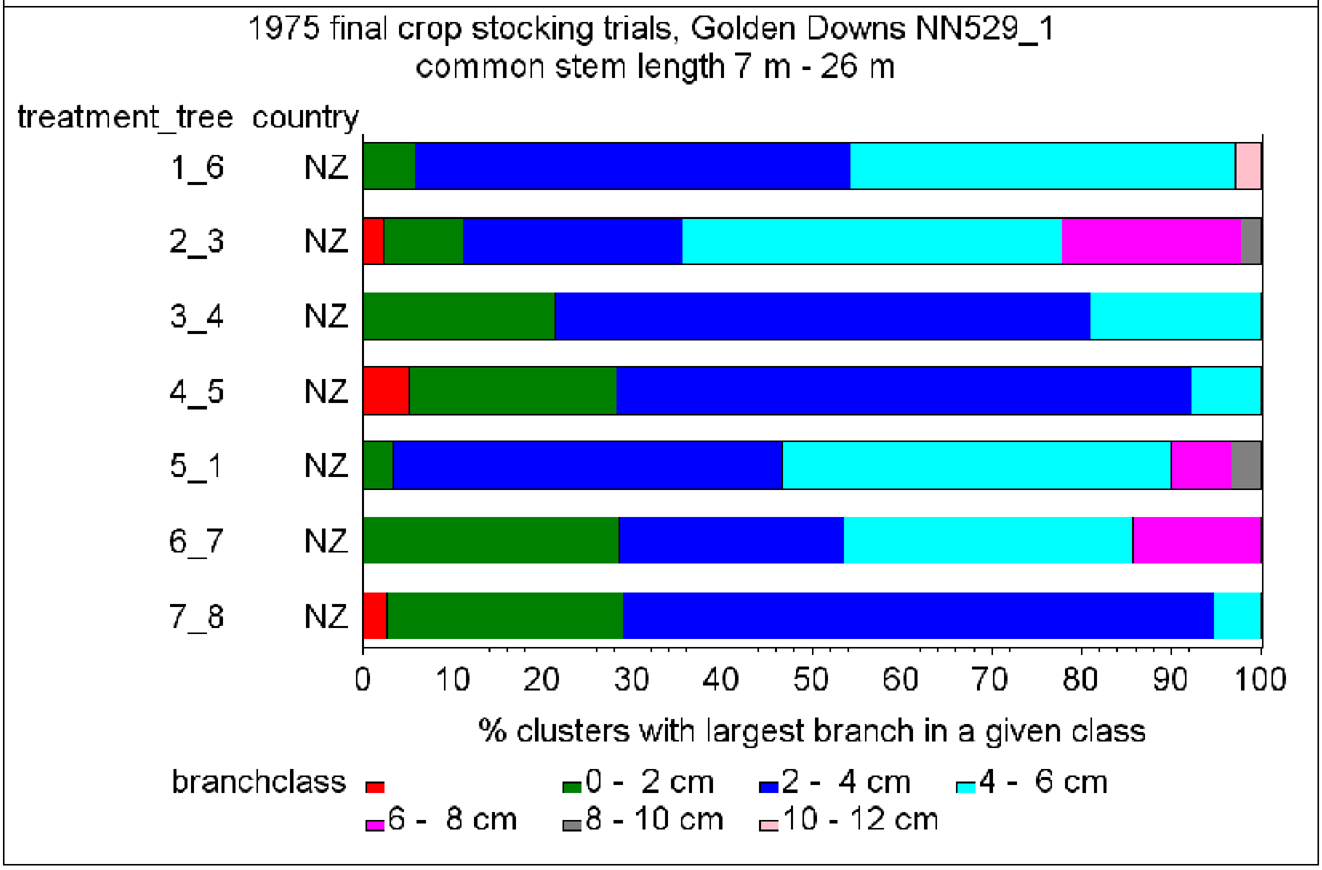
Figure 26. Number of branches in a cluster.



Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph.

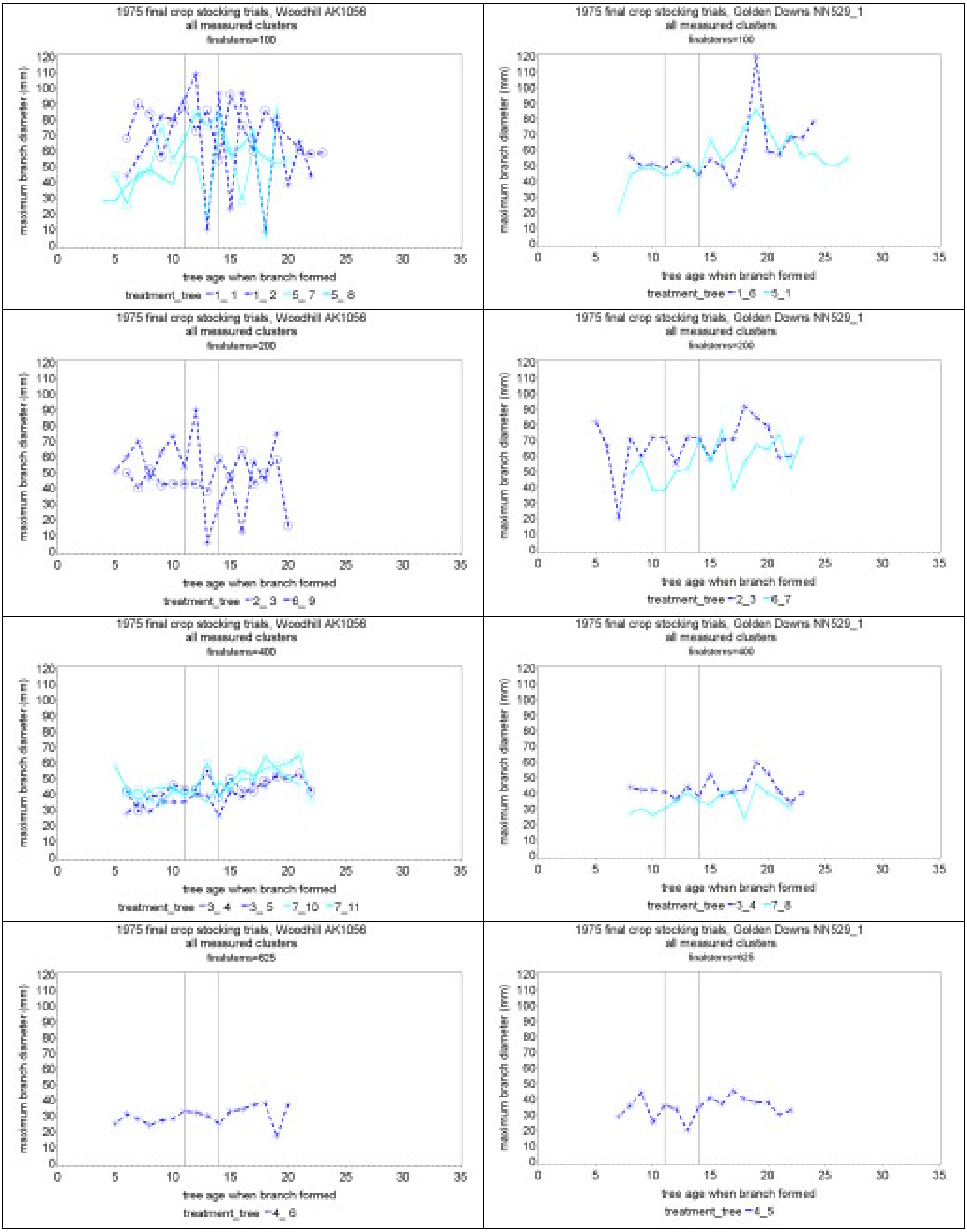
Figure 27. Number of cones in a cluster.





Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph.

Figure 28. Diameter of the largest branch in a cluster.



Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 29. Distribution of maximum branch diameter with respect to tree age and silvicultural treatment.

