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Western Australian Softwood Resource Evaluation: a survey of key characteristics of the *Pinus radiata* and *Pinus pinaster* resources in Western Australia with links to product performance of trees sampled from each resource, as determined by a processing study.

This report can also be viewed on the FWPA website
www.fwpa.com.au
FWPA Level 4, 10-16 Queen Street,
Melbourne VIC 3000, Australia
T +61 (0)3 9927 3200 F +61 (0)3 9927 3288
E info@fwpa.com.au W www.fwpa.com.au

Western Australian Softwood Resource Evaluation: a survey of key characteristics of the *Pinus radiata* and *Pinus pinaster* resources in Western Australia with links to product performance of trees sampled from each resource, as determined by a processing study.

Prepared for

Forest & Wood Products Australia

by

P. Blakemore, D. Cown, I. Dumbrell, R. McKinley, A. Lyon, B. Barr and R. Northway

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Principal Researcher:

P. Blakemore, Richard Northway
CSIRO material Science and Engineering
philip.blakemore@csiro.au

Dave Cown, Russell McKinley
SCION (Trading name of Forest Research Institute ltd)
Dave.Cown@scionresearch.com

Ian Dumbrell, Andrew Lyon
Forest Products Commission WA
ian.dumbrell@fpc.wa.gov.au

Brad Barr
WESPINE Industries Pty ltd
brad.barr@wespine.co

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Forest & Wood Products Australia Limited
Level 4, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@fwpa.com.au
W www.fwpa.com.au

Executive summary

<u>*Major objectives:*</u>

- Assess the Western Australian softwood plantation resource (radiata pine –*P. radiata* and maritime pine – *P. pinaster*); determine the extent of variation in wood quality characteristics and link such variations to site or silvicultural practices.
- Apply standing tree tools (increment cores for wood density, ST300 for acoustic velocity, visual branch and resin assessment) to document within-stand and between-stand variation and provide data to assist prediction of timber quality in a processing study.
- Relate stem and log features to grade recovery and value.
- Compare resource data with other regional studies.

Key results

- Forest variation in wood properties was not significant within the study region; hence forest maps of wood quality would be of little benefit and therefore were not produced.
- Outer wood density was generally the best predictor of average board stiffness from a given tree.
- The HM200 provides a useful prediction of the average stiffness of boards cut from mill log. However, if an explanation could be found for several possible outliers, the usefulness would be improved.
- Variation in wood properties in *P. pinaster* was generally much less than in *P. radiata*. This particularly relates to density variation. The relationship of density with age was generally confirmed to be consistent with patterns observed in Eastern Australia and New Zealand. *P. pinaster* tends to be planted on poorer quality sites and is generally slower grown. Hence the age of the trees included in this study tended to be older, and this age effect is most likely responsible for the uniformity of density.
- Within stand variation in the relationships means that the ability to rank standing trees for stiffness prior to harvesting may be marginal. However, the ability to use acoustic tools and density to rank site averages appears to be excellent, particularly for *P. radiata*. Unfortunately, having only evaluated four stands per species means that further work at the stand level is required to confirm the robustness of this conclusion.
- The MSG recoveries for the different site and branching characteristics generally reflected the pattern of density variation within these groupings.
- There is an indication that silvicultural practices and targeted genetic improvement to minimise the size of branching and increase internodal distances, would be of benefit for improving recovery of full length structural graded (MGP) material

- In-grade testing showed a problem with the MoR characteristics of the MGP12 boards for *P. pinaster*. Combining the two species resulted in an overall acceptable test result for a single test. The implications of this test result need to be interpreted cautiously given the non-random nature of the sampling used in this study.

Application of results

The use of density cores in forest inventory should be continued. The use of outerwood density cores is reliable and verified as a measure of wood quality, and can be used for forward predictions of wood quality. The ST300 provides a useful immediate estimate of stiffness if required, but the data is a less accurate predictor of wood quality and more prone to other sources of error (e.g. tool calibration, operator error). Visual assessments of branching (e.g. BIX[1], number of nodes per log) are also useful for predicting board stiffness, particularly with regard to *P. radiata*.

[1] For ease or reading, BIX (Branch Index) is a term used to describe the branch size categories used throughout this report.

Contents

Introduction

The Australian pine resource is predominantly used for products that require good strength and stiffness properties. Research to date in Eastern Australia and New Zealand has demonstrated that the plantations exhibit a high degree of within-stand variation in the major wood properties contributing to these characteristics. This has been found in previous benchmarking studies in New Zealand and Australia (Cown *et al.* 1991; Roper *et al.* 2004) and is likely to become more apparent in the short term as the current resource is harvested at progressively younger rotation ages. The high level objective of Forest and Wood Products Australia (FWPA) benchmarking studies is to benchmark the wood quality of the pine resource across Australia with regard to structural grade outturn and better understand how wood quality characteristics are influenced by site, silviculture, crop age and genotype and the implications for structural grade recoveries. The current study of the West Australian resource was intended to provide a much greater degree of confidence for wood processors in the purchase of raw material and give forest owners more flexibility to monitor and control the quality of their stands.

Overview – Western Australia

The WA softwood plantation estate comprises some 50,000ha of radiata pine in the South West and about 50,000 ha of Maritime pine, mostly on the Swan Coastal Plain. The bulk of the forest is managed by the Forest Products Commission (FPC) in a few large contiguous plantations (Appendix 1), but increasingly, expansion of the softwood supply will depend on sharefarmer or private investments further from the main population centres.

Pinus radiata (Radiata pine) is the main species as it has been proven suitable for the growing conditions of the region and achieves commercial growth rates on a range of the better soils.

Radiata pine is used to produce structural timber that is competitive in the construction industry with the residue suitable for particleboard and MDF production. It can also be peeled to produce LVL (laminated veneer lumber) and plywood.

It is estimated that planting 2000 additional hectares of radiata pine per year over 20 years will supply sufficient resource to expand the existing sawlog mill at Dardanup and maintain its competitiveness. The additional structural timber produced can be sold to meet the expanding demand in WA.

Maritime pine (*Pinus pinaster*) has been planted on infertile sands and drier sites not suited to radiata pine and will continue to be planted where it can be grown within an economic haul distance of customers at Neerabup and Dardanup. Since 1974, all material has come from genetically-improved seed of the Leirian provenance (Siemon, 1983; Butcher, 2007). Increasing the area of maritime pine to 70,000 ha has been identified as a goal over the next 20 years (FPC, 2007).

There are a few very significant wood processing industries dependant on material from the plantations:

Wespine:	Structural timber
Wesbeam:	Structural LVL
Laminex:	MDF and particleboard

Soil and rainfall in the south west of WA are variable, resulting in a forest resource with varying growth rates and wood quality. Silvicultural regimes and tree breeding objectives have been modified over past decades to balance commitments to industry (tree form and branching characteristics), crop health, volume production and to a lesser degree wood quality. The result is an existing wood supply of variable and largely undocumented wood quality. Increasingly, the major industries are refining their quality needs to suit specific products, and are seeking more comprehensive data from the forest grower (FPC) in order to improve operational efficiency and strategic planning.

Modern tools are now available for non-destructive resource assessment, which allow the capture and storage of crop data during the rotation and facilitate prediction of quality. Some of these tools (e.g. the ATLAS suite, acoustic tools) are now being implemented by FPC. There is a timely opportunity to initiate the process of collection of pertinent wood quality data which will provide increasingly relevant information to forest growers and wood processors.

The wood from softwood plantations of Western Australia is highly suitable for the production of structural wood products, but is also variable due to the influence of site, silviculture and genetics. The site effects are greatest between ex-bush and ex-farmland plantings. The silvicultural effects are likely to include the differences between initial stocking, pruning, thinning and fertiliser regimes. The heavy early thinning of one of these regimes (Silvics 70) has been producing wood of lower density and large limbs, which has been a major concern to Wespine. This regime is no longer employed but areas so treated still remain.

Variation in wood quality creates unpredictability in the quality of the products. This study was designed to survey some of characteristics identified as important for wood processing, and therefore to:

- Initiate documentation of the variation in major wood characteristics (stiffness, wood density, branching) in relation to site and silviculture and “mapping” major quality zones within the resource (for example, ex-bush vs. ex farmland and pruned vs. unpruned).
- Document the influence of specific wood quality factors on product yield and quality.
- Develop efficient stand measures to document log and wood quality, using measures to link with the Atlas suite of forest management models.
- Relate stem and log features to grade recovery and value.

Past Research on Wood Quality

A number of wood quality studies have been carried out on the plantations of Western Australia, with a focus on wood density and structural timber recovery.

Siemon (1983) tested the mechanical properties of samples from maritime pine using "small clear" specimens and concluded that the density, stiffness and strength increased with stand age, and compared favourably to similar samples from radiata pine. A subsequent sawing trial comparing stands of maritime pine of different stand ages (13 to 28 years old) and histories (agroforestry, fuel-reduced buffer and conventional forest) indicated that despite log size distributions being similar, fast-grown material gave poorer results due to the higher proportion of juvenile wood (Siemon *et al.*, 1989).

Siemon (1995) carried out a wood density survey in maritime and radiata pine trial plots ranging from 11 to 24 years of age in the Donnybrook Sunkland area. Maritime pine showed about 10% higher density values and the anticipated trend of decreasing density with log height class was confirmed. Differences between sites were minimal, and average density values were well above those considered acceptable at the time.

A later wood density survey was carried out in 19 to 29-year-old stands by Brennan *et al.* (1997), who confirmed the considerable density variation within and between stems due partly to the impact of juvenile wood – similar to most other plantation softwoods. Siemon (2001) carried out a further density survey of improved pinaster stands planted in the 1970's and 1980's with older unimproved stock, planted 1965 to 1972. Improved stands showed slightly lower density mainly because of the effects of heartwood resin which increased with tree age. The improved stands were deemed to have acceptable density for sawlogs, MDF and LVL production.

These studies confirmed the influence of basic wood density on timber properties. Tools are now available to estimate stiffness directly from standing tree measures, using acoustic time-of flight velocity and log resonance (Carter and Lausberg, 2004). Once fully validated, these can potentially replace the more time consuming wood density assessments (Roper *et al.* 2004; Cown *et al.,* 2006).

Objectives

In 2008 a study was initiated to document variation in important stand and tree wood quality features from non-destructive tests and select stands for wood processing studies. Subsequently, it was intended to compare these data with other Australian regional studies (Green Triangle – Roper *et al,* 2004; Tasmania – Cown *et al.* 2006).

Expected Outputs

Survey of the forest estate

- Preliminary "Quality Maps" of the forest estate (radiata and maritime pines). This will include sawlog and small log characteristics (density, sonics).
- Recommendations of wood quality attributes to be included in future stand assessments (ATLAS Cruiser).
- Data and tools to assist in silvicultural evaluations – to help design "optimum" regimes – algorithms for predicting quality at prospective rotation ages.
- Mutual understanding of quality issues between growers and wood processors.

Processing study

- Quantified site and silvicultural differences for specific "representative" sites, covering some site and age variables.
- Quantified log height class effects.
- Quantified influence of specific log characteristics, density, sonics, branching on yield and full length grade recovery.

Approach

In conjunction with the major forest grower (FPC), local wood processor (Wespine), and a tool supplier (FibreGen), a forest survey was designed for collection of wood quality information related to sawmill recoveries (BH diameter; outerwood density; standing tree acoustics; branching; external resin bleeding). The survey was conducted on *P. radiata* and *P. pinaster* pines in the south-west of Western Australian, encompassing major site types, silvicultural regimes and crop ages. This approach is similar to that successfully used in the Green Triangle and Tasmanian studies (Roper *et al.* 2004; Cown *et al.* 2006). A mixture of stand types was included in the initial phase, and the intention is for FPC to continue the work by incorporating procedures into routine plantation inventory assessments. The results will also enable processing companies to evaluate the use of sonic tools at the mill for log segregation.

The processing study was planned to completely follow normal processing methods at Wespine, with full identification of logs and all boards from each log tracked through all processes.

Materials and methods

Survey

The Western Australian softwood resource was initially divided into eight distinct regions for sampling purposes (Appendix 1). During two weeks of field work, 59 stands from within these regions (from north of Perth to Pemberton — 42 *P. radiata* and 17 *P. pinaster*) were assessed. The sites sampled were selected from mid-rotation (17 – 24 years-old) and mature stands (25+ years-old) (Appendix 2), and an attempt was made to cover the major geographic distribution of both species within the major softwood estate of Western Australia. Soil types varied greatly from deep coarse sands on the Swan Coastal plain, to duplex (sand over clay) soils of the Sunklands, to gravelly loams in steep incised valleys of the Blackwood Valley, and to deep loams of the Warren region. Mean annual rainfall decreases from 1300 mm in the Warren region in the south to 750 mm at Gnangara in the north.

The field work was carried out during November 2008, with assistance from the companies concerned. At each location, 30 standing "crop" trees were selected (avoiding severely suppressed, severely swept, malformed, double leaders and dead trees) and uniquely identified with spray paint.

The following stem characteristics were assessed:

- DBHOB – Diameter at breast height over bark was measured (mm) - the average DBHOB of the sample trees from a stand was selected visually to be as close as possible to that of the whole stand.
- *Outerwood density* - Two 5mm outerwood cores, 50mm in length, were collected at breast height – the cores were selected to be free of defects and were labelled using indelible pencils with Site and Tree number. Cores were stored in field core tubes until site core sampling was finished; they were then transferred to plastic bags and refrigerated as soon as possible. In the laboratory (Scion) all cores were assessed using the Maximum Moisture Method (Smith, 1954).
- *Standing tree acoustics* - Two measurements per tree were undertaken using an ST300 (Fibregen) time-of-flight tool. Measurements were taken at approximately 90˚-180˚, depending on the location of branches and knots. Measurements were random with regard to compass and aspect orientation.
- *Branch Size* - Thirty stems per plot were visually scored for branching in the butt, second, third and fourth logs assuming 5m log lengths as per Table 1.

Figure 1: Field team measuring trees in sample plot.

Table 1: Descriptions of branch size scores[2]

Branch Size Score	Estimated Mean Branch Size (cm)	Range
0	0	No branches
1	1.5	3 cm or less
2	4.5	3 - 6 cm
3	7.5	6 - 9 cm
4	>9.0	9 cm or greater

Note: Assessment made for the 1st 4 logs (5 m each)

External resin bleeding - The 30 stems per plot were also visually assessed for external resin using the assessment method described in the New Zealand "Field Guide to Assist Recognition and Classification of Resinous Defects On The Bark Of Radiata Pine" (McConchie, 2003). See Table 2 for a summary of the scoring descriptors. Any bark damage resulting from previous commercial thinning operations, was ignored. All sample stems were numbered to allow later selection of targeted individuals for the processing studies.

[2] Traditionally in New Zealand stems and logs have been assessed either visually or with callipers and classified using a Branch Index (average of the largest branch in each log quadrant). In this case, branches were estimated for each log height class using the same system, but expressed as a diameter (cm.)

Table 2: Descriptions of resin assessment scores

Score	Resin	Description
0	0	No Signs
1	low	Low - minimal visual signs
2	medium	Some lesions, bleeding, visually noticeable
3	high	Extensive visual signs, lesions, extensive bleeding

Note: One assessment made for the tree.

Tree selection and harvesting

Twelve trees were selected from each of eight plots: four *P. radiata* and four *P. pinaster*. The four plots for each species were selected to represent two mid-rotation and two late-rotation stands with contrasting branch size classification (Table 3).

The selection of trees within plots was based on DBHOB and ST300 classifications. Table 4 presents the selection criteria for 12 sample stems within each of the eight plots.

Table 3: Age and branching selection criteria for the 8 plots selected for the processing trial.

Species	Age	Bix	Branch Diameter Category	Plot
P. radiata	Mid Rotation	0–1	Small	6
P. radiata	Mid Rotation	2–3	Large	34
P. radiata	Late Rotation	0–1	Small	10
P. radiata	Late Rotation	2–3	Large	22
P. pinaster	Mid Rotation	0–1	Small	55
P. pinaster	Mid Rotation	2–3	Large	58
P. pinaster	Late Rotation	0–1	Small	5
P. pinaster	Late Rotation	2–3	Large	57

Table 4: Diameter and ST300 selection criteria for the 12 trees within each plot.

Tree DBHOB Class	Low ST300	High ST300
Large DBHOB	2	2
Average DBHOB	2	2
Small DBHOB	2	2
Total	12 Trees	

Small Bix were trees with branch scores of predominately 0 or 1 (with the occasional 2 up the stem); large Bix were trees with branch scores of predominately 3 or 2. All 12 trees with similar branching characteristics could be sourced from within individual plots in the late rotation plots for both *P. radiata* and *P. pinaster*. Some substitutions had to be made between the mid-rotation plots in order to make up the 12 trees with similar branching, age and species characteristics.

Tree and log measurements

In each plot, the total height of the tree, height to crown base, pruned height and stump height were measured on each of the selected trees after they were felled (Appendix 5). The stems were delimbed and docked to a minimum small end diameter of 180 mm. Acoustic velocity of the whole stem was measured using the HM200 (FibreGen, Auckland, New Zealand) before logs, 4.85 m long, were prepared and discs were cut at the base and at the top of each log to allow density determinations. Knots were avoided where possible. Acoustic velocity was again measured with a HM200 tool on each log before maximum branch size and location was recorded.

Disc measurements

Disc over and under bark diameters were measured. Diametrically-opposed pith-to-bark wedges were marked on the discs, avoiding defects and compressions wood, then divided into blocks of at least 10 growth rings for green and basic density and moisture content determination using the water volume displacement/oven-drying method.

Preparation of logs for sawing

Logs were laid out by Wespine staff in the logyard in rows for preparation.

Prior to de-barking, log-end numbers were checked and the identifying numbers were transferred from the bark to the log-end when absent from log-end.

Logs were de-barked and diameters scanned. Wespine staff recorded log numbers against diameter data.

Individual log-end masks (Appendix 6) were applied using un-diluted 'Bondcrete™' to both ends of all logs. The paper masks had been printed with individual numbers in a grid and with radial and circular spaced lines. The masks were placed with the centre approximately over the pith and oriented to log sweep (zero = horns-up). This was intended to anticipate, but not necessarily match, orientation during processing. Mask number was recorded against log identity.

Figure 2: Paper masks glued on log ends

Logs were loaded into the green mill step feeder and log mask number was recorded against sawing sequence.

Species were segregated for sawing & drying; *P. radiata* logs were processed first.

Figure 3. Logs on the green mill step feeder

Logs were then scanned by 'Mill-Expert' on the sawing line before sawing, giving log information (SED, LED, 3-D profile/sweep, length) providing log orientation, cutting pattern and hypothetical board dimensions and numbers per log. 'Mill-Expert' scan numbers were matched to log identity.

Estimated board numbers for each log were entered into Wespine's 'Data recording & sample selection' spreadsheet in which an algorithm determined the number of sample boards required from each log, based on Wespine's criteria for the trial.

Sawing

Logs were sawn to produce the maximum number of nominal '90x35' structural boards from each log, following Wespine's standard practices.

Kiln drying

Boards were stacked and kiln dried using Wespine's standard high-temperature kiln drying practices for each species and for 'heart-in' and 'free-of-heart' material separately.

Preparation of boards for machining and grading

Sequential bar-coded labels were stapled to the end of all boards. Sample boards received a bar-code on each end. The sample boards were selected as board data was entered into a spreadsheet used to record board data. The selection algorithm ensured representation of major tree and log variables (diameter, branch size etc) in the sample set. The bar-codes were later used to retrieve the sample boards for subsequent testing.

Also recorded for each board were relative position (from log-end mask), an alpha (A-Z) indicating a relative radial distance from pith (from log-end mask photocopied size) and angular position of board (degrees, from log-end mask).

Machining and grading

All trial boards were machined and graded using Wespine's standard practices. Boards were handled in batches so that the barcodes could be scanned in sequence and the MSG and board scanning data recorded for each board. Data recorded for each board from the MSG included the $MoE_{(average)}$ (average of all stiffness measurements measured along the length of a given board) and $MoE_{(low)}$ (lowest stiffness measurement recorded for a given board).

Quality assurance testing

Sample boards were tested for bending strength and stiffness in accordance with AS/NZS 4063:1992. The boards were tested to destruction using a four-point bending machine at the Wespine mill. This testing simulated the quality assurance testing that is required under AS/NZS 1748:1997 and was carried out in compliance with AS/NZS 4063:1992.

An acoustic velocity test was also carried out on the sample boards by FPC using the HM200.

As it was not possible to condition the boards to 20^{o}C and 65% humidity before testing, cross-sections were subsequently cut from the sample boards as close to the break point as possible and average board moisture content was determined by oven-drying. AS/NZS 4063:1992 requires that the moisture content of test specimens be in the range of 10-15%. All static MoE and MoR values for boards with a moisture content below 10% where initially adjusted to 10% using the corrections described in ASTM 2915-03. For comparison, the MoE and MoR of all boards were also adjusted to 12% moisture content using the same corrections.

Results

Survey

The Western Australian softwood resource was initially divided into eight distinct regions for sampling purposes (Appendix 1). During two weeks of field work, 59 stands from within these regions (from north of Perth to Pemberton — 42 *P. radiata* and 17 *P. pinaster*) were assessed. Plot locations and details of planting year are shown in Appendix 2, and plot data in Appendix 3. Summaries by region and crop type are given in Table 5 and Table 6. The information is presented as site groups (mid-rotation and clearfell ages) within species within regions.

Table 5: Plot averages by region and crop type — DBHOB, Density and ST300.

Region	Age (years)	DBHOB (cm)		Density (kg/m^3)		ST300 (km/s)		No. of stands
		Mean	SD	Mean	SD	Mean	SD	
***P. radiata* – Mid rotation stands**								
2. Mundaring	20	29.9	5.5	427	33.2	4.1	0.30	3
3. Harvey Coast	19	24.8	4.9	474	36.4	4.7	0.27	2
4. Hills	20	32.6	5.5	439	31.9	4.3	0.28	4
5. Sunklands	20	29.6	5.0	463	31.5	4.6	0.30	2
6. Blackwood Valley	19	30.8	5.6	420	32.2	4.3	0.31	4
7. Grimwade	18	29.5	4.7	437	29.2	4.4	0.24	2
8. Warren	19	27.5	5.0	485	29.4	4.6	0.27	2
***P. radiata* – Clearfell stands**								
1. Gnangara	34	47.8	5.6	511	34.6	4.6	0.25	1
2. Mundaring	31	45.5	8.9	483	29.8	4.2	0.31	2
3. Harvey Coast	28	39.9	6.2	476	34.2	4.5	0.27	3
4. Hills	34	40.0	8.8	506	36.1	4.7	0.26	3
5. Sunklands	27	42.9	7.5	493	30.4	4.8	0.28	5
6. Blackwood	29	49.0	7.7	449	28.7	4.4	0.27	3
7. Grimwade	27	44.2	8.1	466	30.6	4.6	0.26	3
8. Warren	24	47.2	7.1	456	28.0	4.6	0.27	3
P. pinaster – Mid rotation stands								
1. Gnangara	21	24.5	3.9	452	26.6	4.5	0.24	2
5. Sunklands	21	29.4	5.3	439	28.9	4.4	0.35	1
P. pinaster - Clearfell stands								
1. Gnangara	29	39.3	4.5	505	36.5	4.5	0.22	6
2. Mundaring	28	34.6	5.3	505	32.3	4.6	0.24	2
3. Harvey Coast	34	42.8	4.2	511	29.7	4.7	0.23	2
5. Sunklands	28	42.9	6.9	493	33.8	4.7	0.27	4

Table 6: Plot averages by region and crop type – branch size and resin (visually assessed)

Region	Age (years)	Average branch size (cm)				Resin		No. of Stands
		Log 2		Log 3				
		Mean	SD	Mean	SD	Mean	SD	
***P. radiata* - Mid rotation stands**								
2. Mundaring	20	2.9	1.34	4.5	1.52	0.6	0.56	3
3. Harvey Coast	19	2.4	1.48	3.1	1.72	0.5	0.77	2
4. Hills	20	3.2	1.95	4.0	1.85	0.6	0.57	4
5. Sunklands	20	3.0	1.60	3.3	1.58	0.4	0.63	2
6. Blackwood Valley	19	2.7	1.47	3.2	1.88	0.4	0.55	4
7. Grimwade	18	2.8	1.29	3.9	1.89	0.6	0.61	2
8. Warren	19	2.0	1.07	2.0	1.10	0.4	0.48	2
***P. radiata* – Clearfell stands**								
1. Gnangara	34	5.3	1.36	6.3	1.49	0.9	0.61	1
2. Mundaring	31	5.1	1.85	6.4	1.44	0.8	0.77	2
3. Harvey Coast	28	3.5	1.40	4.9	1.27	1.0	0.59	3
4. Hills	34	2.9	1.57	4.4	1.99	0.3	0.47	3
5. Sunklands	27	2.4	1.37	3.2	1.79	0.4	0.63	5
6. Blackwood Valley	29	4.0	1.97	5.7	1.73	0.3	0.49	3
7. Grimwade	27	3.9	1.48	5.0	1.60	0.6	0.62	3
8. Warren	24	3.8	1.77	4.0	1.91	0.5	0.60	3
P. pinaster – Mid rotation stands								
1. Gnangara	21	3.1	1.85	-	-	0.0	0.00	2
5. Sunklands	21	4.3	1.40	-	-	0.0	0.18	1
P. pinaster – Clearfell stands								
1. Gnangara	29	4.3	1.45	5.9	1.60	0.0	0.00	6
2. Mundaring	28	3.7	1.82	5.2	1.59	0.0	0.18	2
3. Harvey Coast	34	2.5	1.42	3.8	1.69	0.1	0.22	2
5. Sunklands	28	2.9	1.78	4.7	1.92	0.0	0.00	4

Stem Diameter (Breast Height)

Plot values of DBHOB are given in Appendix 3A, and summarised in Figure 4. Age for age, the *P. radiata* showed faster average growth rates, at least up to about 30 years of age. This is not surprising given that this species is generally grown on more favourable sites. Annual average diameter growth for *P. radiata* was 1.61 cm yr^{-1} while for *P. pinaster* it was 1.41 cm yr^{-1}. Annual average diameter growth for the unthinned plots (unshaded points) was 1.15 cm yr^{-1} and 1.10 cm yr^{-1} for the *P. radiata* and *P. pinaster* respectively.

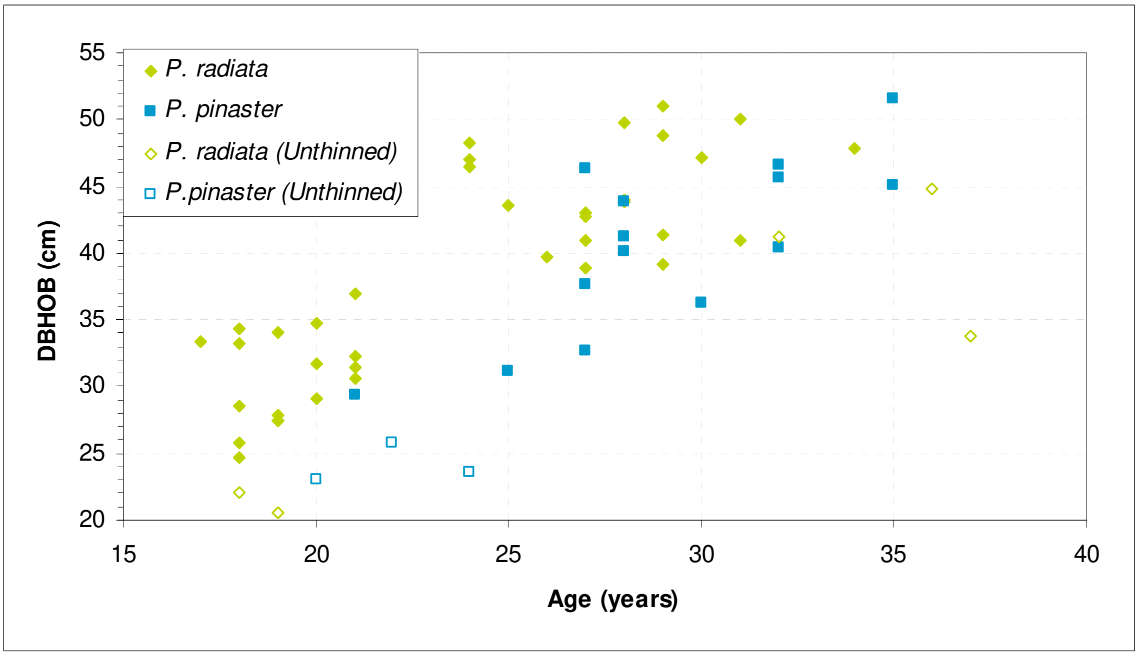


Figure 4: Mean DBHOB by age for all plots.

Mean DBHOB for individual plots of each species for each region are shown in Figures 5 and 6. The unthinned plots have been plotted separately regardless of region. All regions show increasing DBHOB with age without evidence of stagnation over the age range sampled. For *P. radiata* the Warren region data shows fast early growth rates (MAI 1.76 cm yr^{-1}) in comparison to the other regions, which were all comparable. The unthinned plots showed increasing DBHOB with increasing age but at a reduced rate. The *P. pinaster* data suggests continuous linear growth across the regions for the age range sampled (Figure 6).

