Resource Characterization of slash pine plantation wood quality

Resource Characterization of slash pine plantation wood quality

Prepared for

Forest & Wood Products Australia

by

K. Harding

Publication: Resource Characterization of slash pine plantation wood quality

Project No: PN06.3016

Researcher:
K. Harding
Horticulture and Forestry Science
Department of Primary Industry and Fisheries
PO Box 1085, Townsville, Qld 4810

Final report received by FWPA in July, 2008

EXECUTIVE SUMMARY

Four return to log and tree sawing studies of 50 trees each were planned for this project and two were completed. The trees were selected from sites identified by interrogating the Forestry Plantations Queensland inventory data-base as being representative of the remaining slash pine mature clearfall harvest resource. Additionally a reference document reviewing wood quality research undertaken on slash pine in Queensland and northern NSW was prepared.

The first two planned sawing studies were undertaken by processing industry partners Weyerhaeuser Australia and Hyne and Son after which the project's steering committee reviewed the results. The steering committee decided that these initial two return to log and tree sawing studies did not provide a robust enough prediction model to justify further investment in return to log sawing studies. Consequently the project steering committee recommended truncating the project activities and not proceeding with the planned additional sawing studies.

The sites chosen for the sawing studies were large compartments that contained a large variation in site index of stands within each compartment. Site index varied more than 8m in height difference between low site index (22.0m) and high site index (30.5m) samples. Large differences in overall grade recovery between the Beerburrum site (compartment 15 Bluegum) and the Toolara site (compartment 79 Kelly) were observed with more than 10% difference in total in-grade recovery comparisons from logs within trees. The strongest significant (p=0.01) predictor of total in-grade recovery proportion was total tree height as measured on the standing trees with a Vertex. Total tree height accounted for a little over 25% of the variation in total in-grade recovery proportion. Other variables that provided significant prediction of in-grade recovery proportion are not independent of tree height or are correlated to it. These results suggest that tree size is the key determinant of in-grade recovery in slash pine due to the improved recovery of mature wood boards from larger logs.

The project steering committee also agreed to changes in the reference document so that the review covered wood quality research undertaken on slash pine, Caribbean pine and their hybrids in Queensland and northern NSW. This review has been prepared and considers variation in wood properties, genetics, sawing and veneer studies, resin defects, pulp and paper and recommended future research needs. Stiffness and stability are key requirements for the structural timber dominated market for exotic pine from Queensland and northern NSW. The review highlights the considerable variation found in wood properties impacting timber stiffness

and stability such as wood density, spiral grain and microfibril angle. Variation with age, site quality and environment, as well as amongst species, hybrids and genetic stock is reported and opportunities for product focused wood quality improvement are identified.

TABLE OF CONTENTS

INTRODUCTION

Key Project Objectives

The project was designed to address the following objectives:

1. To sample a representative range of the slash pine clearfall age stands for return-to-log/tree sawing studies to relate standing tree assessments to end product graded recovery and value. These stands were to be selected to represent the slash pine resource scheduled for harvest out to 2012/13 (period in which it is the major clearfall species). All trees sawn were to be assessed pre-harvest while standing, with a focus on low-cost non-destructive evaluation (NDE) assessment technologies. The latter technologies, such as standing tree acoustic velocity and increment core density, are practical to combine with DBHOB and predominant height to be readily incorporated into a practical pre-harvest inventory assessment. The intention was to use these sawing studies to develop a methodology for pre-harvest inventory to reliably rank stands for their predicted graded recovery, thereby providing a linkage between pre-harvest assessments and recovered product quality.

2. To use the key standing tree variables identified in Objective 1 in a broadscale survey of the SE Queensland slash pine resource to be harvested up to 2012/13 to produce a wood quality map of the resource for this harvesting horizon.

3. To produce a single reference document summarising available published and unpublished wood property and sawing research studies on Queensland slash pine. This document was planned to provide the timber industry with a single reference source for key wood property trends and sawing research study findings, including the results of this project.

Introduction to the Return to log studies

The project aimed to sample a representative range of the slash pine clearfall resource (age 28-30 years) to be harvested in the next 5-7 years. Forestry Plantations Queensland's (FPQ) inventory database was interrogated to quantify volumes expected to be harvested by site index over the next 5-7 years and to identify sampling points within compartments that match these site index requirements. These initial studies assessed and sawed 50 tree samples from two key forest areas at Beerburrum and Toolara. The sample trees represented the extreme low and high site indices (20 trees each) with a smaller focus (10 trees) on the average site index. This strategy was based on the Green Triangle experience (PN03.3906: Resource Evaluation for Future Profit: Part B - Linking Grade Outturn to Wood Properties) (Roper *et al.* 2004), where it was observed that more tree-to-tree variation in grade yield and standing tree variables was observed at the extremes of the site index range and less in the intermediate stands.

The sawing studies sampled the Beerburrum and Fraser Coast (Tuan/Toolara) slash pine plantations that are of prime importance to Weyerhaeuser, Hyne and FPQ and as they will supply the majority of the clearfall harvest until 2012/13, after which Caribbean pine is the predominant species. Study trees were measured (DBHOB and height), cored (12 mm core) and assessed for acoustic velocity (Fakopp and ST300) prior to felling. Log dimensions and sweep were recorded using mill log scanning facilities prior to sawing. A 30-50mm disc sample was cut from the top of each log to enable up-the-stem estimation of mean log density for correlation with breast height increment core results. All logs were colour coded so that all recovery could be identified for return to log and stem data capture. Dried recovery was uniquely numbered to match machine stress grader output for individual boards.

Predictive regression modelling was undertaken to identify the key standing tree variables that might be used to predict the proportion of structural grade timber recovered in mill. These initial sawing studies were analysed to indicate whether any relationships provided encouragement that a strong predictive model might be developed and it was intended to assess the results to adjust the sampling approach for two follow up return to log/tree studies to target trees or site indices if this was indicated as needed to improve the robustness of the model/s

MATERIAL AND METHODS

Site Selection

Sample sites were selected by the project team in consultation with FPQ resources manager, FPQ regional marketing managers and industry partner resource managers.

