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Resource and processing properties of hoop pine (*Araucaria cunninghamii*)

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by

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EXECUTIVE SUMMARY

Objectives

The major project objectives were to:

> *"Create a Log and Lumber Database and determine the principle drivers of grade outturn for each of the major log types in Araucaria stems. Generate Log Value Models providing for revision of gross log value gradients according to changes in product values; and the calculation of residual log values. Develop and demonstrate systems to characterize, assess and monitor the resource prior to harvest."*

This was to be achieved by undertaking sawing studies in 3 Stages to produce:

- A database of Araucaria log variables and actual grade outturn.
- Relative value gradients for major Araucaria log types to improve understanding between growers and processors.
- Multiple regressions relating the major log characteristics influencing value
- Interactive Log Value Models, driven by log characteristics, and Tree Value Models accumulating output from the individual Log Value Models.
- Suggestions of improved systems to accommodate key log quality variables that impact on grade outturn and log value.
- Value signals for tree breeders.

Stage 3 (Improved Inventory Systems) is still under consideration pending industry discussion of the results of Stages 1 and 2 (reported here).

Key Results

Sawing studies were carried out in two stages to document the variation in value associated with variation in log quality. Samples were selected by the industry collaborators to represent a range of sites and log characteristics. They can in no way be considered as representative of the Hoop pine resource as a whole. In total, about 400 logs were sawn, graded and gross log values derived, using a relative lumber pricelist (provided by industry collaborators[1]). A Log and Lumber Database was created and the detailed measurements of log and lumber characteristics use in analyses to identify the main drivers of value. Good relationships were derived for both Pruned and Upper logs. Unpruned butt logs (confirmed only after sawing) were treated as a separate group but proved more variable. All relationships were included in the Log Value Models provided to FWPRDC and all collaborators.

The information collected was used to first derive basic relationships between log variables and grade recovery, and then to construct logical and robust log and stem models to predict relative gross value and recovery by grade by any nominated processing standard and lumber pricing structure.

Findings were:

[1] The use of an agreed pricelist was to enable consistent **relative** lumber and log values to be calculated.

- The drivers of value in the different log types were defined. Diameter alone is not an adequate descriptor of value. The log characteristics driving quality and value are few and simple – combinations of diameter, size of defect core, log shape (Pruned logs) and size and whorl spacing (Unpruned butt and Upper logs). Models derived from SED, % sweep and external measurements of internodes proved significantly better predictors of grade and relative value than log size alone.
- The Pruned Log Index (PLI) was proven to relate well to grade, clearwood recoveries and relative gross values from the Pruned butt logs, but relies on good data on defect core sizes. There was only a very weak relationship between stem diameter and Defect Core in the sample logs.
- The drivers of value in Mid and Top logs were found to be similar so they can be considered as a single group – Upper logs. For Upper logs, the log diameter and whorls/m are the most influential factors - followed by log sweep. Similar relationships apply to the Unpruned butt logs. Study samples indicated that the average nodal habit may not vary much between sites, but that variation in Whorls/m between individual stems and logs may be high.
- Existing resource information in terms of quality factors in stands and blocks scheduled to be harvested is limited. While there are historic stand inventory records of the extent of pruning, there is little data on actual distributions of defect core size for the Pruned butt logs nor on the range and variation in nodal habit for the Unpruned and Upper logs. In recent years, more comprehensive data has been collected, but these crops will not be harvested for some time in the future.
- There are no consistent visible external indicators to identify the Unpruned butt logs and even the most experienced operators cannot reliably differentiate between pruned and unpruned stems in mature stands. Currently, the information available on % Pruned relies on historic data collected at time of last silvicultural intervention.
- Differences in the conversion standard between the two studies were noted, and while instructive, did not affect the overall results.
- **The real value of the project has been in the creation of Tree and Log Value Models which allow users to test various scenarios, and examine relative influences on log values, through changes in resource characteristics, lumber prices and processing costs for specific situations. If stands about to be harvested can be sampled appropriately, in combination with existing FPQ data, the models will give good predictions.**

Implications

The studies highlighted the need for good resource information if the full value of the resource is to be exploited. Both Pruned and Unpruned logs are highly variable, and while there is qualitative data available on some stand level characteristics, greater value could potentially be recovered. Some salient points are:

1. There is currently no accepted measure of quality of Pruned logs (such as Pruned Log Index - PLI). A key factor in any useful measure of clearwood potential is the maximum diameter over pruned branch stubs - DOS. The defect

core, and eventually PLI, can (in conjunction with currently available basic stand data) be derived from accurate estimates of DOS.