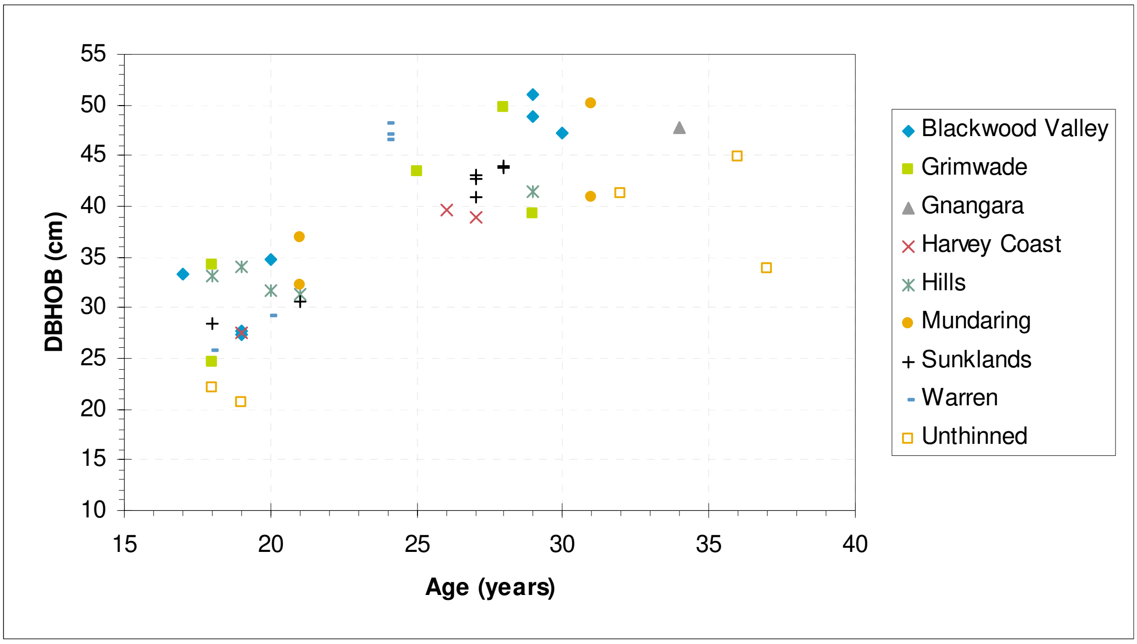


Figure 5: DBHOB by region – *P. radiata*

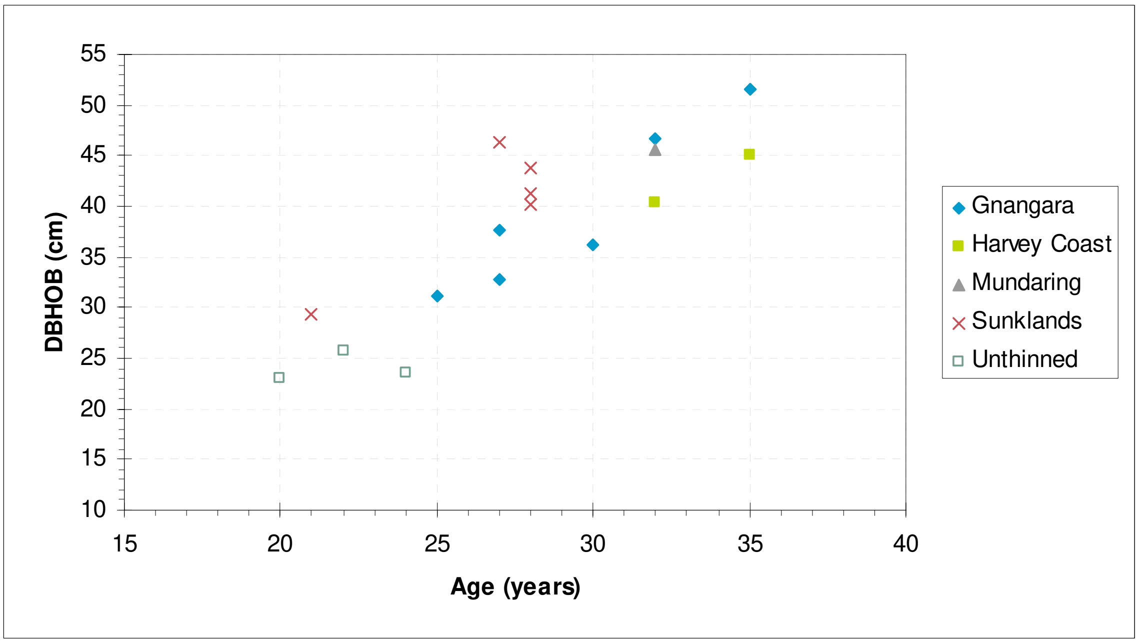


Figure 6: DBHOB by region – *P. pinaster*

Outerwood Density

Plot values are provided in Appendix 3B and summarised in Figure 7 below.

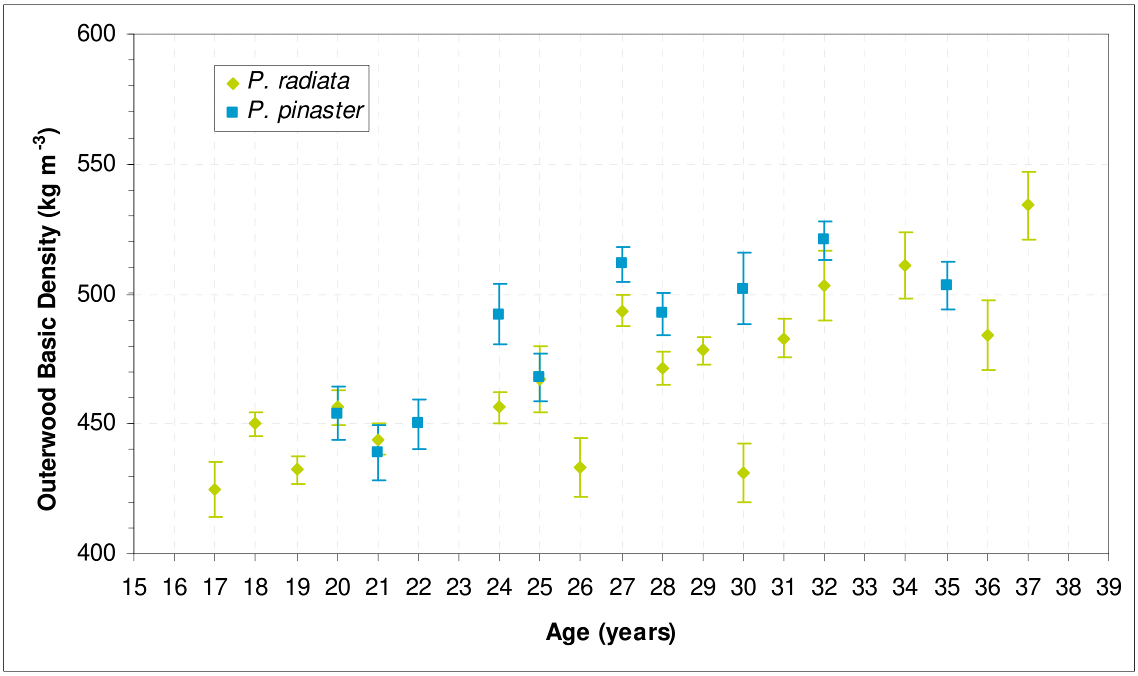


Figure 7: Mean outerwood density by age class.

The data are examined by species and region in Figures 8 and 9. Both species show increased outerwood density with increased age, as in all other surveys (Roper *et al.* 2004; Cown *et al.* 2006). The outerwood basic density (around 450 kg m^{-3} at age 20 years and 500 kg m^{-3} at age 30 for *P. radiata*) are generally similar to other Australian sites and to the higher density regions of New Zealand (Cown *et al.* 1991). The observed values for *P. pinaster* tend to be higher at all ages by around 25 kg m^{-3} on average. Siemon's (1995) survey also showed *P. pinaster* to have a higher wood density by about 10%.

There were no obvious differences in outerwood densities between the regions sampled, which were not consistent with the age effect. Figure 10 shows smoothed data (5-year age classes) of *P. radiata* outerwood basic density from New Zealand, Tasmania, Green Triangle, Western Australia, along with the WA *P. pinaster* results. In terms of comparison with other areas sampled, the Western Australian material averaged between the Medium and High density zones established for radiata pine in New Zealand (Cown *et al.*, 1991) and is similar to that of the Green triangle (Roper *et al.*, 2004).

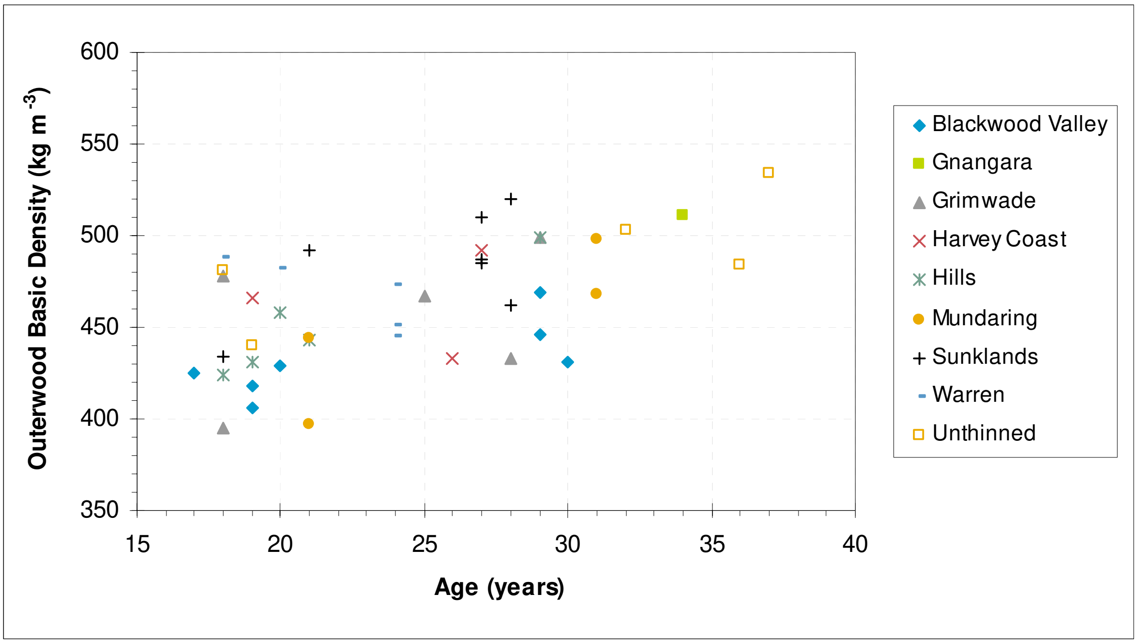


Figure 8: Outerwood basic density by age and region – *P. radiata*

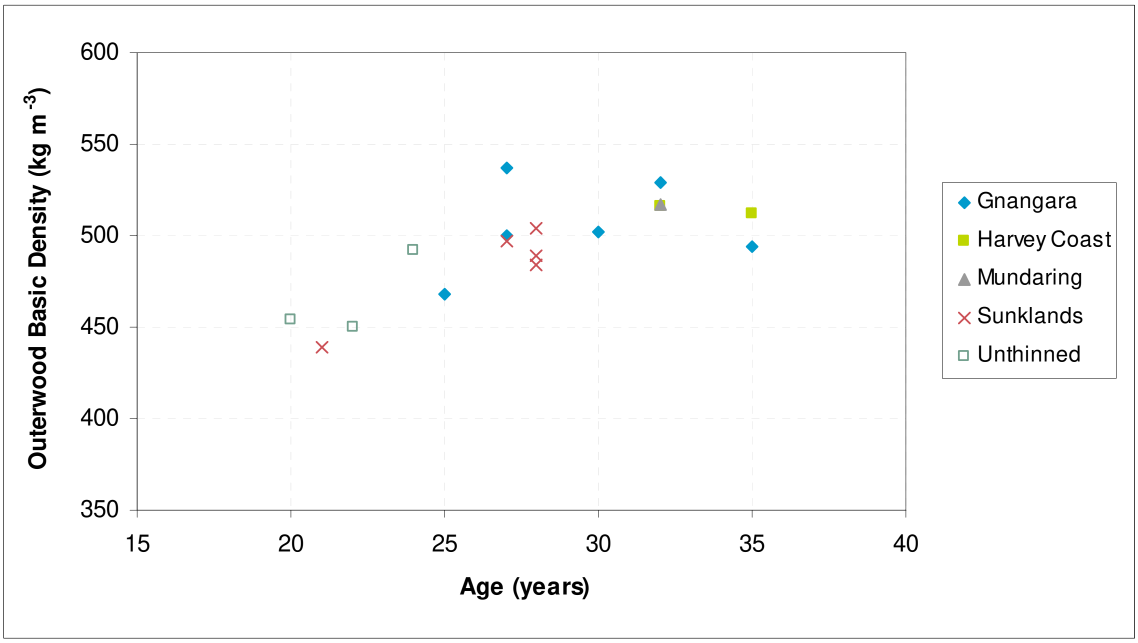


Figure 9: Outerwood density by age and region – *P. pinaster*

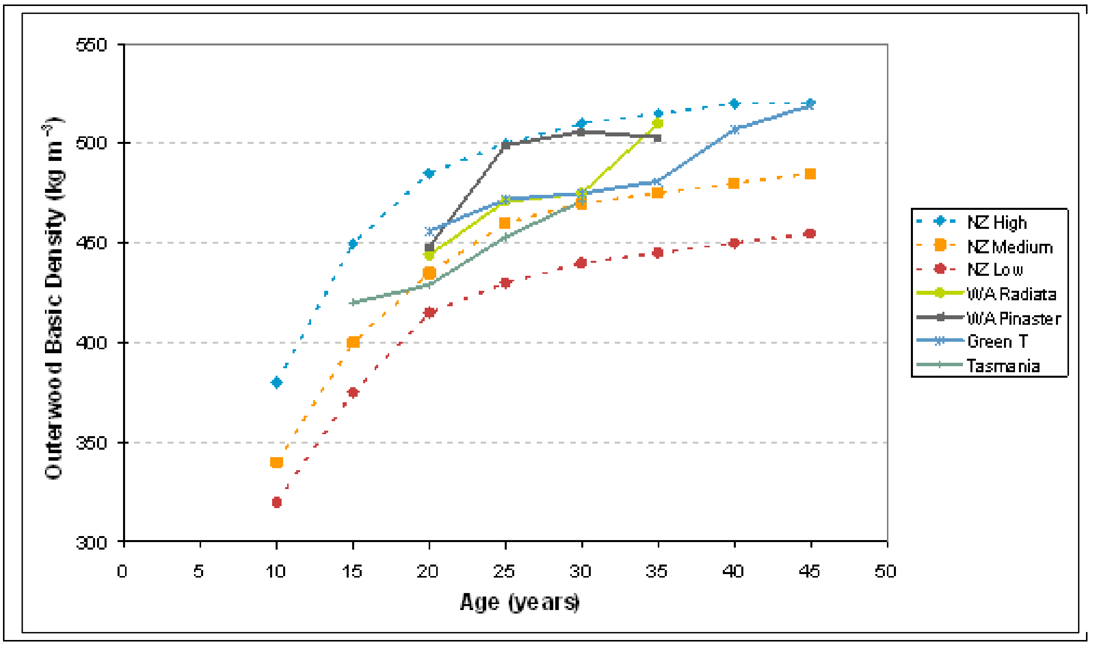


Figure 10: Regional (Australia/New Zealand) differences in the density-age relationships for *P. radiata* and Western Australian *P. pinaster*.

DBHOB and Outerwood Density

Over all sites (Figure 11), there is a very weak positive association between DBHOB and outerwood density, which is clearly a reflection of stand age. Within crops, there is commonly a weak negative relationship between growth rate and wood density in radiata pine (Cown *et al.* 1991). In this case, there was virtually no connection (Appendix 4), with only two plots (one *P. radiata* and one *P. pinaster*) showing a significant negative association. The relationship between radial growth and density is complex, and probably dependant on regional temperature and rainfall patterns, interacting with cambial activity and influencing latewood %. In some areas (e.g. NZ) faster growth tends to be associated with more earlywood growth.

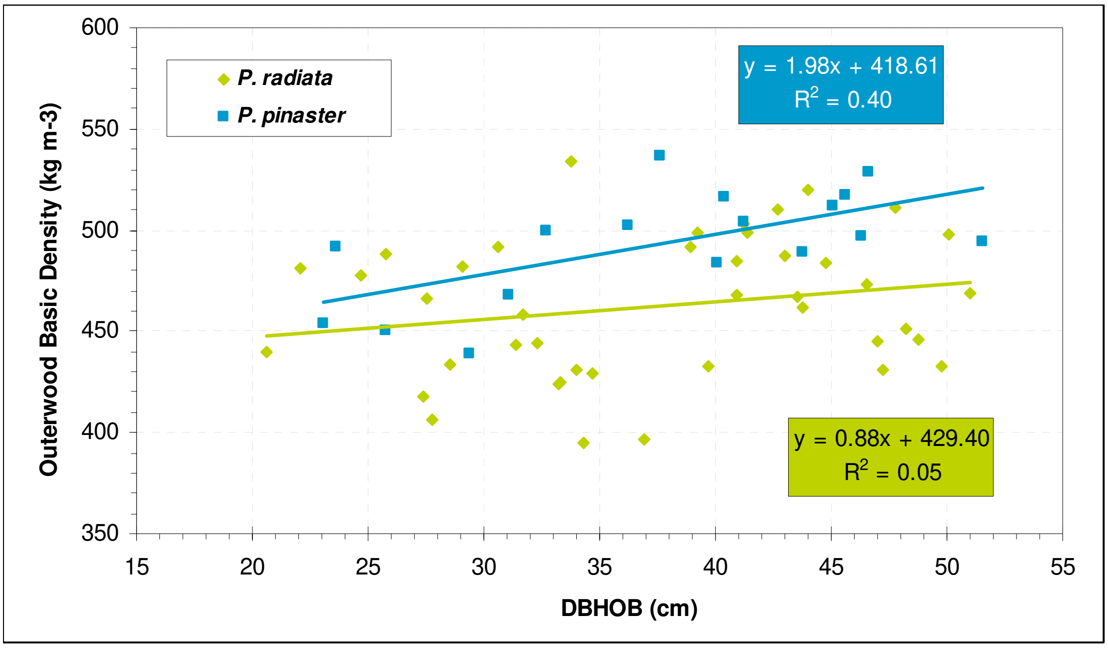


Figure 11: Outerwood basic density as a function of diameter at breast height over bark (based on plot means).

Standing Tree Acoustic Velocity

Sample plot values are given in Appendix 3B, and shown in Figure 12 for stand ages, and across sites. There is a weak overall trend of increasing velocity with stand age for radiata, and a lack of a clear trend in the overall *P pinaster* averages. Results by species and region are given in Figures 13 and 14, where acoustic values appear to be much more variable than outerwood density values, although they assess similar portions of the stem.

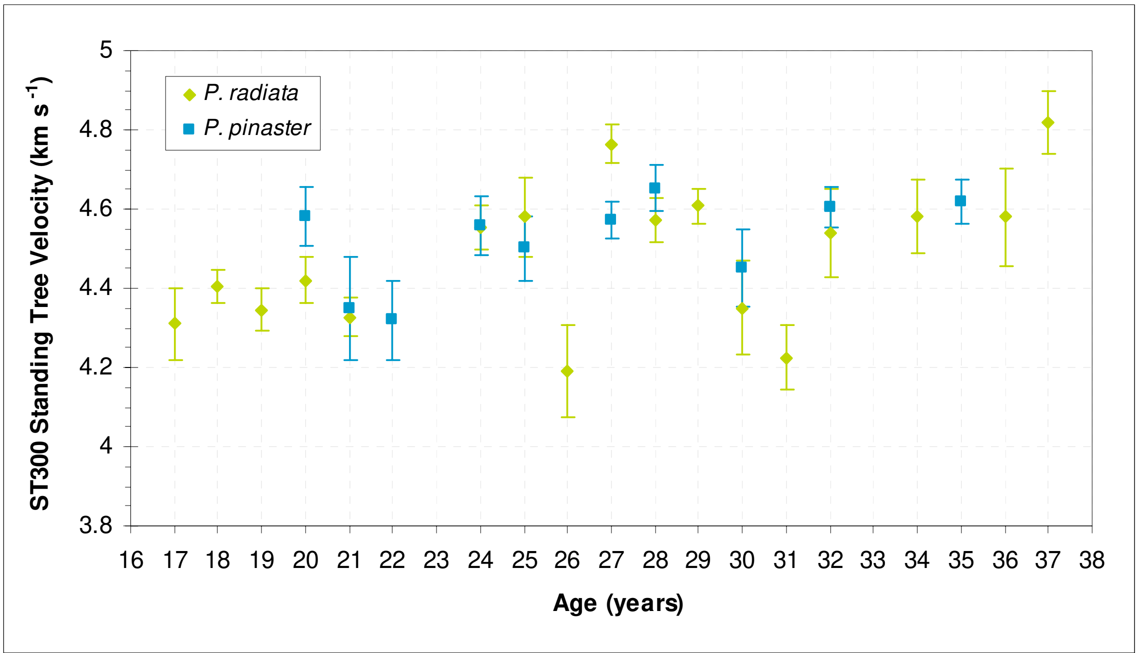


Figure 12: ST300 standing tree velocity plotted by age class (95% confidence intervals shown)

Figure 13 shows *P. radiata* site averages, with very little apparent pattern. The Mundaring plots are outstanding as having consistently the lowest values, whereas most other regions show a wide variation.

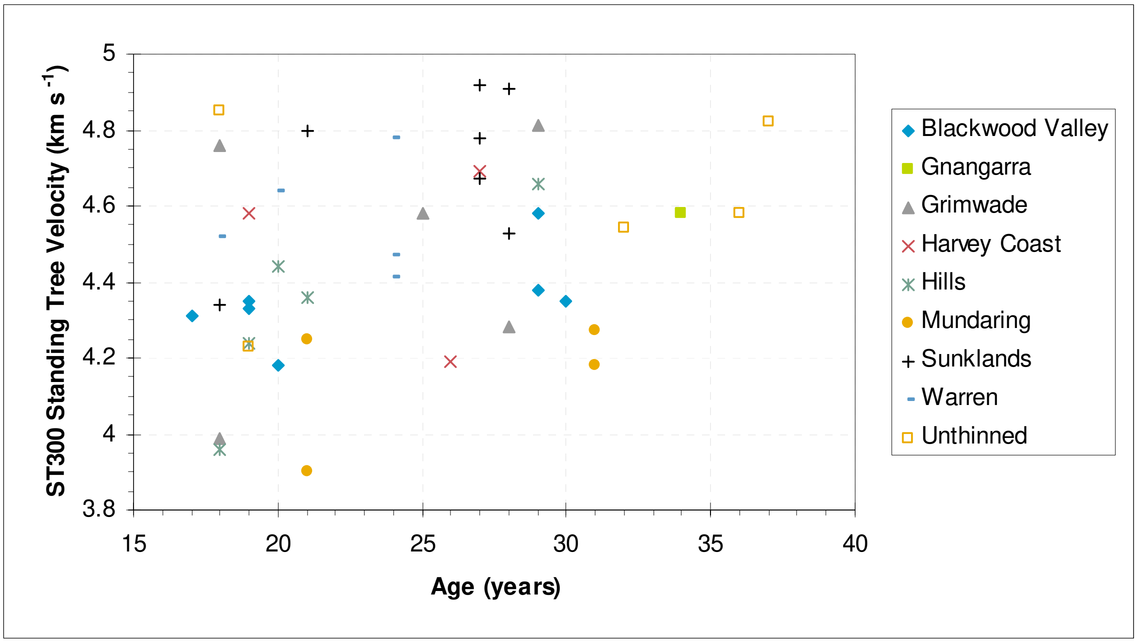


Figure 13: ST300 standing tree velocity by region and age class – *P. radiata*

The *P. pinaster* (Figure 14) shows a similar picture, with Gnangara at the lower end, apparently unaffected by age.

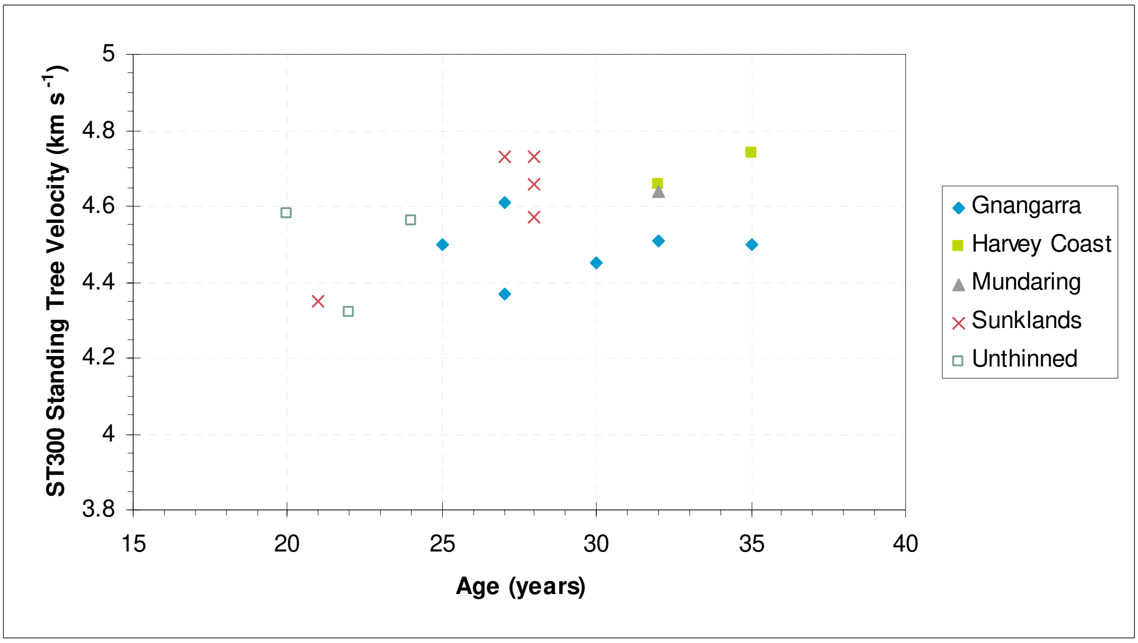


Figure 14: ST300 standing tree velocity by region and age class – *P. pinaster*

ST300 Values and Outerwood Density

When the plot means for ST300 and outerwood density are examined (Figure 15) a reasonable positive correlation is seen for the *P. radiata,* which covers a wider density range.

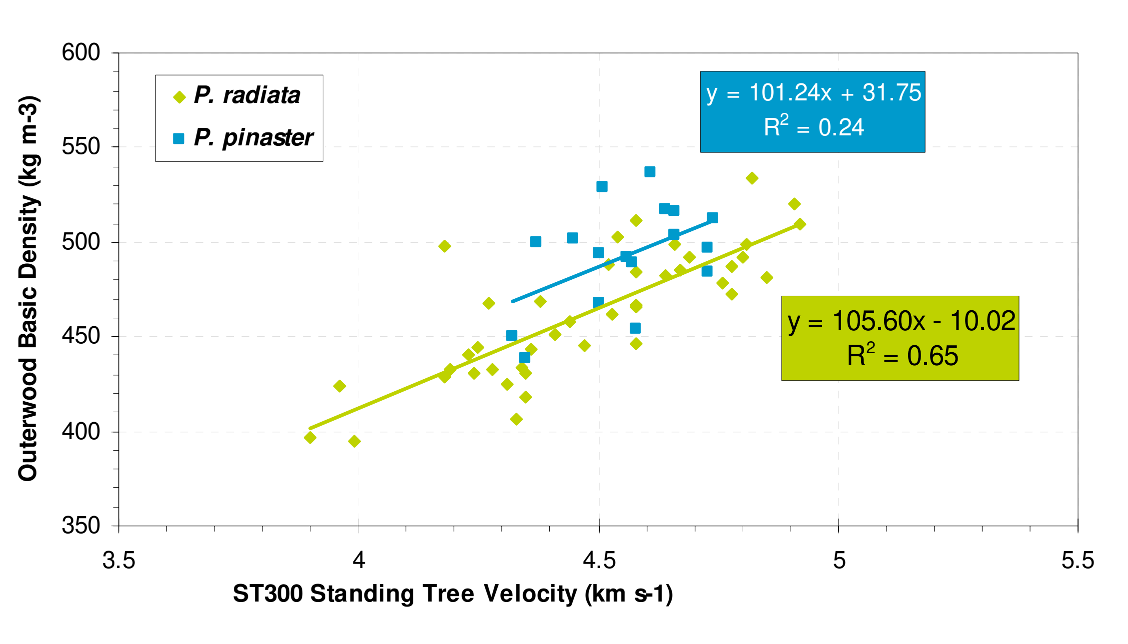


Figure 15: Outerwood basic density as a function of ST300 velocity (Based on plot means)

Density and acoustic velocity have been shown to be fairly well correlated on a plot average basis (Figure 15), but variable for individual trees. In this case, standing tree acoustic velocity and density had an R^2 of 65% for *P. radiata*, but only 24% for *P. pinaster*. The main factor was the much narrower range of ST300 values for *P. pinaster*.

Interestingly, Appendix 4 indicates that very few individual plots showed a significant association between outerwood density and ST300, although both tools assess a similar part of the stem. While both variables are assumed to have some impact on timber stiffness, very few studies have actually taken stem measures of velocity and density and related them to sawing study results (see section 5 – Discussion).

Branch Size (Second Log)

Values for branching of the second and third logs are given in Appendix 3C. Butt logs were excluded from the analysis due to approximately 40% of the stands having a pruning treatment. Overall averages for the second log are shown in Figure 16, and by species and region in Figures 17 and 18. In all, there is little difference between species, and when individual plots within regions are examined, both species show a slight increase in average values from the younger to older sites.

