



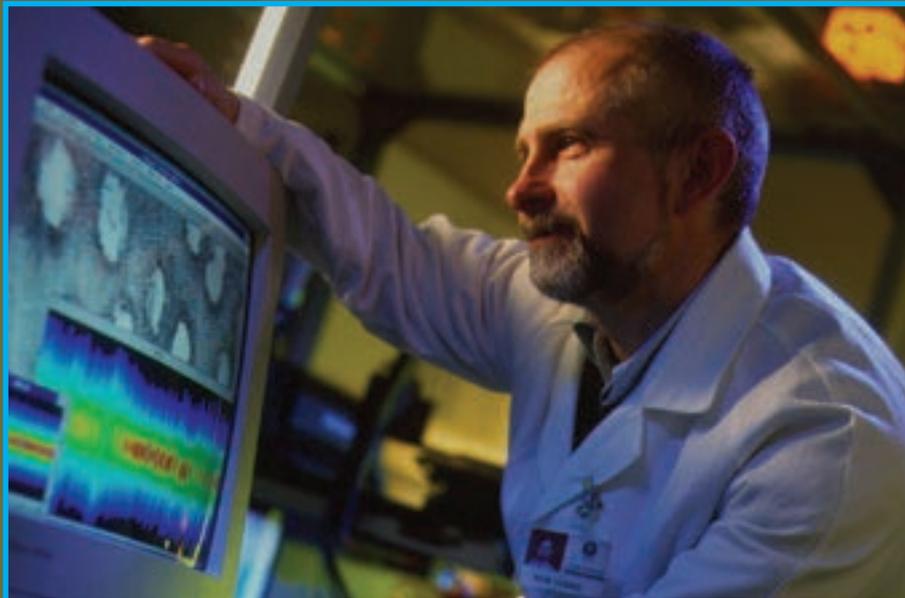
Australian Government

Forest and Wood Products
Research and Development
Corporation

Resource Evaluation for Future Profit:

Part C

Procedures Manual - Based on Green Triangle Case Study



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***Publication: Resource Evaluation for Future Profit:
Part C – Procedures Manual – Based on Green Triangle
Case Study***

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**Resource Evaluation for Future Profit:
Part C – Procedures Manual – Based on Green Triangle
Case Study**

Prepared for the

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by

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and the Australian Government.*

EXECUTIVE SUMMARY

Objective

The major project objectives of the Green Triangle Resource Evaluation for Future Profit were to:

- Demonstrate the value of resource evaluation tools that can predict future trends in structural grade recovery, using the Green Triangle region as the case study.
- Validate the methodology for application to other resources, such as exotic pine in southern Queensland or radiata pine in other areas.

This report is the third report from this project and outlines the procedures used in the Green Triangle study that could be adapted for new studies.

Key Results

This report covers the activities of:

- Sample design and stratification
- Resource density survey
- Intensive sampling and falling
- Sawing study
- Machine stress grading data collection

Application of Results

The procedures outlined in this report could be adapted to further resource evaluation studies for radiata pine in new regions or to other softwood species in new regions.

While this report outlines the procedures necessary to conduct an effective resource evaluation survey, utilising experienced practitioners will ensure that pitfalls are avoided. The outerwood density values must be taken under strict conditioners to ensure spurious data are not collected and board integrity must be maintained throughout the process.

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INTRODUCTION

The suitability of the Australian plantation resource for production of structural grade timber is changing as a consequence of growers striving to increase productivity and yield and continued demand by processors for quality feed stock. There is a significant benefit in evaluating existing resource to assess variability in wood property characteristics and quantify the impacts this variability has on structural timber outturn.

This “how to” procedures manual documents and describes resource evaluation tools and techniques used in the FWPRDC supported project titled “Resource Evaluation for Future Profit”. The project, undertaken in the South Australian and South Western Victorian Green Triangle Region over a 2-year period between July 2002 and June 2004, demonstrated the value of resource evaluation tools to predict trends in structural grade recovery.

The Green Triangle study encompassed four separate forest owners’ estates (Forestry South Australia, Green Triangle Forest Products, Auspine, and Hancock Victorian Plantations). The area of *Pinus radiata* included the survey region was approximately 150,000 hectares with a variety of age classes from new plantings up to over 50 years old, with both first and second rotation stands. The resource spanned a wide range of site qualities, stand ages, stand management regimes and genetic material, all factors known to influence wood properties.