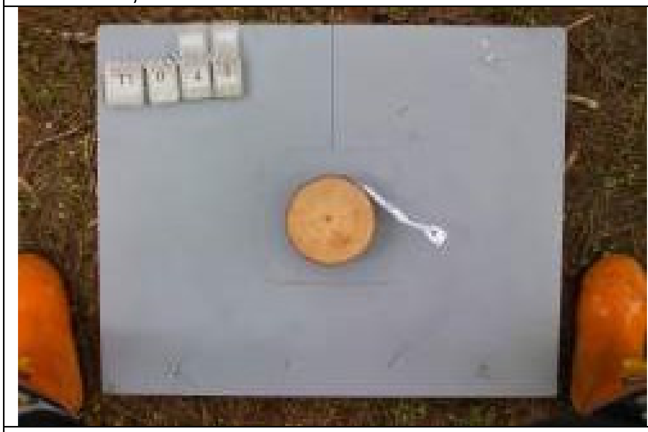
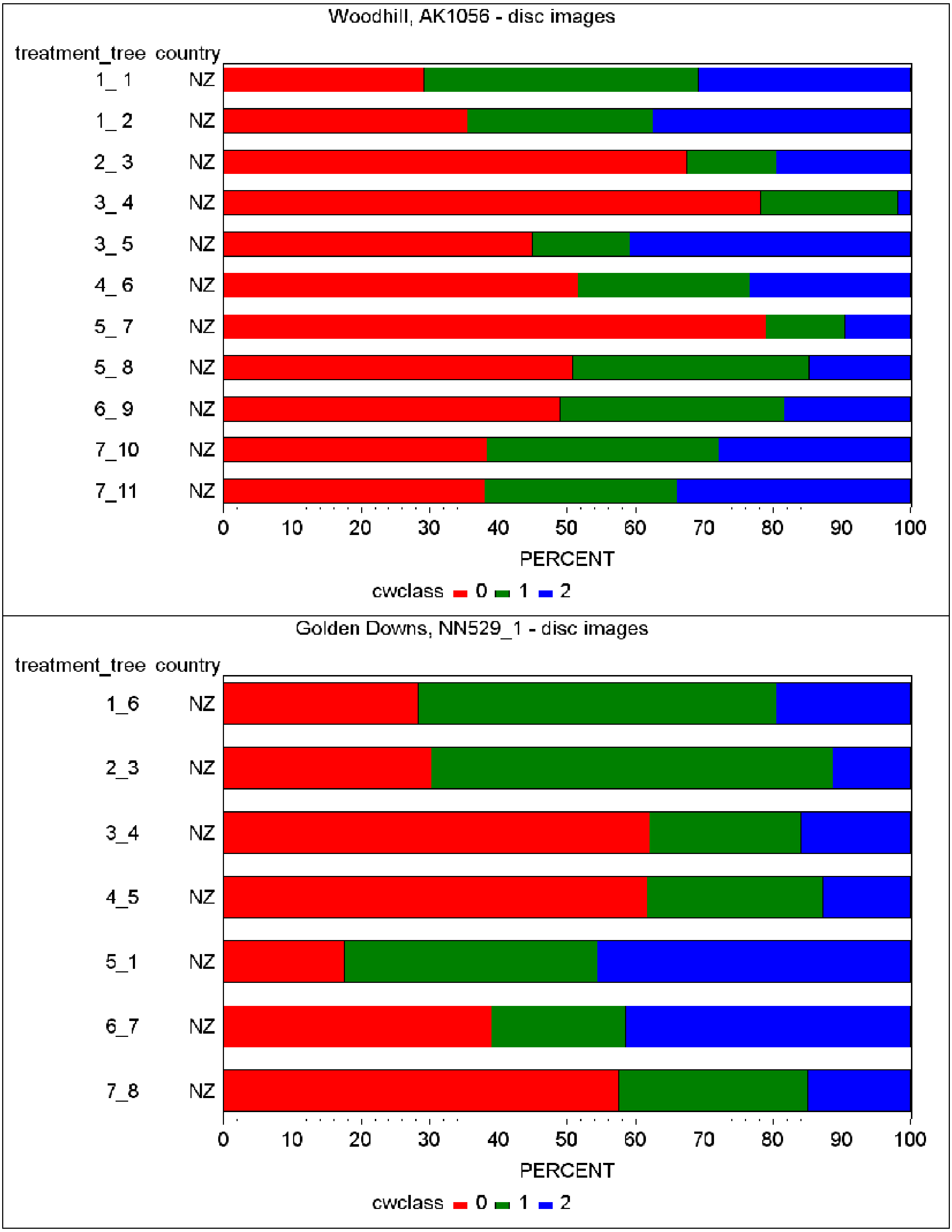
Woodhill, cwclass=2	Golden Downs, cwclass=2
	
Woodhill, cwclass=1	Golden Downs, cwclass=1
	
Woodhill, cwclass=0	Golden Downs, cwclass=0
	

Figure 30. Images showing the distribution of visible compression wood in selected discs.



Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 31. Distribution of compression wood classes with respect to silvicultural treatment.

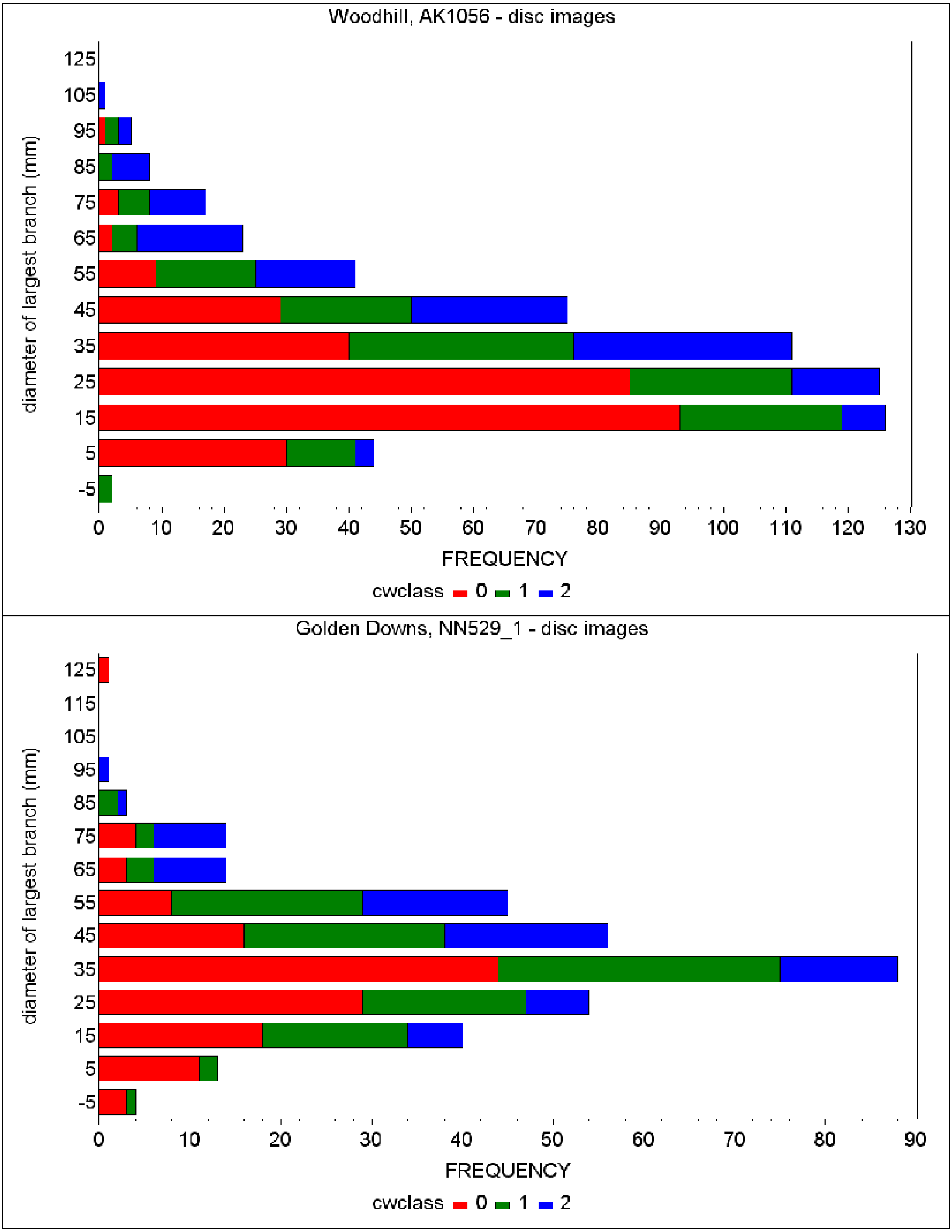
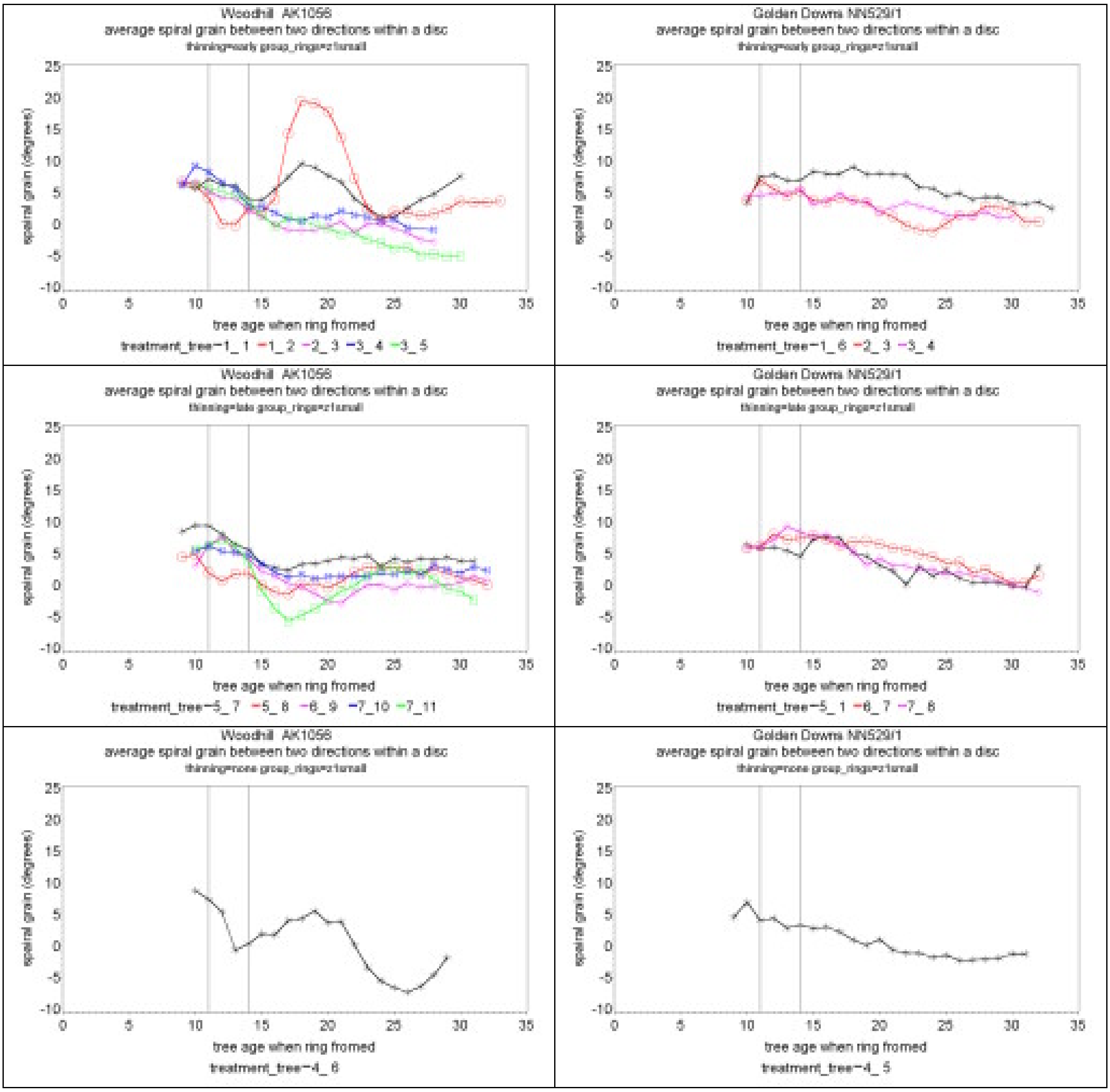
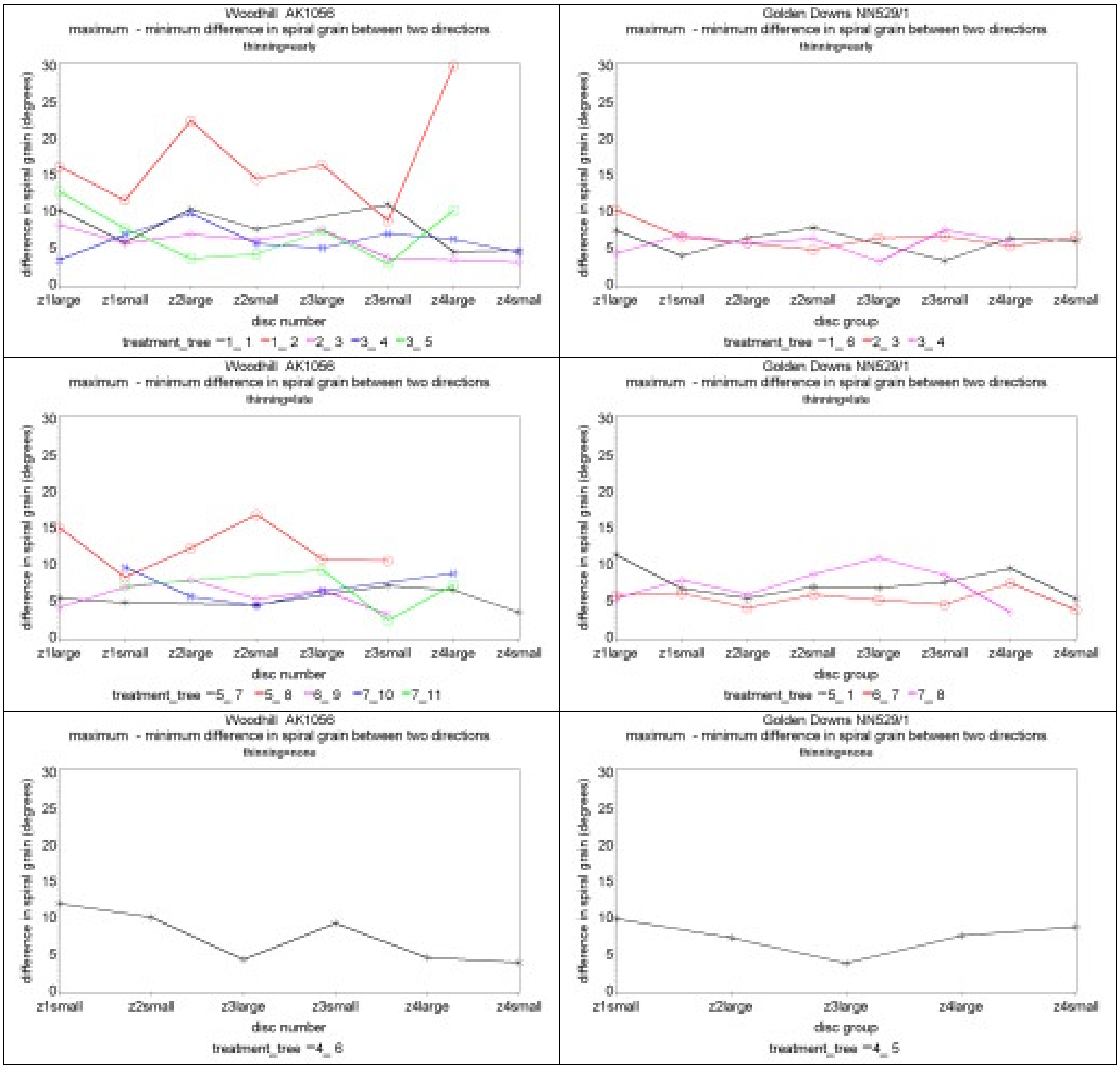