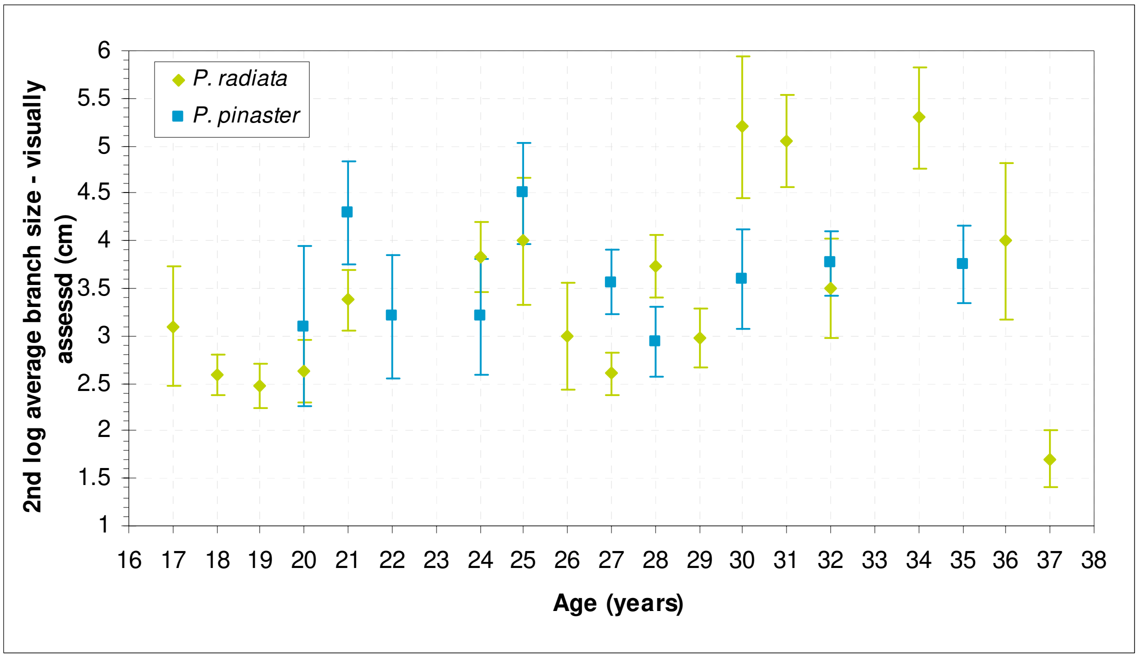


Figure 16: Mean branch size (2nd log) by age class (95% confidence intervals shown)

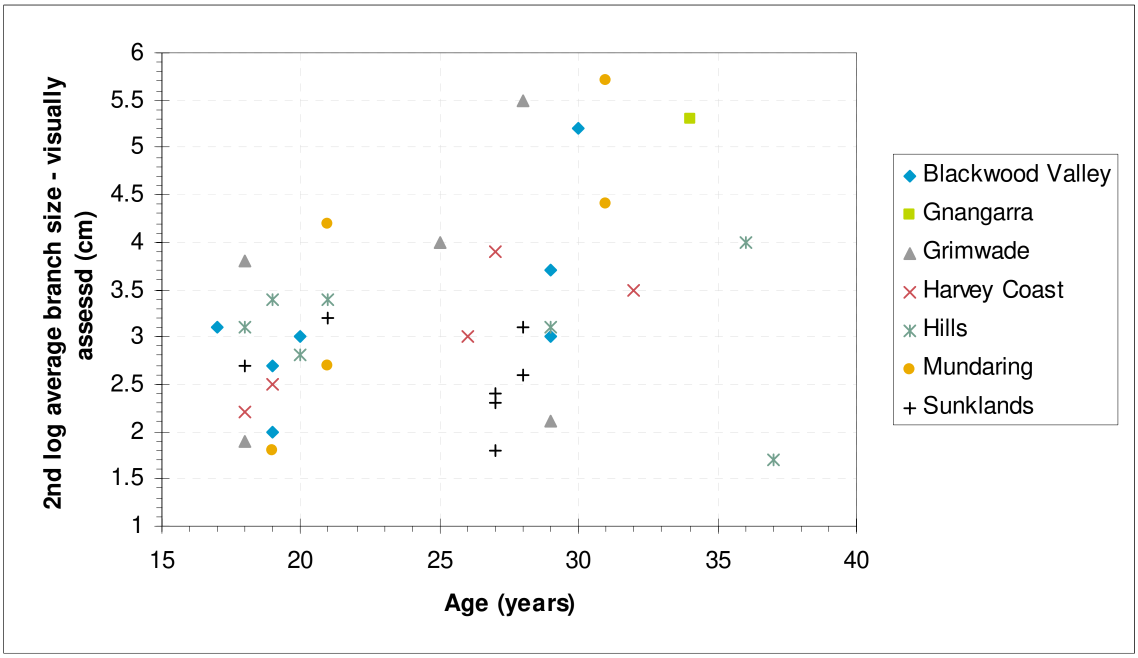


Figure 17: Mean branch size (2nd log) by region and age class – *P. radiata*

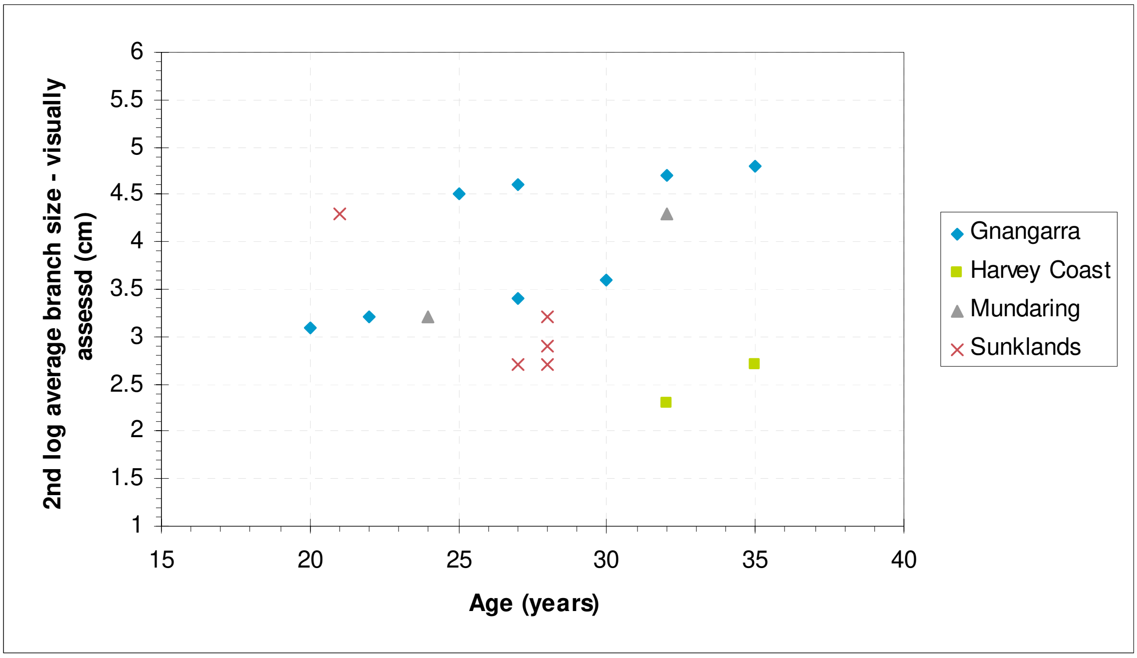


Figure 18: Mean branch size (2nd log) by region and age class – *P. pinaster*

The *P. radiata* branch sizes are highly variable between sites across all ages, with individual plots ranging between 1.7 and 5.7 cm. In contrast, the *P. pinaster* was more uniform (2.3 – 4.8 cm).

Resin Score

Resin scores were collected on the basis that they are easy to assess and may give information on the relationship between external visual signs and resin characteristics in timber, as they have for radiata pine in NZ (McConchie, 2003).

The resin scores are attached in Appendix 3A. *P. pinaster* showed virtually no external signs of resin on the tree stems. All *P. radiata* sites had some visible symptoms of resin bleed, however with mean scores ranging up to only 1.2 this is considered low and no assessments of the impact of external resin bleed on sawn timber quality were made. The highest scores were for Harvey Coast sites.

Silviculture

P. radiata in Western Australia is generally planted with an initial stocking of 1333 stems per hectare (sph), first thinned between 14 –16 years-of-age, fertilised, second thinned between 22–24 years-of-age, fertilised and then clearfelled at age 30. *P. pinaster* follows a similar pattern, but thinning and clearfell are delayed by 3–5 years due to slower growth on poorer sites. Silvicultural records were used to examine potential relationships between initial stocking, final stocking, thinning schedules, fertiliser applications and pruning schedules and wood density, standing tree acoustics (ST300) and branching characteristics for both species across all ages and regions.

The application of fertiliser was consistent across all sites with adequate nutrition for tree growth. Therefore no distinctions between the sites could be found in which to analyse the influence of fertiliser application on wood properties or branch development.

The variation of site means for ST300 is large (3.90 to 4.85) and seems unaffected by stand ages or stocking. The silvicultural data showed no influence of initial stocking, final stocking or pruning on the properties measured. This is rather surprising, given the strong effect of spacing often seen in silvicultural studies in *P. radiata* (Cown, 1973, 1974; Siemon, 1973; Shepherd and Forest, 1973; Wood and Siemon, 1981; Sutton and Harris, 1974; Cown and McConchie, 1981, 1982; Downes *et al.,* 2002) and many other species (Zobel and Sprague, 1998).

Mean breast height diameters (DBHOB) are shown in Table 5 (region) and Appendix 3A (plot). A simple one dimensional view of growth rate for these plots is obtained by dividing the mean DBHOB by age (cm yr^{-1}). This can be refined to a two dimensional measure by converting the DBHOB to basal area (BA) and growth rate expressed as $m^2\ yr^{-1}$. Growth rates were generally greater in the *P. radiata* for both mid-rotation (0.0037 $m^2\ yr^{-1}$) and late-rotation (0.0058 $m^2\ yr^{-1}$) stands than the *P. pinaster* (0.0025 $m^2\ yr^{-1}$ and 0.0047 $m^2\ yr^{-1}$). There was no real indication of a decline in growth rates for either species over the age range of the plots sampled.

With both species and all ages combined, there was no correlation between growth rate and either outerwood density (R^2 0.0008) or standing tree acoustic velocity (R^2 0.0037). However, when the plots were separated into mid-rotation and late-rotation age classes there was a moderate negative relationship between growth rate and outerwood density for both age classes (Figure 19) but only in the younger age class for the standing tree acoustic velocity (Figure 20).

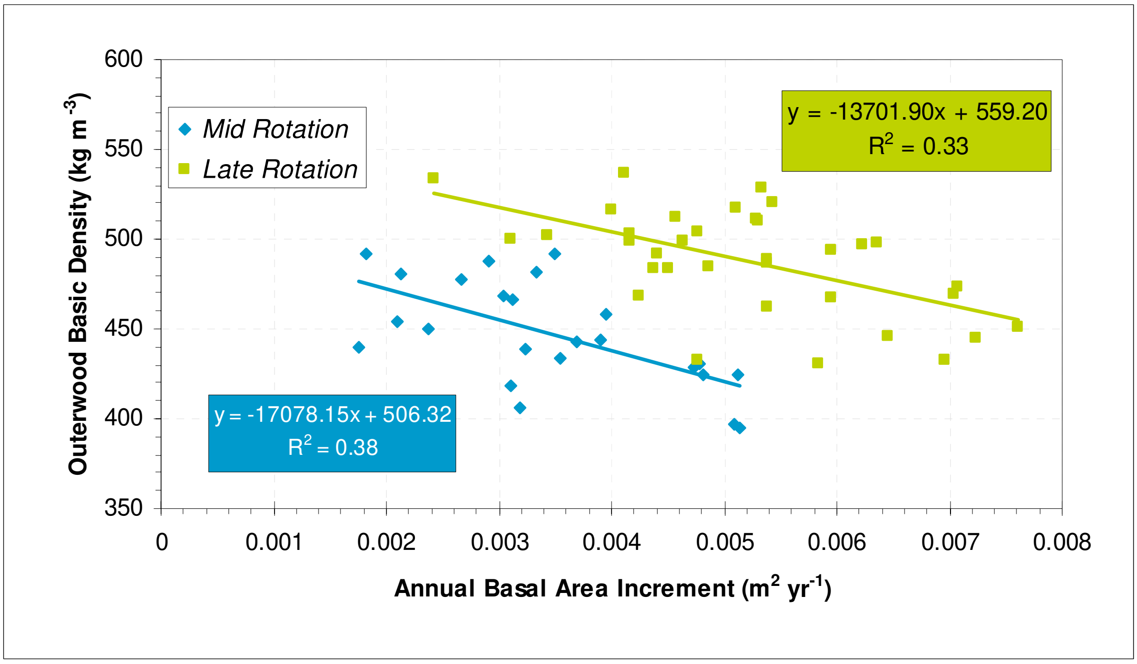


Figure 19: Influence of growth rate (BA m^2 yr^{-1}) on outerwood density in mid-rotation and late rotation stands of Western Australian softwoods.

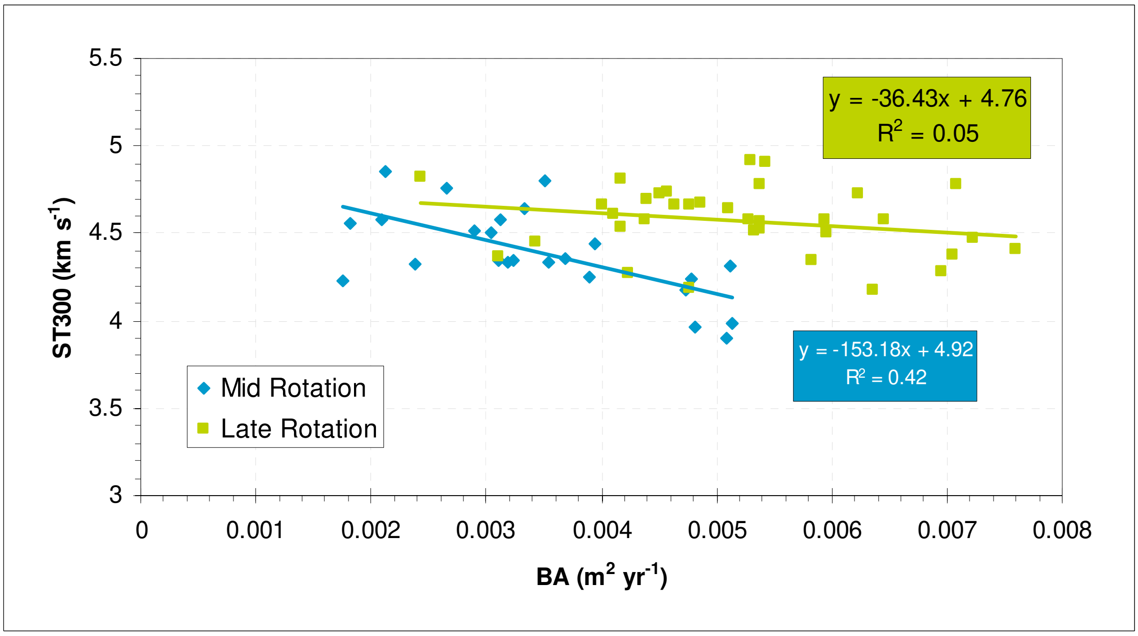


Figure 20: ST300 (acoustic velocity) as a function of growth rate (BA m2 yr-1) in mid-rotation and late rotation stands of Western Australian softwoods.

There was a moderate positive correlation ($R^2 = 0.36$) between growth rate (BA m^2 yr^{-1}) and branch size regardless of age or species (Figure 21). There was no effect on branch size of initial stocking, age at first thinning, thinning intensity or final stocking.

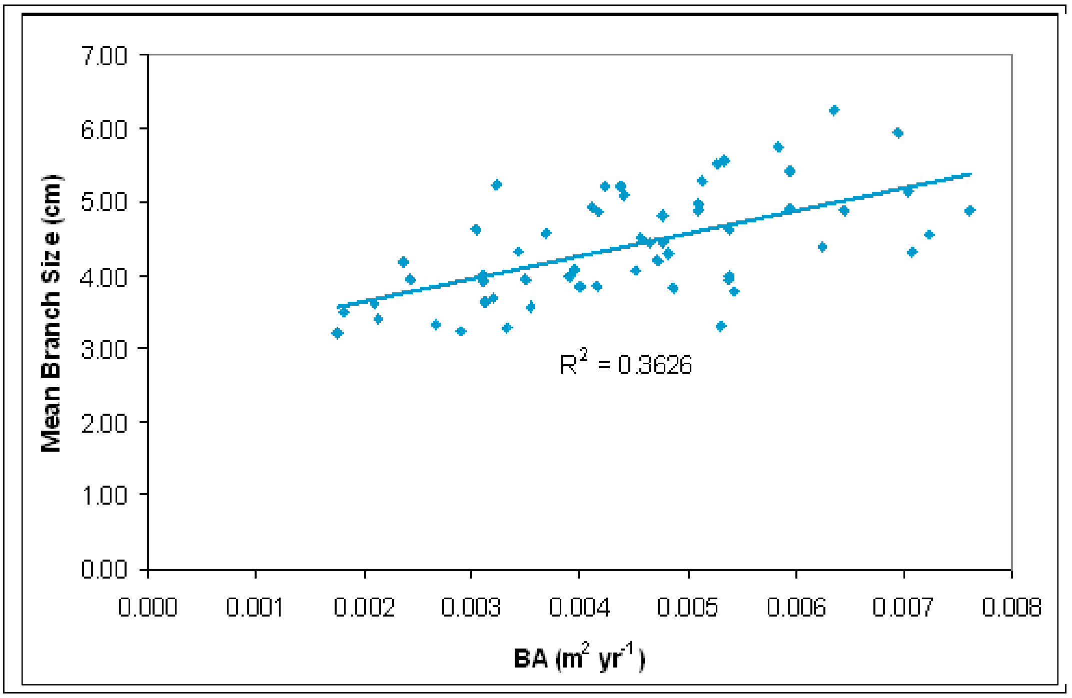


Figure 21: Mean tree branch size (cm) as a function of basal area growth rate (m^2 yr^{-1})

Processing study

Log properties

Table 7 summarises the main wood properties of the trees that were included in the sawmilling component of this study. Table 8 summarises the acoustic properties of the logs included in the sawmilling study. Figures 22 to 26 show the profiles of the variation in the main properties with height up the stem. These profiles show that for *P. pinaster* there was very little difference in density between the BIX classifications within the same rotation length (Figure 23). For *P. radiata* there was a more obvious difference, with the larger branched trees being lower in density. A similar pattern is seen in the HM200 data (Table 8) and this relationship will be explored more fully later. Figures 27 to 29 show the radial variation in basic density, green density and moisture content at 5m stem height. This shows that for *P. pinaster*, the radial variation in properties was more uniform than for *P. radiata*, which tended to have a pronounced lower density core.

Table 7: Average whole tree properties.

Rotation length	BIX Class	Site No.	Forest	Age (years)	Log Volume (m^3)	Basic Density (kg/m^3)	Green Density (kg/m^3)	Moist. Content (%)	Bark Depth (%)	N
				P. radiata						
Mid	Small	6	Myalup	18	0.307	469	889	90	10	11
Mid	Large	34	Mandalay	18	0.646	382	802	110	11	13
Late	Small	10	Vasse	27	1.500	444	871	97	14	12
Late	Large	22	Ellis	30	1.671	411	815	99	15	12
All			**Mean**	**23**	**1.031**	**427**	**844**	**99**	**13**	**48**
				P. pinaster						
Mid	Small	55	Yanchep	22	0.280	451	935	109	18	12
Mid	Large	58	Yanchep	25	0.543	453	959	113	17	12
Late	Small	5	Mclarty	32	0.926	487	944	95	19	12
Late	Large	57	Yanchep	35	2.067	483	967	101	21	12
All			**Mean**	**29**	**0.954**	**469**	**951**	**105**	**19**	**48**

Table 8: HM200 stem and log measurements.

Rotation length	BIX Class	Site No.	Forest	Age (years)	Acoustic data (km/s)					N
					Stem	Log 1	Log 2	Log 3	Log 4	
				P. radiata						
Mid	Small	6	Myalup	18	3.29	3.37	3.36			11
Mid	Large	34	Mandalay	18	2.85	2.78	2.96	2.78		13
Late	Small	10	Vasse	27	3.46	3.54	3.60	3.46	3.30	12
Late	Large	22	Ellis	30	3.04	3.04	3.17	3.08	2.92	12
All			**Mean**	**23**	**3.16**	**3.18**	**3.27**	**3.11**	**3.11**	**48**
				P. pinaster						
Mid	Small	55	Yanchep	22	2.99	3.03	2.87			12
Mid	Large	58	Yanchep	25	2.93	3.10	2.97			12
Late	Small	5	Mclarty	32	3.05	3.30	3.21	2.87		12
Late	Large	57	Yanchep	35	3.00	3.22	3.12	2.94	2.67	12
All			**Mean**	**29**	**2.99**	**3.16**	**3.04**	**2.91**	**2.67**	**48**

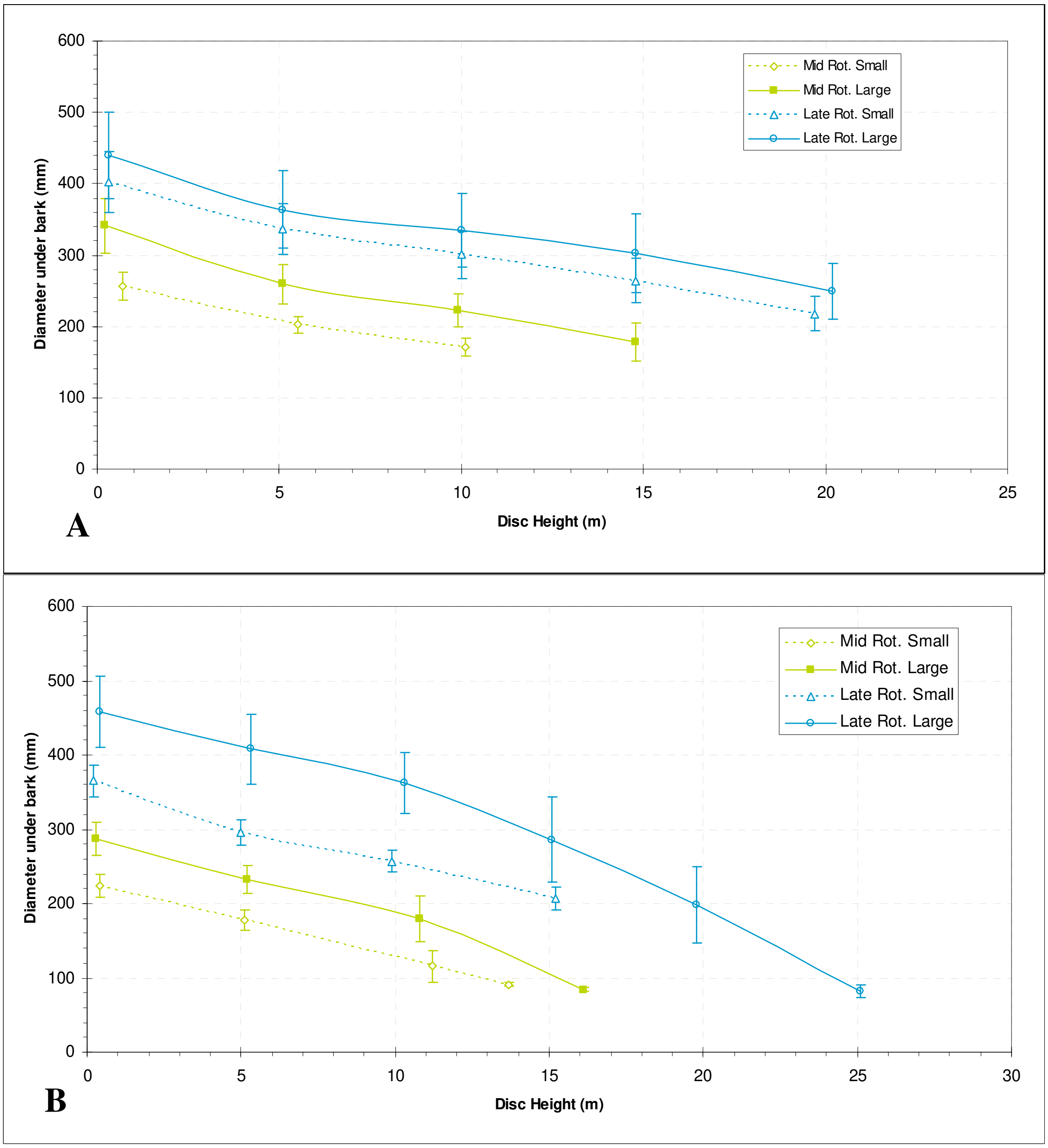
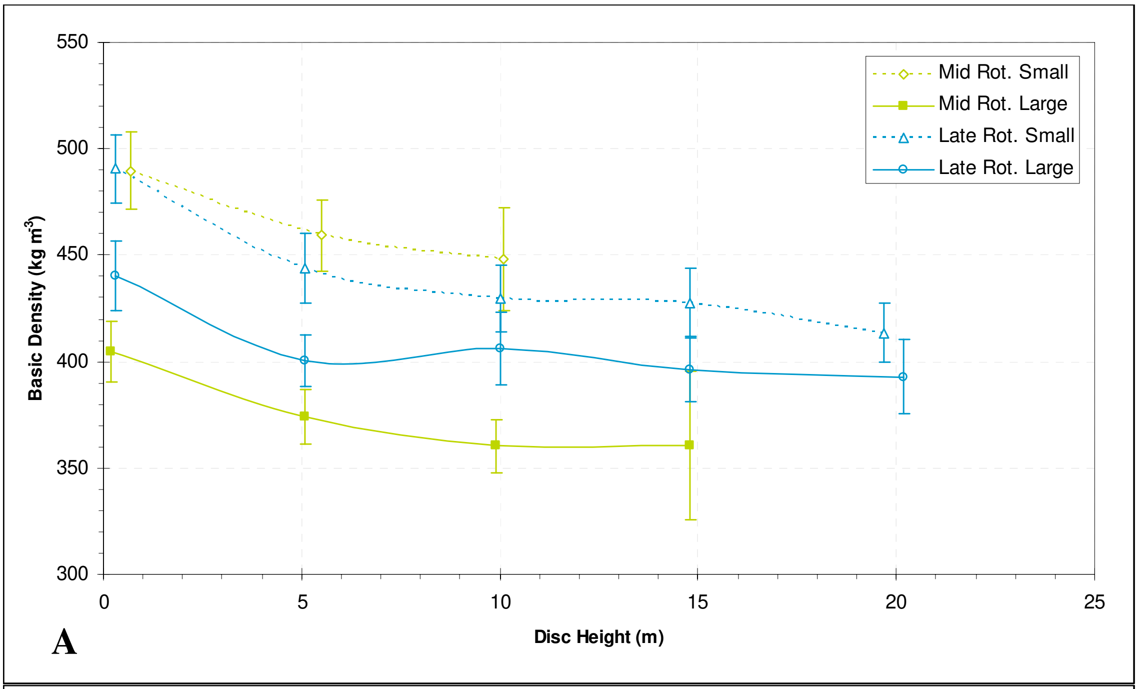


Figure 22: Profile of average disc diameters with height up the stem for (A) *P. radiata* and (B) *P. pinaster*. Profiles are further categorised by harvesting age (mid or late-rotation) and branch size (Small = BIX 0-1; Large = BIX 2-3).