2. Pruned and 'Unpruned' butt logs cannot be reliably differentiated at harvest, but even logs which are technically Unpruned butt logs can provide valuable lumber from clearwood derived from internodal sections resulting from natural pruning and partial pruning.
3. The range and variation in quality factors of the Upper logs in particular stands is well known, so the critical variable of internode spacing (Whorls/m – used to calculate the CCI – Clearwood Component index) is not well documented at the stand or block level.

Acquisition of data on the items listed above could be addressed at various levels of intensity - but none of it is prohibitively difficult.

Recommendations

- Use the Araucaria Log Value Models to compare predicted value gradients under different log grading and timber pricing scenarios.
- Utilise FPQ systems, in conjunction with Log and Tree Value Models to predict resource characteristics and values in stands scheduled to be harvested.
- Initiate sampling for DOS (and hence PLI indicators), along with estimates of % Pruned, % Peeler, Whorls/m, and % Sweep for stands and/or blocks approaching the time of sale, using FPQ systems where possible and validating historical data.
- Evaluate the benefits of formally adopting PLI to assist in crop descriptions.
- Ensure quality factors are adequately recorded for future use in planning.

In terms of future crops, it is clear that the most important variables are stem size, straightness and internode frequency. Breeding programmes should concentrate on those in the first instance.

Introduction

The wood from natural stands of Hoop Pine (*Araucaria cunninghamii*) is renowned as a premium decorative timber. The available tracts of natural stands are long gone, but Queensland has successfully established about 45,000 ha of Araucaria plantations on ex-rainforest sites in both South Eastern and Northern Queensland, comprising some 20% of the softwood plantation resource. Plantation-grown Araucaria is capable of yielding timber and veneer of uniform medium density, light colour and excellent working properties and stability. Current harvesting is on stands 50 to 60 years old but the intention is to use silviculture to reduce the rotation age to 45.

The species sheds branches naturally over time in closed stands but artificial pruning of the butt log is recognized as essential to ensure long clear lengths from the butt log. However, not all trees have been pruned and most crops include a small proportion of Unpruned butts and stems with natural pruning. An issue at harvest is that it is very difficult to identify Pruned butts with certainty[2]. The solid wood processing of Araucaria (sawmills and veneer plants) centres on recovery of long length clears or clear veneer from the Pruned butts and clear-cuttings from the internodes of Mid logs. The longer and cleaner clear-cuttings are processed into component lengths and the remainder for finger-jointing. The fall-down grades recovered from knotty sections and log cores are allocated to structural and packaging uses.

The Forest Plantations Queensland (FPQ) resource of plantation grown is known to be of variable quality, but much of that variation is currently undefined and its influences on timber grade recovery poorly understood. There is no pre-harvest inventory; rather stand population characteristics are predicted from inventories undertaken at the last thinning - which is often 20+ years before harvest. At that time an assessment of the proportion of unpruned stems is made, and some measurements of diameter (DBH or DOS). Forest blocks are traded on a stumpage basis with sawmills taking responsibility for harvesting. While some volume is sold by competitive tender, non-competitive supply contracts are mostly for 10-year terms or longer, with 5-yearly price reviews and an indexing system operating in the intervening period. A single price is established for each forest region, taking into consideration the average stem volume (ASV), the percentage Pruned stems and the difficulty of harvesting. There are no other established measures of stem or log quality so variations of intrinsic value and product potential, both within and between forest regions, remain partially unaccounted for.

The yield of high quality timber from the various Araucaria log types can vary from stand to stand, with the quality of the standing resource and recoveries affected by site and silvicultural factors. There is an increasing need for the establishment of quality/size/value gradients for the major log types to provide better pricing signals to underpin more efficient log processing and marketing, and support the development of more targeted inventory systems.

A proposal was accepted by FWPRDC to undertake a two-stage project to address key value drivers affecting the Araucaria resource and its processing, as a preliminary to developing an improved inventory system. This project was designed to determine the key drivers of grade outturn for each of the major log types by undertaking carefully

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[2] This may be an issue where logs are reallocated to specific processes, e.g Peelers.

designed sawing studies in 2 stages[3]. The studies created a Log and Lumber Grade Recovery Database as the basis for generating Log Value Models.