The aim in selecting sites was that:

- Sites were to be stratified across as wide a range of representative site indices as possible.

- Trial locations were selected on basis of :
    - Site quality was representative of harvest areas for next 5 years
    - Areas of excessively poor tree form or wind damage were avoided
    - Resource with abnormal fertilizer or planting history were avoided
    - Breaks or existing gaps in the plantation were avoided
    - Each trial sourced sample trees from 3 sites of divergent site index (to provide greatest representation of diversity of site index in the sawing trials undertaken for this study)
    - Bendy trees and any trees with significant ramicorn branches or double leaders were avoided.

    These criteria were applied to ensure that confounding of results with unusual or poorly represented trees in the resource was minimized, being mindful of the very small sample size in terms of representing a large resource.

- Sites were selected from compartments allocated to Weyerhaeuser and Hyne in current logging plans. At Toolara this included logging areas selected only from State Forests 915 and 1004 as they are the most representative of the resource. Sites were selected as close as possible to current harvest operations to minimise felling and haulage costs but SF 915 was preferred at Toolara to provide more contrast with the first sawing study material from Beerburrum. This ensured that the preliminary modelling from first 2 sawing studies and 100 trees to have the widest applicability to the main forest harvest areas.

- Latest available inventory plot assessment data was referred to so as to identify site index extremes within compartments as compartment level site index averages are too crude to represent large site index differences in the resource.

In each case a single compartment was identified that contained sufficient variability in site index (based on recent inventory plot survey data) to provide samples that covered the extremes of site index needed to represent the resource. The sites chosen to sample were Compartment 15 Bluegum, Beerburrum and Compartment 79 Kelly, Toolara.

Tree Selection and Measurements

- Study trees were chosen to avoid edge effects, excessive lean, stem malformation, multiple leaders or trees with large ramicorn branches.

- The trees were chosen to represent the range of diameters on the site, based on a weighted diameter distribution at each site (a minimum of 100 trees was measured to establish the diameter distribution) and tree height was measured to ensure that they represented the nominal site index.

- Test trees were numbered with spray paint and the following standing tree measurements were obtained:
    - Height and DBHOB
    - Stress wave velocity measurements were taken using a modified Fakopp (on loan from Weyerhaeuser Australia, Caboolture) and FibreGen Director ST 300. A single Fakopp reading was taken at the shortest radius of each tree to emulate standard inventory practice, which targets the radius least likely to contain compression wood. Two readings were also done on each side of the tree along what was deemed to be the shortest diameter (i.e. at right angles to the shortest radius) – these readings correspond to the increment core sample orientation and again should minimize any influence of compression wood on the readings. At Beerburrum these latter readings were taken with the ST300 whereas at Toolara all acoustic readings were done using the Weyerhaeuser Fakopp tool (as the ST300 was unavailable).
    - A breast height 12 mm diameter, pith to bark increment core was sampled along the shortest diameter (i.e. perpendicular to any sweep or tree lean).

Tree Felling and Harvesting and Log Merchandising

Weyerhaeuser and Hyne organized felling and haulage of stems to mill. All sample stems were cut to a standard log length of 4.8m (final product length) plus top log (between 2.4 and 4.8m) and allowance for a 75 mm disc sample from the top of each. All logs were identified (uniquely numbered plastic log tags) to tree and position in tree. Logs were de-barked at mill and scanned for variables listed below (see "Log Measurements").

Disc and Increment Core Samples

- At the DPI&F Wood Quality Improvement Lab a high quality digital image was taken of each disc sample (including a 100mm scale) to facilitate assessing disc sections for resin affected area, resin shakes (length and width) and heartwood proportion using image analysis.

- Discs were reduced to 2 opposite wedge samples, approximately 2cm thick for weighted average density measurement.

- The 12mm diameter increment cores were cut to exactly 50 mm (±0.5 mm) long outer-wood sample and the balance of each core assessed as a whole sample or two segments (e.g. 0-10 rings and intermediate zone). Basic density was assessed using saturated samples and the maximum moisture content method. The number of growth rings in each 50mm outerwood sample was recorded as were ring numbers in the other pith to outerwood segments. These 50mm outer-wood increment core samples provided a site average unextracted outer-wood basic density as used in the FWPA Green Triangle study (Roper *et al.* 2004). Increment core results were used to predict up-the-stem average basic density.

Log Measurements

- Logs were passed through the debarker and scanner (tagged, small end first).

- Data captured for each log included: sweep, LED, SED, taper

- As the logs were being debarked/scanned they were sorted into bins by log size sort classes required for sawmilling and stored separately in the log yard in these sort classes prior to sawing.

- The sorted logs were laid out along base bearer log skids for measurement and colour coding.

- Logs were assessed for:
    - Director HM200 Hitman stress wave velocity
    - Cross dimensions of any resin and radial length of any resin splits (on LED of butt log – other log assessments done on disc samples from the top of each log.

- Logs were uniquely colour coded by allocating an end paint pattern to the large end – a base coat brush applied and then a second stenciled coat spray applied to provide unique colour and stencil pattern combinations

- Horns down position for orientation at the breakdown saw was marked on the upper log surface as a guide to the breakdown operator.

Sawmilling
- Normal commercial sawing patterns were used for sawing but restricted to minimize recovery of non-structural board cross sections and to maximize the recovery of 90 and 70 mm structural product rather than larger piece sizes.
- All 25 mm recovery boards were collected and visually graded in green sawn form.

Kiln Drying
- Wood was placed into full kiln stack lifts or mixed stacks (separate widths of same thickness) separated by using 70x70 mm bearers between different widths.
- Test lifts were high temperature kiln dried ASAP after sawing using standard mill schedules and procedures.
- Dry lifts received normal stabilization under cover before being released for drymill processing.

Planing and Machine Grading
- Dry-mill processing of all cross sections was completed during a single shift.
- During planing and visual grading all end trimmers were switched off but normal visual grading was done with standard crayon markings used to indicate end trim or cross cut intentions.
- E-mean and E lowpoint data as well as grade were captured for each board during machine stress grading.