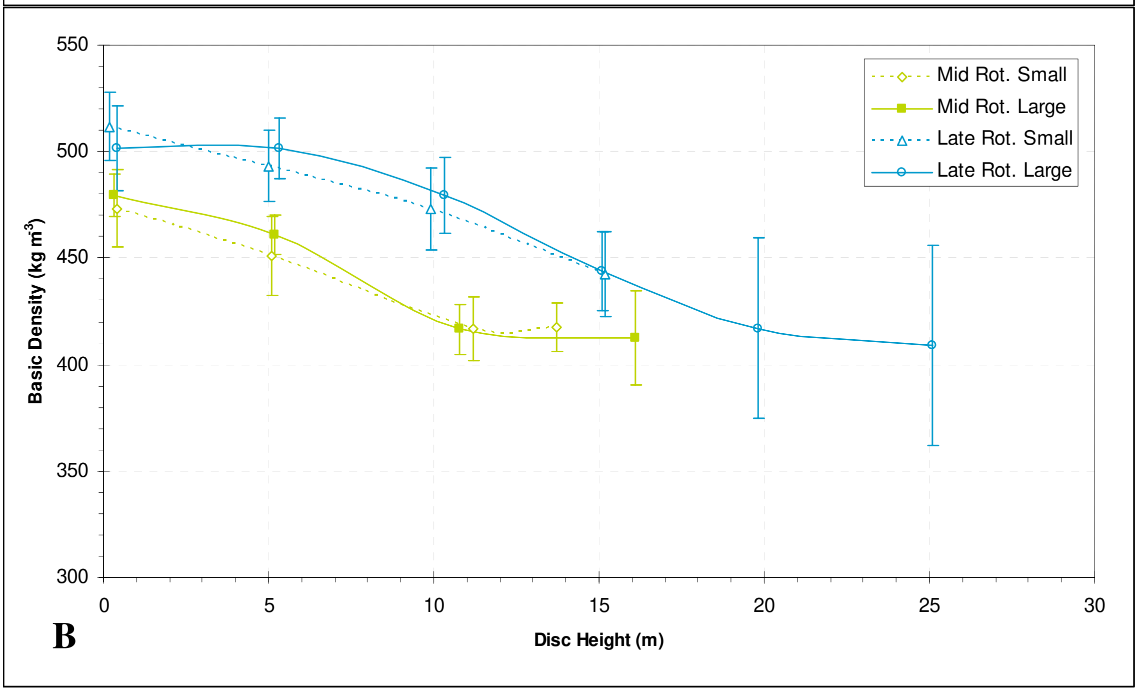


Figure 23: Profile of average disc basic density with height up the stem for (A) *P. radiata* and (B) *P. pinaster*. Profiles are further categorised by harvesting age (mid or late-rotation) and branch size (Small = BIX 0-1; Large = BIX 2-3)

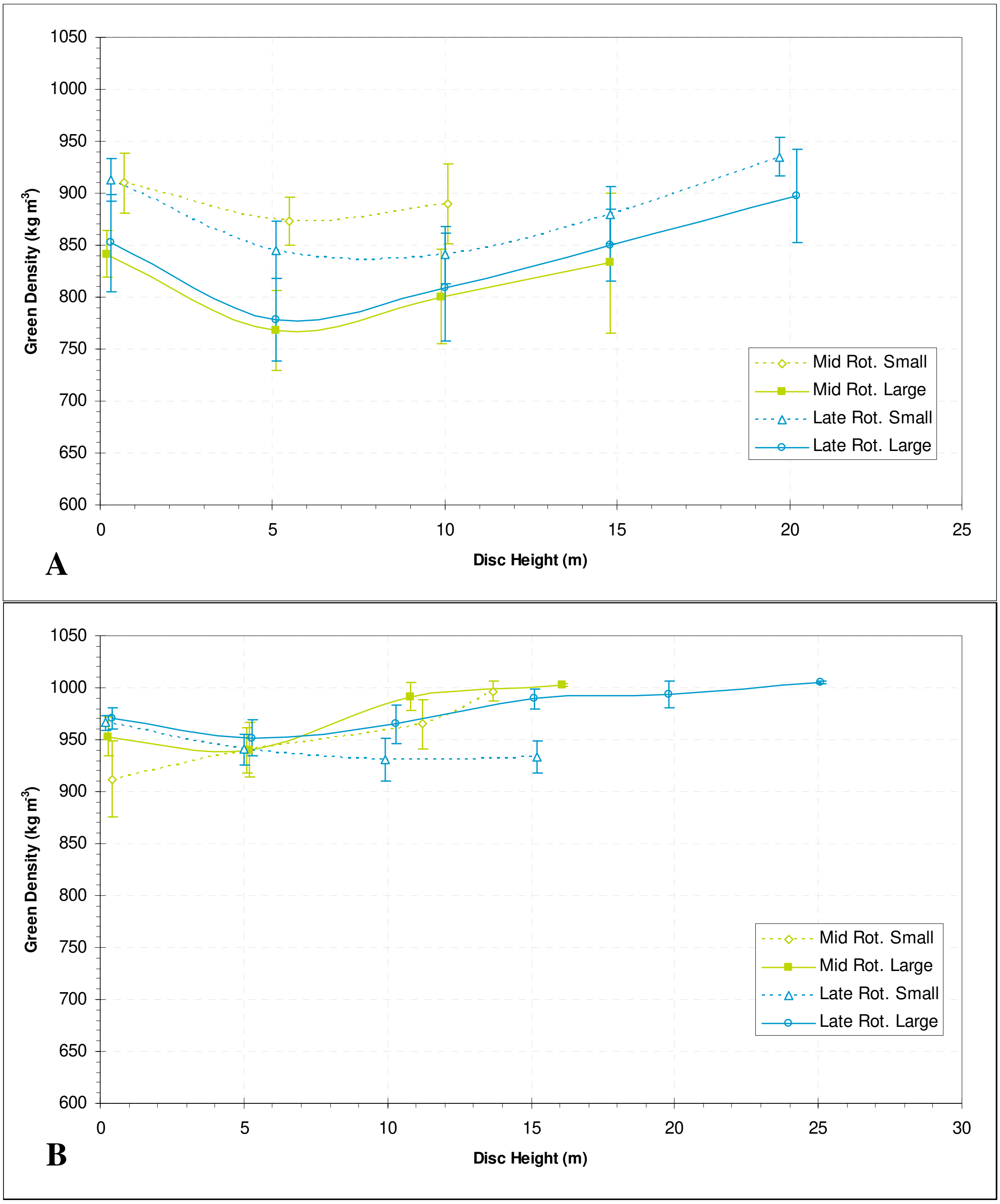
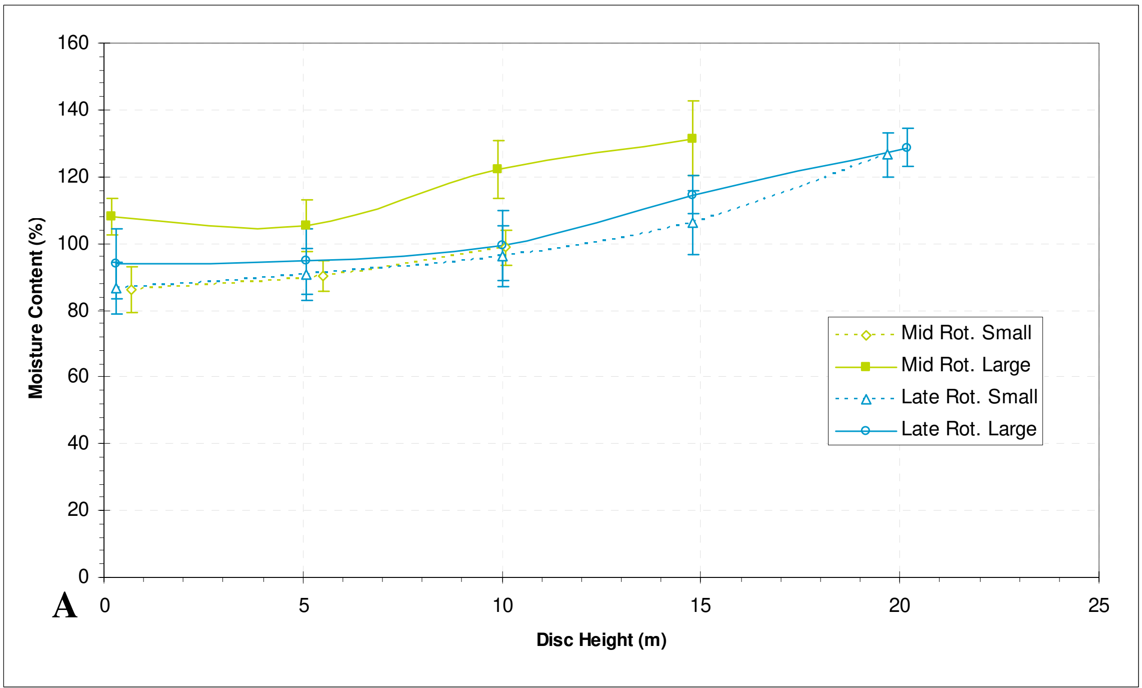


Figure 24: Profile of average disc green density with height up the stem for (A) *P. radiata* and (B) *P. pinaster*. Profiles are further categorised by harvesting age (mid or late-rotation) and branch size (Small = BIX 0-1; Large = BIX 2-3)



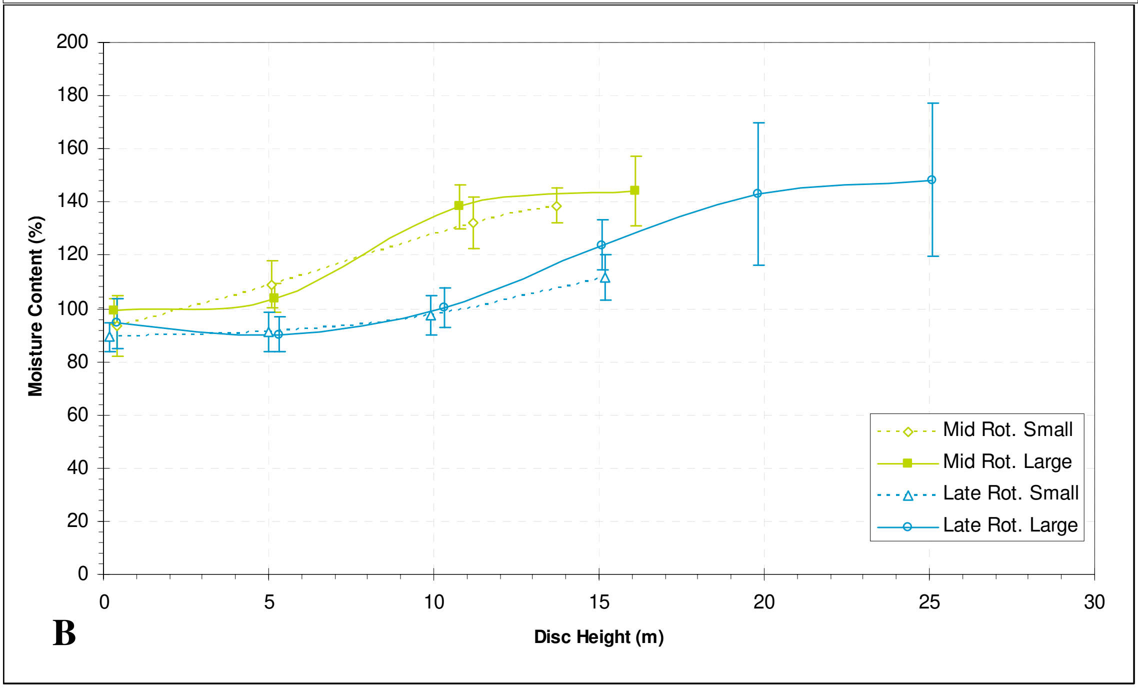
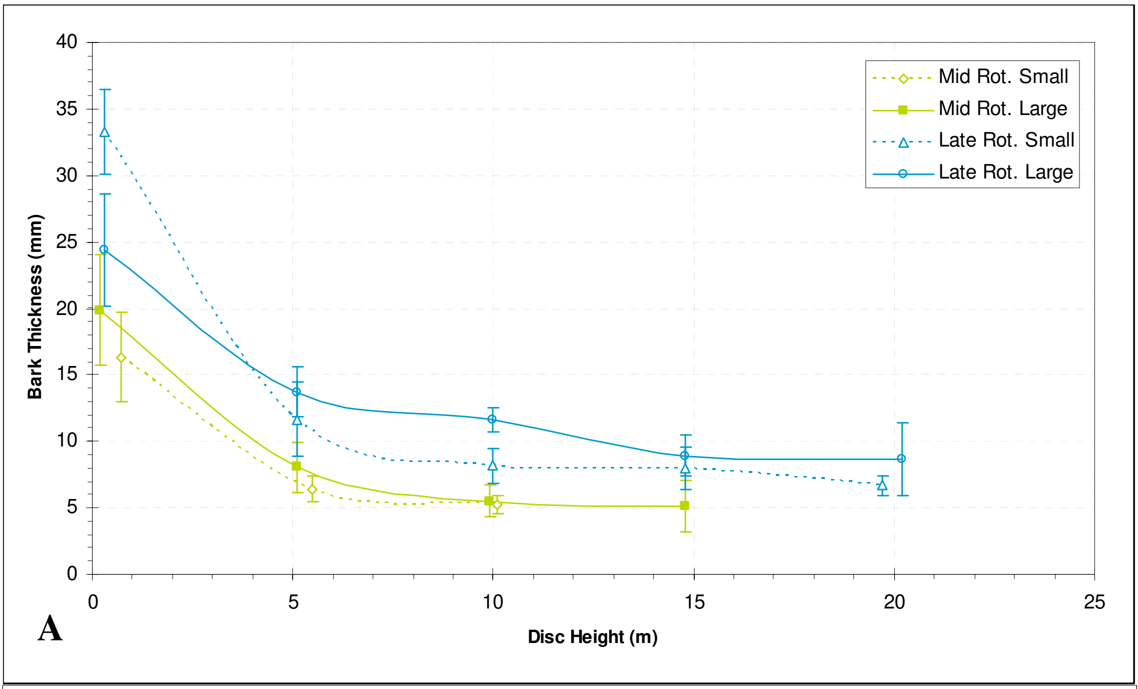


Figure 25: Profile of average disc green moisture content with height up the stem for (A) *P. radiata* and (B) *P. pinaster*. Profiles are further categorised by harvesting age (mid or late-rotation) and branch size (Small = BIX 0-1; Large = BIX 2-3)



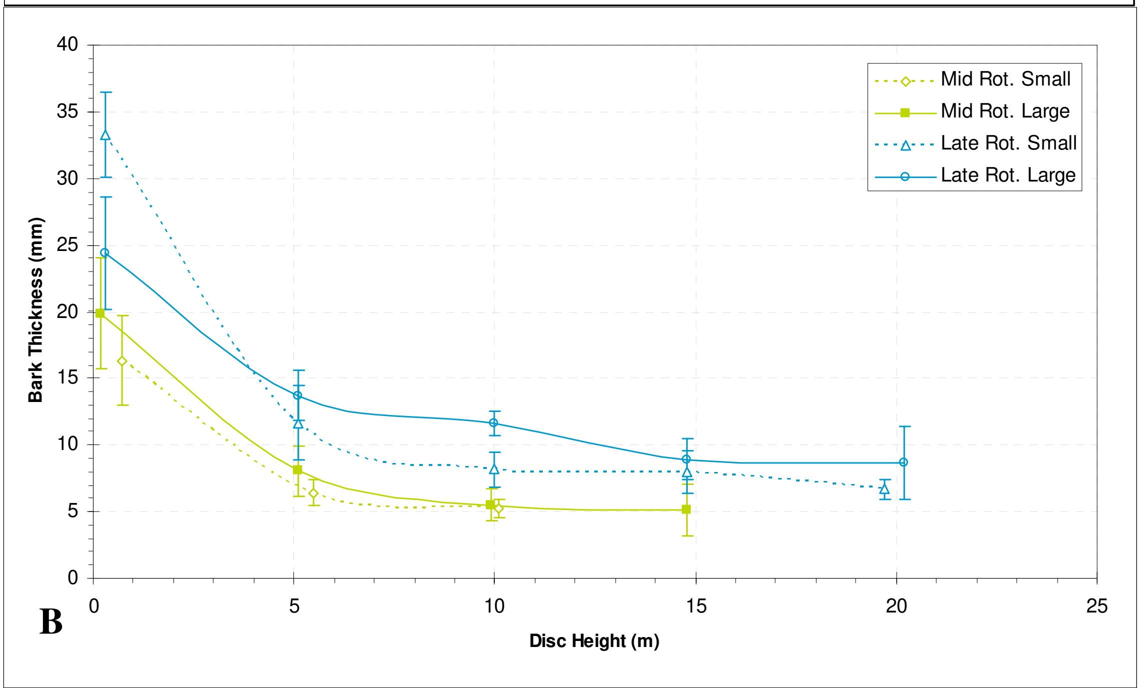


Figure 26: Profile of average disc bark thickness with height up the stem for (A) *P. radiata* and (B) *P. pinaster*. Profiles are further categorised by harvesting age (mid or late-rotation) and branch size (Small = BIX 0-1; Large = BIX 2-3)

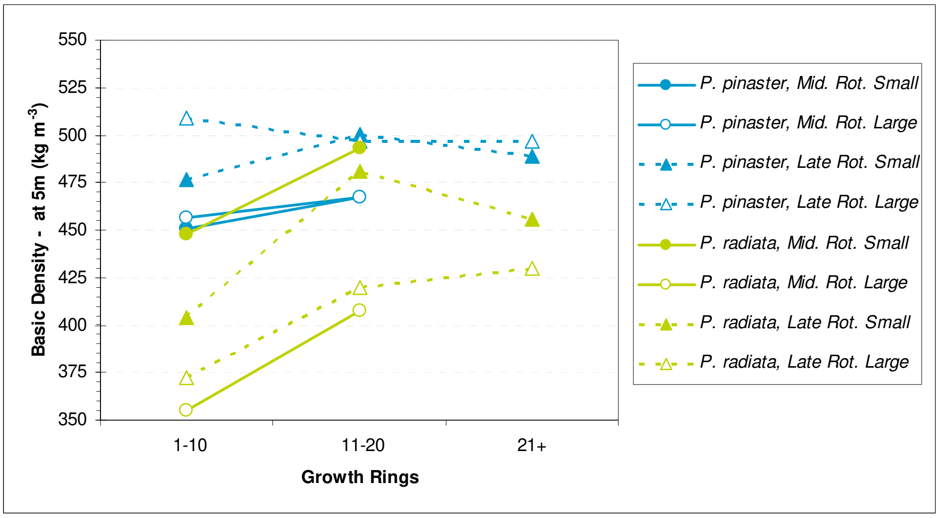


Figure 27: Radial variation in basic density at 5m height in the stem.

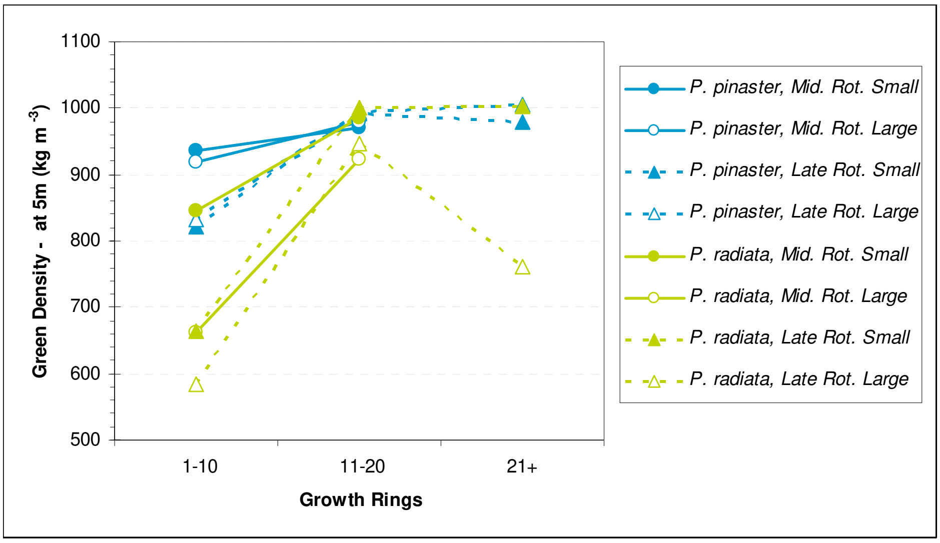


Figure 28: Radial variation in green density at 5m height in the stem.

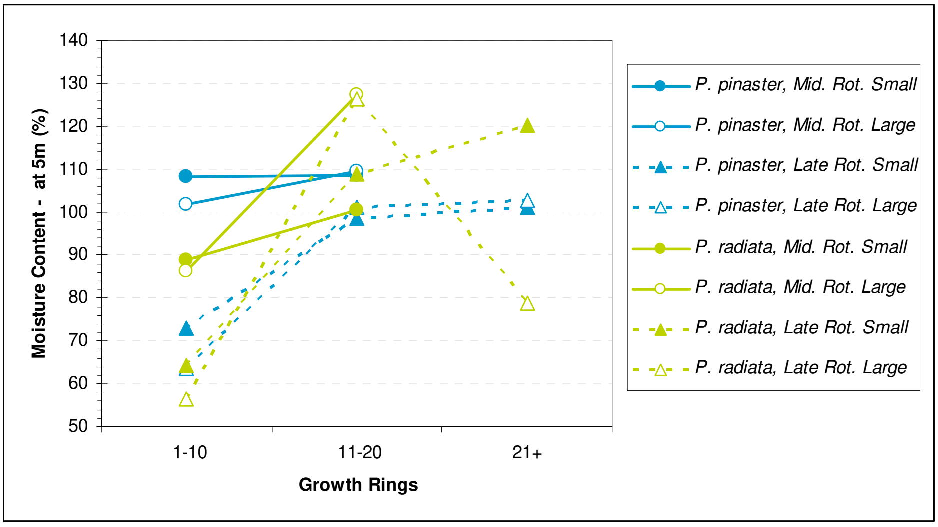


Figure 29: Radial variation in moisture content at 5m height in the stem.

Predictors of whole tree density

Given the fundamental importance of whole tree density for log handling and wood quality, it is of interest to see which of the more rapid measurements that have been undertaken here may provide a useful predictor of whole tree density. Figure 30 shows that the relationship between increment core density and whole tree density is good for *P. radiata*, but only moderate for *P. pinaster*. Partly, the difference in R^2 is due to there being less variation in density in *P. pinaster*, but there may also be slightly more noise (variation in the y-axis direction above and below the fitted line) in the data points shown in Figure 30. The *P. radiata*, result is in keeping with other studies (e.g. Cown *et al.*, 1991).

Figure 31 shows that there was no relationship between whole tree density and diameter. The acoustic measures have only a weak to moderate relationships with whole tree data, and were generally better for *P. radiata*. Figures 32 and 33 show that for *P. pinaster* the HM200 had a slightly higher R^2 than the ST300, while the opposite was true for *P. radiata*.

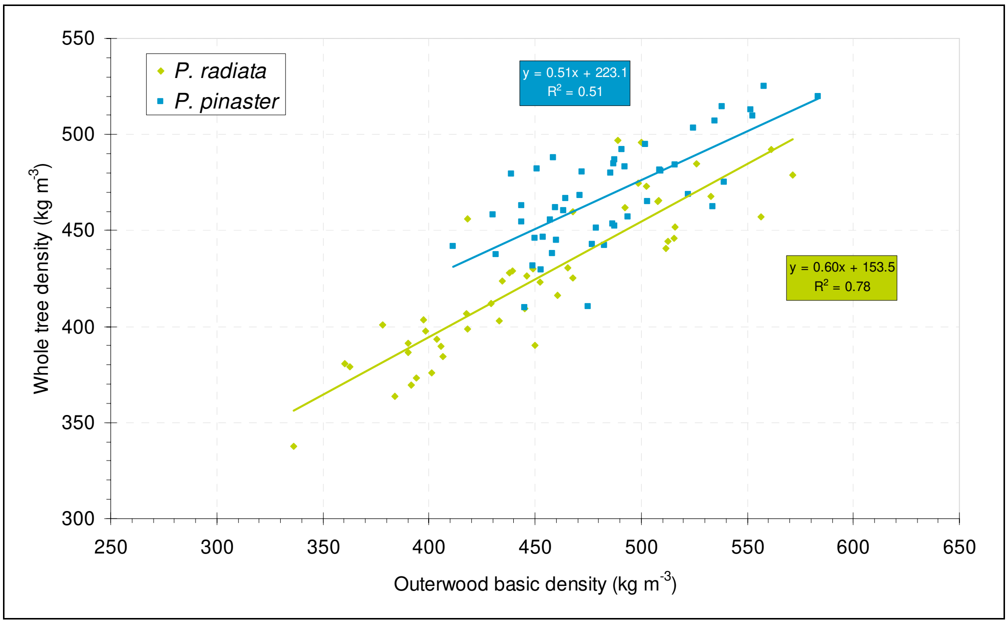


Figure 30: Whole tree basic density (disc derived) as a function of outerwood basic density (core derived).

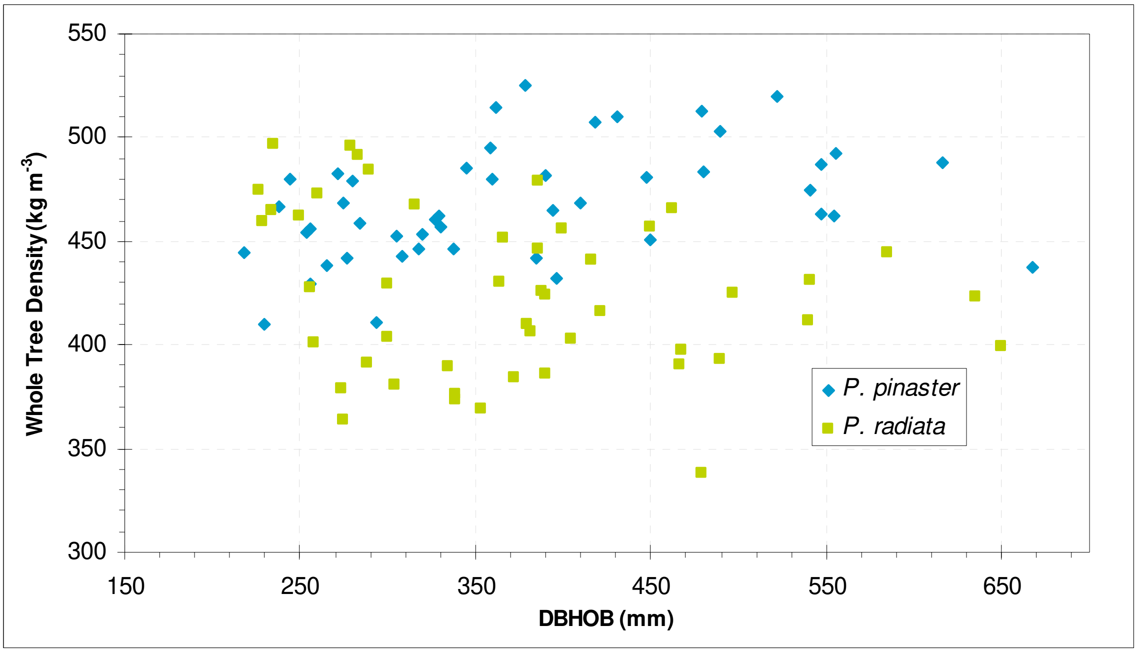


Figure 31: Mean whole tree basic density plotted against DBHOB

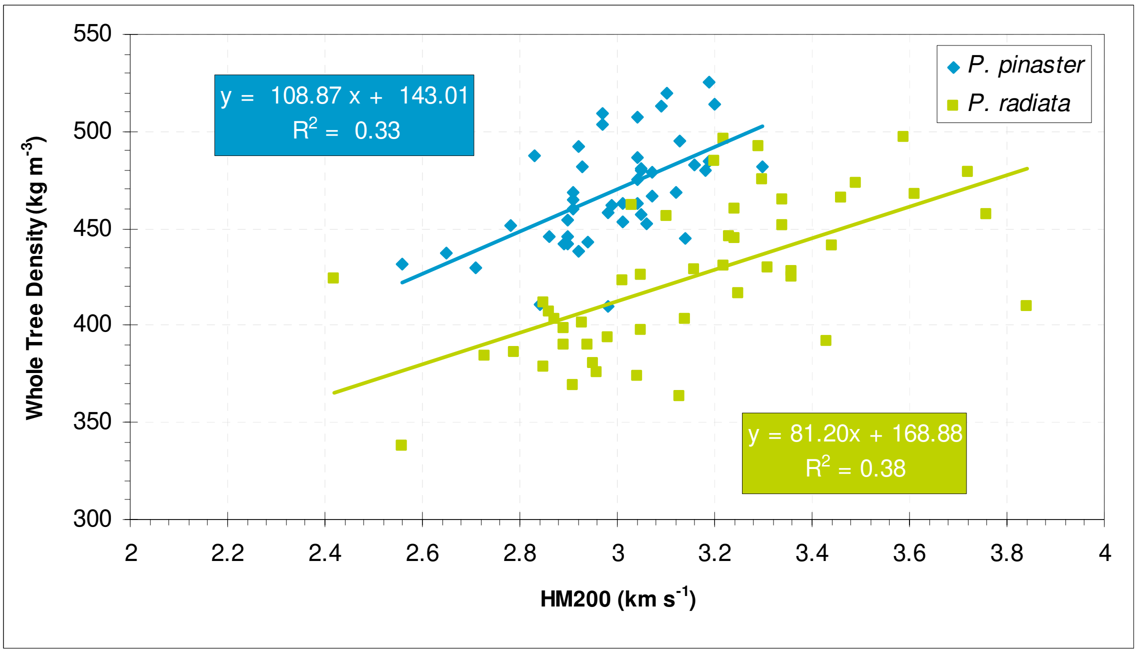


Figure 32: Whole tree density as a function of whole stem HM200 velocity.

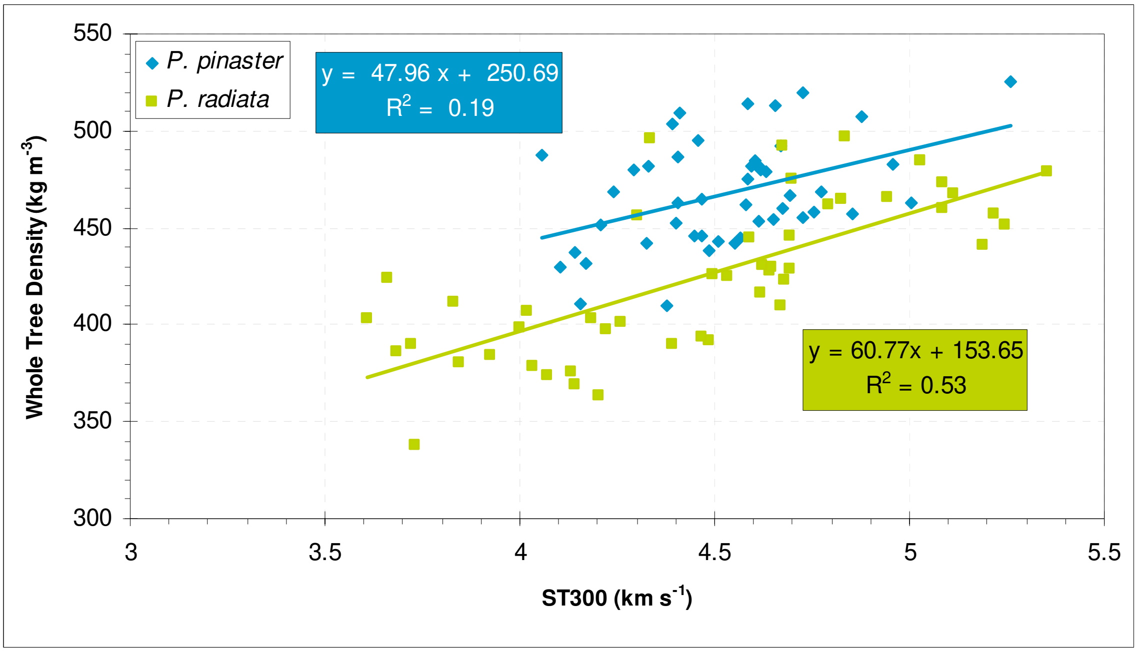


Figure 33: Whole tree density as a function of ST300 measurements.

Machine Strength Grade (MSG) Recoveries

Figure 34 shows the plot means of $MoE_{(average)}$ and $MoE_{(low)}$ for full-length boards recovered in the sawmill study. Individual tree means are provided in Appendix 7. The nominal branch size classification (BIX) for each plot is also included in this figure.

The major factors in the selection of plots for the processing study were based on the rotation age of the plots and the average branching characteristics of the trees. Tree selection was then stratified to try to ensure a range of diameter and acoustic velocity was included from each plot (Section 0). Within each plot, it was not always possible to select 12 trees with the appropriate combination of characteristics. In one or two cases, trees that meet the criteria from the other plots being sampled (rotation age had to match) were used. Figures 35 and 36 show the average trees grouped by branch and age classifications, without regard to the actual plots they came from. They show that averaged board stiffness (both $MoE_{(average)}$ and $MoE_{(low)}$) appear to be negatively affected by branch size classification, *P. radiata* more strongly so than *P. pinaster*. Figure 37 shows that diameter was related to branch size. This is expected, as trees with greater branching are likely to have greater photosynthetic potential to drive diameter growth. Figure 38 shows that for *P. radiata* the smaller branched trees were also higher density, while the pattern for *P. pinaster* was mixed. Hence, it is likely that density is contributing strongly to the board stiffness patterns noted above.