Material and Methods

A two-stage approach was adopted, the first to establish basic relationships for the construction of provisional log value models; and the second to expand the database, consolidate the first results, validate relationships and finalise the log value models. The plantation resource of Araucaria was regarded as being comprised of 4 basic log types (Pruned butts; Unpruned butts, Mid logs; Top logs). In the studies, only sawlogs were considered and sites at Yarraman, Central Range and Mary Valley forests yielded sawlogs for the sawing studies conducted at Yarraman Pine Sawmill.

Sawing studies were conducted by the Baseline System of Interface Forest & Mill Ltd. which provides for grade and conversion results at the individual log level and includes detailed measurements of all important mill variables at the time of the study. The system also includes log profile measurements and a method of reconstructing, mapping and measuring the defect cores of pruned logs. Those measures provide for the calculation of Pruned Log Index (PLI - Park, 1989; 1994; 2005).

PLI is derived from measurements of log size, log shape and the size of the defect core and has been proven as an accurate measure of clearwood potential and log value on a range of pruned softwood species in New Zealand and Chile. A sub index, Conversion Potential factor (CP), combining log size and shape only has also proved effective in explaining differences in total conversion to sawn timber. Full descriptions of CP and PLI, together with the formulae, are given as Appendix 1a.

In the first study log measurements were made only after the bark was removed. This proved problematic in defining whorl positions on the Unpruned butts and on a number of second logs where natural pruning had occurred. Consequently whorl positions on those logs could only be derived from measurements made on their central boards. In the second study first measurements made on all log types were with bark on. This effectively solved the problem and provided for accurate external measurements of all nodal positions to provide for the eventual calculation of branch frequency (whorls/m). After debarking, log size, shape and volume were acquired for all by profile measurements with calipers, centering devices and stringlines which were the manual equivalent of twin axis scanning.

All logs were sawn at the Yarraman Sawmill by mill control and to their current standard. Timber grades were assessed in the green condition, first with and then without randomly occurring defects such as needle fleck (Appendix 2a). All clears and clearcuttings down to a minimum of 200mm were similarly measured, both with and without random defects, on all pieces except those graded as Utility or Pith In. Timber values were assigned using a relative price list (Appendix 2b).

Full details of the sawing systems applied in each study, and further details of the study methods including demonstrations of the significant differences found in conversion standards, are given in Interim Reports 1 and 2.

[3] A proposed third stage – Review of Mensurational Options – was put on hold subject to the utcomes of the first two stages.

Summaries of all measured log variables and conversion and lumber grade recoveries per log are contained in the Log and Timber Database available to FWPRDC and collaborators.

Stage 1:

Samples of Araucaria sawlogs were drawn from three forests in South East Queensland for sawing studies.

The criteria for site and log selection were discussed with collaborators[4]. Twelve Pruned stems were selected across the available diameter range at each site (2 stems in each of 6 diameter classes above 250mm SED). The top whorl of the pruned section was crosscut to confirm pruning. All sawlogs (4.9m) in each tree were included except when damaged at felling or too swept. All logs were recovered from 25 of the 36 pruned stems. (One Pruned butt got lost in transit). A further 12 Unpruned stems were selected at each site to match the Pruned samples and provide equivalent Unpruned butt logs only. The total of logs selected and studied was 211 (Table 1).

Table 1: Sample Logs – Stage 1

Site	Pruned	Unpruned	Mid (Upper)	Top (Upper)	Total
Mary Valley (Dwyer Cpt. 002)	11	12	40	7	70
Central Range (German Cpt. 003)	12	12	33	12	59
Yarraman (Grimstone Cpt. 4a)	12	12	36	12	72
	35	36	109	31	**211**

Sawing studies were carried out at the individual log level on the first three log types using the Baseline System of Interface Forest & Mill Ltd and a batch study was carried out on the top logs to complete the picture. Detailed measurements on all boards provided for assessment of recoveries and values under two alternative clearwood recovery options; (Appendix 2a).

Families of relationships derived for each log type were used to construct provisional Log Value Models, driven by PLI and CP for the Pruned butts; and whorls/m and CP for the Unpruned log types. Starting values for the models were established using a relative timber pricelist based on information supplied by Yarraman and Hyne sawmills.

[4] Trees were selected from stands in line with the requirements indicated by Jim Park. Jim Saunders from Hyne and Son assisted with the selection of the Central Range and Mary Valley sample trees. Steve Wyvill and Chris Windley visited the site while stems were selected from Yarraman .