Board Grade Assessment and Recording
- Immediately after green mill sawing, green 25 mm boards were individually assessed and data directly entered into a computer. Board data recorded included:
  - Log number (from end colour pattern)
  - Cross section size and length after allowance for end trim
  - Grade (Standard or Merchantable)
  - Reason for downgrade from Standard (knot, hole, wane, pith, other)
- Dried, dressed scantling boards were individually assessed and data recorded included:
  - Log number (from colour pattern)
  - Cross section size and length after considering end trim
  - MGP grade

o Warp recorded if in excess of Australian Standard allowance and type of warp (spring bow, twist)

Data Analysis

Sawing study data were analysed using SPSS correlation analysis and stepwise regression procedures to identify significant predictive variables and to consider regression models that provided the best prediction of grade recovery using field based assessment variables. Phenotypic correlations among density results were estimated using GenStat (2002)

RESULTS and DISCUSSION

Descriptive statistics are provided in Table 1 for 10–tree samples so that random samples of the low and high quality stands (where 20 trees were sampled) can be compared to medium site index stands (10 trees sampled) without weighting adjustments for sample size. The actual tree heights varied from 17.8 m to 31.8m in 15 Bluegum and 19.1m to 29.8m at 79 Kelly. The site index range approximates to 8.5m (22.0m to 30.5m) across the two sites.

Table 1: Average descriptive results for 10-tree samples of trees from sites at Beerburrum (15 Bluegum) and Toolara (79 Kelly) sampled to represent site index classes.

Compart.	Sample tree numbers	Site index class	Average DBHOB (cm)	Average tree HEIGHT (m)	Predominant height (m) (6 tallest trees)	Average Volume based on total tree hgt (m^3)	Average velocity of Fakopp short radius (km/sec)	Average proportion ingrade recovery (MGP10 + 12 +15) #	Outer wood basic density (kg/m^3)
79 Kelly	.31 - 40	Low	26.6	21.5	22.0	0.446	3.097	0.237	625
79 Kelly	. 41 - 50	Low	23.4	21.7	22.1	0.338	3.112	0.242	617
15 Bluegum	.61 - 70	Low	26.3	21.2	22.5	0.424	4.126	0.335	637
15 Bluegum	.51 - 60	Low	28.2	22.8	23.6	0.548	4.255	0.314	630
79 Kelly	.21 - 30	Medium	31.1	24.7	24.9	0.709	3.192	0.335	634
15 Bluegum	.71 - 80	Medium	30.4	24.9	25.1	0.696	4.259	0.320	643
79 Kelly	.11 - 20	High	28.5	27.6	27.8	0.645	3.284	0.336	640
79 Kelly	.1 - 10	High	31.2	28.1	28.5	0.800	3.285	0.336	634
15 Bluegum	.81 - 90	High	37.8	29.8	30.1	1.343	4.413	0.363	645
15 Bluegum	.91 - 100	High	35.3	30.0	30.5	1.168	4.420	0.364	651

The overall recovery in volume and percentage terms from the two sawing studies is summarised in Table 2. It is clear from these results that there were very significant differences between the two plantation sites sampled. In general terms the Beerburrum resource tends to produce larger trees then the Fraser Coast with higher average site index due in part to better average rainfall.

However, as the material was sawn at different mills the results are not directly comparable and should be regarded as indicative only of differences in the resource quality. The recovery figures from Bluegum were a little higher than those typically achieved at Weyerhaeuser and may reflect the high proportion (40%) of very high site index material included in the sample. In contrast, the results from Kelly are below average for Hyne and may reflect a skewing from normal averages due to the 40% of low site index trees in the sample or could suggest some other factor such as levels of resin defect has impacted on the recovery.

Table 2: Summary of sawing study recovery volumes and grade proportions by log position for 50 trees per site sawn by Weyerhaeuser Australia (Bluegum) and Hyne and Son (Kelly).

Log Position	Beerburrum - Compartment 15 Bluegum				Toolara - Compartment 79 Kelly			
	Butt	2nd Sawlog	3rd Sawlog	4th Sawlog	Butt	2nd Sawlog	3rd Sawlog	4th Sawlog
SAWLOG Averages								
SED (mm)	243	217	210	188	174	187	178	179
LED (mm)	303	239	237	224	211	225	215	214
Taper (mm/m)	12	5	6	7	7	8	8	7
Sawlog Length (m)	4.9	4.87	4.87	4.87	5.0	5.0	5.0	5.0
Sweep (mm)	24	19	14	15	18	18	18	19
BIX (mm)	14	40	52	61				
Density (kg/m^3) - whole core	583				593			
Density (kg/m^3) - outerwood 50 mm	641				630			
Fakopp Stress Wave Velocity (m/sec)	4290				3194	-	-	-
Hitman SWV (m/sec)	3850	3850	3685	3494	3781	3786	3630	3492
Number of Logs in Study	50	49	33	21	50	50	47	25
Sawlog (m^3)	13.3	10.3	6.5	3.5	10.5	8.1	5.7	2.4
Recovery (%)	39%	41%	39%	39%	56%	53%	57%	49%
Recovered (m^3)	5.23	4.22	2.55	1.37	5.89	4.27	3.22	1.18
MGP15 Percent	34.80%	24.90%	14.10%	9.50%	26.50%	24.10%	12.70%	0.00%
MGP12 Percent	22.40%	28.00%	27.80%	21.20%	23.20%	26.30%	36.30%	30.90%
MGP10 Percent	28.10%	32.70%	46.30%	54.70%	17.90%	21.90%	25.30%	33.90%
MGP10 & Better %	85.30%	85.50%	88.20%	85.40%	67.60%	72.30%	74.20%	64.80%

Correlation analysis (see Table 3 below) was conducted on the pooled results from the 100 trees sawn. This individual tree level analysis revealed that that there were significant (P= 0.01) positive relationships between DBHOB (r = 0.433), total tree height (r= 0.508), tree volume based on tree height (r = 0.264) and total in-grade recovery proportion (i.e. MGP10. MGP12 and MGP15 combined). However, Fakopp and outer wood density were also positively correlated

with tree size (DBHOB, tree height and tree volume) as well as with each other. Significant correlations considered to have implications for this study are highlighted in the table.