Figure 32. Distribution of compression wood classes with respect to the diameter of the largest branch in a cluster.



Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 33. Average spiral grain values for growth rings versus tree age when the ring was formed. Each individual graph represents is a site/time of thinning combination. Graphs in the left hand column are from Woodhill, and graphs in the right hand column are from Golden Downs.

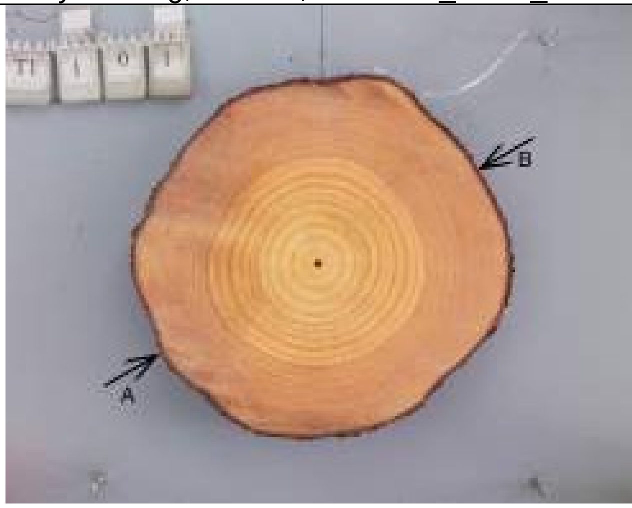
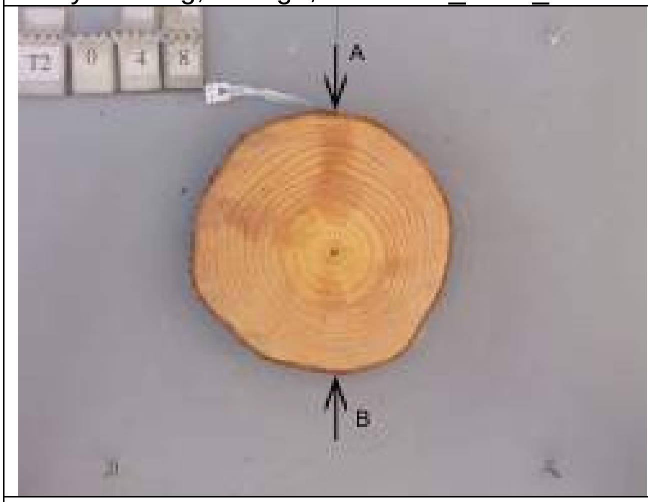
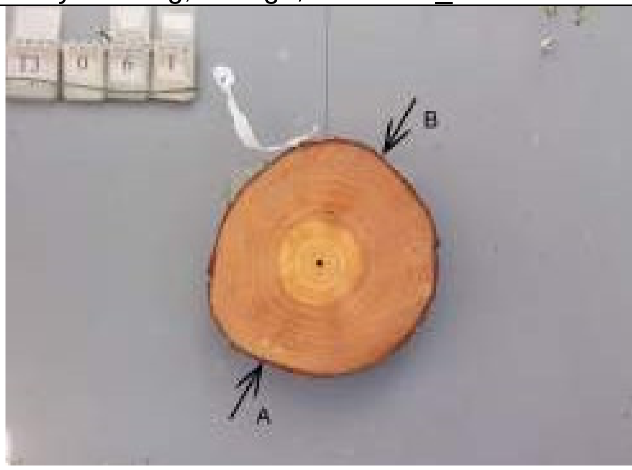


Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Note: disc number codes[10]:

- z1: from clusters with 24 or 25 growth rings (excluding current year)
- z2: from clusters with 21 or 22 growth rings (excluding current year)
- z3: from clusters with 18 or 19 growth rings (excluding current year)
- z4: from clusters with 15 or 16 growth rings (excluding current year).
- small - cluster where the largest diameter was small relative to other clusters in that zone
- large - cluster where the largest branch diameter was large relative to other clusters in that zone.