A number of tree and log quality evaluation tools and techniques were used to assess and quantify variability in stand level wood property characteristics which were then related to structural timber outturn via a batch sawing study.

The study demonstrated that by quantifying wood quality characteristics such as standing tree breast height outerwood basic density, microfibril angle and log sonic velocity, future structural grade recoveries could be reasonably well estimated. The study also highlighted the benefits that can accrue to both forest growers and sawn timber processors if logs destined for production of structural grades are allocated based on measured and/or predicted wood quality characteristics known to strongly influence structural grade recovery.

This manual is an adjunct to the main project reports

- Report #1385: Wood Property Survey of the Green Triangle Region. July 2004.
- Report #1384: Linking Grade Outturn to Wood Properties. August 2004.

These two reports contain full details of the specific approaches used and outcomes from the Resource Evaluation for Future Profit project, and are available from the FWPRDC on request.

This Procedures Manual includes an overview of the various project stages along with descriptions of the tools, sampling techniques, evaluation methodologies and procedures used in the Green Triangle study. It is intended to provide guidelines for forest growers and processors interested in undertaking resource evaluation studies of a similar nature on softwood plantations in other regions.

The following diagram summarises the project methodology, approach and outcomes.

Resource evaluation for future profit

Staged objective approach to resource evaluation.

- A. To define regional boundaries and forests to be included in study in consultation with participating companies. Confirm regional industry buy in and input to project.

A. Geographic Region

Tasks - Identify companies, consult with Company staff, secure cooperation and in-kind

Increased knowledge of Wood quality variability

- B. To identify, in consultation with regional industry, resource level site variation indicators know to influence wood properties and stratify resource accordingly

B. Stratification

Tasks - Document site-related characteristics and crop types to determine range of stand variability across the region. Stratify resource into wood quality

- C. To determine a representative sample of site related and crop type variability for assessment.

C. Sampling strategy

Tasks - Assessment planning and design, select number of site /crop types, age classes to be sampled.

- D. To assess wood properties linked to specific stand characteristics

- E. To determine the influence varying stand level wood properties have on structural grade outturn

D. Field Assessment

Tasks - Broad assessment: Undertake outerwood density survey of stands across stratified sites. (not less than 50 stands assessed using outerwood increment cores). Analyse map density variation. Utilise data to select stands for intensive assessment.

Intensive assessment: Destructively sample subset of 6 trees from 10 stands representative of regional density variation. Assessments include

1. Obtaining 5m-log height cross-sectional discs (5 discs per tree) to determine basic wood density by log height class. Utilise data to compare wood density prediction algorithm to NZ derived algorithm.
2. Collecting Breast Height SilviScan cores to assess outer wood and pith to bark density, microfibril angle and stiffness.
3. Measuring spiral grain, documenting branching habit, incidence of compression wood, resin pockets.

E. Sawn outturn study

Tasks - Log segregation: 400 logs (4 logs X 10 trees X 10 stands) 40 logs per stand. Stand batches sorted by 3 stiffness classes within batches.

Sawing study: Batches sawn to nominal 100 x 40 mm, kiln dried, planned and MSG tested. Batch integrity maintained through out entire process

Data analysis: Comparison of average batch outturns linked to stand level resource characteristics.

- F. To undertake analyses, report and present findings

F. Outcomes:

- Increased knowledge of fundamental wood properties and their impacts on structural grade outturn
- Increased knowledge of variability in regional resource characteristics in relation to impacts on wood properties and structural grades.
- Effectiveness and usefulness of resource evaluation tools demonstrated and verified.

- G. Extension to other regions / species

Use experience gained and lessons learnt to extend and apply refined methodology to other defined regions including exotic pines in southern Queensland

PROJECT METHODOLOGY

Project stages

The resource evaluation methodology applied in the Green Triangle study was based on a staged objective approach as follows:

- **Sample design** - Designing a sampling strategy to assess regional variability in wood density and stand age as key determinants of potential structural grade outturn.
- **Stratification** - Stratifying the resource by site-related characteristics and crop types of interest to owners (as represented by the Project Steering Committee), taking into account their particular silvicultural (mainly age related) preferences.
- **Density Survey** - Undertaking an outer wood density survey to assess wood density/age trends in the standing tree resource.
- **Intensive Sampling and Felling** - Intensively sampling a representative 10-stand subset of the resource (as determined by the density survey in liaison with the Project Steering Committee) for detailed wood property assessment and analysis, including SilviScan analysis, and to provide sawlog input for the sawing study.
- **Sawing study** - Undertaking a controlled site & sonic-sort batch sawing study on logs representative of the extrinsic and intrinsic wood properties using recently available sorting tools.
- **MSG Data Collection, Quality Assurance & Analysis** - Comparing the distribution and yield of structural grade outturn from log batches selected and segregated by varying site and log wood property characteristics.
- **Reporting outcomes** - Relating structural grade outturn back to known wood quality characteristics in the log batches and the originating stands.