These linear correlations suggest a degree of auto-correlation between these traits and therefore a lack of independence between them. In practical terms it is suggested that this indicates that rather than variation in outer wood density or stiffness (as assessed by the Fakopp) impacting significantly on in-grade recovery, that it is the tree size influence on simple log breakdown geometry that determines grade recovery. That is, the recovery of higher density and higher stiffness boards is higher from larger logs than smaller logs just because the proportion of higher stiffness volume lost in waney edge boards is lower in big logs compared to smaller logs.
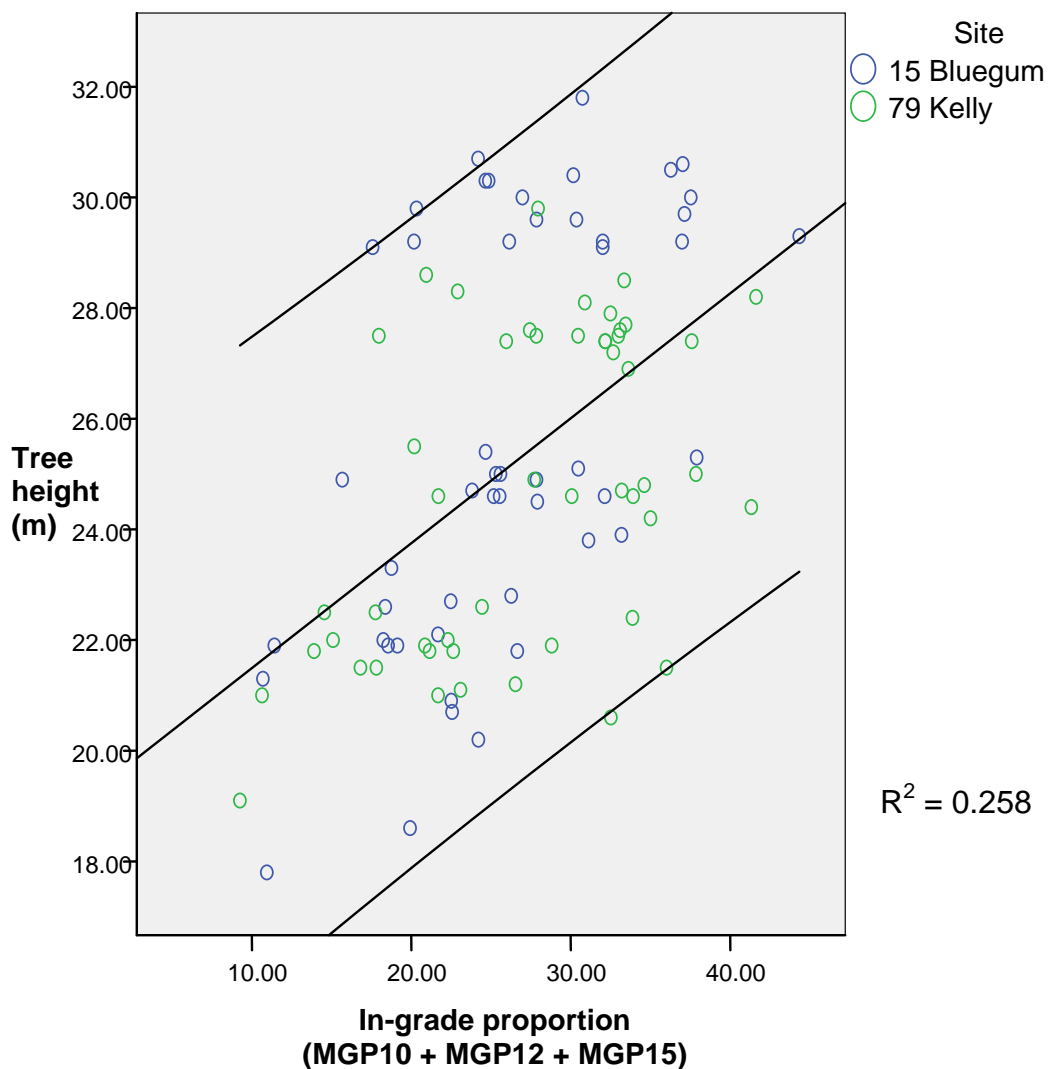

Figure 1: Individual total tree height plotted against proportion of in-grade recovery from each tree with site indicated

The generally positive but weak relationship between tree size (height) and in-grade recovery is indicated in the plots presented as Figures 1 and 2. In Figure 1 although there is a blurring of the

data points across the two sites, the overall weak but significant trend for improved in-grade recovery from taller trees is apparent. In Figure 2 there is a much clearer separation of these data points into the site index classes that they were chosen to represent. Although the overall individual tree relationship is weak (r^2 = 0.258) it is apparent that the taller trees in the high site index class tend to cluster at the higher end of the in-grade recovery range and the shorter trees in the low site index class cluster at the lower end of the in-grade recovery range.