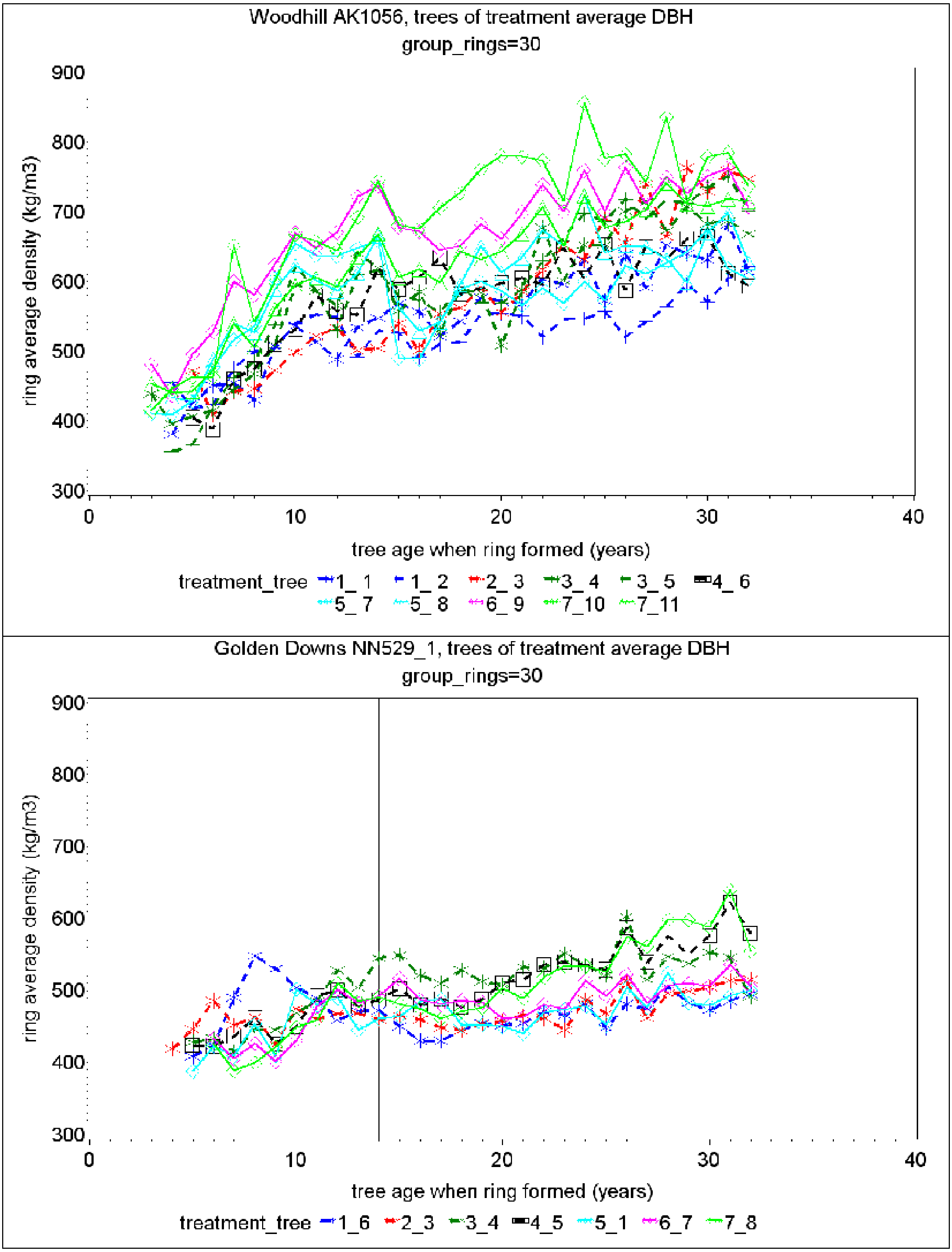
Figure 34. Differences in spiral grain within a disc at selected positions within each tree. Each individual graph represents is a site/time of thinning combination. Graphs in the left hand column are from Woodhill, and graphs in the right hand column are from Golden Downs.

Early thinning, z1small, treatment-tree 1_2	Early thinning, z1small, treatment_tree 1_1
	
Early thinning, z4large, treatment_tree1_2	Early thinning, z4large, treatment_tree
	
Late thinning, z2small, treatment_tree 5_8	Late thinning, z2small, treatment_tree 5_7
	

Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph
Note: disc codes[10]:

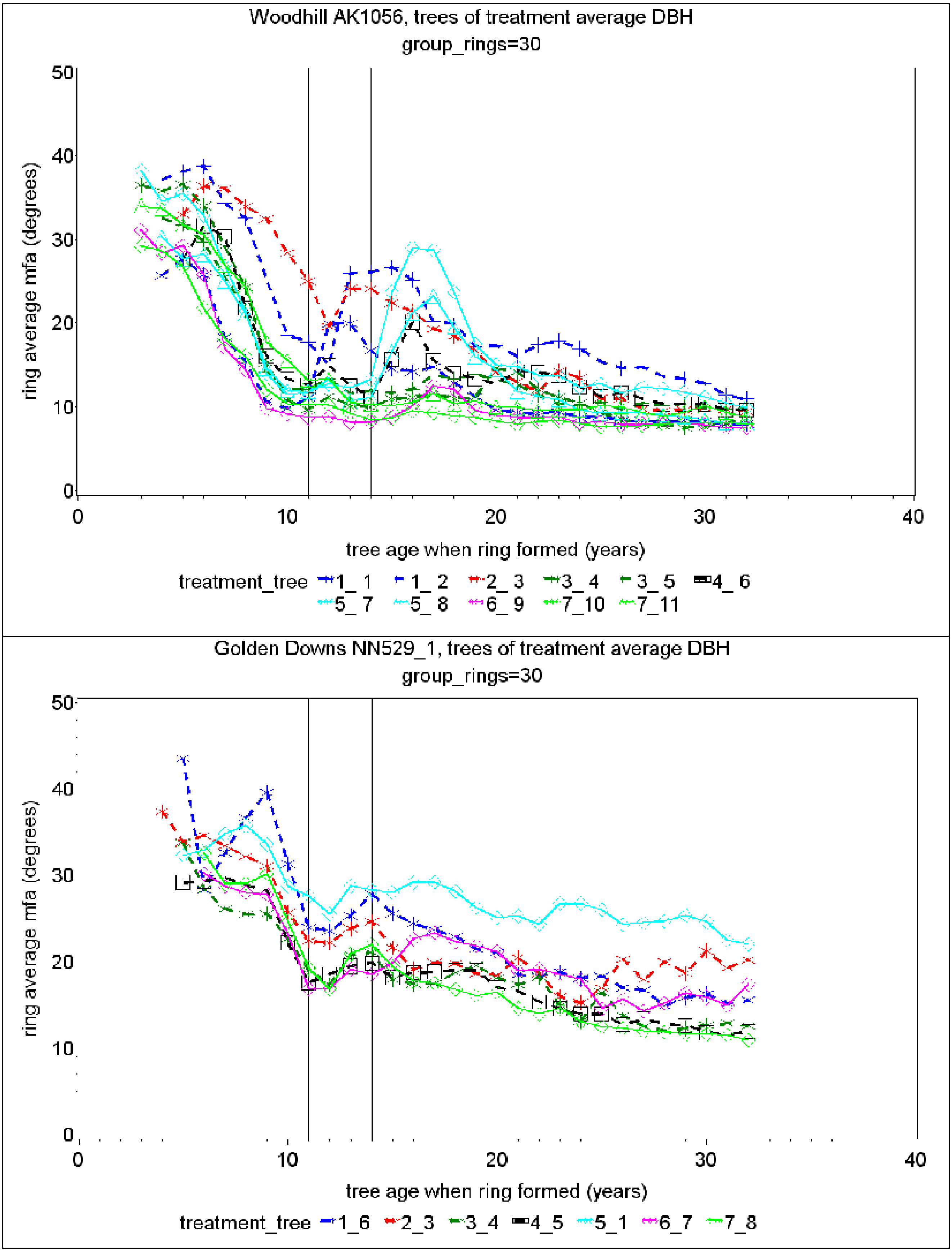
- z1: from clusters with 24 or 25 growth rings (excluding current year)
- z2: from clusters with 21 or 22 growth rings (excluding current year)
- z3: from clusters with 18 or 19 growth rings (excluding current year)
- z4: from clusters with 15 or 16 growth rings (excluding current year).
- small - cluster where the largest diameter was small relative to other clusters in that zone
- large - cluster where the largest branch diameter was large relative to other clusters in that zone.