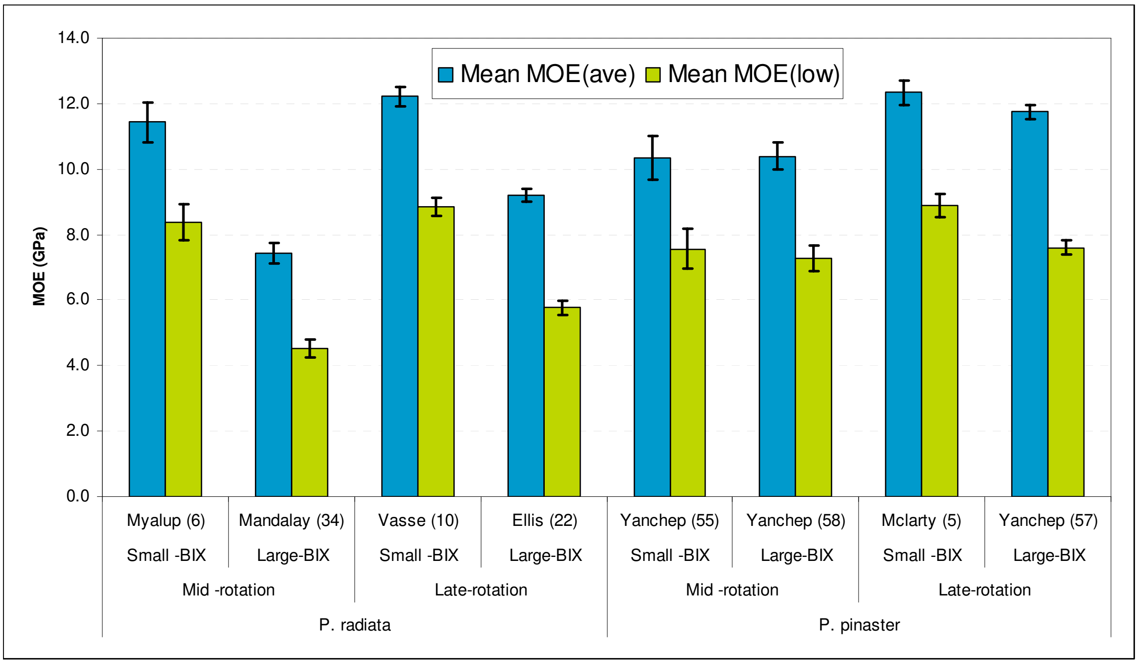


Figure 34: Plot averages (plot number shown in brackets) of $MOE_{(average)}$ and $MOE_{(low)}$ for every board sawn in the sawmill recovery study. Error bars shown are 95% CI for the means.

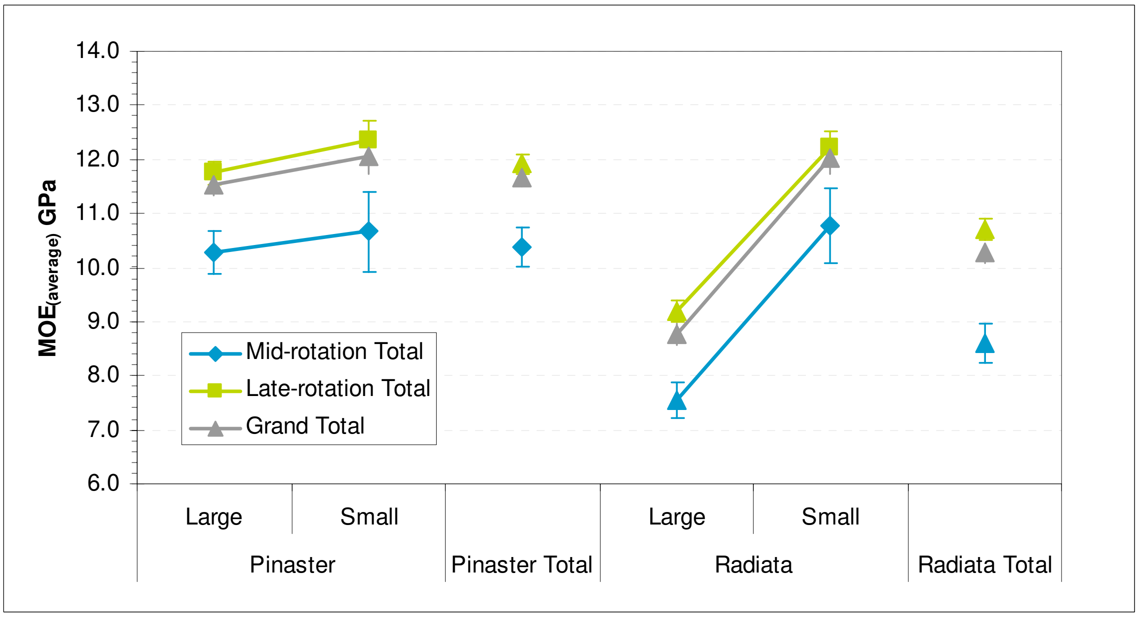


Figure 35: Average of board $MOE_{(average)}$ by branch diameter classification (Large/Small) and harvest type.

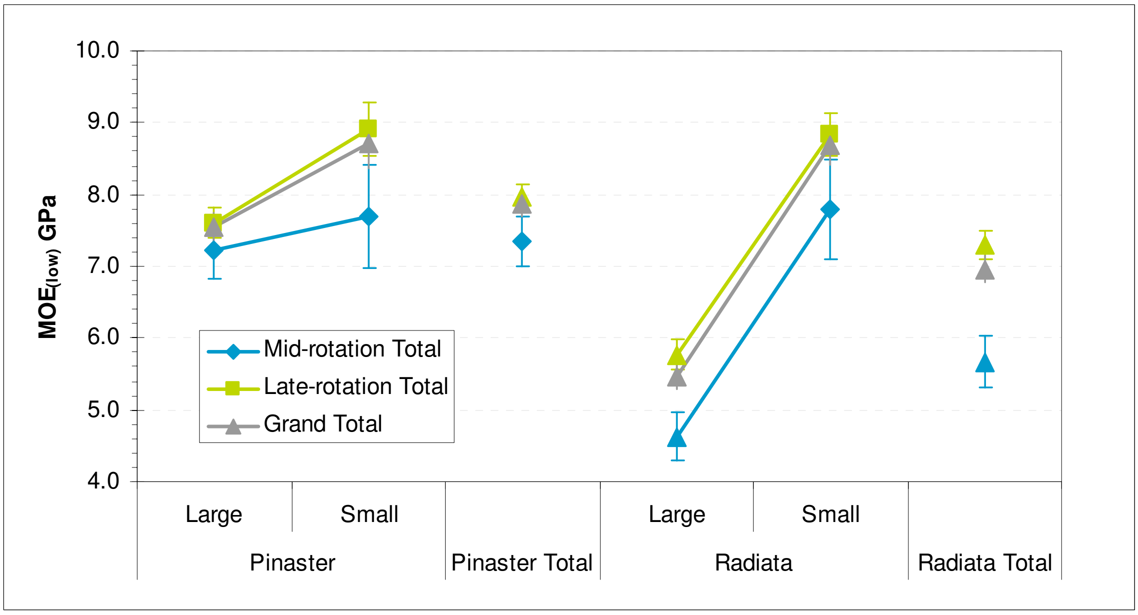


Figure 36: Average of board $MoE_{(low)}$ by branch diameter classification (Large/Small) and harvest type.

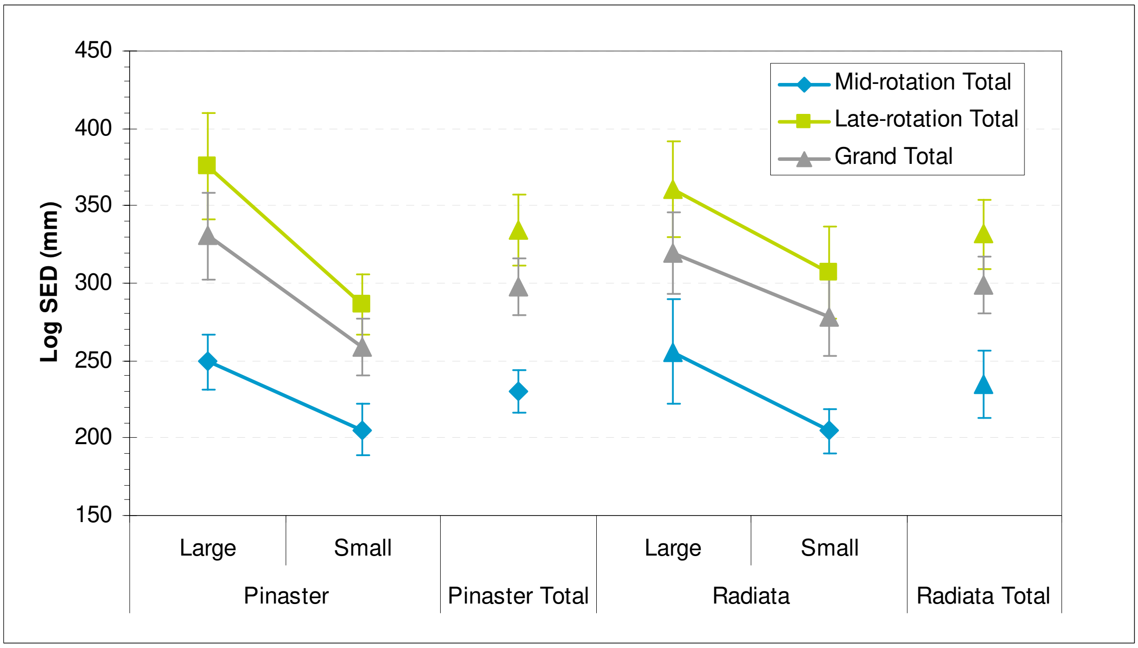


Figure 37: Average of log SED by branch diameter classification (Large/Small) and harvest type.

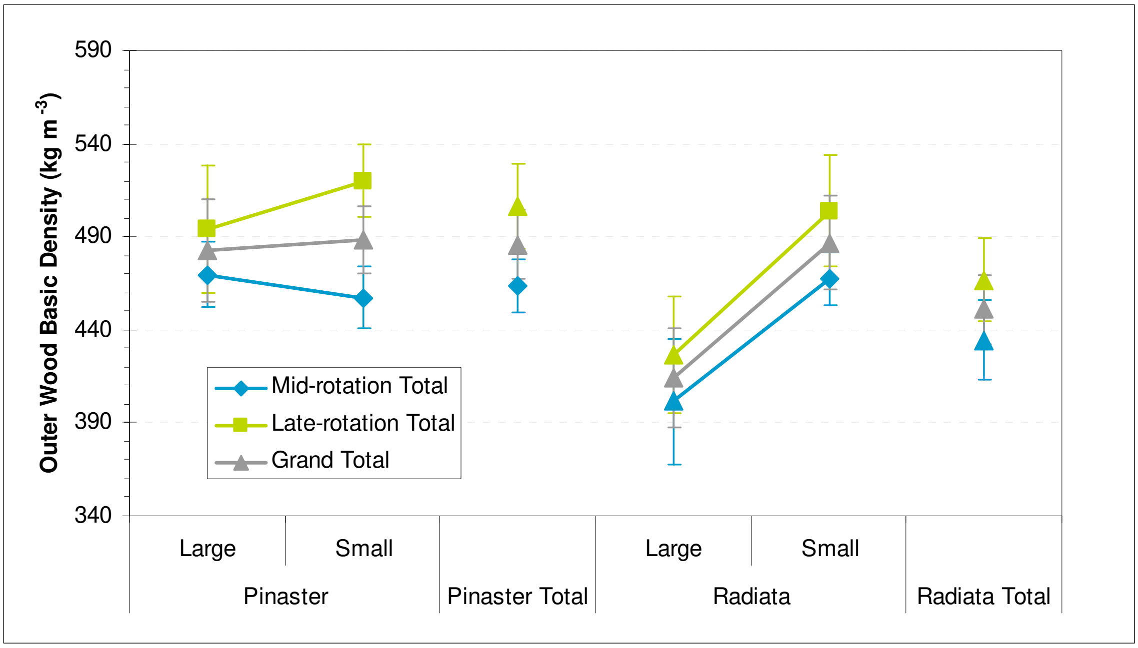


Figure 38: Average of tree outerwood basic density by branch diameter classification (Large/Small) and harvest type.

Prediction of board stiffness

Forest inventory includes the collection of tree data from standing trees, and it is logical as part of this process to try to quantify the expected timber quality from the trees as well. Such relationships between standing tree measurements and wood quality traits are outlined below. A summary of linear relationships between individual variables for each plot is also provided in Appendix 4. The next best thing to inventory tools is for tools that can predict wood quality as part of the harvesting process or in the processing of logs in the mill yard. As there is considerable variation between boards within a tree it, is unlikely any of the log or tree measures will give a good predictor of individual board grades. Hence, most of the predictive relationships examined here are attempted on the average grade recovery at either a tree, stem or plot level. $MoE_{(ave)}$ is of primary concern as a general indicator of wood stiffness and wood quality. However, as $MoE_{(low)}$ is principally what the machine stress grading into MGP grades is based on, attempts at predicting the average of this measure are also discussed.

Prediction of tree average of board $MoE_{(average)}$ from standing tree measurements

Figures 39 to 41 show $MoE_{(average)}$ regressed against three wood quality measures that are possible on standing trees (Outerwood density, ST300, and estimated MoE using a combination of ST300 and OW density). Equation 1 shows the simplified formula used to combine the acoustic velocity and density into an estimate of MoE. Given, that bulk density in this case would be green density, it has been common to use a fixed green value (e.g. 800 or 1000 kg m^3 — see Figure 24) as green density tends to vary much less than basic density. However, as outerwood basic density is reasonably straightforward to collect, it was evaluated to see if the variance in the basic density contributed more to the predictive power of the relationships. Such a benefit has been found before (Cown, Unpublished). However, in this instance, density on its own was the best of these three predictors for tree averaged board stiffness. It explained up to 80% of the variation in tree averaged $MoE_{(average)}$ for *P. radiata*, but only 38% for *P. pinaster*.

$$E_L = \rho \times V_L{}^2 \qquad (1)$$

Where:

E_L = dynamic longitudinal elastic modulus

V_L = acoustic longitudinal wave velocity

ρ = bulk density

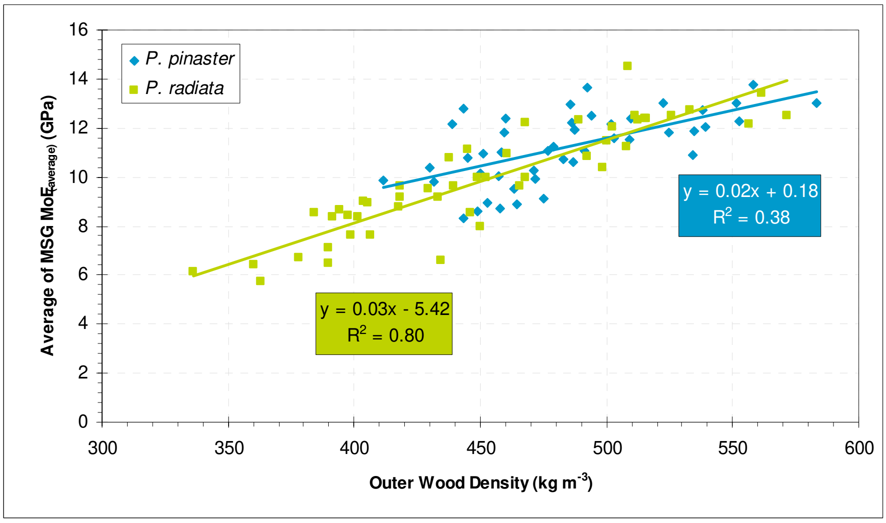


Figure 39: Tree average of board $MoE_{(average)}$ as a function of outerwood basic density.

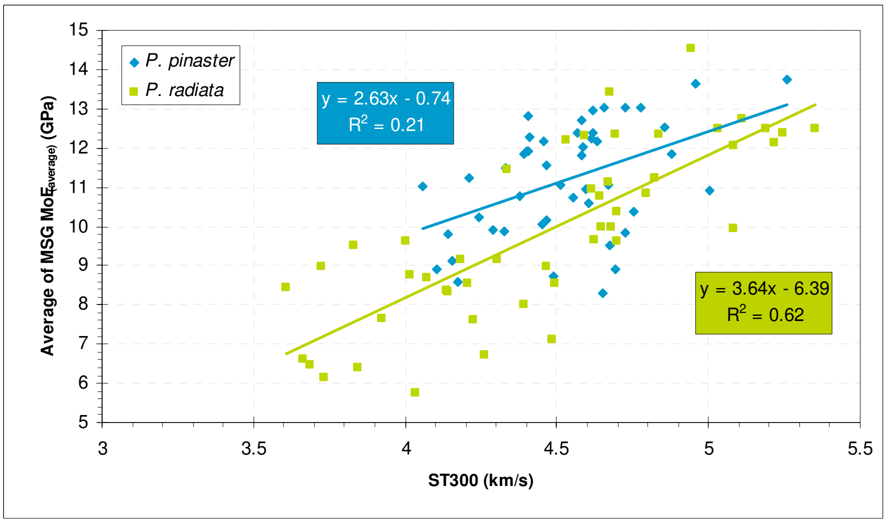


Figure 40: Tree average of board $MoE_{(average)}$ plotted against tree ST300 measurements

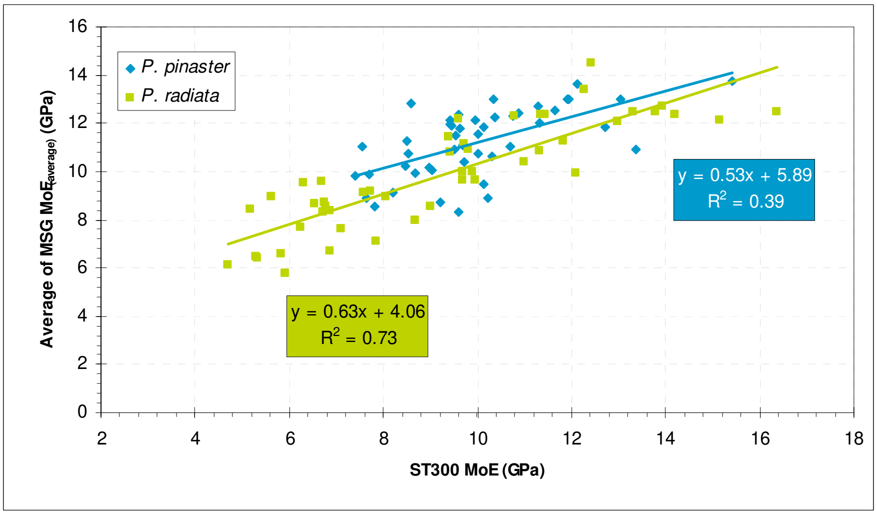


Figure 41: Tree average of board $MoE_{(average)}$ plotted against estimated tree MoE (calculated from BHOW density & ST300)

Prediction of tree average of board $MoE_{(low)}$ from standing tree measurements

Figures 42 to 44 show the relationship between $MoE_{(low)}$ and the standing tree measurements. Again, outerwood density was a better predictor of board $MoE_{(low)}$ (averaged by tree) than ST300 measurements or stiffness calculated from the ST300 and outerwood density measurements. The R^2s are generally lower than the equivalent R^2s for $MoE_{(average)}$. Given that $MoE_{(low)}$ can be more affected by localised defects such as knots, and the acoustic velocity and density are a more general measure of the outer sapwood properties, it is not surprising that the R^2 values are lower for the $MoE_{(low)}$ relationships. This is based on the assumption that most of the problems with knotty wood will occur in boards cut from the corewood.

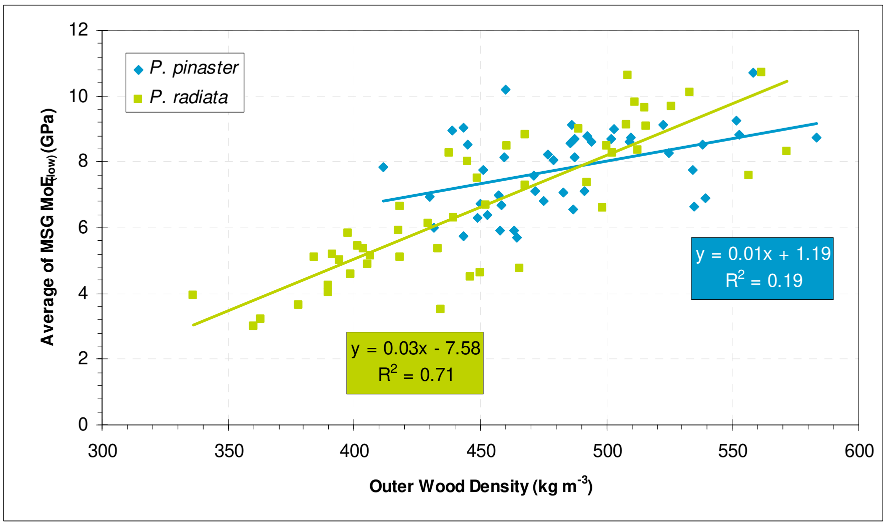


Figure 42: Tree average of board $MoE_{(low)}$ plotted against tree BHOW density measurements.

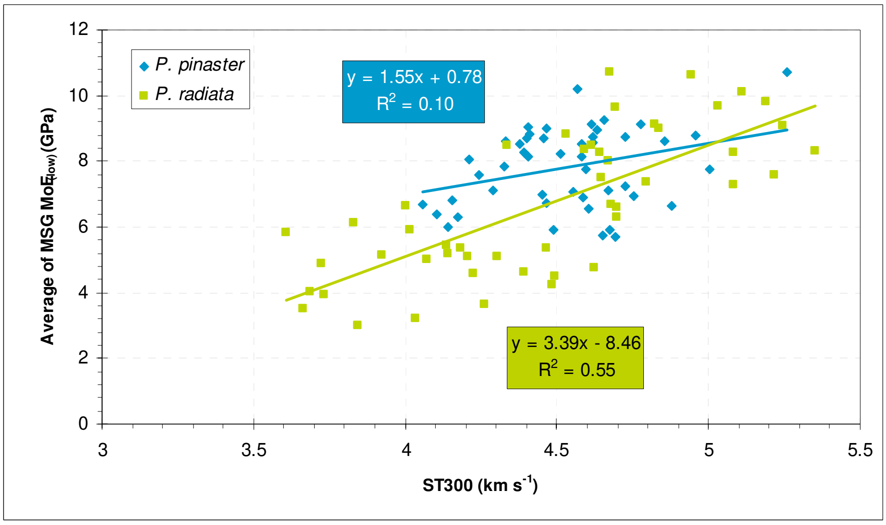


Figure 43: Tree average of board $MoE_{(low)}$ plotted against tree ST300 measurements

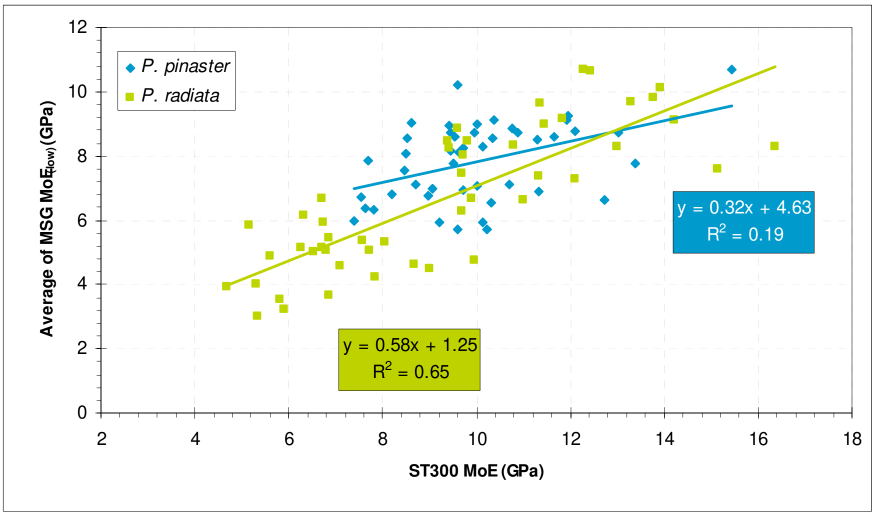


Figure 44: Tree average of board $MoE_{(low)}$ plotted against estimated tree MoE (calculated from BHOW basic density & ST300).

MoE prediction from stem acoustic measurements

Figures 45 and 46 show the relationships between harvested stem HM200 acoustic measurements and board $MoE_{(avg)}$ and board $MoE_{(low)}$ respectively. In this case, a comparison with Figures 40 and 43, shows that for *P. radiata* the HM200 is a poorer predictor of board stiffness than standing tree ST300 measurements ($MoE_{(ave)}$: R^2=0.62 Cf. R^2=0.57 — $MoE_{(low)}$: R^2=0.55 cf. R^2=0.48). However, for *P. pinaster* the R^2s were generally low, but the HM200 generally provided the better predictor ($MoE_{(ave)}$: R^2=0.21 cf. R^2=0.42 — $MoE_{(low)}$: R^2=0.10 cf. R^2=0.29).

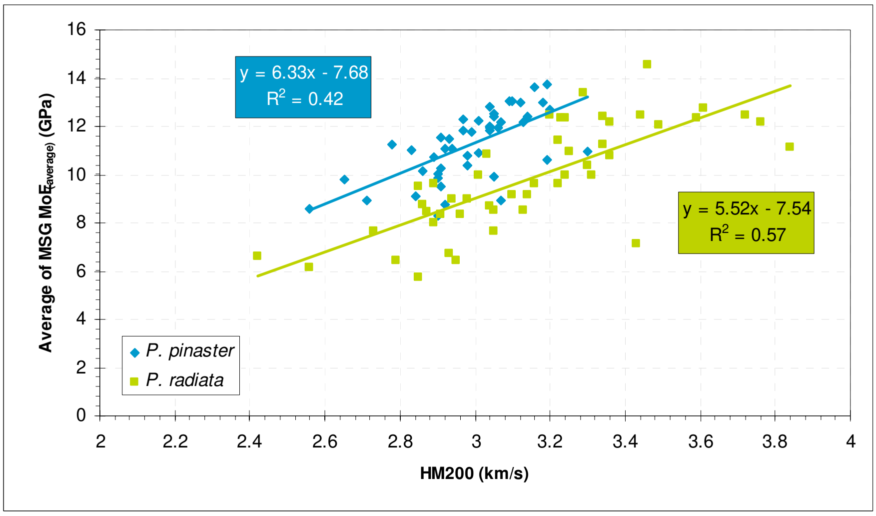


Figure 45: Tree average of board $MOE_{(average)}$ plotted against stem HM200.

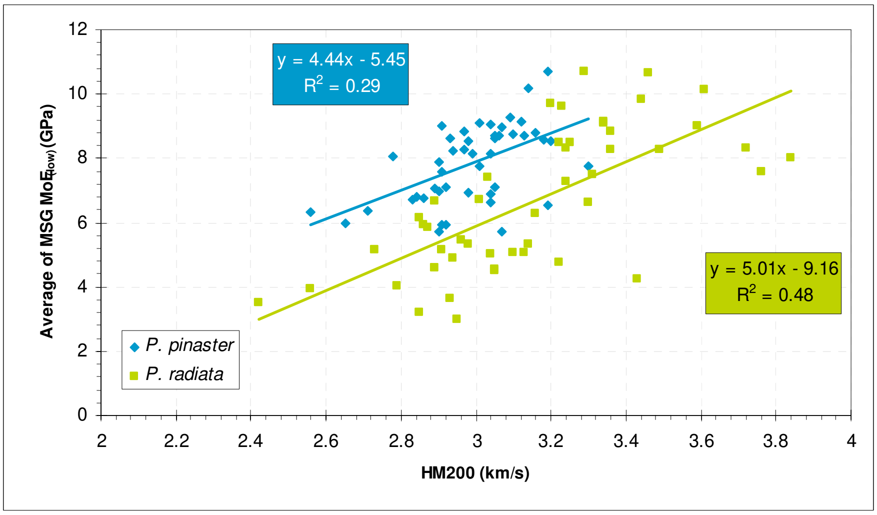


Figure 46: Tree average of board $MOE_{(low)}$ plotted against stem HM200

Mill-Log averaged predictions of board stiffness

Given that the board stiffness relationships at a tree level were only moderate, the next level is to see if the mill-log relationships are better. In theory, as the HM200 measurements are more representative over a shorter length of log, the relationships should be better. Indeed, Figures 47 and 48 show that the R^2s are improved. While the relationships are different between the two species, the R^2s are also much more even between the species. Although this confirms that the HM200 is a useful tool for each species, the R^2s are still only at best good or usable, and it would be interesting to try and identify the reason behind the two or three possible outlier values in both species.

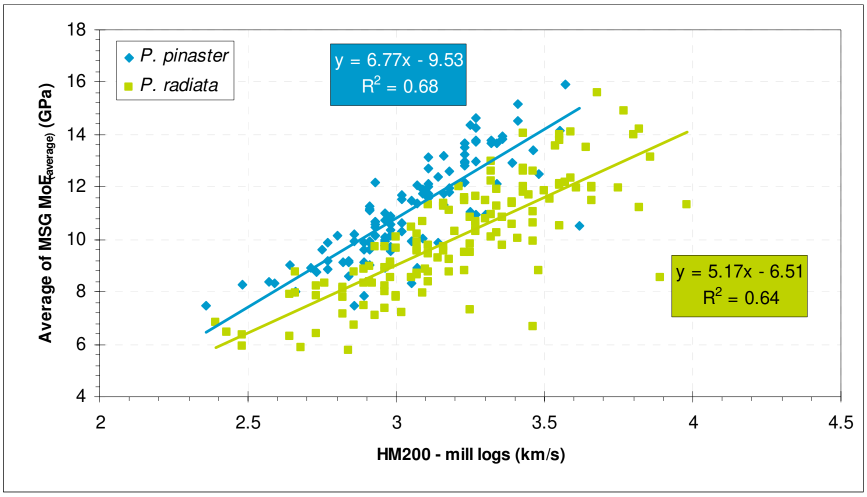


Figure 47: Mill log average of board $MoE_{(average)}$ plotted against mill log HM200 acoustic velocity.

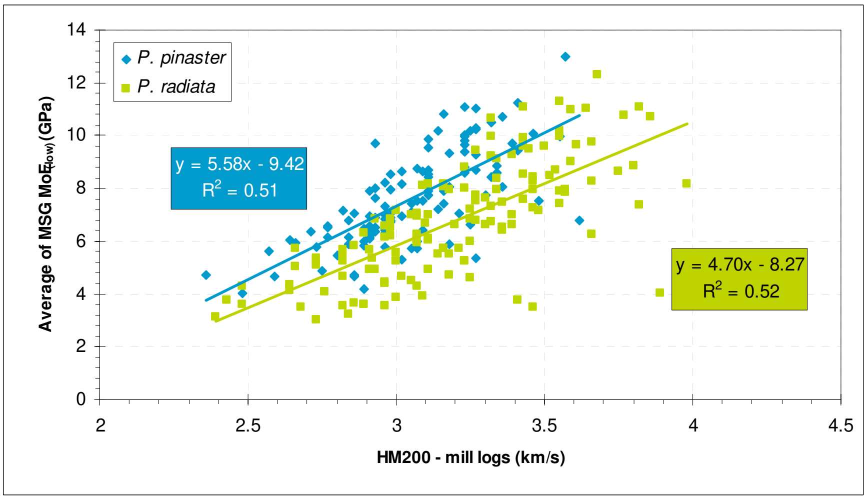


Figure 48: Mill log average of board $MoE_{(low)}$ plotted against mill log HM200 acoustic velocity

Site averaged predictions of board stiffness

As the relationships on a tree or log basis are only at best moderate to good, the usefulness of the acoustic tools was tested again on the basis of their ability to reliably measure plot averages. The relationship between average board stiffness and tree ST300 and stem HM300 (Figures 49 and 50) are strong for *P. radiata*; but much weaker for *P. pinaster*. Again, this is partly due to the reduced variation that is present in both acoustic measurements and stiffness for *P. pinaster*. However, the poor linear fit for *P. pinaster* suggests that something else may be contributing to this low R^2. Given that a similar pattern is observed in the HM200 data below it seems unlikely that a tool or user error is the cause of this problem, unless the error occurred in the machine stress grading machine or data recording – but the density results belie this. Since there are only four sites per species, it is also difficult to rule out that this is just due to random variation in the small number of sites.