A stepwise regression approach was used to investigate multiple linear regressions combined with collinearity diagnostics to identify variables that were not independent and would produce unreliable models. The strongest variable that predicted in-grade recovery (combined total volume percentage of MGP10, MGP12 and MGP15 as a proportion of total scanned log volume per tree) was total tree height. Because height is positively and significantly correlated with Fakopp, tree volume and outer wood density none of these variables could add true predictive power to a multiple linear regression that already contained tree height.
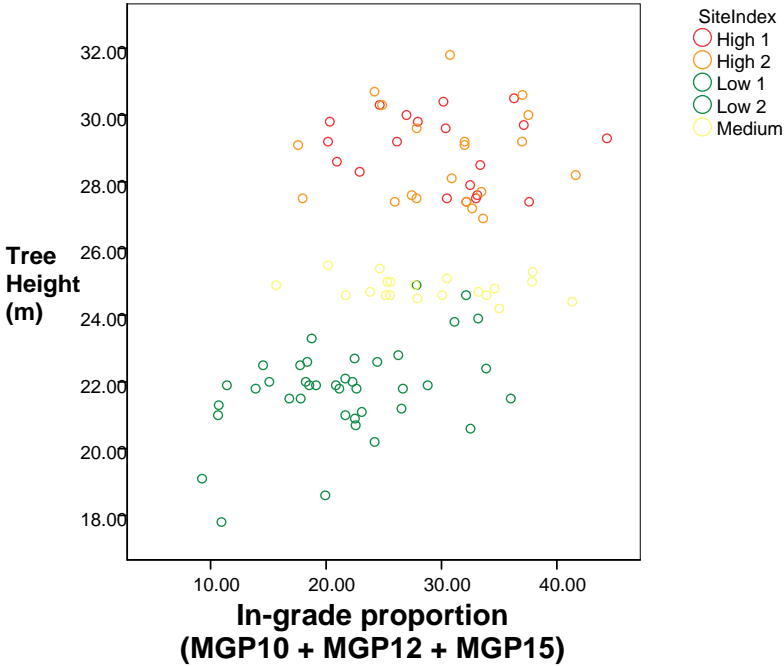

Figure 2: Total MGP in-grade recovery proportion plotted against total tree height with individual tree data points colour coded to indicate site index of their stand.

TABLE 3: Correlation Analysis		DBHOB	Total Tree HEIGHT	Total Tree height Volume (m³)	Fakopp Mean short radius (km/sec)	Total ingrade (MGP10_12_15)	Outerwood 50mm basic density (kg/m³)	Juvenile wood basic density (kg/m³)ykgm3	Whole Core basic density (kg/m³)
DBHOB	Pearson Correlation	1	0.731(**)	0.969(**)	0.331(**)	0.433(**)	0.354(**)	-0.076	-0.100
	Sig. (2-tailed)		0.000	0.000	0.001	0.000	0.000	0.454	0.324
	N	100	100	100	100	100	100	100	100
Total tree HEIGHT	Pearson Correlation	0.731(**)	1	0.818(**)	0.300(**)	0.508(**)	0.285(**)	-0.062	-0.031
	Sig. (2-tailed)	0.000		0.000	0.002	0.000	0.004	0.541	0.759
Total Tree height Volume (m³)	Pearson Correlation	0.969(**)	0.818(**)	1	0.378(**)	0.394(**)	0.323(**)	-0.085	-0.106
	Sig. (2-tailed)	0.000	0.000		0.000	0.000	0.001	0.399	0.296
Fakopp Mean short radius (km/sec)	Pearson Correlation	0.331(**)	0.300(**)	0.378(**)	1	0.036	0.230(*)	-0.022	0.024
	Sig. (2-tailed)	0.001	0.002	0.000		0.720	0.021	0.831	0.815
Total ingrade (MGP10_12_15)	Pearson Correlation	0.433(**)	0.508(**)	0.394(**)	0.036	1	0.264(**)	-0.011	0.016
	Sig. (2-tailed)	0.000	0.000	0.000	0.720		0.008	0.910	0.871
Outerwood 50mm basic density (kg/m³)	Pearson Correlation	0.354(**)	0.285(**)	0.323(**)	0.230(*)	0.264(**)	1	0.184	0.361(**)
	Sig. (2-tailed)	0.000	0.004	0.001	0.021	0.008		0.067	0.000
Juvenile wood basic density (kg/m³)	Pearson Correlation	-0.076	-0.062	-0.085	-0.022	-0.011	0.184	1	0.829(**)
	Sig. (2-tailed)	0.454	0.541	0.399	0.831	0.910	0.067		0.000
Whole Core basic density (kg/m³)	Pearson Correlation	-0.100	-0.031	-0.106	0.024	0.016	0.361(**)	0.829(**)	1
	Sig. (2-tailed)	0.324	0.759	0.296	0.815	0.871	0.000	0.000	

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

If we plot the average values of the 10-tree samples summarised in Table 1 we see an almost perfect correspondence between average tree volume and the average volume of in-grade recovery as plotted in Figure 3. Plotting these average values removes the noise in the 100 individual tree plots and emphasises how closely the geometrical recovery of structural boards is linked to log and therefore tree size. The strength of this relationship also indicates how well the processors for this resource have streamlined their log sorts and cutting patterns to optimise recovery from each sort class and achieve such consistency of recovery across size classes.