Figure 35. Selected spiral grain disc images from Woodhill



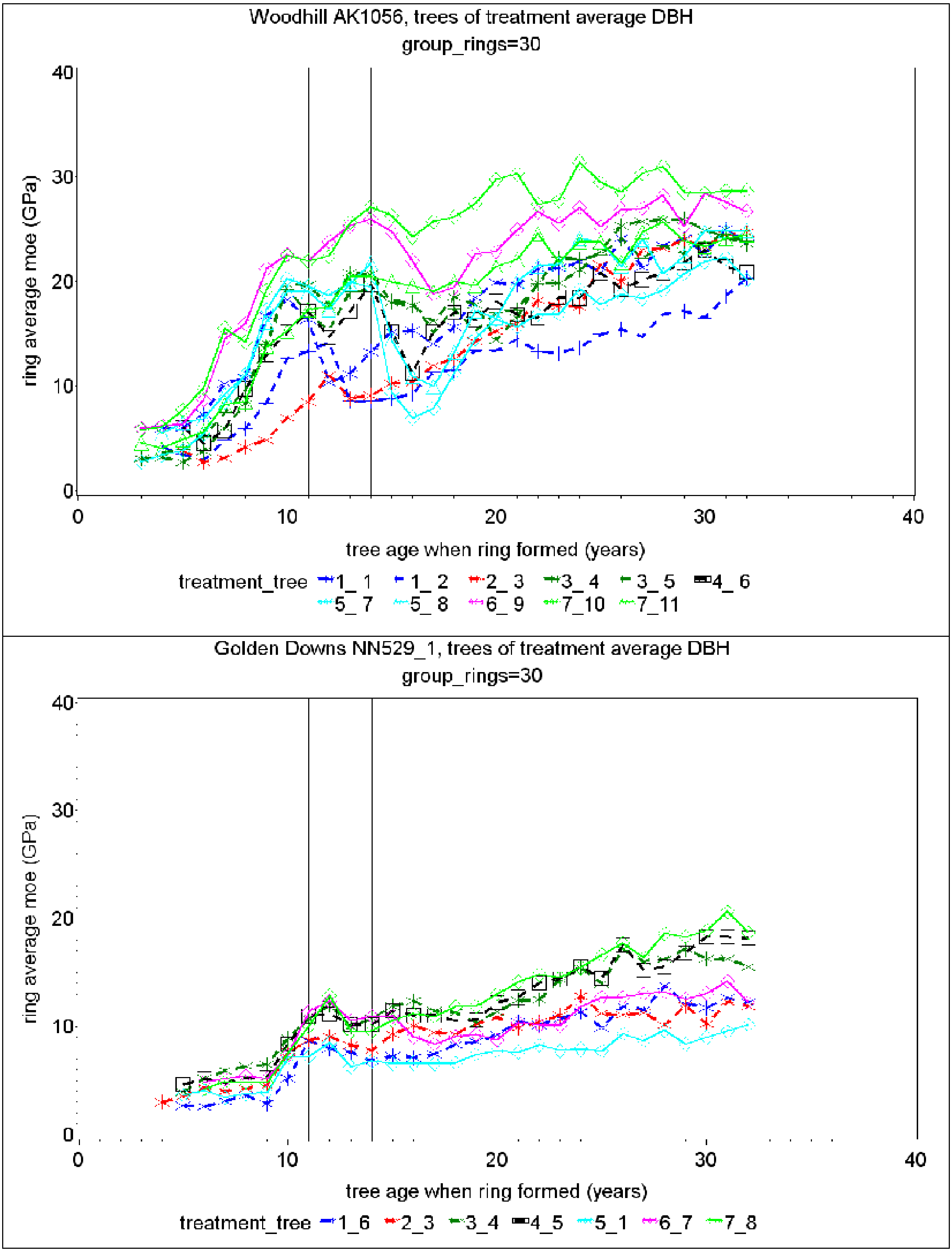
Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 36. Ring average SilviScan density with respect to tree age when the ring was formed.



Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 37. Ring average SilviScan microfibril angle (MFA) with respect to tree age when the ring was formed.



Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 38. Ring average SilviScan modulus of elasticity (MOE) with respect to tree age when the ring was formed.