Sample Design and Stratification

Radiata pine wood properties are known to be extremely variable. At a macro level site, age, genetic origin and stand management are all contributors to between-stand variability in wood properties such as basic density. At the individual tree level factors such as density, density gradients, juvenile core size, presence of compression wood, cellular microfibril angle and spiral grain all contribute to variation in wood properties within and between trees.

For the Green Triangle study a three stage sampling strategy was applied to ensure that the logs finally milled were as representative as possible of the broad range of macro level influences on wood quality variation throughout the region.

A stand level sampling strategy was developed in consultation with the Project Steering Committee including defining boundaries and identifying potential key wood quality delineating strata by stratifying the resource into crop types characterised by site quality (South Australian classification system), stocking, thinning history, age, genetics and silviculture.

The Project Steering Committee selected 58 stands covering the range of variability in stand characteristics identified in the initial crop type stratification from which a sample of 30 trees per stand would be assessed to determine mean outerwood density. Wood density is considered to be a major factor affecting wood quality in the broad sense, being strongly influential in timber strength and stiffness. One of the benefits of wood density as a quality parameter is that the patterns of variation are such that sampling can be used to provide data at the stand, tree and log level.

Density survey

Outerwood density surveys are a relatively cost effective and an essentially non-destructive means for documenting the variation in wood density throughout a resource. Variation, if established, can be linked to contributing factors such as site, silviculture and genetics. Extensive wood density surveys carried out on the New Zealand radiata pine resource have established that:

- Mean breast height outerwood density can be accurately estimated using breast height outerwood cores. A sample of single cores from 10 trees will provide a 95% PLE (Probable Limit of Error) of 5%-6%, while 30 trees will give a 95%PLE of 3%.
- Outerwood density within a stand is generally unrelated to stem diameter, provided that any very suppressed 'runt' trees (which by their size have a negligible contribution to harvested volume) are ignored.
- Selection of individual trees is not critical, however it is recommended that severely suppressed, badly malformed or trees with excessive lean are excluded from the sample.
- A good relationship exists between outerwood density and whole-tree density.

Forest Research has developed effective sampling procedures to map wood density variation within a resource and has captured the resulting valuable information in a wood density prediction algorithm. In New Zealand, many forest growers today routinely collect breast height outerwood cores as part of their pre harvest assessments. The mean outerwood density is determined and used to predict log and tree density values using either the New Zealand "National Wood Density Prediction Algorithm" or their own customised version.

One of the objectives of the Green Triangle study was to calibrate Forest Research's Wood Density Prediction Algorithm for use within the Green Triangle region.

In the Green Triangle study a total of 58 sites were selected for inclusion in the initial wood density survey. Field crews consisting of research providers and company staff, visited each stand and established a 30-stem transect plot for outerwood core density sampling with a 6mm increment corer, collecting and labelling a 50mm-long breast height outerwood core from each stem. Trees were numbered for later relocation, diameters measured, sample heights recorded and branch characteristics assessed visually.

Cores were uniquely identified and analysed individually with mean and standard deviations in outer-wood density derived for each stand. Wood density analysis is a specialised research laboratory procedure undertaken with specialised equipment able to saturate cores, oven-dry them, and record results to high levels of accuracy. Moreover, the cores need specialised handling and storage at all times to prevent spurious data being derived.

After laboratory analysis, distributions of within and between stand outer wood density (kg/m^3) were tabulated and mean stand average values calculated.

Intensive Sampling & Felling

Intensive sampling of the 10 stands representative of the variation in mean outer-wood density and age, as selected by the Project Steering Committee, was subsequently undertaken. To aid selection, stands were segregated into three outerwood density classes (low, medium and high) with stand ages used as additional selection criteria to narrow selection down to a representative ten stand sample for more intensive assessment. Table 1 shows the final ten-stand matrix.

Table 1: Density and age sample matrix.