It is suggested that the inherently high wood density of slash pine mature wood is above the density thresh-hold needed to consistently produce in-grade structural timber. Therefore it is defects in the wood such as knots and resin defects that create the bulk of the variability in in-grade recovery from tree to tree. Additionally, silviculture history combined with environment (seasonal changes due to extended drought or wet seasons) may speed up or slow down growth for several consecutive seasons creating variation in ring patterns that may impact on wood properties that contribute to structural grade determination as well as wood stability. Even so these variations in growth rate and in knot area ratio from branch architecture (the size, frequency and distribution of branches within the tree) have a somewhat random impact on grade recovery and stability as they depend on where saw cuts fall as the log is broken down. Although saw patterns are set by log size the influence of sweep and taper will affect where cuts are made and thus whether knot area ratio is maximised or minimised or whether growth ring patterns create homogeneous or heterogeneous density profiles within a board. Hence it is not surprising that tree size, or in this case tree height specifically, only accounts of 25% of the variation in in-grade recovery in slash pine. This species differs from radiata pine in that the density and stiffness distribution of mature wood in radiata would appear to straddle the quality threshold to make it suited to structural product recovery. Therefore density and acoustic tools have provided an effective means of segregating radiata pine into structural and non-structural product log classes but fail to segregate logs for this purpose in slash pine.
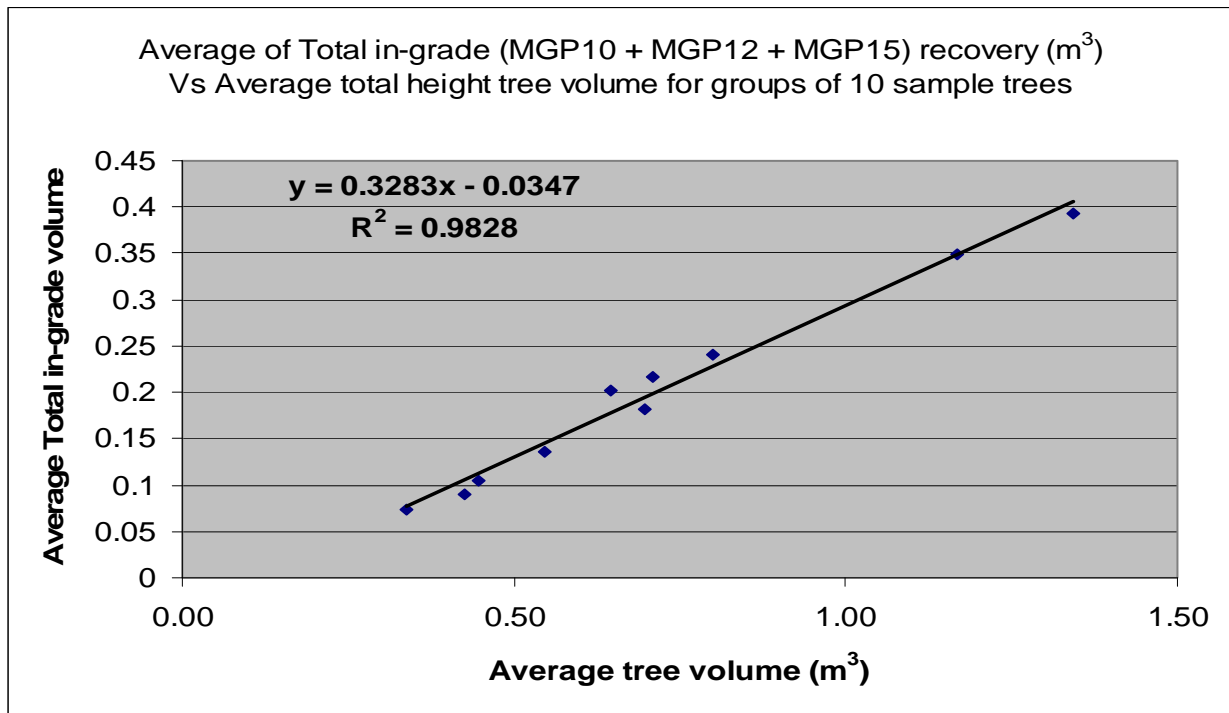
Figure 3: Average in-grade volume plotted against average tree volume for 10-tree samples randomly selected from within high, medium and low site index study samples.

Up the stem density variation

This study utilised the opportunity to collect samples at the top of each 4.8m log sampled to allow up the stem variation in average basic density to be studied and to examine relationships with breast height increment core density values.

Table 4: Average unextracted basic density (kg/m^3) variation assessed on wedge samples sawn from disc samples taken at the top of each log.

Site Index	n	15 Bluegum, Beerburrum				79 Kelly, Toolara			
		Butt log	2nd log	3rd log	4th log	Butt log	2nd log	3rd log	4th log
HIGH	20	491	477	465	448 (19) [†]	551	523	491	457 (19)
MED	10	524	510	486 (8)	462 (1)	539	506	465	423 (6)
LOW	20	516	491 (19)	447 (5)	408 (1)	541	520	478 (17)	—

[†] Numbers in parentheses indicate lower sample size than the n indicated due to smaller trees not producing all logs in commercial sizes.

Table 5: Average unextracted basic density (kg/m^3) variation assessed in increment core samples removed at breast height.

Site Index	Compartment 15 Bluegum			Compartment 79 Kelly		
	50mm Outer segment	Juvenile † Wood	Weighted‡ Whole Core	50mm Outer segment	Juvenile Wood	Weighted Whole Core
High (n=20)	648	482	574	627	534	598
Medium (n=10)	643	506	590	635	500	583
Low (n=20)	633	503	589	641	509	593

† juvenile wood = first 10 growth rings from the pith
‡ whole core estimates weighted by basal area proportions

Phenotypic correlations between basic density estimates from increment core samples removed at breast height and densities estimated at the top of each log (Table 6) show differences between the two sites, which is to be expected given the differences in sawing outcomes and average density patterns in Tables 4 and 5. The 50mm outer wood core estimates of basic density and weighted whole core estimates are sometimes very similarly correlated with up the stem densities but also more weakly correlated in others. Estimates of density at the top of the 2nd log (approximately 10m height above ground) were generally more weakly correlated with other density estimates than those form the butt and upper logs. The latter suggests some growth or maturity factor or interaction creating more variability in density at this point in the stem. An F-test of variances of the 50mm outer wood and weighted whole core samples showed no significant differences between the sites for these density estimates so correlations for the two sites combined are also presented in Table 6.

Table 6: Phenotypic correlations (r values) between basic density estimates from unextracted breast height increment core samples (juvenile wood = first 10 growth rings from pith, 50mm outer wood and weighted whole core) and from wedge samples recovered from the top of the butt, 2nd, 3rd and 4th logs of sample trees from 79 Kelly and 15 Bluegum.

Site		Butt Log	2nd Log	3rd Log	4th Log	Juvenile wood	50mm Outer wood core
79 Kelly, Toolara (n=50)	2nd Log	0.834 ***†	–	(n=47)	(n=25)		(n=50) ‡
	3rd Log	0.819 ***	0.887 ***	–			
	4th Log	0.688 ***	0.772 ***	0.889 ***	–		
	Juvenile wood	0.434 *	0.327 NS	0.368 *	0.337 *	–	
	50mm Outer wood core	0.773 ***	0.658 ***	0.664 ***	0.491 **	0.467 **	–
	Whole Core	0.781 ***	0.656 ***	0.668 ***	0.532 **	0.741 ***	0.914 ***
15 Bluegum, Beerburrum (n=50)	2nd Log	0.557 **	– (n=49)	(n=33)	(n=21)		(n=50)
	3rd Log	0.825 ***	0.554 **	–			
	4th Log	0.611 **	0.506 **	0.692 ***	–		
	Juvenile wood	0.805 ***	0.482 *	0.659 ***	0.535 **	–	
	50mm Outer wood core	0.775 ***	0.384 *	0.762 ***	0.644 ***	0.648 ***	–
	Whole Core	0.882 ***	0.564 **	0.788 ***	0.640 ***	0.853 ***	0.916 ***
Sites combined (n=100)	2nd Log	0.719 ***	– (n=99)	(n=80)	(n=46)		(n=100)
	3rd Log	0.799 ***	0.685 ***	–			
	4th Log	0.505 ***	0.515 ***	0.770 ***	–		
	Juvenile wood	0.682 ***	0.505 ***	0.564 ***	0.409 **	–	
	50mm Outer wood core	0.509 ***	0.356 **	0.627 ***	0.548 ***	0.479 ***	–
	Whole Core	0.790 ***	0.614 ***	0.747 ***	0.562 ***	0.816 ***	0.842 ***