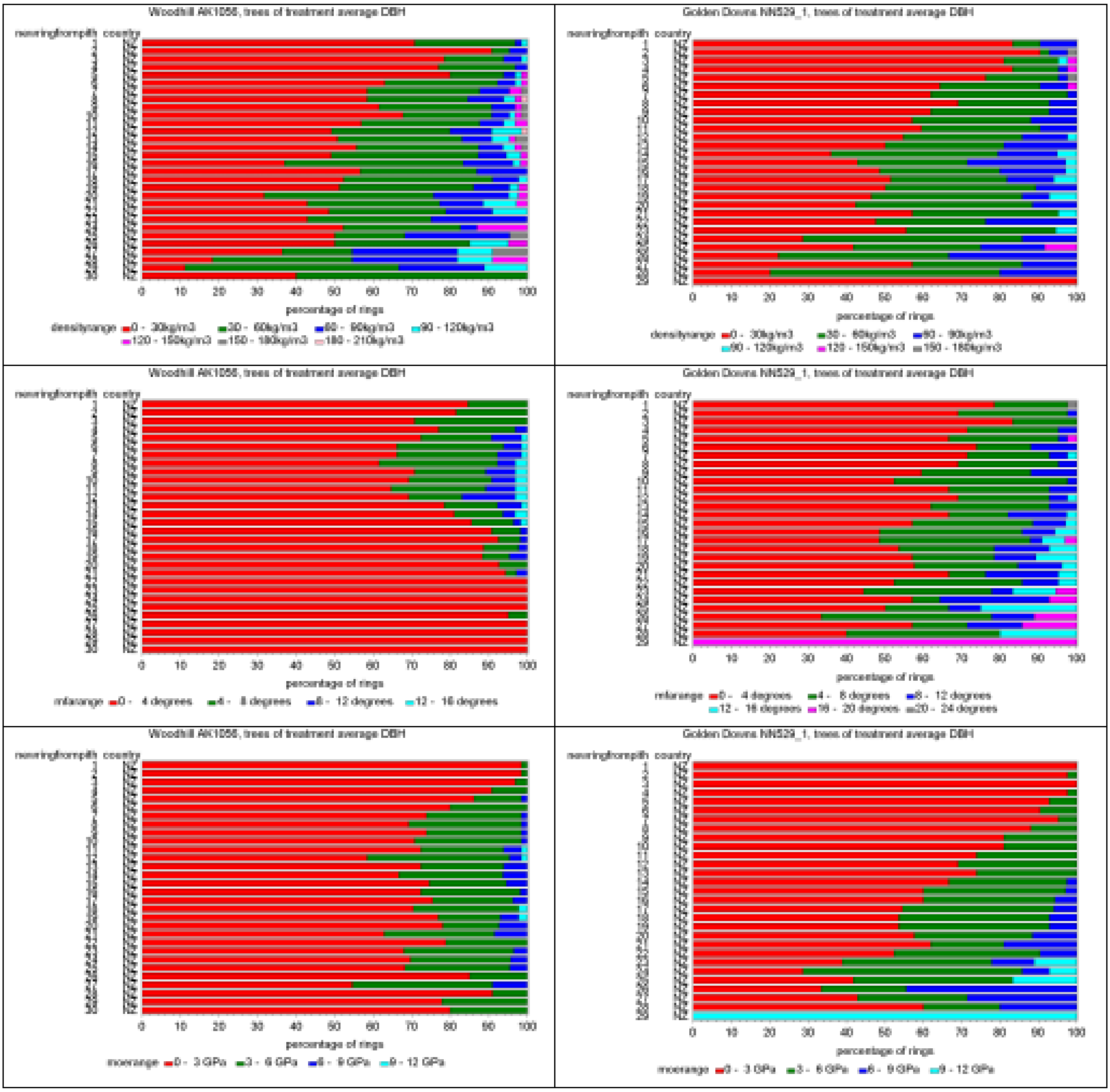
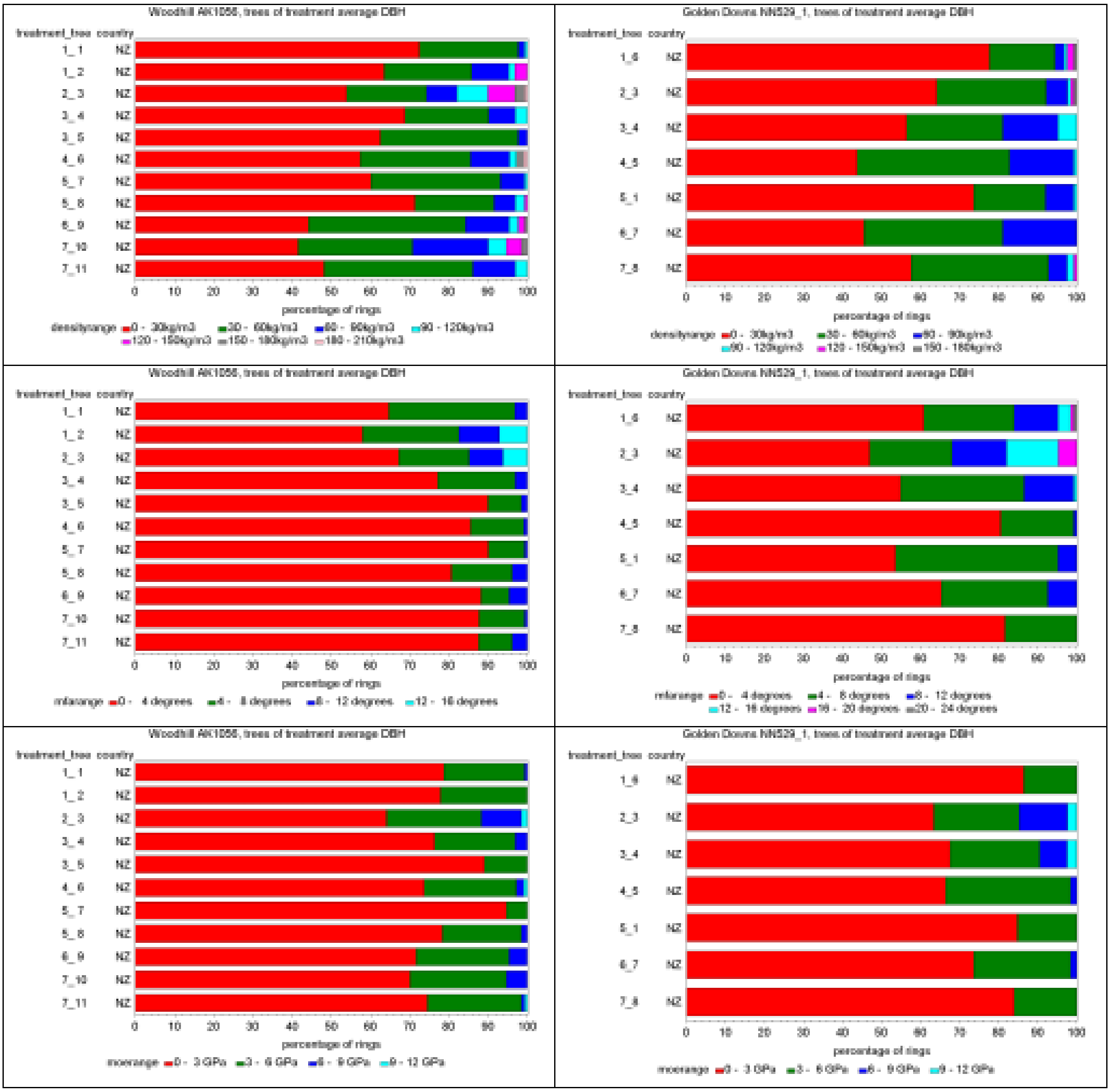
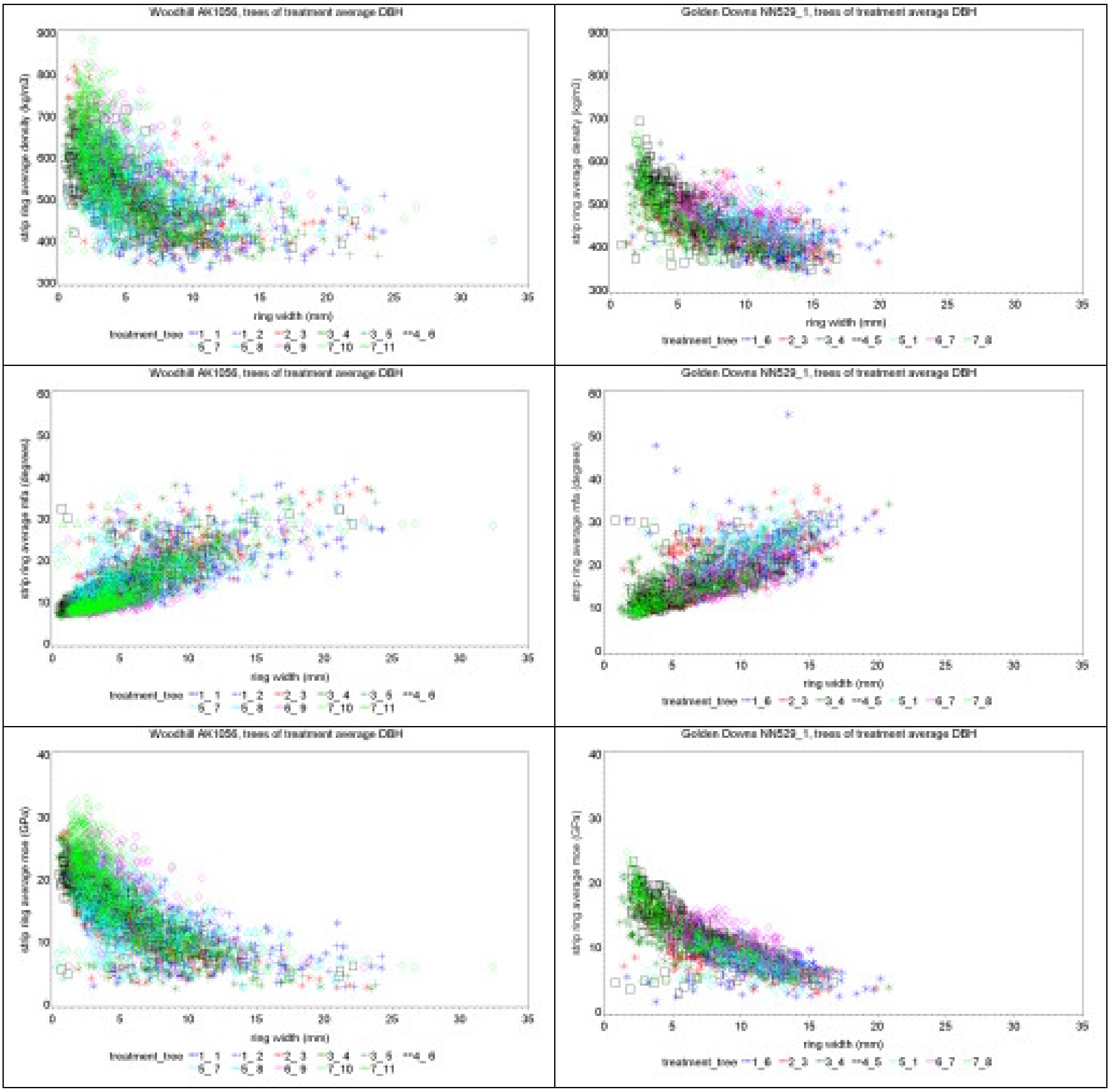


Figure 39. Variation (difference) in SilviScan properties for different samples from the sample growth ring with respect to ring number from the pith (new ring from pith).



Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 40. Variation (difference) in SilviScan properties for different samples from the sample growth ring with respect to treatment and sample tree (treatment_tree).



Note: Treatment to silviculture conversion: 1: Thin early to 100 sph; 2: Thin early to 200 sph; 3: Thin early to 400 sph; 4:Control; 5: Thin late to 100 sph; 6: Thin late to 200 sph; 7 Thin late to 400 sph

Figure 41. Relationship between SilviScan properties from individual sample strips and ring width.

Appendix 6: Chapter 4 - Figures 42 to 47

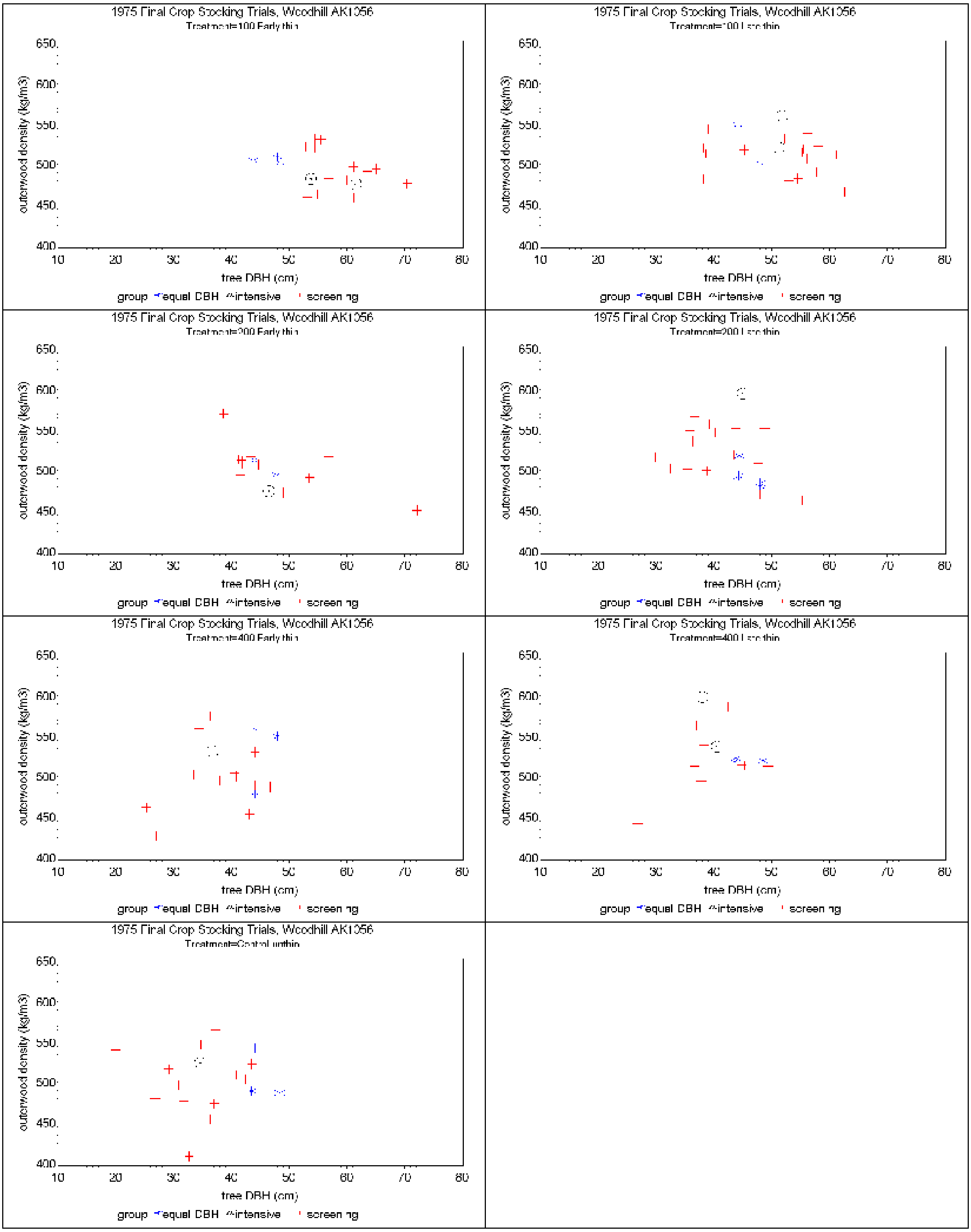


Figure 42. Relationship between outerwood density and tree DBH at Woodhill.