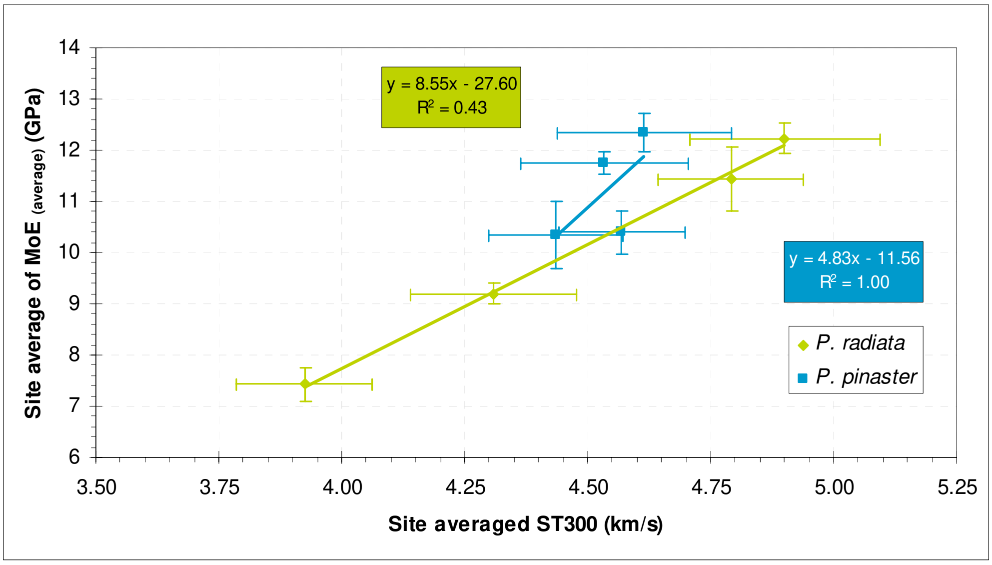


Figure 49. Average $MoE_{(average)}$ of all boards from a site plotted as a function of average ST300 measurement for the site, for *P. radiata*, *P. pinaster*. Error bars are 95% CI for the means.

Similar relationships with board stiffness prevail for the stem HM200 acoustic measurements (Figure 50). The larger displacement between the fitted lines for *P. radiata* and *P. pinaster* may result from the observation that the corewood of *P. pinaster* tends to be higher in density than for *P. radiata* (see Figure 27). It seems likely then that the HM200 measurements are more heavily weighted to measuring the corewood properties than the outerwood properties.

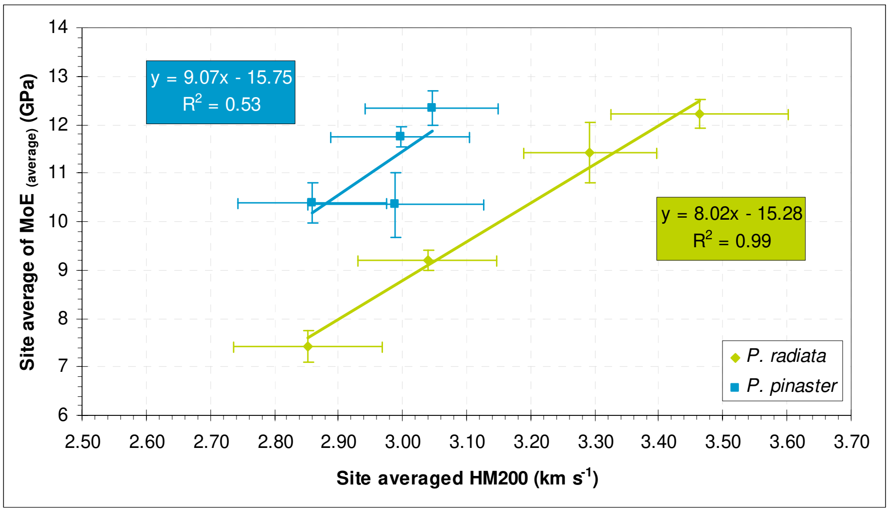


Figure 50: Average $MoE_{(average)}$ of all boards from a site as a function of average HM200 measurements (on full length stem) for each site.

Figure 51 shows that outerwood density was the much better predictor for *P. pinaster* and that the relationship was much more consistent across both species. Interestingly, there is a suggestion that the general pattern for the *P. pinaster* matches the pattern in the HM200 and ST300 data.

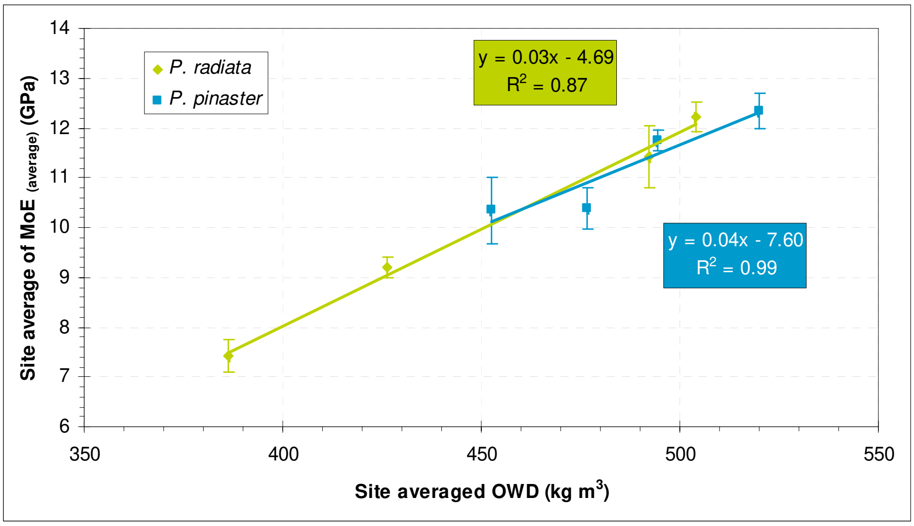


Figure 51: Average MOE of all boards from a site plotted against average outerwood basic density for each site.

Prediction of log averaged $MoE_{(low)}$ using multiple variables

Multiple regression analysis was used to see which combination of a range of tree and log variables was most useful in predicting the average $MoE_{(low)}$ recovered from each log. This analysis was undertaken as the ability to predict $MoE_{(low)}$ (which is the main criterion for MGP grading) is a major step in predicting the value of timber that can be expected from a log. The tree predictors used were the breast height outer wood density and ST300 measurement. The log predictors included log height, large end diameter, small end diameter, number of branch nodes, maximum branch size, average size of largest branch in each node, and total size of largest branch in each node. These predictor variables were selected on the basis that, while the branch and diameter measurements are much more difficult, they can still be done on standing trees. A forward stepwise regression was undertaken to determine which variables were kept in the predictive model. The R^2s ranged from 0.54 to 0.57 for both species. The 'B values' in the tables are the values that are actually used in the fitted regression equation and can be used to calculate the predicted values. The Beta values (standardised B values) are the B values divided by the variance in that variable. The magnitude of the Beta values gives an indication of the relative importance of each variable in terms of the variation explained by each predictor variable.

An important assumption of multiple regression is that the predictor variables are not correlated with each other. However, as is common in many biological systems, many of the predictor variables here are correlated to various degrees. Hence, as variables are included or removed from the regression model, the significance of different variables can change markedly. Thus, whether or not the variables are progressively added to the model (forward stepwise), rather than starting with all variables and progressively removing variables (backward stepwise) can result in very different variables being included in the final regression model. There is no correct way of avoiding this problem. In this case, only the forward stepwise results are presented as they generally included more variables in the final model. This was felt to give a better idea of all the variables that may possibly be important for a predictive model. Of course, which of the variable data can be collected on a cost effective basis should also be taken into consideration if a regression model was to be used extensively.

As expected from the earlier analysis, density was one of the strongest predictor variables for both species. The 'number of branches' (number of branch nodes) was then the only other variable that was included in the regression models for both species. The ST300 was included in the model for *P. pinaster* but not for *P. radiata*. This is not to suggest that the tool is not related to the stiffness of boards cut from the tree, it is just that most of the relationship is already being explained by, or attributed to, the density variable.

Table 9: Result of forward stepwise regression analysis for predicting board $MoE_{(low)}$ for *P. pinaster*. (R^2=0.56496, Adjusted R^2=0.544438).

	Beta	B	p-level
Intercept		-1.07352	0.629690
Number of Branches	-0.325232	-0.29552	0.000750
OW Basic Density	0.266647	0.01163	0.000770
Log Height	-0.392311	-0.76072	0.000047
ST300	0.149471	1.06630	0.051780
SED	0.098900	0.00187	0.159107

Table 10: Result of forward stepwise regression analysis for predicting board $MoE_{(low)}$ for *P. radiata*. (R^2=0.5811, Adjusted R^2=0.5715).

	Beta	**B**	**p-level**
Intercept		-3.03422	0.011410
OW Basic Density	0.639205	0.02438	0.000000
AVG Branch Size	-0.243181	-0.02583	0.000278
Number of Branches	-0.076462	-0.08084	0.215410

Prediction of the number of full length MGP 10 or better boards

In the softwood industry, there is still a premium for longer length or full-length boards that meet MGP grade requirements. The ability to assess stands or individual trees and assess their ability to produce full-length boards is therefore also desirable. Firstly then, an attempt was made to predict the percentage of boards from each 4.8m long mill log that were graded MGP10 or better, and not cut up into short length pieces. This was done using measurements that could be undertaken on standing trees. Primarily, this involved ST300 measurements and outerwood density, but as shortening mostly involves docking out knots, assessments of branching were also considered critical. In this case, the branch measurements made on the felled logs were used. Similar measurements, whilst more difficult and less robust, can be made on standing trees. As there were only a limited number of full length boards nominally recovered in this study, the analysis was also run again to include boards that had had only small lengths docked from either end, but were still longer than 4.2m.

Results for each species are discussed in the following sections.

P. pinaster

Table 11 summarise the results of multiple regression analysis to predict the percentage of boards per log that were MGP 10 or better and were either full-length or longer than 4.2m. The first column gives the results of the multivariate analysis, which was run on both dependent variables at the same time. This was undertaken due to the assumed correlation and similarity between the two univariate regressions. There is a risk with undertaking multiple univariate analysis on the same data set that the risk of Type I errors are higher than the assumed level of 5%. The multivariate analysis also gives a better indication of which independent variables are more important generally for the predicted variables being considered.

However, the univariate results are what would be used predictively, so the results of the forward stepwise univariate regressions are shown in the following columns. In this case, the predictor variables explained almost none of the variation in the percentage of full-length boards recovered from the *P. pinaster* logs (i.e. R^2s are very low).

Table 11: Results of multivariate multiple regression (Wilks) and univariate forward stepwise multiple regression for predicting percentage of *P. pinaster* MGP grade 10 or better boards that were either full length or longer than 4.2m long. Significant results (<0.05) are highlighted in red.

	Wilks	**Full Length Adj. R^2=0.0298**		**≥4.2m Adj. R^2=0.0371**	
	p	**Beta**	**B**	**Beta**	**B**
Intercept	0.058				5.8846
Log Height	0.828				
OW Basic Density	0.013	-0.173	-0.0413		
ST300	0.776				
Number of Branches	0.303				
Max Size of Branches	0.881				
Average size of Branches	0.100			0.313	0.1447
Sum of Branch Sizes	0.147			-0.472	-0.0406
LED	0.998				
SED	0.986				

P. radiata

Table 12 shows the results of the multiple regression fitting for the *P. radiata* data. Again, in this case this is no useable relationship for full length boards, but there is a moderate relationship found for the recovery of boards greater than 4.2 m long.

Table 12: Results of multivariate multiple regression (Wilks) and univariate forward stepwise multiple regression for predicting percentage of *P. radiata* MGP grade 10 or better boards that were either full length or longer than 4.2m long. Significant results (<0.05) are highlighted in red.

	Wilks	Full Length Adj. R^2=0.1475		≥4.2m Adj. R^2=0.4276	
	p	**Beta**	**B**	**Beta**	**B**
Intercept	0.415		-2.538		12.870
Log Height	0.289			-0.176	-2.274
OW Basic Density	0.002	0.376	0.080	0.334	0.086
ST300	0.501	-0.149	-3.763		
Number of Branches	0.953				
Max Size of Branches	0.251			0.291	0.141
Average size of Branches	0.581			-0.205	-0.147
Sum of Branch Sizes	0.479			-0.216	-0.027
LED	0.135	-0.295	-0.034	-0.560	-0.078
SED	0.486				

Prediction of MGP grade percentage of boards from individual logs

As the results for predicting recovery of full-length boards were generally poor, partly because of the small number of full length boards recovered, the ability to predict the percentage of boards from each log that were non-structural (NS), MGP10 or MGP12 and better, based on the full-length grades for each board, was attempted.

P. pinaster

Table 13 summarises the results of multivariate regression, and the forward stepwise univariate regressions used to identify which variables contribute to predicting the grade results for *P. pinaster*. In this case, a number of the variables are significant, but the overall R^2 are still poor suggesting the predictions are of little use.

Table 13: Results of multivariate multiple regression (Wilk's) and univariate forward stepwise multiple regression for predicting *P. pinaster* MGP grades (% of boards from a log which is NS, MGP10 and MGP12+). Significant results are highlighted in red.

	Wilks	**NS Adj. R^2=0.2416**		**MGP10 Adj. R^2=0.1929**		**MGP12+ Adj. R^2=0.1929**	
	p	**Beta**	**B**	**Beta**	**B**	**Beta**	**B**
Intercept	0.000		50.46		108.08		-112.07
Log Height	0.087	0.375	10.02	-0.184	-4.85	-0.208	-4.613
OW Basic Density	0.003	-0.238	-0.14			0.271	0.135
ST300	0.151					0.155	12.657
Number of Branches	0.066	0.234	2.93			-0.330	-3.424
Max Size of Branches	0.140	-0.297	-0.21	0.505	0.36		
Average Size of Branches	0.850						
Sum of Branch Size	0.475	0.247	0.04	-0.432	-0.08		
Large End Diameter	0.003	0.874	0.21	-1.277	-0.30	0.299	0.059
Small End Diameter	0.041	-0.728	-0.19	0.874	0.22		

P. radiata

Table 14 shows the results of the multiple regression analyses for *P. radiata*. In this case the R^2 are moderate and may be of some use, possibly not on an individual log basis as attempted here, but it may be more useful on a site average basis. Unfortunately given there are only four sites, it is impossible to try and fit a multiple regression when there are fewer data points than possible predictor variables.

Table 14: Results of multivariate multiple regression (Wilks) and univariate forward stepwise multiple regression for predicting *P. radiata* MGP grades (% of boards from a log which is NS, MGP10 and MGP12+). Significant results are highlighted in red.

	Wilks	NS		MGP10		MGP12+	
		Adj. R^2=0.5352		Adj. R^2=0.3157		Adj. R^2=0.4046	
	p	Beta	B	Beta	B	Beta	B
Intercept	0.000		176.80		-34.095		-43.27
Log Height	0.049	-0.120	-3.360	0.191	4.426	-0.155	-2.669
OW Basic Density	0.000	-0.597	-0.335	0.430	0.198	0.501	0.172
ST300	0.929						
Number of Branches	0.088					-0.274	-2.602
Max Size of Branches	0.438					0.213	0.137
AVG Branch Size	0.028	0.235	0.366			-0.531	-0.506
Sum of Branch Size	0.363					0.210	0.035
Large End Diameter	0.915	0.086	0.026	-0.198	-0.050		
Small End Diameter	0.990						

Quality assurance (In-grade) testing

The results of the in-grade testing of the sample boards are presented in Table 15. The MGP grades for the sample boards are based on the full length machine stress grading data for each board. Normal practice for Wespine is that, based on MSG stiffness and an override assessment primarily of knot characteristics, optimised lengths of shorter (child) boards are cut from the full length (parent) boards. In this study, while the information for the child lengths and grades were collected, the boards were not physically cut. For this assessment, a full-length MGP grade was assigned to each sample board based on the lowest stiffness measured for each board ($MoE_{(low)}$). This was done using the stiffness cut-off values that were being used by Wespine on the day this material was processed through their drymill.

Table 15 shows that for *P. radiata* the stiffness and strength characteristics of the MGP10 population of boards were both low, but each was still acceptable for a one-off test result. The only outright failure was for the strength of the *P. pinaster* MGP12 boards. However, if the two species were combined, then all MGP grades passed, even though the strength of the MGP12 boards was still a little lower than required. Given the small numbers of boards, particularly in the MGP12 grouping, the combined results are probably more indicative of the characteristics of the MGP grades as a whole. This result also suggests that the in-grade properties of the shorter length material, where knots were often docked out, should comfortably meet the MGP grade property requirements.

Wespine uses a log scanning system, from which it is possible to determine some indication of knot characteristics. They developed a test categorisation of logs as either being ‘clean’ or ‘knobbly’. This characterisation was included as a variable in the grading on the boards that were used for the in-grade testing. In this case, boards were downgraded one grade from the nominal grade assigned using just the machine stress grade cut-offs. Unfortunately, Table 16 shows that this did not lead to a significant improvement in the required properties of the boards in each grade. Partly this is just a reflection of the random location of the four point bending tests. In this case, a number of the low MoR boards are from relatively clean logs, but by chance the testing location must have coincided with the few small knots, or other forms of weakness such as sloping grain on the boards, and resulted in a low value.

Other modifications to the grading groupings were attempted using other branch/knot variables such as number of branch nodes, max branch size, average size of largest branch in each node, total of largest branch in each node and knot area ratio (KAR) of knots that affect in-grade result. As expected, the KAR provided the best improvement (Table 17), although the MoE result for the MGP10 *P. radiata* was still low. This was expected as there is a visual override of the MSG for knots in most MGP production systems. Of the other variables, average branch size provided the next best regrading (Table 18). However, in this case the MoR of the MGP10 *P. radiata* was lower than ideal. The fact that the regrading of one or two boards in the *P. radiata* sample had such a significant effect on the in-grade properties, highlights that with the small sample size here the results should be used cautiously. However, the results can still provide guidance on where grading improvements can be made, and tentatively suggest that there is some possibility for using log measures to improve the grading of boards that are subsequently cut from the logs. A purpose designed study would be required to validate this hypothesis.

Table 15: Verification of MGP grades from 4-point in-grade testing of sample boards (AS/NZS 4063: 1992)

	P. radiata						***P. pinaster***						**Combined**					
	NS		MGP10		MGP12		NS		MGP10		MGP12		NS		MGP10		MGP12	
	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)
Count	76		58		13		28		93		29		104		151		42	
R_k		9.38		15.52		27.71		8.30		16.97		22.94		10.17		17.06		25.27
R_{basic}		3.24		5.39		10.58		2.68		5.96		8.34		3.44		5.96		9.27
$R_{k,norm}$		9.58		**15.93**		**31.23**		7.90		**17.59**		**24.62**		10.15		**17.60**		**27.39**
Required MoR				16		28				16		28				16		28
Allowable MoR (0.91)				14.56		25.48				14.56		25.48				14.56		25.48
Pass/Fail				**Pass**		**Pass**				**Pass**		**Fail**				**Pass**		**Pass**
E_{k1}	6.80		9.58		14.54		8.23		10.52		14.55		7.23		10.20		14.60	
E_{k2}	5.40		9.95		18.12		7.29		10.62		15.75		5.61		10.50		16.88	
E_k	5.40		**9.58**		**14.54**		7.29		**10.52**		**14.55**		5.61		**10.20**		**14.60**	
Required MoE			10		12.7				10		12.7				10		12.7	
Allowable MoE (0.94)			9.4		11.94				9.4		11.94				9.4		11.94	
Pass/Fail			**Pass**		**Pass**				**Pass**		**Pass**				**Pass**		**Pass**	

Table 16: Modifed MGP in-grade properties when log scanned ‘Knobbliness’ was included as a grading criteria (boards from logs identified as knobby were downgraded 1 grade from original machine stress grade).

	P.radiata						*P. pinaster*						*Combined*					
	NS		MGP10		MGP12		NS		MGP10		MGP12		NS		MGP10		MGP12	
	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj
	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)
Count	96		46		5		38		112		0		134		158		5	
R_k		10.69		15.29		24.72		9.27		19.06				10.98		17.15		24.72
R_{basic}		3.67		5.24		9.43		3.05		6.53				3.72		5.86		9.43
$R_{k,norm}$		10.83		15.49		27.83		9.02		19.28				11.00		17.29		27.83
Required MoR				16		28				16						16		28
Allowable MoR (0.91)				**14.56**		**25.48**				**14.56**						**14.56**		**25.48**
Pass/Fail				**Pass**		**Pass**				**Pass**						**Pass**		Pass
E_{k1}	7.45		10.23		14.08		8.62		11.63				7.83		11.28		14.08	
E_{k2}	5.52		9.52		18.32		6.89		10.87				5.88		10.70		18.32	
E_k	5.52		9.52		14.08		6.89		10.87				5.88		10.70		14.08	
Required MoE			10		12.7				10						10		12.7	
Allowable MoE (0.94)			**9.4**		**11.94**				**9.4**						**9.4**		**11.94**	
Pass/Fail			Pass		Pass				**Pass**						**Pass**		**Pass**	

Table 17: Modifed MGP in-grade properties when board KAR was included as a grading criteria (nominal MGP 12 boards with a KAR greater than 40% where downgraded 1 grade, while nominal MGP10 boards with a KAR greater than 30% were downgraded).

	P.radiata						*P. pinaster*						*Combined*					
	NS		MGP10		MGP12		NS		MGP10		MGP12		NS		MGP10		MGP12	
	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)	MoEj (GPa)	MoRj (MPa)
Count	81		53		13		48		75		27		129		128		40	
Rk		10.04		15.73		27.71		10.30		18.12		26.78		10.95		17.07		29.45
Rbasic		3.47		5.48		10.58		3.49		6.33		9.87		3.75		5.95		10.91
Rk,norm		10.24		16.18		31.23		10.29		18.70		29.16		11.06		17.57		32.22
Required MoR				16.00		28.00				16.00		28.00				16.00		28.00
Allowable MoR (0.91)				**14.56**		**25.48**				**14.56**		**25.48**				**14.56**		**25.48**
Pass/Fail				**Pass**		**Pass**				**Pass**		**Pass**				**Pass**		**Pass**
Ek1	6.97		9.57		14.54		9.07		10.64		14.64		7.79		10.25		14.67	
Ek2	5.41		9.93		18.12		8.75		10.32		16.69		5.82		10.17		17.30	
Ek	5.41		9.57		14.54		8.75		10.32		14.64		5.82		10.17		14.67	
Required MoE			10.00		12.70				10.00		12.70				10.00		12.70	
Allowable MoE (0.94)			**9.40**		**11.94**				**9.40**		**11.94**				**9.40**		**11.94**	
Pass/Fail			**Pass**		**Pass**				**Pass**		**Pass**				**Pass**		**Pass**	

Table 18: Modifed MGP in-grade properties when the average of largest branch in each node of each logs was included as a grading criteria (nominal MGP 12 boards with a average branch greater than 40 mm where downgraded 1 grade, while nominal MGP10 boards with an average branch size of greater than 60 mm were downgraded).

	P.radiata						*P. pinaster*						*Combined*					
	NS		MGP10		MGP12		NS		MGP10		MGP12		NS		MGP10		MGP12	
	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj	MoEj	MoRj
	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)
Count	80		53		14		39		79		32		119		132		46	
Rk		9.96		14.99		26.56		9.73		15.97		28.32		10.74		16.67		29.89
Rbasic		3.46		5.20		9.87		3.25		5.45		10.38		3.67		5.71		10.98
Rk,norm		**10.22**		15.34		29.15		**9.60**		16.09		30.66		**10.83**		16.87		32.44
Required MoR				16.00		28.00				16.00		28.00				16.00		28.00
Allowable MoR (0.91)				**14.56**		**25.48**				**14.56**		**25.48**				**14.56**		**25.48**
Pass/Fail				**Pass**		**Pass**				**Pass**		**Pass**				**Pass**		**Pass**
Ek1	6.91		9.65		13.93		8.71		10.63		14.03		7.54		10.29		14.06	
Ek2	5.42		10.12		16.73		8.35		10.49		16.33		5.74		10.60		16.53	
Ek	**5.42**		9.65		13.93		**8.35**		10.49		14.03		**5.74**		10.29		14.06	
Required MoE			10.00		12.70				10.00		12.70				10.00		12.70	
Allowable MoE (0.94)			**9.40**		**11.94**				**9.40**		**11.94**				**9.40**		**11.94**	
Pass/Fail			**Pass**		**Pass**				**Pass**		**Pass**				**Pass**		**Pass**	

Prediction of strength

Although prediction of strength would be extremely valuable, the small sample of boards that were tested to failure do not provide for any reliable relationships to be established with tree or log features. This is because the random location of the bending test adds a considerable amount of variation to the MoR results. The testing point could be in clear wood, resulting in a high MoR, or right on a knot resulting in a low MoR value. In this study there was between one and ten boards per tree sampled for the in-grade testing. An example of the lack of relationship is shown in Figure 52, which plots tree averaged MoR results against ST300 acoustic velocity.

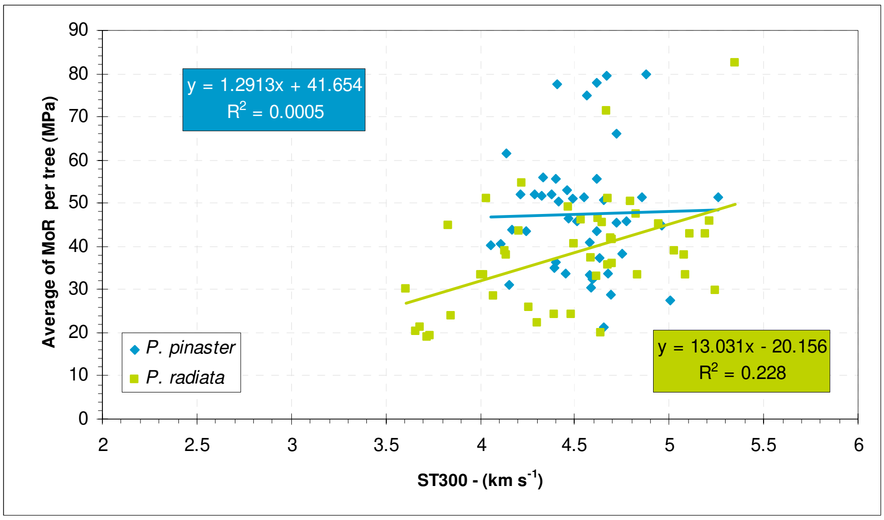


Figure 52: Tree average of MoR as a function of ST300 measurements.

Discussion

Previous wood quality studies have revealed significant regional variation in wood density and acoustic values (Cown *et al.*, 1991, 2005, 2006; Roper *et al,* 2004). In the case of Western Australian plantations, site differences were found to be small and mostly related to crop age. The variation between stems within plots contributed most to the observed variation. For instance the typical standard deviation for outerwood density is about 30 kg m^{-3} and for ST300 around 0.25 km sec^{-1}, which means that the range within stands is about 120 kg m^{-3} and 1 km sec^{-1} respectively — much greater than the differences recorded between sites and associated with silvicultural operations. However, these values are absolutely typical of stands elsewhere (Cown *et al.* 1991, 2004, 2005*).* This suggests that the greatest gains are likely to be made through application of material segregation techniques, and in the longer term, tree breeding (Ridley-Ellis *et al.*, 2008). These levels of within site variation were comparable with those observed in the other regional studies conducted in Australia and New Zealand.

In terms of prediction of timber properties, site averages of basic tree characteristics (e.g. DBHOB, wood density, acoustics, branching) gave a good indication of relative average quality between sites. *P. pinaster* generally showed much less variation than *P. radiata* in all measurements including density, perhaps because of greater age at harvest. Hence, most relationships and predictions for *P. pinaster* were generally weaker than for *P. radiata*. However, if younger stands were to be assessed the predictive assessment tools may become more useful.

An unexpected result was that the outerwood density measurements performed significantly better than either the ST300 or the HM200 for predicting timber stiffness. It should be noted though, that the Green Triangle study also indicated that density was the most important variable for predicting grade recovery. The current study is one of the first to include standing tree density and acoustics as well as log HM200 and timber recovery. Associations between assessed variables were few – even the “normal” negative correlations between diameter and density and ST300 were not confirmed in the data. However, a moderate to poor correlation was established between outerwood density and ST300 values (65% and 24% for *P. radiata* and *P. pinaster* respectively). Few studies have examined relationships between wood density and acoustic values in relation to timber stiffness, and most (e.g. unpublished WQI studies) have shown variable levels of association (Gaunt *et al.,* 2004*).* Some of the variation has been attributed to variable stand ages and different tool performance. However, a UK study in Sitka spruce (Moore *et al.,* 2009) found that at an individual log level acoustics could explain at most about 50% of the variation in sawn timber stiffness. WQI results have shown that the HM200 values in particular are affected by the green density of the logs, which is strongly related to heartwood %. It is unrealistic to expect HM200 predictions to be consistent across species without calibrating for this effect.

Density cores are a very convenient and fairly accurate measure in the forest, and the values can be used for “growing forward” with a density algorithm. This is not yet proven with any degree of confidence for stem velocity. This may happen in the future, but a lot of research will be needed to confirm projections of standing tree values in terms of present and future log values, and the relationship of log velocity to actual timber stiffness in the sawmill.

The variation in individual stem and log characteristics presents opportunities for log segregation either in the forest or at the mill. The results of this study indicated that at the bush-log level, wood density is the most important variable. Unfortunately, it is not as convenient to assess as using the HM200. And especially at the mill-log scale, this study generally supports that log acoustic tools are likely to be the most cost-effective tool for this type of segregation. Further research (such as assessing green density or branching) may reveal improvements to the measurement method.