All results from this first stage were treated as provisional prior to the second set of studies in April 2007, designed to expand the database and validate or rework these initial basic relationships and create "final" Log Value Models.

Stage 2:

The prime objectives of Stage 2 were to validate or adjust findings from the first study, extend the database that had been created, and finalise the Log Value Models that had been initiated.

Limitations of Stage 1, (acknowledged in the Milestone Report), were that log length had purposely been held constant at 4.9 m to eliminate a possible source of variation; and that the sample logs, particularly the mid logs, were straighter than the range and average in the mill's normal supply. Both those issues were addressed in the design of this second set of studies.

Sampling further intentionally differed from Stage 1 in that logs were not sampled as standing stems, no whole trees were sampled, log length was allowed to vary and the full range of allowable sweep was included. Representatives from Hyne and Yarraman Pine actively participated in the location of sample sites and the collection and measurement of individual logs for the trial. The particular harvest sites selected were chosen by industry and represented the mid to lower end of log and stand quality.

Samples were drawn from active logging sites in each of Mary Valley, Central Ranges and Yarraman Regions. Pruning was not verified by cross-cutting at the top whorl (as in Stage 1) but rather all butts were classified by external visual assessment conducted jointly by FPQ and an industry representative. Several logs were misclassified and this study has highlighted an ongoing problem. Only after sawing and then 'rebuilding' log centres could study personnel accurately define which logs had been completely pruned. The original visual assessments proved incorrect on 12 of the 'Pruned' and 5 of the 'Unpruned' butts. After reclassification there were actually 29 Pruned butts and 43 Unpruned butts with a good spread of sizes and qualities in each set so the main study objectives were not compromised. The final configuration of sample logs is shown in Table 2.

Table 2: Sample Logs – Stage 2

Site	Pruned	Unpruned	Mid (Upper)	Top (Upper)	Total
Mary Valley (Araucaria Cpt. 13)	6	18	30	8	62
Central Range (Tankallaman Cpt. 2)	9	15	30	8	62
Yarraman (Cooyar Cpt. 4)	14	10	30	8	62
	29	43	90	24	**186**

For Stage 2, all sawing was carried out at the individual log level. Mid logs and Top logs were combined and were measured, sawn, analysed and modelled as a single set of Upper logs.

Results

Stage 1:

The log selection process worked well and good overall relationships were derived relation log characteristics to gross value[5].

Pruned Butt Logs

Degrade by random defects was very minor in the Pruned butts and the little that did occur was mainly in the Central Range logs and due to random brown streaks or intrusion of brown heart. There was no degrade at all in the Yarraman logs and those from Mary Valley were almost as clean[6].

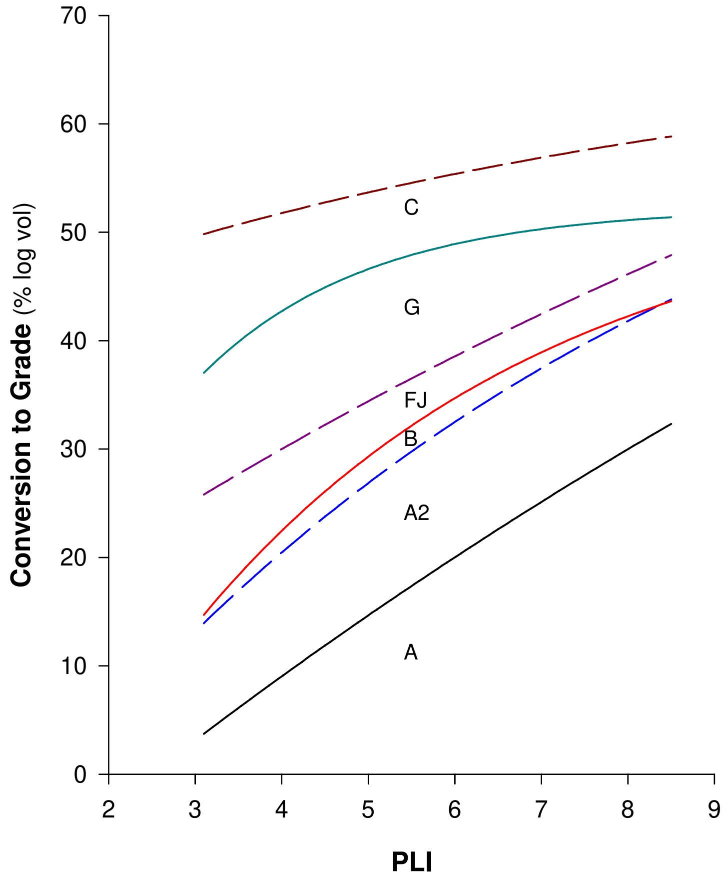
Analyses of the Pruned butts in this section were limited to 34 of the original 36 logs sampled, as 2 logs from Mary Valley were excluded as incompletely pruned (an issues discussed later in Stage 2). Details of conversion and grade recovery are given in the Milestone 2 Report (Cown and Park, 2007).