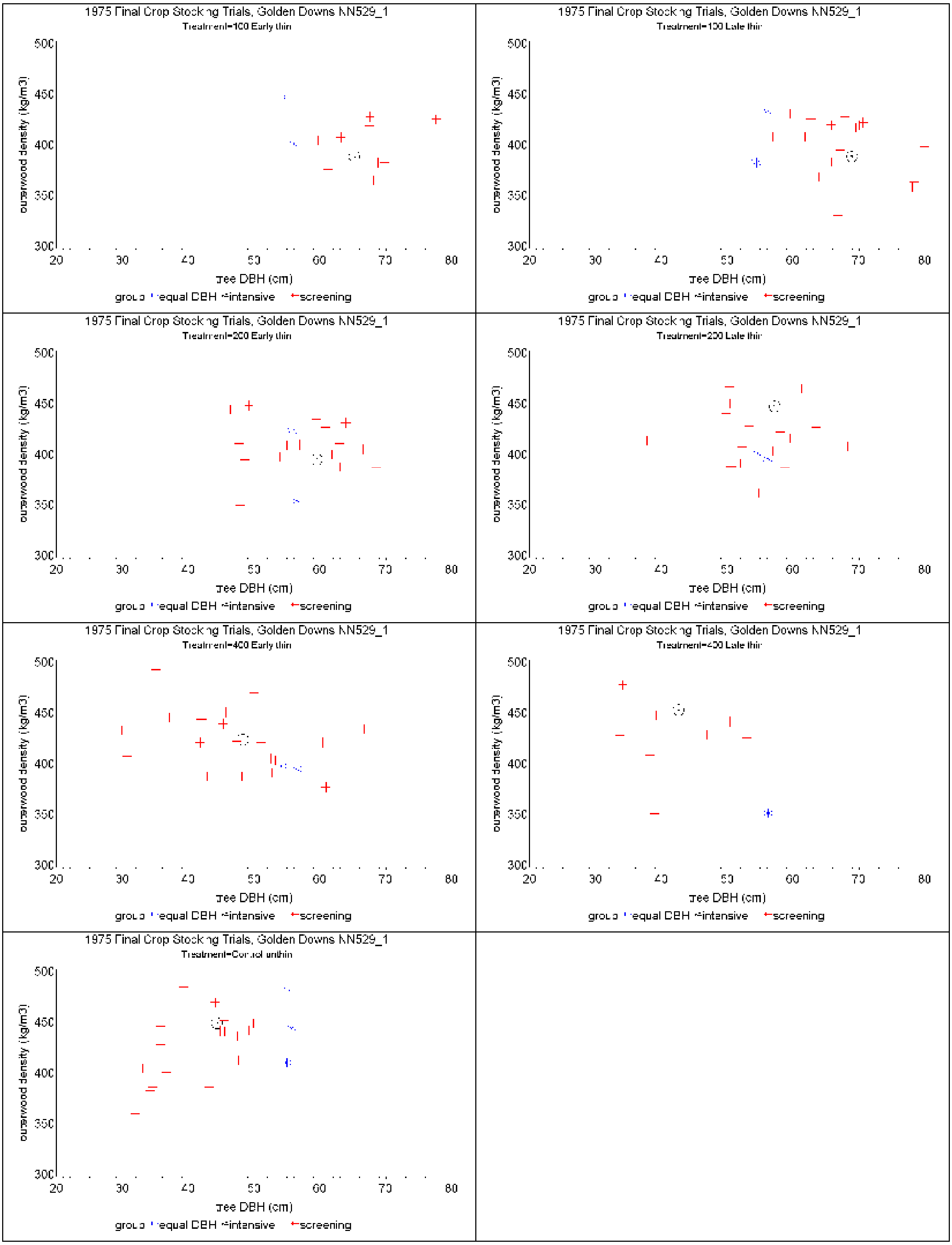


Figure 43. Relationship between outerwood density and tree DBH at Golden Downs.

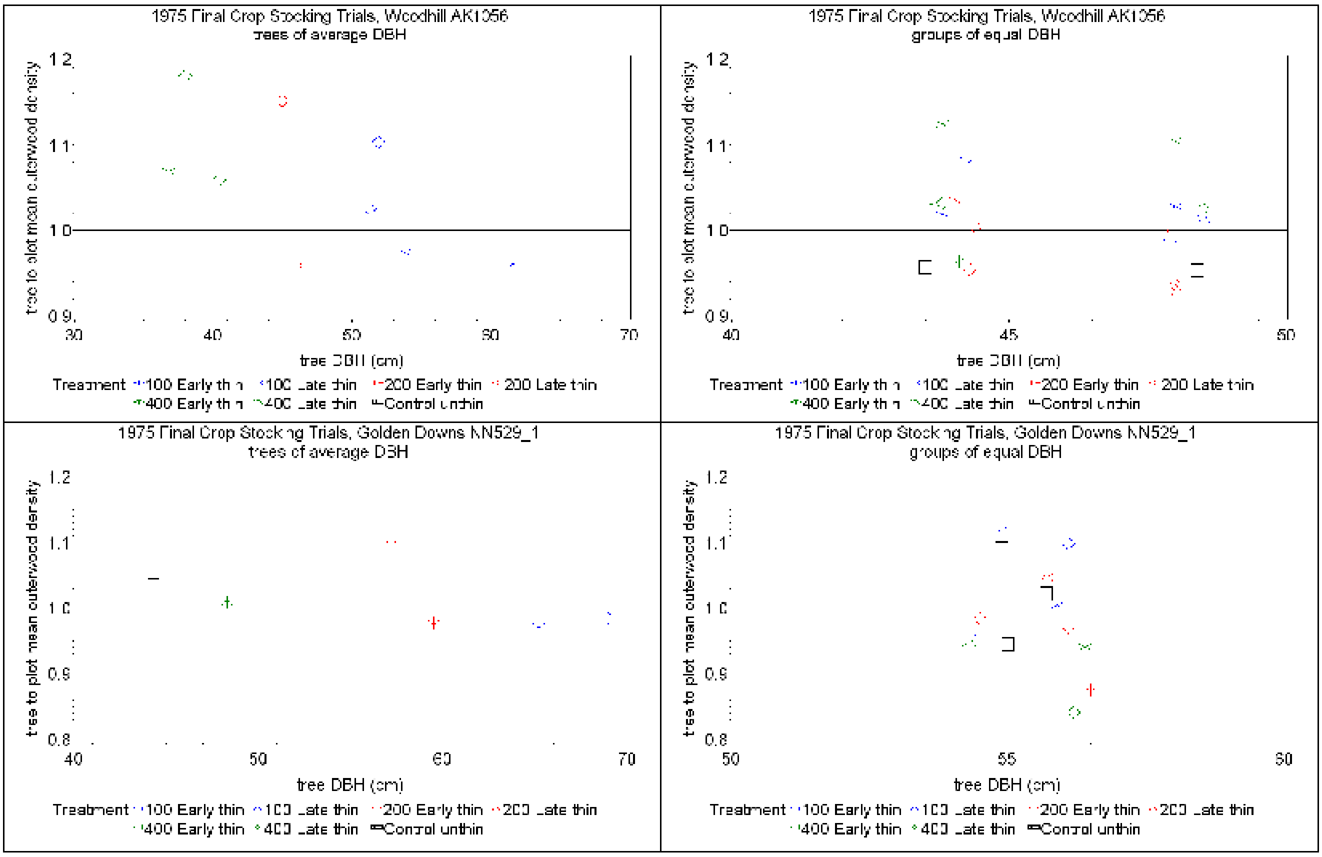


Figure 44. Ratio of tree to plot mean outerwood density for trees of "equal" DBH at Woodhill and Golden Downs.