Intuitively, branching characteristics should be important for board stiffness and especially important for board strength. For *P. pinaster*, the branching criteria used to select trees for the processing study did not appear to have a large effect on the board stiffness, nevertheless as the density pattern was mixed it is likely that at least some of this difference is uniquely due to branching. However, for *P. radiata* possible associations between density, log diameter, and branching makes it difficult to statistically quantify the unique contributions of these variables to the significant differences observed in board stiffness. The importance of branching should be most clear in measures of $MoE_{(low)}$, which typically corresponds to the localised grade-limiting section of the board. However, even here the inclusion of branching characteristics in the statistical models developed to predict average board $MoE_{(low)}$ from a mill-log, generally only provided a marginal improvement in the predictive power of the HM200 measurements on their own.

For the in-grade testing, branching and knots are intuitively likely to be critical for strength properties. Anecdotally, the WA resource is thought to mostly have a problem producing boards that meet the strength requirements for MGP. Unfortunately, the sample size and random nature of the sampling point in this study, did not allow for good predictive relationships between branching characteristics and MGP grade characteristics.

In comparison to results here, WQI studies have shown variable results when relating standing tree properties to actual timber recovery (Cown *et al.*, 2004; Fife *et al.* 2004; Gaunt *et al.* 2004; Shakti and Walker, 2004). A recent study of NSW radiata pine also indicated that standing tree acoustic velocity was more closely related to log acoustic velocity (HM200) and static MoE, than was outerwood density (Raymond *et al.,* 2008). The conclusions were that the acoustic tree tools can provide estimates of timber stiffness – the standing tree approach being less accurate than the log tool (HM200). Wood density was seen to be an equally effective predictor in older stands. Comparison of the NSW results to this study need to be interpreted a little cautiously though given that the NSW study measured static MoE on short-clear specimens, not on industry production of structural boards.

Conclusions and recommendations

The analyses showed that wood density levels increased with age in a similar fashion to medium- and high-density sites in NZ and Australia. No clear differences were found between sub-regions within the sample region in wood density or standing tree acoustic values, although the later were found to be highly variable. Branch sizes and external resin bleed in *P. radiata* were also seen to be highly variable. Visible resin in the *P. pinaster* stands was negligible.

The anticipated sub-regional differences in wood quality, as determined by the methods used in this study, did not eventuate. In general terms, the resource was very uniform and of high quality in relation to basic wood density and stiffness. It was also found that the variation in wood quality assessment parameters was much greater within sites than between sites. A stated outcome from this project was to produce wood quality maps for the resource in order to better manage inputs to sawmills. However due to the general regional uniformity and the within-site variability it was deemed that producing the maps would be of little benefit. In examining the wood quality data in relation to thinning and pruning, no obvious relationships were uncovered.

For forest resource evaluation it is recommended that outerwood density cores be collected on a routine basis, along with standing tree velocity values for the same stems, and visual assessments of branch size. Atlas Forecaster allows prediction forward in time of these variables, and given the relationship between density and stiffness, this is a useful management tool. The stand average values are indicative of the expected timber quality from forest stands, but for more accurate segregation of logs, tools such as HM200 will be useful, provided they are calibrated for each species. It is expected that with time, better predictions of timber stiffness will be possible as the impacts of other log properties such as average moisture content are incorporated into the system.

The in-grade testing identified a possible strength problem with MGP12 graded boards from *P. pinaster.* However, the in-grade testing conducted here was not necessarily representative of the wider population resource.

A separate study specifically designed to address these questions would be required to provide an answer as to which measures of branching provide the optimal information on a cost/benefit basis.

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References

AS/NZS 1748 (1997) Timber – Stress-graded – Product requirements for mechanically stress-graded timber. Standards Australia/Standards New Zealand.

AS/NZS 4063 (1992) Timber – Stress-graded – In-grade strength and stiffness evaluation. Standards Australia/Standards. Standards Australia/Standards New Zealand.

ASTM 2915 (2003). Standard practice for evaluating allowable properties for grades of structural lumber. American Society for Testing and Materials.

Brennan, G.K., Baggetta, C.E., Meacham, G. (1997) Wood density survey of 19- and 29-year old radiata pine trees grown in the south-east of Western Australia. CALM Unpublished Report: 25pp.

Butcher, T. (2007) Achievements in forest tree genetic improvement in Australia and New Zealand 7: Maritime and Brutian pine tree improvement programs in Western Australia. *Australian Forestry* 70(3): 141-151.

Carter, P.; Lausberg, M. (2004) NEW TECHNOLOGIES AND POTENTIAL GAINS FROM SEGREGATING TREES IN THE FOREST AND LOGS ON THE SKID OR LOG YARD – THE CHH EXPERIENCE. Proceedings Wood Quality (2004) Practical Tools and New Technologies to Improve Segregation of Logs and Lumber for Processing. Albury, August 2004.

Cown, D.J. (1973) Effects of severe thinning and pruning treatments on the intrinsic wood properties of young radiata pine. *New Zealand Journal of Forestry Science* 3(3): 379-389.

Cown, D.J. (1974) Comparison of the effect of two thinning regimes on some wood properties of radiata pine. *New Zealand Journal of Forestry Science* 4(3): 540-551.

Cown, D.J. (1999) New Zealand pine and Douglas-fir: Suitability for processing. *Forest Research Bulletin No. 216*: 72pp.

Cown, D.J., McConchie, D.L. (1981) Effects of thinning and fertiliser application on wood properties of Pinus radiata. *New Zealand Journal of Forestry Science* 11(2): 79-91.

Cown, D.J., McConchie, D.L. (1982) Rotation age and silvicultural effects on wood properties of four stands of Pinus radiata. *New Zealand Journal of Forestry Science* 12(1): 71-85.

Cown, D.J., McConchie, D.L. and Young, G.D. (1991) Radiata pine wood properties survey. *FRI Bulletin No. 50* (revised).

Cown, D.J.; Downes, G.; McKinley, R.B.; Kimberley, M.O.; Turner, J.R.; Lee, J.; Holden, G. (2004) Utilisation Study – Golden Downs and Kaingaroa Forests. *WQI Report RES 25*: 48pp.

Cown, D.J.; McKinley, Kimberley, M.O.; R.B.; Downes, G.; Jones, T. (2005) WQI Benchmarking Study- Final Summary Report. *WQI Report RES 34*: 89pp.
Cown, D.J.; McKinley, R.B.; Kimberley, M.O.; Hodgkiss, P. Downes, G.; Bruce, J.; Hall, M.; McConchie, D.L.; Lausberg, M. (2006) Benchmarking the wood properties of radiata pine plantations: Tasmania. *FWPA Project No. PN06.3014*: 58pp.
Downes G.M.; Nyakuengama J.G.; Evans R.; Northway R.; Blakemore P.; Dickson R.L.; Lausberg M. (2002) Relationship between wood density, microfibril angle and stiffness in thinned and fertilized *Pinus radiata* (D.Don). *IAWA Journal 23*(3) 235-266.
Fife, D., Gritton, D., Ilic, J., Kimberley, M.O., Lausberg, M., McConchie, D.L. (2004) Assessment of standing tree stiffness in Australian radiata pine. *WQI Report No. 10*: 35pp.
FPC (2007) Forest Products Commission's Tree Farming and Industry Development Plan: A 20 year vision. Maritime Pine –Mid West. Forest products Commission, 16pp.
Gaunt, D., Guenole, L., Huang, C_L., Kimberley, M.O. Lausberg, M., McConchie, D.L. (2004) Comparison of instruments for measuring sound velocity and wood density in standing trees: West Coast standing tree stiffness project Part 2: Correlation between sound velocity measurement methods and lumber stiffness. WQI Report No. STR 6: 26pp.
McConchie, D.L. (2003) Field guide to assist recognition and classification of resinous defects on the bark of radiata pine. WQI Report No. 12: 35pp.
Moore, J., Lyon, A., Searles, G., Ridley-Ellis, D. (2009) The use of acoustic-based ndt to predict the wood properties of uk-grown sitka spruce at different stages in the wood supply chain. Paper presented at 16th International Nondestructive Testing and Evaluation of Wood Symposium, Beijing, May 2009.
Raymond, C.A., Joe, B., Anderson, D.W., Watt, D.J. (2008) Effect of thinning on relationships between three measures of wood stiffness in *Pinus radiata*: standing trees vs. logs vs. short clear specimens. Canadian Journal of Forest Research 38: 2870-2879.
Ridley-Ellis, D., Moore, J., Lyon, A. (2008) Strength grading and the end-user – lessons from the SIRT project at Napier University. COST E53 Conference, Delft: 223-232.
Roper, J., Ball, R., Davy, B., Downes, G., Fife, D., Gaunt, D., Gritton, D., Ilic, J., Koehler, A., McKinley, R., Morrow, A., Northway, R., Penellum, B., Rombouts, J., and Pongracic, S. (2004) Resource evaluation for future profit: Part A—wood property survey of the Green Triangle region. Forest and Wood Products Research and Development Corporation, Project PN03.3906
Shakti, S. and Walker, J. (2004) Associations between acoustic velocity, MoE and wood density. WQI Report No. STR 5: 31pp.
Shepherd, K.R.; Forest, W.G. (1973) Growth of radiata pine following thinning. For. Rev. 52: 133-142.
Siemon, G.R. (1973) Effects of thinning on crown structure, stem form and wood density of radiata pine. Ph.D. Thesis. Australian National University. Canberra, Australia.
Siemon, G.R. (1983) Strength properties of Pinus pinaster Ait. in Western Australia. Forests Department of Western Australia Research Paper 72: 6pp.
Siemon, G.R., White, K.J., Thomson, A.B. (1989) Sawmilling trial of agroforestry and conventionally-grown radiata pine. Department of Conservation and Land Management Wood Utilisation Research Centre Report No. 8: 16pp.
Siemon, G.R. (1995) Wood density and spiral grain of radiata pine and maritime pine grown in Donnybrook Sunklands trial plots. CALM Science 1(3): 251-257.
Siemon, G.R. (2001) Wood density surveys of pedigreed maritime pine in Gnangara, Pinjar and Yanchep plantations, CALM Science 3(4): 487-498.

Smith, D.M. (1954) Maximum moisture method for determining the specific gravity of small samples. USDA, Forest Products Laboratory Report No. 2014: 8pp.
Sutton, W.R.J.; Harris, J.M. (1974) Effect of heavy thinning on wood density in radiata pine. . NZ Journal of Forestry Science 4(1): 112-115.
Wood, G.B.; Siemon, G.R. (1981) Effect of thinning on wood properties of radiata pine. Aust. For. Res. 11: 149-159.
Zobel, B.J. and Sprague, J.R. (1998) Juvenile wood in forest trees. Springer Series in Wood Science, Springer-Verlag Berlin, Heidelberg, 1998: 300pp.

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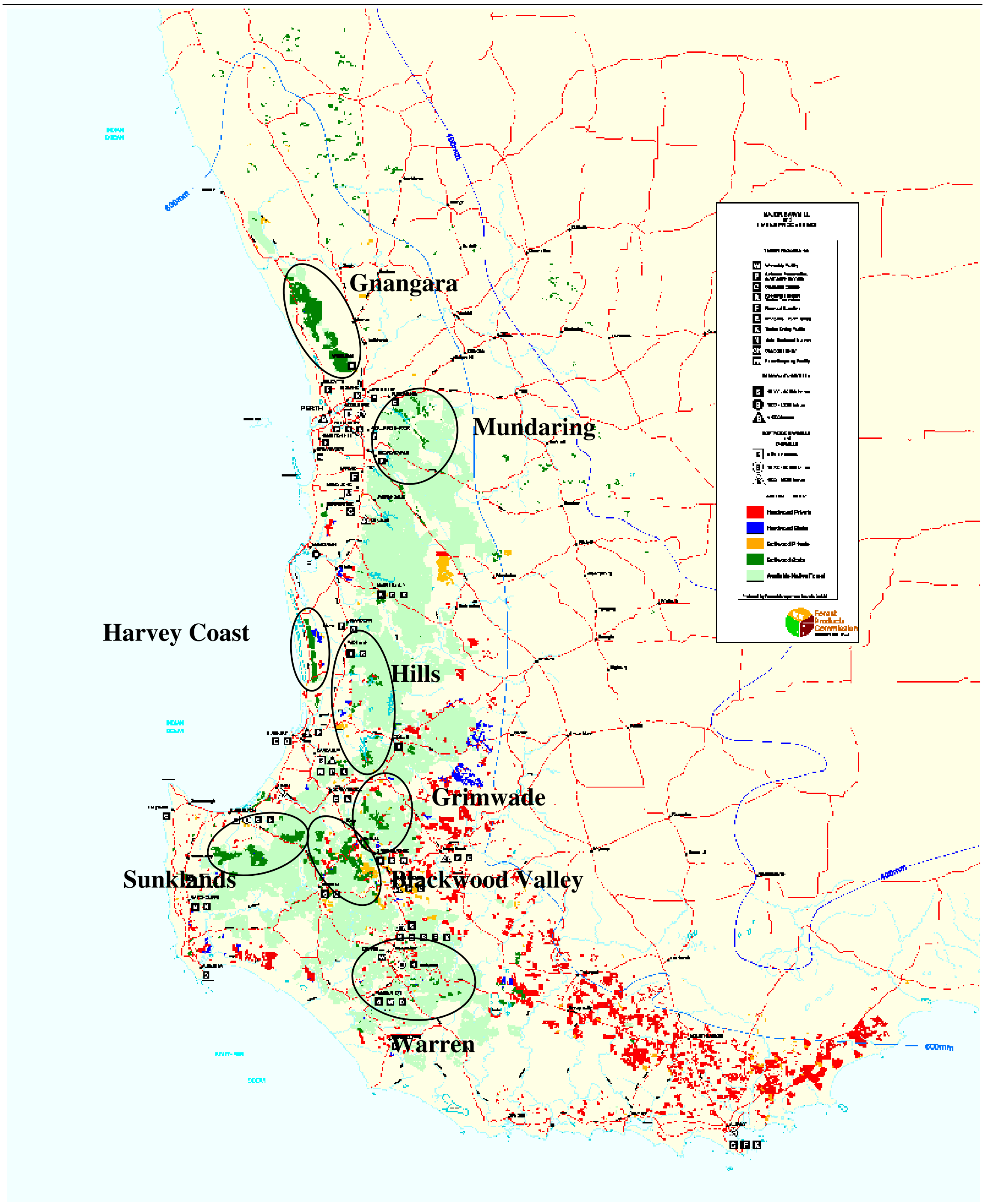
Appendix 1: West Australian Softwood Forests



Appendix 2: Plot details sorted by age and latitude

Age (yr)	Region	Plantation	Cpt	Planted yr	Latitude Deg.	Latitude Min.	Longitude Deg.	Longitude Min.	Site No.
Pinaster Plots selected for the sawing study in bold									
20	Gnangara	Yanchep	243	1988	31	23.544	115	38.576	59
21	Sunklands	Vasse	3	1987	33	49.638	115	17.728	12
22	**Gnangara**	**Yanchep**	**262**	**1986**	**31**	**29.762**	**115**	**44.814**	**55**
24	Mundaring	Greystone	19	1984	31	57.368	116	10.73	49
25	**Gnangara**	**Yanchep**	**266**	**1983**	**31**	**27.089**	**115**	**44.289**	**58**
27	Gnangara	Pinjar	209	1981	31	31.343	115	45.2	54
27	Gnangara	Pinjar	165	1981	31	33.932	115	45.524	52
27	Sunklands	Vasse	2	1981	33	49.556	115	15.306	8
28	Sunklands	Baudin	11	1980	33	49.387	115	26.581	16
28	Sunklands	Vasse	9	1980	33	50.525	115	18.533	11
28	Sunklands	Jalbaragup	15	1980	33	50.57	115	27.061	15
30	Gnangara	Pinjar	174	1978	31	31.343	115	45.2	53
32	Gnangara	Pinjar	135	1976	31	33.295	115	48.651	51
32	Mundaring	Greystone	7	1976	31	58.423	116	12.708	47
32	**Harvey Coast**	**Mclarty**	**78**	**1976**	**32**	**56.619**	**115**	**44.307**	**5**
35	**Gnangara**	**Yanchep**	**222**	**1973**	**31**	**27.089**	**115**	**44.289**	**57**
35	Harvey Coast	Mclarty	62	1973	32	54.806	115	44.282	3
Radiata Plots selected for the sawing study in bold									
17	Blackwood Valley	Ferndale	46	1991	33	49.804	115	52.974	20
18	**Harvey Coast**	**Myalup**	**8**	**1990**	**33**	**4.395**	**115**	**45.02**	**6**
18	Hills	Darrell	9	1990	33	17.726	116	9.897	40
18	**Grimwade**	**Mandalay**	**3**	**1990**	**33**	**34.576**	**116**	**4.148**	**34**
18	Grimwade	Grimwade	29	1990	33	41.783	116	3.912	32
18	Sunklands	Jarrahwood	1	1990	33	46.115	115	36.037	17
18	Warren	Quininup	8	1990	34	23.859	116	16.108	26
19	Mundaring	Beraking	6	1989	32	3.3	116	16.645	45
19	Hills	Darrell	3	1989	33	18.377	116	9.465	39
19	Blackwood Valley	Milward	19	1989	33	57.069	115	46.703	35
19	Blackwood Valley	Folly	45	1989	34	1.493	115	48.101	23
20	Hills	Bussell	74	1988	33	25.037	116	1.722	38
20	Blackwood Valley	Maidment	12	1988	33	50.595	115	50.304	19
20	Warren	Kinkin	10	1988	34	24.025	116	21.32	27
21	Mundaring	Wellbucket	31	1987	31	56.605	116	21.662	50
21	Mundaring	Greystone	7	1987	31	58.423	116	12.708	48
21	Harvey Coast	Mclarty	30	1987	32	53.476	115	43.463	2
21	Hills	Harvey Wier	27	1987	33	4.35	115	56.575	43
21	Sunklands	Vasse	3	1987	33	50.591	115	17.028	9
24	Warren	Murtin	17	1984	34	27.133	116	23.676	28
24	Warren	Nairn	10	1984	34	27.822	116	14.679	25
24	Warren	Dombakup	28	1984	34	36.106	115	58.443	24
25	Grimwade	Grimwade	7	1983	33	41.113	116	2.688	33
26	Harvey Coast	Mclarty	88	1982	32	50.939	115	43.22	1
27	Harvey Coast	Myalup	26	1981	33	4.939	115	46.178	7
27	**Sunklands**	**Vasse**	**8**	**1981**	**33**	**50.543**	**115**	**17.798**	**10**
27	Sunklands	Jalbaragup	9	1981	33	51.047	115	27.943	14
27	Sunklands	Margaret River	1	1981	33	55.404	115	4.953	36
28	Grimwade	Balingup	7	1980	33	48.85	116	0.478	30
28	Sunklands	Shelley	1	1980	33	49.545	115	46.186	18
28	Sunklands	Vasse	10	1980	33	49.972	115	22.449	13
29	Hills	Bussell	40	1979	33	25.938	115	59.964	37
29	Grimwade	Kelly	8	1979	33	43.062	115	56.078	31
29	Blackwood Valley	Ferndale	56	1979	33	49.976	115	55.413	21
29	Blackwood Valley	Dalgarup	13	1979	33	56.942	115	56.739	29
30	**Blackwood Valley**	**Ellis**	**19**	**1978**	**33**	**54.136**	**115**	**50.869**	**22**
31	Mundaring	Helena	14	1977	31	59.092	116	13.565	46
31	Mundaring	Helena	18	1977	31	59.902	116	12.949	44
32	Harvey Coast	Mclarty	76	1976	32	56.581	115	44.257	4
34	Gnangara	Yanchep	198	1974	31	28.114	115	42.981	56
36	Hills	Brunswick	34	1972	33	13.274	115	57.275	41
37	Hills	Brunswick	42	1971	33	12.92	115	58.103	42

Appendix 3A: Plot summaries– DBHOB and resin

Species/Plant date and Plot No.	Age (years)	DBHOB (cm)				Resin (visually assessed)				No.
		Mean	Min.	Max.	S.D.	Mean	Min.	Max.	S.D.	
Pinaster Plots in red text were unthinned										
PP88 - 59	20	23.1	14.4	31.6	4.2	0.0	0	0	-	30
PP87 - 12	21	29.4	19.8	40.2	5.3	0.0	0	1	0.2	30
PP86 - 55	22	25.8	19.2	32.6	3.6	0.0	0	0	-	30
PP84 - 49	24	23.6	15.3	31.1	4.0	0.0	0	0	-	30
PP83 - 58	25	31.1	20.4	41.2	4.5	0.0	0	0	-	30
PP81 - 8	27	46.3	31.3	59.1	7.0	0.0	0	0	-	30
PP81 - 52	27	37.6	30.7	50.9	3.9	0.0	0	0	-	30
PP81 - 54	27	32.7	26.2	40.1	3.7	0.0	0	0	-	30
PP80 - 11	28	40.1	25.7	54.5	7.2	0.0	0	0	-	30
PP80 - 15	28	41.2	31.7	54.2	6.4	0.0	0	0	-	30
PP80 - 16	28	43.8	25.2	56.2	6.7	0.0	0	0	-	30
PP78 - 53	30	36.2	28.0	44.9	4.6	0.0	0	0	-	30
PP76 - 5	32	40.4	31.7	48.4	4.1	0.1	0	1	0.3	30
PP76 - 47	32	45.6	32.4	63.9	6.6	0.0	0	1	0.2	30
PP76 - 51	32	46.6	40.2	53.6	3.4	0.0	0	0	-	30
PP73 - 3	35	45.1	37.8	53.7	4.2	0.0	0	1	0.2	30
PP73 - 57	35	51.5	35.5	66.7	6.8	0.0	0	0	-	30
Radiata Plots in red text were unthinned										
PR91 - 20	17	33.3	21.2	41.5	5.3	0.4	0	1	0.5	30
PR90 - 6	18	22.1	14.4	29.2	4.3	0.5	0	3	0.7	30
PR90 - 17	18	28.5	18.8	38.4	5.2	0.7	0	3	0.8	30
PR90 - 26	18	25.8	18.0	36.0	4.8	0.4	0	1	0.5	30
PR90 - 32	18	24.7	14.5	33.7	4.7	0.4	0	1	0.5	30
PR90 - 34	18	34.3	25.5	47.7	4.8	0.8	0	3	0.7	30
PR90 - 40	18	33.2	22.9	47.9	4.3	0.5	0	1	0.5	30
PR89 - 2	19	27.5	16.8	37.4	5.4	0.5	0	3	0.9	30
PR89 - 23	19	27.4	16.8	36.6	6.0	0.4	0	2	0.6	30
PR89 - 35	19	27.8	18.0	37.3	4.5	0.4	0	2	0.6	30
PR89 - 39	19	34.0	24.6	44.5	4.6	0.5	0	2	0.6	30
PR89 - 45	19	20.6	12.7	29.9	4.9	0.4	0	2	0.6	30
PR88 - 19	20	34.7	22.2	50.0	6.8	0.4	0	2	0.6	30
PR88 - 27	20	29.1	12.9	37.9	5.2	0.3	0	1	0.5	30
PR88 - 38	20	31.7	20.3	40.8	5.7	0.7	0	2	0.6	30
PR87 - 9	21	30.6	22.0	39.4	4.9	0.2	0	2	0.5	30
PR87 - 43	21	31.4	20.2	51.8	7.6	0.6	0	2	0.6	30
PR87 - 48	21	32.3	19.5	50.1	6.5	0.8	0	2	0.5	30
PR87 - 50	21	36.9	27.5	50.1	5.0	0.7	0	2	0.6	30
PR84 - 24	24	46.5	33.5	57.9	6.4	0.6	0	2	0.7	30
PR84 - 25	24	47.0	35.1	63.0	8.0	0.4	0	2	0.6	30
PR84 - 28	24	48.2	35.6	62.5	6.9	0.5	0	2	0.6	30
PR83 - 33	25	43.5	27.4	60.5	9.2	0.5	0	2	0.6	30
PR82 - 1	26	39.7	27.5	56.2	7.2	0.7	0	2	0.5	30
PR81 - 7	27	38.9	27.1	51.9	6.2	1.2	0	3	0.6	30
PR81 - 10	27	42.7	27.5	60.0	7.5	0.5	0	3	0.8	30
PR81 - 14	27	40.9	24.2	54.9	7.5	0.3	0	2	0.5	30
PR81 - 36	27	43.0	29.0	57.5	8.2	0.6	0	3	0.8	30
PR80 - 13	28	44.0	28.0	61.5	7.8	0.6	0	2	0.7	30
PR80 - 18	28	43.8	27.1	57.3	6.7	0.2	0	1	0.4	30
PR80 - 30	28	49.8	36.6	65.0	8.0	0.6	0	2	0.6	30
PR79 - 21	29	51.0	37.3	63.8	7.8	0.2	0	2	0.5	30
PR79 - 29	29	48.8	33.7	61.0	6.9	0.2	0	2	0.5	30
PR79 - 31	29	39.2	23.3	56.5	7.0	0.8	0	2	0.7	30
PR79 - 37	29	41.4	27.6	62.3	8.2	0.5	0	2	0.6	30
PR78 - 22	30	47.2	28.9	62.5	8.5	0.4	0	1	0.5	30
PR77 - 44	31	50.1	31.5	72.5	10.6	0.9	0	2	0.7	30
PR77 - 46	31	40.9	23.8	53.5	7.3	0.7	0	3	0.8	30
PR76 - 4	32	41.2	34.2	53.9	5.1	1.2	0	2	0.6	30
PR74 - 56	34	47.8	37.0	59.9	5.6	0.9	0	2	0.6	30
PR72 - 41	36	44.8	33.0	74.2	10.2	0.3	0	1	0.4	30
PR71 - 42	37	33.8	22.0	45.9	8.0	0.2	0	1	0.4	30

Appendix 3B: Plot summaries– Outerwood density and ST300 velocity

Species/Plant date and Plot No.	Age (years)	Outerwood density (kg/m^3)				ST300 velocity (km/s)				No.
		Mean	Min.	Max.	S.D.	Mean	Min.	Max.	S.D.	
Pinaster										
PP88 - 59	20	454	397	504	27.2	4.58	4.19	5.07	0.20	30
PP87 - 12	21	439	385	504	28.9	4.35	3.41	4.92	0.35	30
PP86 - 55	22	450	404	512	25.9	4.32	3.72	4.87	0.27	30
PP84 - 49	24	492	438	572	31.3	4.56	4.12	4.89	0.20	30
PP83 - 58	25	468	412	534	24.9	4.50	3.76	5.00	0.22	30
PP81 - 8	27	497	457	543	23.6	4.73	4.24	5.29	0.25	30
PP81 - 52	27	537	466	603	38.6	4.61	4.22	4.99	0.22	30
PP81 - 54	27	500	419	580	36.1	4.37	3.87	4.72	0.19	30
PP80 - 11	28	484	441	542	30.9	4.73	4.30	5.33	0.26	30
PP80 - 15	28	504	447	574	34.7	4.66	4.21	5.16	0.23	30
PP80 - 16	28	489	413	604	46.1	4.57	3.92	5.29	0.32	30
PP78 - 53	30	502	446	592	36.7	4.45	4.02	4.89	0.26	30
PP76 - 5	32	516	454	569	29.5	4.66	4.13	5.26	0.26	30
PP76 - 47	32	517	454	605	33.3	4.64	3.99	5.23	0.28	30
PP76 - 51	32	529	460	617	41.8	4.51	4.16	4.89	0.18	30
PP73 - 3	35	512	465	578	29.9	4.74	4.32	5.29	0.20	30
PP73 - 57	35	494	430	584	41.0	4.50	4.06	4.96	0.23	30
Radiata										
PR91 - 20	17	425	365	485	28.5	4.31	3.67	4.77	0.24	30
PR90 - 6	18	481	404	562	38.4	4.85	4.34	5.27	0.24	30
PR90 - 17	18	434	381	517	30.3	4.34	3.66	4.84	0.34	30
PR90 - 26	18	488	440	569	31.2	4.52	3.81	4.93	0.26	30
PR90 - 32	18	478	396	581	36.4	4.76	4.31	5.26	0.19	30
PR90 - 34	18	395	337	437	22.0	3.99	3.44	4.64	0.30	30
PR90 - 40	18	424	356	480	32.5	3.96	3.22	4.58	0.34	30
PR89 - 2	19	466	405	529	34.4	4.58	4.07	5.15	0.29	30
PR89 - 23	19	418	359	483	31.5	4.35	3.25	4.92	0.36	30
PR89 - 35	19	406	351	472	28.9	4.33	3.46	5.07	0.32	29
PR89 - 39	19	431	352	488	35.8	4.24	3.65	4.71	0.26	30
PR89 - 45	19	440	356	496	32.1	4.23	3.42	4.86	0.38	30
PR88 - 19	20	429	349	503	40.0	4.18	3.28	4.83	0.31	30
PR88 - 27	20	482	435	562	27.5	4.64	4.00	5.26	0.28	30
PR88 - 38	20	458	389	545	29.1	4.44	4.04	4.84	0.22	30
PR87 - 9	21	492	425	546	32.7	4.80	4.36	5.22	0.27	30
PR87 - 43	21	443	390	514	30.2	4.36	3.71	4.92	0.28	30
PR87 - 48	21	444	391	505	32.3	4.25	3.66	4.94	0.29	30
PR87 - 50	21	397	320	460	35.1	3.90	3.48	4.59	0.24	30
PR84 - 24	24	473	418	543	33.6	4.78	4.22	5.28	0.25	30
PR84 - 25	24	445	404	494	23.1	4.47	3.76	5.00	0.29	30
PR84 - 28	24	451	399	495	27.3	4.41	3.83	4.89	0.26	30
PR83 - 33	25	467	385	544	33.6	4.58	3.91	5.08	0.27	30
PR82 - 1	26	433	363	493	30.0	4.19	3.46	4.65	0.31	30
PR81 - 7	27	492	419	572	37.1	4.69	4.27	5.03	0.22	30
PR81 - 10	27	510	442	572	34.0	4.92	4.53	5.35	0.22	30
PR81 - 14	27	485	413	566	33.4	4.67	4.00	5.34	0.33	30
PR81 - 36	27	487	405	518	25.0	4.78	4.18	5.26	0.29	30
PR80 - 13	28	520	479	598	30.7	4.91	4.21	5.27	0.27	30
PR80 - 18	28	462	408	521	29.0	4.53	3.96	5.08	0.27	30
PR80 - 30	28	433	365	540	31.3	4.28	3.80	4.87	0.26	30
PR79 - 21	29	469	408	529	29.2	4.38	3.69	4.82	0.25	30
PR79 - 29	29	446	391	490	26.5	4.58	4.11	5.11	0.23	29
PR79 - 31	29	499	441	555	27.1	4.81	4.29	5.24	0.24	30
PR79 - 37	29	499	438	568	36.2	4.66	4.19	5.08	0.25	30
PR78 - 22	30	431	378	505	30.4	4.35	3.52	5.11	0.32	30
PR77 - 44	31	498	413	564	29.3	4.18	3.51	4.66	0.35	30
PR77 - 46	31	468	399	536	30.2	4.27	3.75	4.78	0.27	29
PR76 - 4	32	503	440	588	35.5	4.54	3.81	5.23	0.30	30
PR74 - 56	34	511	406	573	34.6	4.58	4.06	5.02	0.25	30
PR72 - 41	36	484	395	558	36.5	4.58	3.75	5.12	0.33	30
PR71 - 42	37	534	453	606	35.6	4.82	4.28	5.15	0.21	30