† Significance level indicated: *** = P<0.001; ** = P< 0.01; * = P<0.05; NS = not significantly different
‡ sample size indicated for core samples applies to core estimates and butt logs and second logs unless a smaller 'n' value is indicated in parentheses under 2nd, 3rd and/or 4th log columns.

16

CONCLUSIONS

Sawing studies

The results from two sawing studies did not provide a prediction model that the project partners considered justified further return to log sawing studies to improvements to the level of prediction from the 100 tree sample. The indication from this work is that for slash pine the key determinant of in-grade recovery that can be readily assessed in the field is tree size. Tree height measured with a vertex provided the strongest prediction with 25% of variation in in-grade recovery accounted for. As site index maps of the resource are available based on inventory plot measures of predominant height it would seem that this is the most cost-effective way of ranking stands and compartments of the slash pine clearfall resource for potential in-grade recovery.

The capacity to capture large sample size assessments of stem or log stiffness will become both cost effective and practical if the adoption of acoustic velocity technology and its incorporation into harvesting and processing equipment applications becomes common in the future. This would enable more effective resource classification opportunities if links between complete compartment log velocity averages can be linked to sawmill recovery. The sample size of this study must be considered extremely small to represent the resource and did not provide an improved sensitivity to relationships compared to batch study results as used in the Green Triangle Study (Roper *et al.* 2004), as had been hoped in planning return to tree and log studies. Looking to the future, an alternative useful approach may develop if the inclusion of acoustic technologies in to harvesting cutting heads is achieved. The latter would provide a very cost effective and practical method to fully capture the variation in predicted wood stiffness for whole compartments. This could then be used to link with sawmill product data capture records if their log yards were managed to batch process logs from discrete single compartments. For large compartments representing several days processing time, the middle day of sawing could then be used to represent the output for the compartment with confidence that it was not confounded by wood from other sources. Records over a period of months should establish if robust links between compartment averages and variances and sawmill product quality exist and can then be utilised to manage wood flows from log yard into sawmill for an improved prediction of grade outcomes.

Wood quality Review

The main points covered and highlighted in the review are summarised as follows:

Wood properties

The main survey trends in Queensland grown slash pine and Caribbean pine plantations were for un-extracted basic density and latewood percentage to:

- increase as latitude decreases along the coastal lowlands (elevation < 100m)
- decrease with elevation for plantations grown at about the same latitude
- increase with decreasing site index for plantings at the same location and elevation.

Similar trends have been observed in slash ×Caribbean (PEE×PCH) pine F_1 hybrids planted from Whiporie in northern NSW to Byfield in central Queensland. These trends should result in improved wood stiffness with increasing latitude in coastal lowland sites and from lower quality sites but reduced stiffness with large changes in altitude and high site index. This variation may be important for the yield and quality of some products and require consideration to optimise planning of harvest schedules and processing requirements to achieve predicted value returns.

Compared with parental taxa PEE×PCH F_1 hybrids grown on the same site tend to be intermediate between parental means for mean basic density, latewood percentage and fibre length with some tendencies to be closer to the Caribbean pine parental values. Comparisons of F_1 and F_2 PEE×PCH hybrids have revealed little difference in wood properties between these taxa. Other varieties of Caribbean pine and PCH variety hybrids displayed very similar wood density to the established deployment taxa of PEE×PCH hybrids in southern Queensland and PCH in central and northern Queensland. Variation observed in wood properties of PEE×PCH hybrid clones has been quite large. This indicates a need to screen for clones with preferred properties for improved recovery of high quality end products.

A decrease in average basic density of about 30 kg/m^3 has been observed in 15 to 17-year-old PCH grown on ex-pasture land. This has product and grade implications for the use of this part of the resource and different management and processing strategies may be needed to optimise the value recovery from it.

Genetics

Studies of the inheritance patterns of wood properties in slash pine, Caribbean pine and in their F_1 interspecific hybrid has revealed that basic density has a generally strong level of heritability (> 0.6), spiral grain has moderate inheritance for individual tree estimates (~ 0.25) but family parameters calculated for the hybrid were quite strong (~0.6).

Genetic correlations between basic density and DBHOB are low for slash pine but negative for the hybrid (-0.71) and Caribbean pine (-0.68). Basic density and stem volume under bark have also been estimated to be strongly negative in Caribbean pine (-0.84) and weakly negative for the hybrid (-0.19). These adverse correlations need consideration in tree improvement strategies to ensure that selection strategies achieve gains in both tree volume and wood quality traits. Failure to consider these adverse correlations would almost certainly result in lower density and poorer structural quality timber in the future.

Screening of clones and parents within the tree improvement program has highlighted considerable variation in wood properties among superior clones and parents selected for growth and form. This variation provides opportunities to screen and select clones and parents that combine both superior growth and wood property performance.