Age (years)	Outerwood density class* (kg/m ³)		
	Low (≤ 450)	Medium (451 – 499)	High (≥ 500)
≤ 25	L (23)	M (25)	Not sampled
26 - 30	L (26)	M (28)	H (27)
31 - 35	L (33)	M (31)	H (32)
≥ 36	Not sampled	M (37)	H (44)

* In the 58 site survey, to divide all the density plots into three equal classes the breakpoints would be $<460 \text{ kg/m}^3$ for “low” and $> 490 \text{ kg/m}^3$ for “high”. These have been rounded to $<450 \text{ kg/m}^3$ and $>500 \text{ kg/m}^3$ for simplicity.

This sub-set was used to quantify within and between stand variability, through measurement and assessment of individual tree and log wood property characteristics. This intensive assessment data was required from individual trees and logs. These data were bulked to provide stand level averages.

For each of the 10 chosen sites, a sample of between 9 and 16 stems (trees) were selected to broadly represent both the range and average tree (or stem) properties for that site.

Selection criteria used for these stems, to try to match as closely as possible, were;

- diameter (breast height)
- outerwood basic density
- would yield sufficient sawlogs to achieve approximately 40 logs of 4.9m length per site.

Within the 9 to 16 tree sample a representative subset of six trees were selected for intensive sampling, involving collecting cores for SilviScan analysis and cross sectional discs to quantify variability in wood density by log height class. Trees were selected to cover the range of between tree wood density and tree size variability specifically 2 small diameter, 2 medium diameter and 2 large diameter trees with contrasting densities for each diameter class.

Selection of the 9 to 16 trees to be sawn (from within the 30 trees originally assessed for density) proved reasonably simple in practice. Tree selection favoured those trees which could be merchandised into 5m logs (actual log length was 4.9m after discs were sampled) with a minimum of waste, as regular disc sampling at 5m intervals was required. Malformed or strongly swept stems were avoided, and the low occurrence of these in the resource, meant that this was not difficult in practice. Trees yielding logs just physically too big for the sawmill to cut, were also avoided. In practice, there were only one or two sites affected, and selection from a slightly smaller diameter class still enabled the surveyed stand average diameter to be maintained in the sub-sample. The large size variation encountered between sites resulted in some stems on the biggest sites making 5 logs, while some on the smallest sites only managed 2 or 3 logs. The overall objective was to obtain at least 40 logs per site, which could be subsequently split into 3 sonic sort batches of 13 to 15 logs each. Minimum merchantability limits of 4.9m long and approximately 17cm SED (small end diameter) were set for the sawlogs. All trees harvested were fully merchandised, to minimise waste and minimise possible biasing of the results.



Prior to tree felling, at the breast height sampling position the following samples were also taken:

1. An extra 5mm outerwood core at breast height (for calibration of density algorithm) and label with indelible pencil identifying Site and Tree No
2. A pith-to-bark 12mm core (for SilviScan analysis) and label with indelible pencil identifying Site and Tree No

Following tree felling (9 to 16 trees selected per site to achieve approximately 40 logs per site across 10 sites):

1. Record total tree and stump height
2. Measure whole stem sonic velocity using an acoustic tool (e.g. Director HM 200) after trimming to breakpoint or SED limit for the trial (around 17cm this case).
3. On the 6 trees/site identified for intensive wood quality assessment, cut discs from butt, 5m, 10m, 15m and consecutive 5m intervals down to a small end diameter of approximately 100mm. Discs to be approximately 40mm thick and free of branches and other defects likely to affect wood properties. In some instances whorls will be encountered at the 5m disc sampling point and efforts need to be made to avoid discs containing branches.
4. Label discs clearly using an indelible pencil with Site ID, Tree No. and sampling height e.g. A/1/5 for Site A, Tree 1 and 5m height
5. Label both log ends with Site/Tree/Log Height Class using stapled labels and indelible pencil e.g. A/1/1 – these form a unique numbering system useful for logs sonic measurements and subsequent resorting into sonic batches.
6. All logs to be cut to 4.85m if possible. Merchantable log diameter limits inside bark range from SED 170mm to LED 600mm but this may be varied depending on the sawmill's log diameter limitations (if any).