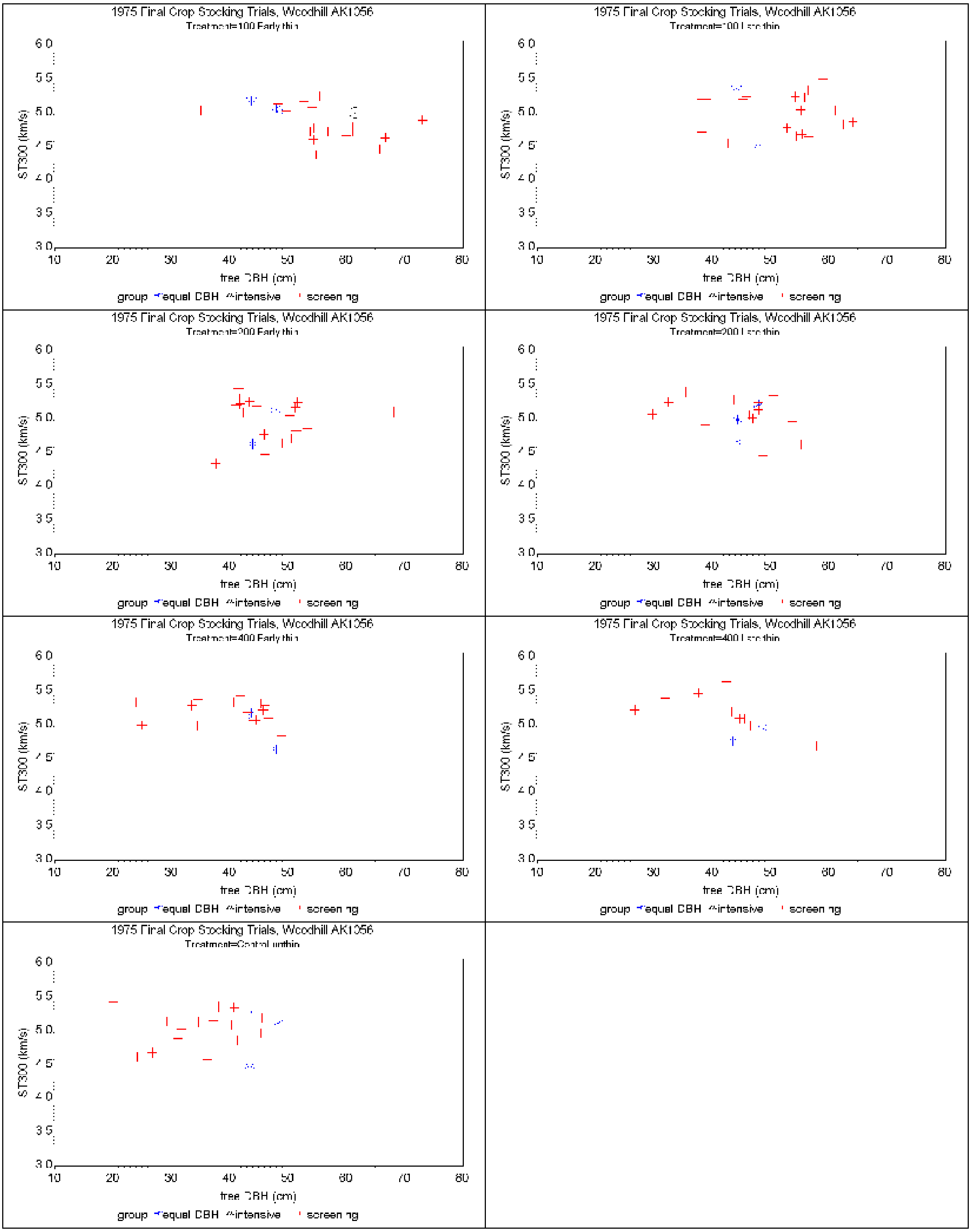


Figure 45. Relationship between standing tree sonics and tree DBH at Woodhill.

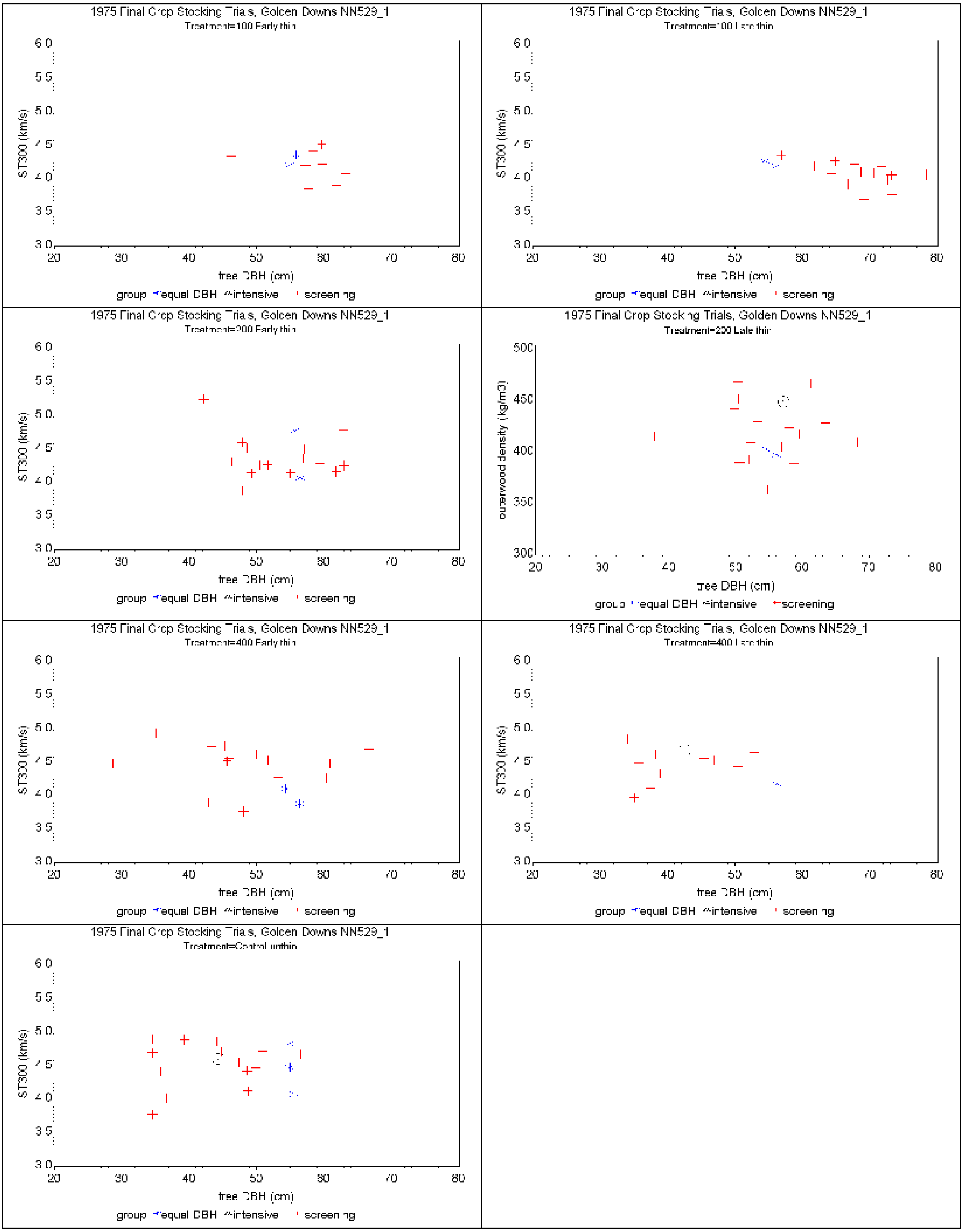


Figure 46. Relationship between standing tree sonics and tree DBH at Golden Downs.

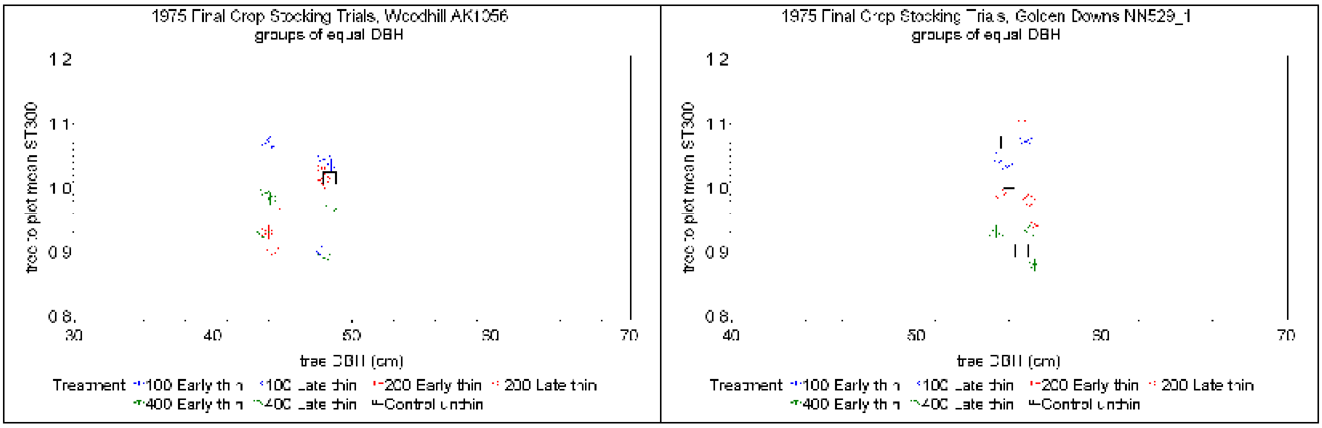


Figure 47. Ratio of tree to plot mean ST300 for trees of "equal" DBH at Woodhill and Golden Downs.