Processing studies

Green off saw recovery of structural product from slash pine and Caribbean pine samples sawn at the Salisbury research sawmill averaged about 50% (range ~ 44 to 52%) for stands aged between 20 and 28 years of age. Structural dimension green product averaged about 88% of total green recovery for 26-28 year old slash pine and 86% for 20-24 year old Caribbean pine. For 32-year-old hybrid pine the green off saw recovery was also about 50% but the proportion of structural product in the green recovery rose to over 95%. Results from validation batches sawn at the Hyne and Son Tuan sawmill produced lower green off saw recoveries (43.4 to 46.4%) but structural product proportions were similar (82.5 to 88.8%). Comparison of total MGP grade recovery from 30-year-old slash pine and PEE×PCH hybrid grown in the same experiment at Toorbul (near Beerburrum) produced 88.2% recovery from the slash pine and 90.0% from the hybrid.

Studies carried out on young hybrid clones from 6.8 to 13 years of age have shown considerable variation in average stiffness of structural dimension recovery. The studies indicate that an average juvenile wood density of around 400 kg/m^3 is required to produce MoE values in excess of 7500 MPa in at least 50% of the recovered boards. Density and a standing tree prediction of MoE using a time of flight acoustic tool were found to predict 3m butt log stiffness (r^2 ~ 0.50) in a study of two clones sampled at 7 years. However, a study of 3m butt logs from 32 clones sawn at 6.8 years found ST300 acoustic velocity as the only significant predictor of average stiffness in the recovered boards.

Modelling MGP grade in slash pine boards found board density as the strongest predictor of stiffness and average growth ring width as the most significant predictor of strength.

In veneering studies, the relationship between average plywood panel stiffness and average log acoustic velocity for log velocity groupings in mature northern NSW slash and loblolly pine was strongly linear. The slash pine stiffness was superior to the loblolly and ranged from 12659 to 17190 MPa in the slash and from 8927 to 12309 MPa in the loblolly. Very good mechanical properties of plywood and LVL produced from north Queensland grown Caribbean pine have been demonstrated. The mean MoE and MoR results of plywood from three sites were very high suggesting that a substantial amount of F17 and F22 plywood would be able to be produced from a mill based on the Cardwell resource tested. LVL produced and tested from Cardwell grown PCH was at least comparable to commercial material and equivalent to an F14 grade.

Resin streaks and shakes

The occurrence and severity of resin defects in plantations of slash pine and Caribbean pine and their hybrid in Queensland varies considerably with environment and within stems. The economic consequences of resin defects are significant as they are a major cause of lost recovery and sawn product rejection for solid wood processors in Queensland and can result in shifts in market preference to alternative wood and non-wood products. Resin shake is the major cause of lost recovery and sawn product rejection for solid wood processors in Queensland but resin streaks also impact on sawn, veneer and reconstituted products. Lost recovery and grade fall down due to resin defects has been valued at between \$4 and \$5 million /annum in Queensland (Harding *et al.*, 2007).

Studies have not been able to define the causes of resin defect occurrence and severity in Queensland exotic pine plantations. Early studies established the relationship between resin defects and branches but were unable to link this incidence or severity to site factors. More recent work suggest an impact of wind and engineering models pinpointing the maximum stress point for torsional forces resulting from wind action on crowns at around 2 to 4 m above ground is supported by observations of maximum extent of resin defects.

The correlation between resin defects in increment core samples and visible defects on log ends and the proportion of recovered wood affected by it, as well as the severity of the defects present, has been found to be weak and of no practical value for sorting logs.

Internal log scanning tests to assess their potential for resin defect detection for log segregation and sorting has been shown to require x-ray helical computed tomography (CT) modality. The adoption of CT scanning technology will require a detailed financial assessment of the potential returns and a compelling business case to justify the investment in its development for commercial implementation. The latter is unlikely to occur until this technology is more widely researched and developed for other log scanning uses internationally.

Pulp and Paper
The emphasis on sawn structural dimension framing timber as the main market for Queensland exotic pine plantations has meant that pulp and paper properties have not been the subject of any large studies since the 1970's. A comparison of the pulping and papermaking properties of Queensland conifer plantation properties provided detailed wood properties and pulp test results for four selected Caribbean pine and 10 selected slash pine trees. Weighted mean fibre tracheid length results for individual slash pine trees ranged from 2.77mm (11-year-old tree) to 3.82mm (20-year-old tree) and for 11.5- year-old Caribbean pine trees ranged from 2.86mm to 4.31mm.

Future research recommendations
Areas of wood quality research recommended for further study in Queensland and northern NSW exotic pine plantations include:

- An updated survey of plantation wood properties to capture density and wood stiffness variation with planting stock across key planting locations representing changes in latitude and elevation for a structured set of site indices.
- Examining the relationship between MoE predictions obtained using standing tree acoustic tools and log and sawn timber MoE predictions and static test results to improve our understanding of the relationships between these predictions and examining how best to use these tools and apply their results, particularly for genetics studies and genotype screening.
- Establishing critical values of wood properties needed to ensure improved grade recovery from future planting stock to improve genetic screening of parents, families and/or clones.
- Investigating variation in graded recovery of structural timber with age from different genetic stock (taxon, seed batch, family or clone) to develop optimal silviculture regimes and to ensure product quality and recovery opportunities are realised.

- Modelling of wood properties linked to product outcomes from different genetic stock and its interaction with silvicultural regimes. Work in this area is currently being undertaken by FPQ and DPI&F.
- Look for opportunities to investigate the causes of resin defect incidence and severity. New technologies are needed to provide practical and cost-effective methods of internal stem and log scanning. New technologies that develop and provide opportunities to characterise genetic material for resin defect severity in standing trees or logs would provide allow definitive investigations of correlated variables useful for prediction of resin defect severity.

REFERENCES

GenStat for windows, 6th edition, Version 6.1.0.205. Lawes Agricultural Trust, Rothamsted Experimental Station.

Harding, K., Davis, J., Copley, T., Selleck, A. and Haslett, T. (2007) Resin defect impacts on the value of graded recovery and evaluation of technologies for internal defct detection in slash pine logs. Report to FWPRDC available from
http://www.fwprdc.org.au/content/pdfs/new_pdfs/PN04.3005_resin-report_(2).pdf

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 B – Linking grade outturn to wood properties. Report for Forest & Wood Products Research & Development Corporation Project PN03.3906 77pp. (http://www.fwprdc.org.au/content/pdfs/PN03.3906_part_b.pdf)