Disc measurements can include (approximately 300 discs = 6 stems x 5 discs (approx) x10 sites):

1. Measure DOB, DIB, heartwood, juvenile wood (inner 10 growth rings), compression wood and assess discs for resin pockets and green internal checks
2. Mark discs according to Figure 1 and cut samples using a heavy duty band saw
3. Measure basic density using the volume displacement method on 10 ring blocks
4. Measure spiral grain for rings 2, 4, 6, 8, 10, 15, 20, 25 and 30
5. SilviScan analysis on pith-to bark strip (density, microfibril angle and stiffness)

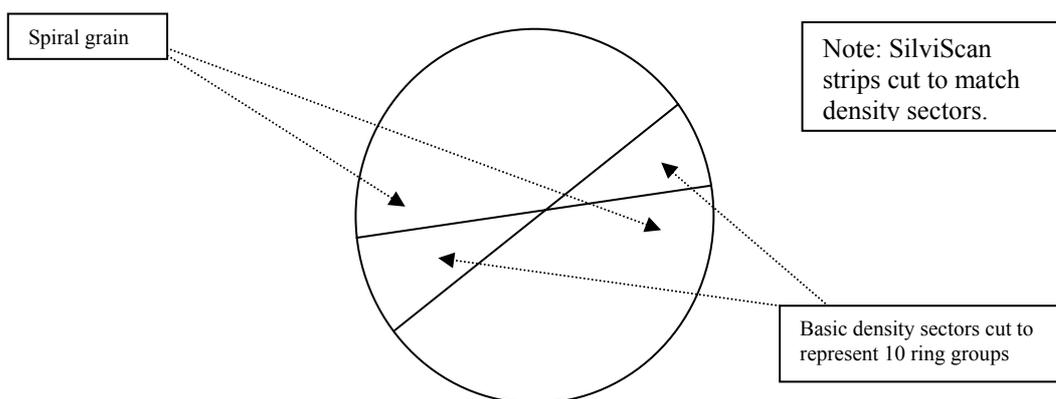


Figure 1 - Disc sampling breakdown (70mm thick approx)

The SilviScan technology, developed by CSIRO FFP, combines x-ray densitometry, diffractometry and image analysis, to measure a variety of properties in the one sample including air dry density, microfibril angle, fibre diameter and others. A combination of the density and microfibril angle measurements provides an estimate of MOE. Readings are provided 100 to 1000 times faster than conventional methods for these wood quality parameters and are undertaken from 12 mm increment cores.

NB. Discs sampled from above 20m tree height are only assessed for basic density using two sectors (not broken down by 10 ring groups) for the calibration of the density algorithm.

Sawing study

Individual log studies, although producing much more detailed data are much more expensive to undertake, as they require each individual piece of sawn timber to be tracked and tallied individually. In a production mill this is extremely difficult, and as most trees are harvested transported and processed in batches, a batch study is more representative of a real world situation. However, a limitation is that analysis is restricted to batch averages, and arising data cannot be related back to individual logs or trees.

For the Green Triangle study a batch sawing study was undertaken on logs merchandised from the 10 stand intensive sampling stage. Logs were batched into Low, Medium and High sonic velocity readings on a site basis, using sonic velocity values measured using CHH's Director HM 200 acoustic tool.

Log measurements (on approximately 400 logs at 4.9m length) included the following

1. Measure SED, LED, length, BIX, internode index and sweep and record against unique site/stem/log position I/D number and paint/spray **large**-end log-ends with identifying site colour (e.g. 10 sites = 10 colours but avoid **black and dark brown** at this stage). (Note that some colours can appear remarkably similar in poor or artificial lighting conditions often



encountered in mills. Pale light greys, blues, mauves, and greens are the most easily confused under these conditions, and their use should be minimised).

2. Measure log sonic velocity using and record values for all logs in a spreadsheet.
3. Order data in increasing numerical sonic velocity values to segregate logs into 3 equal batches of 12-14 logs each based on acoustic sound velocity i.e. Low, Medium and High. (Note that the cut-off values for each batch will vary from site to site – this is necessary to achieve equal numbers of logs in each site/sonic sort batch – but does not present any significant limitations to subsequent data analysis.)
4. Over-spray log *large-ends* with **black** paint using one of three grids (e.g. ▽ □ ○ - corresponding to low/medium/high acoustic sorts) to identify the sonic batch. The base site colour will be visible through grid over spray. Note -This painting assumes there will be **no end-docking** of boards during the subsequent sawmilling to retain site/sonic sort I/D.
5. Spray/paint the *small end* of butt-logs **dark brown** – this effectively segregates butt-logs from all other logs – but do so only if separate butt-log data is required for analytical purposes. Otherwise this step can be avoided

Log batches should be processed one at a time allowing sufficient time between batches so batch integrity is not compromised. The Green Triangle study focused on structural timber outturn and consequently the sawing pattern described below was aimed at maximising recovery of structural grade dimensioned timber.