Appendix 3C: Plot summaries– Visually estimated branch size

Species/Plant date and Plot No.	Age (years)	Visually estimated branch size (cm)								
		Butt log			2nd log			3rd log		
		Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.	n
Pinaster										
PP88 - 59	20	2.1	1.2	30	3.1	2.0	24			
PP87 - 12	21	3.0	1.5	30	4.3	1.4	28			
PP86 - 55	22	Predominantly pruned			3.2	1.7	29			
PP84 - 49	24	1.8	0.9	30	3.2	1.5	25			
PP83 - 58	25	3.4	1.8	30	4.5	1.4	29			
PP81 - 8	27	Predominantly pruned			2.7	1.9	30	4.5	2.1	30
PP81 - 52	27	3.0	1.5	30	4.6	1.2	30	6.3	1.5	28
PP81 - 54	27	1.6	0.5	30	3.4	1.7	30	4.8	2.0	23
PP80 - 11	28	2.3	1.3	30	3.2	1.7	30	4.6	2.0	30
PP80 - 15	28	Predominantly pruned			2.7	2.0	30	4.2	1.8	30
PP80 - 16	28	Predominantly pruned			2.9	1.5	30	5.3	1.7	30
PP78 - 53	30	1.8	0.9	30	3.6	1.4	30	5.8	1.5	26
PP76 - 5	32	Predominantly pruned			2.3	1.3	30	3.2	1.7	30
PP76 - 47	32	2.6	1.7	29	4.3	2.1	29	5.2	1.6	22
PP76 - 51	32	Predominantly pruned			4.7	1.3	30	6.4	1.5	29
PP73 - 3	35	Predominantly pruned			2.7	1.5	30	4.4	1.7	30
PP73 - 57	35	Predominantly pruned			4.8	1.6	30	6.1	1.5	29
Radiata										
PR91 - 20	17	3.5	1.5	9	3.1	1.7	30	2.9	1.7	30
PR90 - 6	18	2.1	1.2	29	2.2	1.5	30	2.5	1.5	29
PR90 - 17	18	2.0	1.1	30	2.7	1.7	30	2.5	1.4	30
PR90 - 26	18	2.2	1.5	30	1.8	0.9	30	1.8	0.9	29
PR90 - 32	18	2.0	1.1	30	1.9	1.0	30	2.4	1.8	28
PR90 - 34	18	3.2	1.7	30	3.8	1.5	29	5.4	2.0	28
PR90 - 40	18	3.2	1.7	27	3.1	1.7	28	4.4	1.4	25
PR89 - 2	19	2.0	1.1	30	2.5	1.4	30	3.6	2.0	29
PR89 - 23	19	3.2	1.7	30	2.7	1.5	30	3.6	2.1	24
PR89 - 35	19	1.9	1.0	30	2.0	1.1	30	2.8	2.1	27
PR89 - 39	19	2.8	1.8	21	3.4	2.0	29	4.2	2.1	26
PR89 - 45	19	1.8	0.9	30	1.8	0.8	24			
PR88 - 19	20	Predominantly pruned			3.0	1.5	30	3.5	1.6	30
PR88 - 27	20	1.9	1.0	30	2.1	1.2	30	2.2	1.3	27
PR88 - 38	20	2.9	1.7	30	2.8	1.9	30	3.6	2.0	30
PR87 - 9	21	2.6	1.5	30	3.2	1.5	30	4.1	1.7	30
PR87 - 43	21	2.8	1.7	30	3.4	2.2	30	3.8	1.9	28
PR87 - 48	21	2.8	1.5	30	2.7	1.5	30	3.9	1.5	28
PR87 - 50	21	3.7	1.9	30	4.2	1.7	29	5.2	1.5	26
PR84 - 24	24	3.0	1.7	30	3.4	1.7	30	4.2	2.0	30
PR84 - 25	24	4.2	2.0	30	4.2	1.6	30	3.7	1.9	30
PR84 - 28	24	3.7	1.7	30	3.9	2.0	30	4.2	1.8	30
PR83 - 33	25	3.5	2.1	30	4.0	1.8	30	5.1	1.7	29
PR82 - 1	26	2.0	1.2	17	3.0	1.5	30	4.9	1.3	30
PR81 - 7	27	Predominantly pruned			3.9	1.2	29	4.9	1.1	28
PR81 - 10	27	Predominantly pruned			1.8	0.9	30	2.1	1.2	30
PR81 - 14	27	2.1	1.2	27	2.4	1.4	30	3.3	2.2	30
PR81 - 36	27	Predominantly pruned			2.3	1.3	30	3.5	2.0	27
PR80 - 13	28	Predominantly pruned			3.1	1.7	30	3.4	1.8	30
PR80 - 18	28	Predominantly pruned			2.6	1.5	30	3.9	1.7	30
PR80 - 30	28	Predominantly pruned			5.5	1.5	29	6.4	1.5	28
PR79 - 21	29	Predominantly pruned			3.7	2.4	30	5.0	1.9	30
PR79 - 29	29	Predominantly pruned			3.0	1.5	30	5.1	2.0	30
PR79 - 31	29	2.0	1.1	30	2.1	1.2	30	3.4	1.7	30
PR79 - 37	29	1.9	1.0	30	3.1	1.7	30	4.7	2.2	30
PR78 - 22	30	4.3	1.7	17	5.2	2.0	30	6.9	1.3	28
PR77 - 44	31	5.0	2.5	30	5.7	2.0	30	6.7	1.3	30
PR77 - 46	31	3.4	1.7	30	4.4	1.7	30	6.1	1.5	29
PR76 - 4	32	2.2	1.3	25	3.5	1.4	30	4.8	1.4	30
PR74 - 56	34	3.2	1.9	30	5.3	1.4	29	6.3	1.5	26
PR72 - 41	36	3.6	2.4	30	4.0	2.2	30	5.6	2.0	28
PR71 - 42	37	1.6	0.5	30	1.7	0.8	30	2.9	1.7	29

Appendix 4: Wood property relationships (R^2) by plot

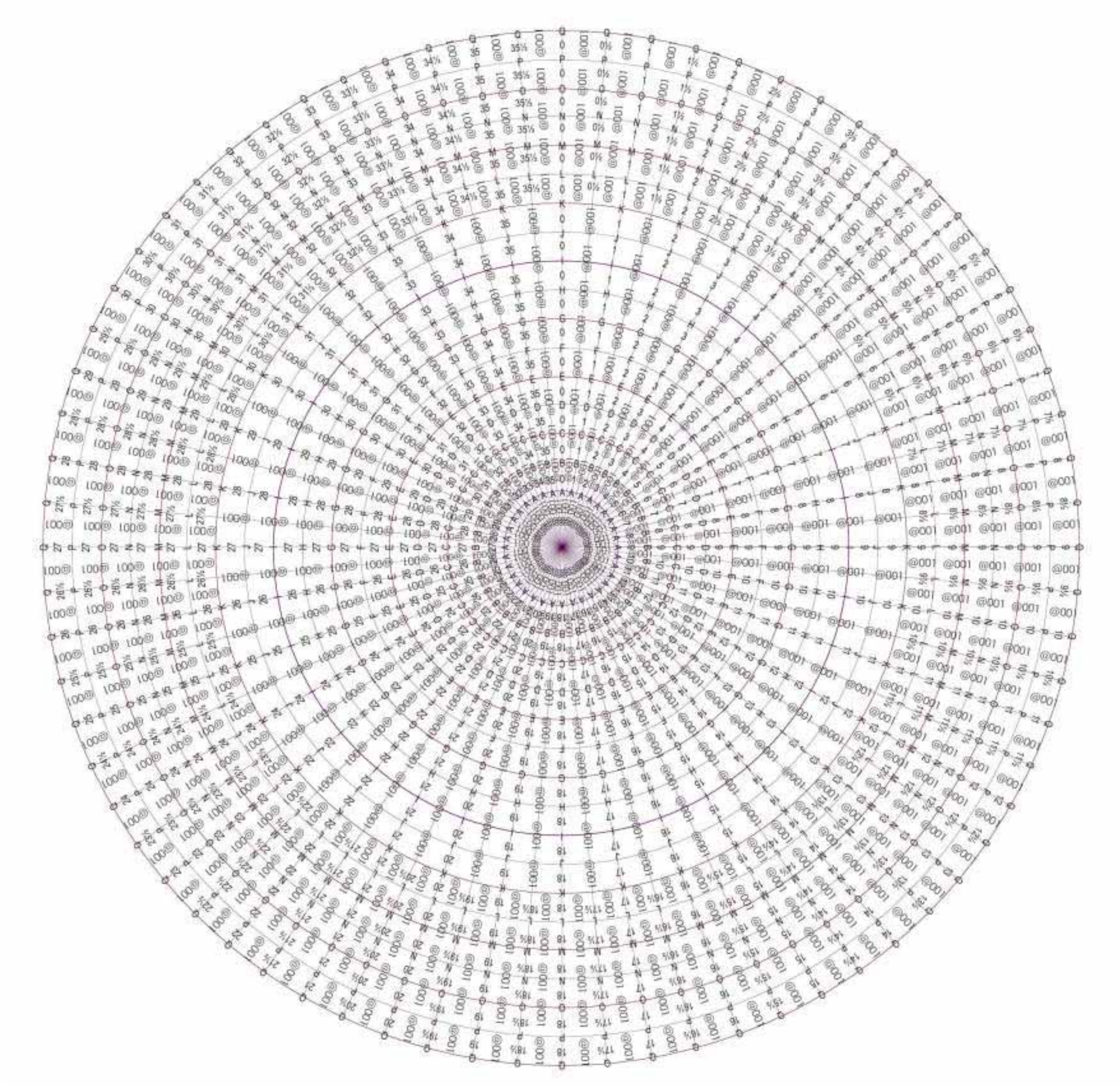
Species/Plant date and Plot No.	Age (years)	DBHOB v Density	DBHOB v ST300	ST300 v Density	DBHOB v Branch size Log 2
Pinaster					
PP88 - 59	20	0.04	0	0.40	0.32
PP87 - 12	21	0.01	0	0.18	0.41
PP86 - 55	22	0.18	0	0.13	0.18
PP84 - 49	24	0.03	0	**0.44**	**0.49**
PP83 - 58	25	0	0.01	0.12	0.10
PP81 - 8	27	**0.40**	0.44	0.16	0
PP81 - 52	27	0.04	0.06	0.17	0.26
PP81 - 54	27	0.01	0.04	0.05	0.22
PP80 - 11	28	0.06	**0.48**	0.26	0.34
PP80 - 15	28	0.23	0.27	0.13	0.10
PP80 - 16	28	0.14	0.38	0.4	0.12
PP78 - 53	30	0.08	0.01	0.32	0.02
PP76 - 5	32	0.12	0.10	0.18	0.06
PP76 - 47	32	0.03	0.07	0.23	0.10
PP76 - 51	32	0.14	0.36	0.24	0
PP73 - 3	35	0.05	0.12	0.17	0.06
PP73 - 57	35	0.15	0.38	0.32	0.18
Radiata					
PR91 - 20	17	0.16	0.06	0.07	0.13
PR90 - 6	18	0.07	0.01	0.01	0.10
PR90 - 17	18	0.04	0.29	0.04	0.10
PR90 - 26	18	0	0.20	0.02	0.05
PR90 - 32	18	0.11	0.06	0.01	0.01
PR90 - 34	18	0.01	0.20	0.02	0.29
PR90 - 40	18	0.04	0.08	0.09	0.03
PR89 - 23	19	0.07	0.01	0.19	0.28
PR89 - 35	19	0.01	0.03	0.34	0.10
PR89 - 39	19	0.05	0.01	0.37	0.22
PR89 - 45	19	0.02	0.01	0.36	0.09
PR88 - 19	20	0.01	0.27	0.18	0.16
PR88 - 27	20	0.01	0.24	0.35	0.03
PR88 - 38	20	0	0.08	0.12	0.18
PR89 - 2	19	0.06	0.22	0.07	0
PR87 - 9	21	0.01	0.04	0.19	0.15
PR87 - 43	21	0.17	0	0.12	0.17
PR87 - 48	21	0.01	0.29	0.32	0.35
PR87 - 50	21	0.14	0	0.21	0.53
PR84 - 24	24	0.13	0.18	0.07	0
PR84 - 25	24	0.04	0.30	0.26	0.04
PR84 - 28	24	0.02	**0.53**	0.08	0
PR83 - 33	25	0.01	0.25	0.20	0.19
PR82 - 1	26	**0.23**	0.26	**0.59**	0.34
PR81 - 7	27	0.01	0.01	0.13	0.03
PR81 - 10	27	0	0.18	0.28	0.23
PR81 - 14	27	0.05	0.01	0.55	0.20
PR81 - 36	27	0.06	0.17	0.22	0.01
PR80 - 13	28	0.04	0.41	0.28	0.40
PR80 - 18	28	0.01	0.09	0.3	0
PR80 - 30	28	0.05	0.05	0.23	0
PR79 - 21	29	0	0.11	0.27	0
PR79 - 29	29	0.01	0.14	0.07	0.01
PR79 - 31	29	0.06	0.20	0.27	0.04
PR79 - 37	29	0.12	0.08	0.31	0.04
PR78 - 22	30	0.04	0	0.35	0
PR77 - 44	31	0.02	0.20	0.20	**0.67**
PR77 - 46	31	0.05	0.06	0.18	0.21
PR76 - 4	32	0.02	0.20	0.19	0.10
PR74 - 56	34	0.01	0.09	0.18	0.01
PR72 - 41	36	0.09	0.14	0.31	0.49
PR71 - 42	37	0	0.12	0.07	0.03

Appendix 5: Characteristic measurements of trees including in processing study

Species	Plantation	PLOT	TREE	DBHOB	Tree Height (m)	Height to Crown Break (m)	Prune Height (m)	Stump Height (m)
P. pinaster	**Mclarty**	**5**	1	358	21.6	12.9	5	0.25
			2	362	22	12.1	4	0.15
			5	450	22.5	9.05	4.5	0.15
			6	448	22	11.3	6	0.15
			7	394	22	10.3	4.5	0.25
			8	330	21.2	9.8	4.5	0.25
			9	410	23	14	5	0.2
			17	410	23.2	12.7	5	0.15
			19	390	23	12.3	4.7	0.15
			22	378	23	10.1	5	0.15
			26	431	23.2	13.4	4	0.15
			27	479	22.2	10	4	0.2
	Yanchep	**55**	1	238	17.65	8.2	5	0.39
			4	230	16.1	4.75	4.75	0.22
			16	277	17.68	5.47	5.47	0.32
			18	244	17.06	6.79	4.7	0.48
			19	275	18.33	6.64	4.32	0.44
			22	284	17.63	4.73	4.73	0.37
			23	265	17.3	4.55	4.55	0.37
			25	293	16.25	4.44	4.44	0.47
			27	256	16.23	4.5	4.5	0.41
			28	280	17.4	5.84	5.84	0.44
			29	271	16.63	5.78	4.55	0.41
			30	218	13.92	4.94	4.94	0.215
	Yanchep	**57**	1	360	21.95	8	4.94	0.38
			4	555	25.55	9.34	5.99	0.45
			9	554	28.9	6.8	6.8	0.43
			10	489	27.8	14.4	5.1	0.39
			12	418	21.6	12.8	5.87	0.38
			13	547	27.47	13.6	3.2	0.29
			14	522	27.5	12.36	2.5	0.4
			15	541	29.31	17.1	5.55	0.41
			18	616	25.04	11.35	5.52	0.43
			20	668	27.5	11.02	4.5	0.37
			27	547	27.5	12.86	6.13	0.22
			30	480	25.1	4.86	2.7	0.43
	Yanchep	**58**	7	254	17.1	6.16	1.2	0.26
			14	318	25.68	9.68	0.79	0.27
			15	256	19	9.65	0.96	0.32
			18	305	20.17	7.9	1.96	0.25
			21	308	18.06	7.76	2	0.35
			22	329	18.46	8.6	0.63	0.34
			23	320	20.18	5.95	1.49	0.33
			24	327	20.09	9.12	0.55	0.22
			25	396	20.77	7.78	2.02	0.27
			27	337	18.56	6.78	2.18	0.23
			28	345	18.62	8.07	1.3	0.5
			29	385	19.87	7.78	2.95	0.45

Species	Plantation	PLOT	TREE	DBHOB	Tree Height (m)	Height to Crown Break (m)	Prune Height (m)	Stump Height (m)
P. radiata	Myalup	6	3	226	21	4.1	0	0.22
			9	235	19	8.8	0	1.5
			10	249	20.5	8.3	0	0.7
			16	283	22.5	9.1	0	0.34
			22	300	23.4	6.5	0	0.27
			23	289	21.5	7.8	0	0.37
			24	229	20.5	6	0	0.32
			25	234	20.3	8.9	0	2.4
			26	260	22.7	7.6	0	0.66
			28	256	22.4	6.8	0	0.3
			30	279	21.3	7.9	0	0.2
	Vasse	10	2	364	31.6	8.8	5.25	0.29
			3	316	29.95	6.95	5.1	0.35
			4	416	31.8	18.14	5.9	0.25
			8	462	34.8	14.15	2.58	0.26
			14	379	31.82	11.63	2.3	0.26
			15	585	35.5	13.58	4.86	0.19
			17	421	31.9	14.79	2.07	0.32
			19	450	37.3	13.32	4.76	0.21
			21	386	31.1	18.09	4.37	0.23
			22	386	31.8	15.52	4.38	0.3
			26	366	32.2	15.18	6.35	0.255
			30	497	32.48	9.51	5.21	0.27
	Ellis	22	2	381	26.7	11.26	1.9	0.27
			3	288	25.2	19.2	4	0.3
			5	635	33.2	12.25	5.5	0.26
			7	405	34	17	3.8	0.23
			9	540	32.8	12.65	0	0.29
			13	650	33.8	15.45	0	0.42
			15	399	30.4	17.5	0	0.3
			17	388	31.9	18.3	0	0.24
			20	541	34.9	16.55	4.7	0.2
			23	489	33.2	18	0	0.2
			24	467	32.8	12.3	4.9	0.37
			26	466	31.2	17.9	5	0.22
	Mandalay	34	1	334	22.4	8.5	0	0.24
			4	479	25	8.5	0	0.24
			5	274	22.1	9.1	0	0.15
			6	300	22.5	6.3	0	0.18
			8	304	24	8.3	0	0.25
			9	258	23.3	10	0	0.12
			13	339	25	7.4	0	0.22
			15	353	26	8.3	0	0.17
			17	275	24.4	8.1	0	0.19
			24	372	24	8.7	0	0.24
			27	339	23.7	8.6	0	0.2
			29	390	23	5.3	0	0.15
			30	390	24.6	12.5	0	0.25

Appendix 6: Example of paper masks glued on the ends of trial logs.



Appendix 7: Summary of MSG recoveries (full length boards) for each tree

Forest	Plot	Tree	Mean MOE$_{(ave)}$	Mean MOE$_{(low)}$	Count	Forest	Plot	Tree	Mean MOE$_{(ave)}$	Mean MOE$_{(low)}$	Count
P. radiata						*P. pinaster*					
Myalup	6	3	10.38	6.62	7	**Yanchep**	55	1	8.91	5.72	2
		9	12.34	9.01	3			4	10.77	8.55	3
		10	10.83	7.39	7			16	9.86	7.86	6
		16	13.41	10.71	9			18	9.91	7.11	2
		22	9.63	6.28	8			19	10.24	7.56	7
		23	12.48	9.69	11			22	10.38	6.95	5
		24	9.95	7.29	3			23	8.73	5.92	5
		25	11.25	9.15	3			25	9.13	6.80	3
		26	12.06	8.28	6			27	8.92	6.37	3
		28	10.79	8.25	8			28	12.16	8.95	10
		30	11.44	8.48	10			29	10.94	7.77	3
								30	12.39	10.20	1
Sub-total			**11.43**	**8.38**	**75**	**Sub-total**			**10.34**	**7.57**	**50**
Mandalay	34	1	8.97	4.90	12	**Yanchep**	58	7	8.31	5.72	3
		4	6.13	3.93	34			14	10.05	6.99	9
		5	5.76	3.23	4			15	9.86	7.24	4
		6	8.44	5.84	8			18	11.93	8.71	10
		8	6.41	3.01	6			21	11.07	8.23	10
		9	6.72	3.66	5			22	10.91	7.77	12
		13	8.36	5.46	16			23	12.23	9.11	11
		15	8.34	5.17	16			24	9.50	5.93	10
		17	8.55	5.08	10			25	8.58	6.32	18
		24	7.65	5.15	18			27	10.17	6.74	9
		27	8.68	5.02	15			28	10.61	6.54	7
		29	6.60	3.53	16			29	10.75	7.05	14
		30	6.46	4.02	18						
Sub-total			**7.42**	**4.53**	**178**	**Sub-total**			**10.39**	**7.27**	**117**
Vasse	10	2	9.99	7.48	27	**Mclarty**	5	1	12.15	8.71	15
		3	12.73	10.13	21			2	12.72	8.53	21
		4	12.47	9.82	37			5	11.25	8.07	32
		8	14.52	10.65	44			6	12.39	8.72	20
		14	11.13	8.01	26			7	11.56	9.01	25
		15	12.32	8.34	88			8	12.51	8.61	17
		17	10.93	8.48	40			9	13.01	9.12	24
		19	12.15	7.58	45			19	11.50	8.60	21
		21	12.48	8.30	27			22	13.74	10.69	19
		22	12.36	9.63	36			26	12.28	8.84	23
		26	12.38	9.10	27			27	13.02	9.26	32
		30	12.22	8.99	60						
Sub-total			**12.23**	**8.84**	**478**	**Sub-total**			**12.34**	**8.90**	**249**
Ellis	22	2	8.75	5.93	24	**Yanchep**	57	1	12.97	8.56	15
		3	7.11	4.25	9			4	11.05	7.10	44
		5	10.02	6.78	83			9	11.79	8.13	75
		7	9.15	5.35	19			10	11.83	8.29	45
		9	9.51	6.13	67			12	11.85	6.63	28
		13	9.61	6.66	90			13	11.92	8.15	56
		15	9.16	5.08	19			14	13.02	8.74	51
		17	8.55	4.49	7			15	12.02	6.90	71
		20	9.65	4.76	43			18	11.04	6.70	66
		23	8.98	5.34	48			20	9.79	6.06	94
		24	7.66	4.71	33			27	12.80	9.04	58
		26	8.00	4.61	42			30	13.63	8.78	42
Sub-total			9.19	5.77	484	**Sub-total**			11.75	7.61	645
Total			**10.27**	**6.96**	**1215**	**Total**			**11.67**	**7.87**	**1061**

Appendix 8: Mean radial wood property trends for basic density, green density and moisture content by branch diameter classification and harvest type

P. pinaster

Rotation type	Branch diam. class.	Plot no.	Disc ht. (m)	Basic density (kg/m^3) Rings 1-10	Rings 11-20	Rings 21+	Green density (kg/m^3) Rings 1-10	Rings 11-20	Rings 21+	Moisture content (%) Rings 1-10	Rings 11-20	Rings 21+	N*
Mid	Small	55	0	453	487		851	957		89	97		12
			5	451	467		936	971		108	108		12
			11	416			964			132			12
			14	418			997			139			5
Mid	Large	58	0	475	484		907	988		91	104		12
			5	456	468		919	980		102	110		12
			10	418			990			137			11
			16	412			1003			144			11
Late	Small	5	0	507	513	502	866	996	994	71	95	98	12
			5	476	500	489	821	991	979	73	99	101	12
			10	461	476		881	962		92	103		12
			15	428	466		914	946		115	104		11
Late	Large	57	0	527	498	491	842	1003	1003	60	103	105	12
			5	509	497	497	832	995	1006	64	101	103	12
			10	490	478	449	870	1005	990	78	111	121	12
			15	451	440		966	1005		115	129		12
			20	432	424		991	1007		131	137		11
			25	409			1005			148			6

Predominantly represents Rings 1-10

P. radiata

Rotation type	Branch diam. class.	Plot no.	Disc ht. (m)	Basic density (kg/m^3) Rings 1-10	Rings 11-20	Rings 21+	Green density (kg/m^3) Rings 1-10	Rings 11-20	Rings 21+	Moisture content (%) Rings 1-10	Rings 11-20	Rings 21+	N*
Mid	Small	6	1	471	531		868	994		85	88		11
			6	448	493		845	986		89	101		11
			10	448			888			99			8
Mid	Large	34	0	380	427		724	938		91	120		13
			5	355	407		662	923		86	127		12
			10	359	371		794	881		121	137		12
			15	359			833			133			5
Late	Small	10	0	471	501	493	763	994	997	63	99	103	12
			5	404	481		664	1001		64	109		12
			10	412	454		755	998		83	120		12
			15	420	442		831	1005		98	128		12
			20	412	428		926	1003		125	134		12
Late	Large	22	0	421	452	451	651	968	988	55	115	119	12
			5	373	420	430	585	947	760	57	126	79	12
			10	386	425		637	944		65	123		12
			15	383	410		756	948		97	132		8
			20	388	424		881	980		127	131		7
			25	381			945			148			2

* Predominantly represents Rings 1-10

Appendix 9: Industry Workshop

Forest Products Commission WA, Bunbury Office
Wednesday 2nd December, 2009. 9:00am -12:30 pm

Attendees

Ian Dumbrell (FPC), Philip Blakemore(CSIRO), Andrew Lyon (FPC), Brad Barr (WESPINE), Richard Schaffner (WESPINE), James Szabadics(FPC), John McGrath (FPC), John Kaye (FPC), Byron Yeo (FPC), Andrew Milne (FPC), Richard Hartwell (FPC), Russell Wornes (FPC), Scott Wood (FPC).

Phone Attendees: Dave Cown (SCION - NZ), Richard Northway (CSIRO)

Workshop Notes:

Presentation (9:00 -10:30 am)

Ian Dumbrell welcomed everyone, and provided a brief background for how this project was initiated and how it evolved. Philip Blakemore then provided a presentation that summarized the project. Some questions and discussion were undertaken during the presentation.

Discussion (10:50 – 12:15)

<u>FPC issues</u>

P. pinaster

- More sampling of resource required
  - Establish if resource is just relatively uniform (high density), or if better prediction relationships for wood quality can be established if more variation is found.

P. radiata

- Density and general wood quality are reasonable
- Need to better understand branching
  - Determine silvicultural effects of thinning and fertilizer particularly on branching characteristics.

Wood quality tools

- General acceptance that OWBD would continue to be of importance for inventory and growth modeling as part of ATLAS system.
- Use of acoustic tools is likely to be continued and refined
  - Acoustics tools allow more data to be collected on a wider number of trees more quickly and the data can be analyzed immediately.
  - This may be particularly important for pre-harvest assessments.
  - Trials of harvesting heads with acoustic tools incorporated (currently being developed and tested in Scotland) may be trialled in WA next year as part of other research in the CRC-Forestry.
  - Information gained from such tools can be used to assess localized regional and silvicultural effects on a wider and finer scale than was possible in this project.

        - While the evidence was not strong to map wood quality at a regional scale, there was some evidence to possibly support mapping within certain regions.

Sawmill (WESPINE) issues

Wood Quality Information

- The earlier that wood quality information of future log supply can be obtained by the sawmill the better.
    - From this project, it is accepted that site averages of acoustic information are the most useful as a general indicator of expected wood quality. However, measurements of variance will still be important for assessing the expected level of variation in wood quality of logs from a given site.
    - Individual tree and log measurements may best be done in mill logyard.
        - Acoustic tools (e.g. like Fibregen LG640) may become part of in-line log merchandising and log sorting in the future.
        - Currently, limited use HM200 (or equivalent) in the logyard provides some information about 1 month ahead of sawing.
    - Ideally, it would be optimal if FPC could mix supply from various sources so that average wood quality is maintained over time. However, it is accepted that this is just not practical. Nevertheless, advanced knowledge of expected wood quality provides a chance for the sawmill to optimize cutting patterns and target suitable products for the expected level of wood quality.
    - There is scope for information collected in the logyard to be provided back to the growers to help evaluate the site and silvicultural practices.

- This study has generally confirmed that density and stiffness of WA resource is good.
    - WESPINE experience is that strength is the main concern for them (i.e. an MOR limited resource).
        - Some limited evidence for this in this study
    - WESPINE has been tending towards tension testing as it is a less localized test
        - Internationally, the conventional theories suggest bending tests are better.

Branching and Knots

- Given above concerns about strength with structural products, and also given the localized effects of knots on bending strength, branching is logically an important concern for growers and processors.
    - The effects of knots on any given board are complex
        - e.g. same knot on tension or compression side of board will result in very different strength measurement.

- Size and frequency of branches and knots is currently understood to be critical for structural properties.
    - Most trends in plantation management are going in the right direction for this.
        - Genetics.
        - Silviculture.
        - Stumpage pricing.
    - More work needs to be done to establish which measurements of branching (values or categorizations) provide the most cost/effective basis for assessing branching with regard to their impact on structural board quality and consequent value.
        - Second generation ATLAS moved away from categorization to measured values, but the cost of detailed branch measurements may be prohibitive.
            - Just how good ground based/visual measurements are is open to question.

    - Thinning strategies may be critical to branching characteristics.
        - May be better to thin from above and below to improve uniformity of logs supplied in final harvest.
            - Stumpage pricing is starting to reflect this.
                - Not always best to produce big trees.