Sawing Pattern

The saw pattern used:

- at the headrig was a cant sawing pattern to maximise 100X40mm (cut size 102x42mm & 90X35 D4S K/D) with a single 100mm cant from the logs.
- at the cant gangsaw - all 40mm (→ 100X40mm)
- at the edger - all 40mm flitches edged to produce target size 100X40mm with 75X40mm (cut size 80x41mm) as recovery.

The aim in this study was to recover the maximum number of 100X40mm 4.8m lengths with shortest length to be recovered 2.4m. The 75X40mm was considered down recovery size (becomes 70X35 D4S K/D). There were no 25mm boards to cut. The sawing pattern used in the Green Triangle study is show in Figure 2.

During these activities there was no end trimming of any boards to preserve site/sort/butt log information painted thereon.

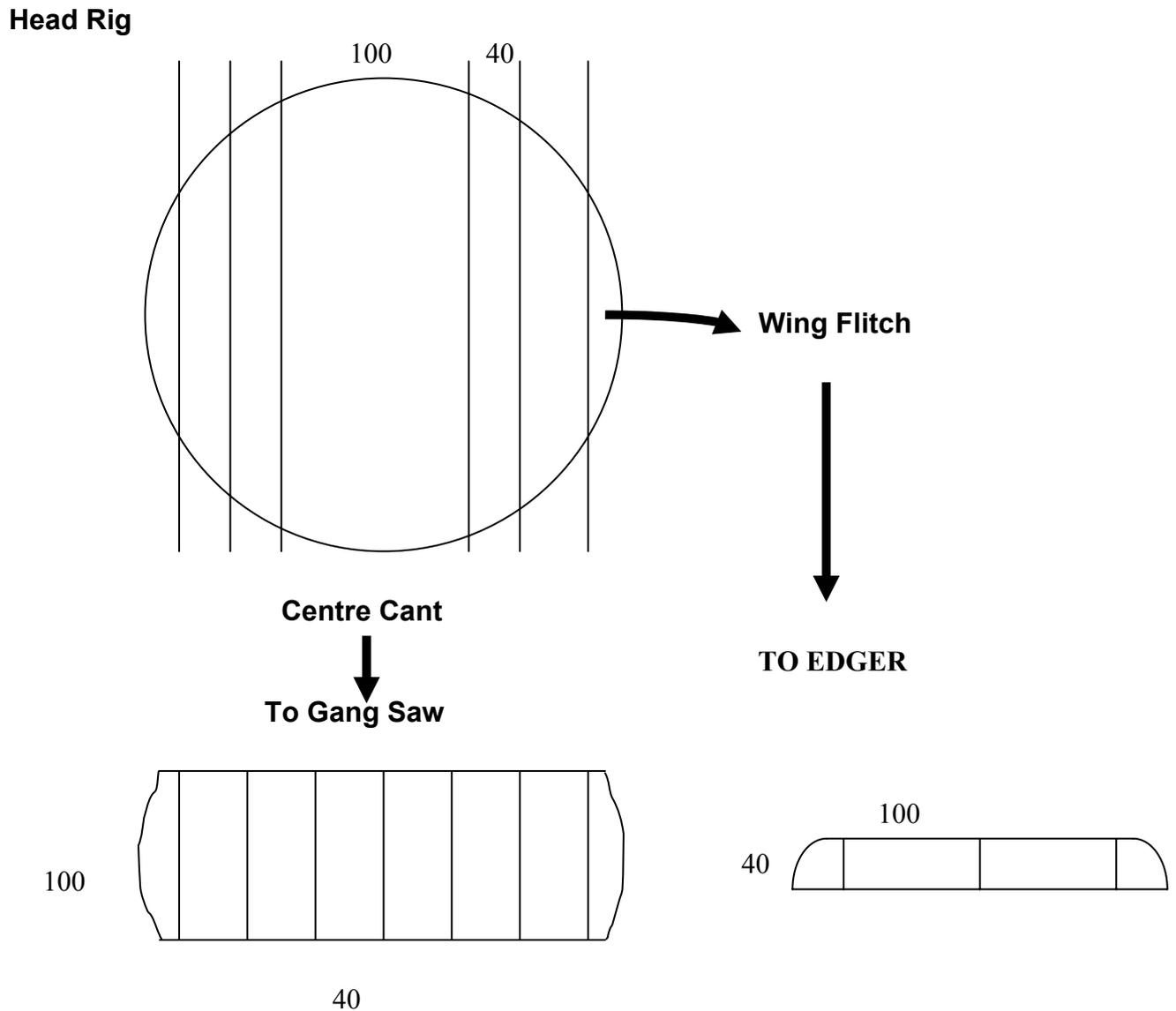


Figure 2 – Saw pattern used at Whitehead’s sawmill

Green Tally

The 100X40mm boards were tallied into 2.4m - 4.8m packets (maintaining batch unity as far as possible). Segregation of heart/sap material was undertaken visually to assist drying. In the Green Triangle study, 96.4% of the timber was produced in the main 100x40 nominal size. The balance (3.6%) in the 75x40 recovery size was tallied for conversion calculations, but not machine graded, and hence did not contribute to the MSG grade yields.



Kiln Drying

The timber was filleted prior to high temperature kiln drying in 3 separate kiln charges as follows:

- Sapwood (SAP as 2 charges)
Drying time approx 13.5 hours @ 135/90 degrees C.
Reconditioning time 4 hours 10 mins @ 95 degrees C & 100% RH
- Heartwood (Heart-In as 1 charge)
Drying time approx 8.75 hours @ 125/90 degrees C.
Reconditioning time 5.5 hours @ 95 degrees C & 100% RH.

After drying the timber packets were de-filleted, and resorting back into the 60 batches (30 sonic sort batches consisting of sapwood and heart-in subgroups). The colour coding, which remained on timber ends, enabled easy identification of individual pieces back to their originating sawing batch. De-filleting is a significant undertaking and re-batching should be undertaken under cover where possible, in order to reduce variability in post drying moisture content.

Moisture Content

Random samples of moisture content readings for each batch should be taken at various stages during de-filleting to ensure the timber has been dried to within specification prior to machine stress grading. In the Green Triangle study a set of 6 to 8 random board samples from each of the 60 (Sap & Heart) batches (making 440 readings in total), were taken during planer gauging and docking using a Carrell & Carrell Model 901 moisture meter with a conventional hammer needle probe. Results from this sample showed very little difference between sapwood batches (average 12.0% m.c. and range from 8.8% to 14.8%) and heartwood batches (average 12.6% m.c. and range from 10.0% to 15.6%). Quality assurance standards in Australia require that 90% of samples lie between 8 and 15% moisture content, which was clearly achieved in the Green Triangle study.

Planer Gauging, Docking and Final Tally.

Rough sawn kiln dry timber must be gauged to 90x35mm prior to machine stress grading. In the Green Triangle study timber batches were planer-gauged through a Weinig planer, and end-docked to standard lengths in 0.3m multiples (4.8m, 4.5m, 4.2m, down to 2.1m). This end-docking removed the paint code colours, and batch details were then represented by an alphanumeric numbering system for the 60 batches written on the end of each piece of timber (e.g. H30b is the Heartwood sort, batch 30, butt-log).

A final tally of all timber needs to be made in order to calculate sawing recovery. A full stick tally for sawing recovery purposes should include both 100x40mm, and 75x40mm. Most effort should be spent on the 100x40mm (now planer gauged to 90x35mm) as this is the timber that will be machine stress graded.

Distortion Assessment

Distortion should be assessed after planer gauging to a pass or fail based on commercially applied distortion limits, while the timber is being stacked and tallied. Commercial distortion limits used in a 90x 35mm @ 4.8m length are twist at 10mm, crook (spring) at 29mm and bow at 45mm. (These limits become lower for shorter lengths).

MSG Data Collection, Quality Assurance & Analysis

The MOEp for each board and batch need to be data logged recording MOEp(min) and MOEp (average). The MSG machine should be checked and calibrated prior to stress grading of batches. In the Green Triangle study the timber was docked (minimally to remove excess wane) after dressing, and before machine stress grading. This minimal docking was favoured so as to not bias the results in any way. In addition, the modest knot size in the Green Triangle meant that no visual override on un-MSG-graded ends was required.

The resulting data should be collated, including assignment of MGP grade cut-off boundaries (used for sorting the lumber into MGP grades), ready for final analysis.

Note: It is important to make sure that the machine stress grader is grading accurately or this will obviously distort final results. In order to independently verify the accuracy of the production mill based Machine Stress Grading, a sub-sample of the Green Triangle study material was selected for testing at the Forest Research Timber Engineering laboratory in Rotorua, New Zealand. This sub sample comprised of one packet of each of the four structural grades produced.

- one packet (120 pieces) Reject (35 pieces)/F4 (85 pieces)
- one packet (120 pieces) MGP 10
- one packet (120 pieces) MGP 12
- one packet (120 pieces) MGP 15

All of the sample timber was tested for bending strength and stiffness testing in accordance with AS/NZS 4063:1992. The timber was tested to destruction to determine the bending strength (MoRj) and stiffness as a joist (MoEj). The results for each packet (grade) supplied were then compared against the published design stresses for that grade. This testing simulates the quality assurance testing that is required to be done under AS/NZS1748. Timber grades assessed by the mill may need to be adjusted in line with the quality testing.

OUTCOMES

The Green Triangle case study demonstrated that, at an individual stand level, it is possible to quantify wood properties that are strongly related to variability in structural grade outturn.

The study has provided local industry with a more thorough understanding of the variation in wood properties across different sites and ages, and possibly varying silviculture, in the Green Triangle region. Insights gained from this study will assist industry players to better understand factors influencing quality differences between stands and the influence these have on sawn timber outturn.

Industry in the Green Triangle region can now utilise tools and techniques used in this initial pilot study, such as the Density Prediction Algorithm to predict future wood density trends across a range of sites in the Green Triangle region.

Generally studies such as the one on which this manual is based should be carried out by skilled practitioners as there are a number of pitfalls that may occur throughout the process. The readily available tools that were used in the Green Triangle study include:

- Pre-harvest stand **Outer-Wood Breast Height Density** assessment (6mm increment cores each 50mm long with 30 samples per site)
- Pre-harvest **SilviScan** assessment using Breast-height cores.
- **Stem Sonic** assessment at the time of harvest (on whole stems prior to log-making)

- **Log Sonic** assessment at the time of harvest or in the mill yard.

Table 2 lists the site average values arising from the Green Triangle study to rank stands in terms of Outerwood density, Stem sonic velocity, log sonic velocity, SilviScan derived whole tree MoE and machine graded MoEp.

Table 2: Wood quality assessment tools in relation to MOEp

Density High Medium Low / age	Outer Wood Density	Director Stem velocity	Director Log Velocity	SilviScan MOE whole tree	MOEp(adj) (Gpa)
H27	521	3.42	3.47	16.30	11.04
H32	538	3.47	3.55	17.00	12.08
H44	526	3.47	3.61	17.50	12.39
M25	482	3.32	3.41	15.30	10.23
M28	470	3.23	3.32	14.30	10.17
M31	472	3.39	3.48	15.60	11.26
M37	483	3.50	3.43	15.40	10.37
L23	428	3.13	3.15	12.30	8.60
L26	438	3.21	3.35	14.50	10.52
L33	418	3.07	3.14	12.80	9.40
Average	478	3.32	3.39	15.10	10.61

Outerwood breast Height Density Assessment: The Green Triangle study showed that outerwood density provides good predictive ability at the stand average level with an R^2 value of 0.72. (this relationship is explaining 72% of the variation in mean lumber MOE at the stand level). Examination of the outliers showed that younger ages tended to be below the trendline, while older stands tended to be above it. Therefore age was added as a second variable improving the R^2 value to 0.79.

Stem Sonic Assessment: Undertaken at the time of harvest sonic assessment offers another possibility for real-time evaluation of the lumber grades likely to come from the site. The correlation is less strong than for Outerwood density at R^2 of 0.64.

Log Sonic Assessment at the time of harvest has already been shown to have useful ability to sort logs into sonic batches with higher lumber MOE within a site, however the average log sonic value could also be used as a real-time tool to distinguish between sites on a similar basis to the other tools and techniques. Average log sonic velocity as assessed by the Director HM 200 tool, shows excellent ability to distinguish between sites in the prediction of lumber MOE with an R^2 value of 0.90 (or explaining 90% of the between site variation).

SilviScan predicted whole tree MoE used as a predictive tool. SilviScan® whole tree MOE shows very strong predictive ability for the final lumber MOE on a site basis with an R^2 value of 0.92.

These relationships are based on the data in Table 2 which comprise only 10 data points. Extreme care should be taken when applying these relationships in any resource. Further work is needed to determine whether these relationships are sufficiently robust to use routinely, and whether they can be maintained across species and regions.

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