The Pruned Log Index (PLI) was derived for each log (Appendix 1) and the relationship to lumber grade recovery shown in Fig. 1, using the grades and prices in Appendix 2.

[5] Detailed study results were presented in Interim Report 1 – Cown and Park, 2007: 69pp.

[6] **<u>Important</u>:** These were sample logs only from specific sites and do not represent the forest as a whole.

Fig 1: Pruned Butts – Timber Grade Recovery

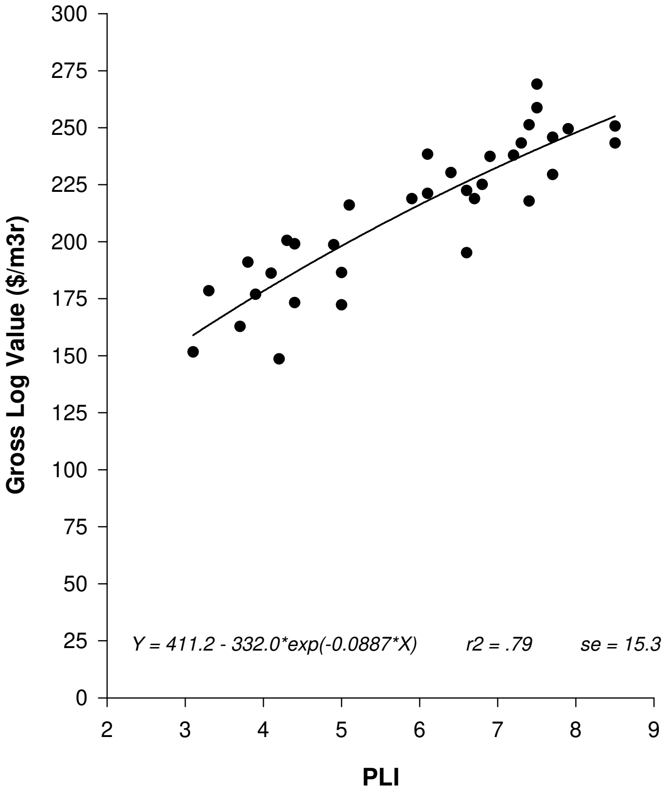


The essential starting point in determining what a log is worth to the mill, and a pivotal number to be derived in log value models, is Gross Log Value.

> *Gross Log Value (\$/m^3r) is the value of all timber and residues recovered from one cubic metre of debarked log. It does not include any production costs.*

Gross Log Values were derived by applying the Relative Pricelist (Appendix 2b) to the recoveries in green grades from these logs and are plotted against in Fig. 2 together with the strong relationship derived. A preliminary Pruned Log Value Model was derived between conversion to grade and PLI.

Fig 2: Gross Pruned Log Value (Relative Pricelist)



The relationships were used to construct a preliminary Araucaria Pruned Log Value Model for conversion to timber grades and Gross Log Values.

The log quality drivers are log size and shape, expressed as Conversion Potential factor (CP), and Pruned Log Index (Appendix 1).

Preliminary Pruned Log Value models were constructed for each of the Clearwood 1 and Clearwood 2 options.

Unpruned Butts

The brown heart centres of the Unpruned butts were larger and contained more blemishes than those in the Pruned logs. There were was a range of defects inside the brown heart zone, many of which seemed to be apparently associated with the natural pruning process and decayed branch stubs. Random defects were not recorded on boards that were predominantly heartwood, since those boards could only be graded as Utility, no matter what else they might contain. Overall degrade due to random defects was low, the main effect being to downgrade 5% of the timber from B to G Grade, with an indication that degrade in the Central Range logs was approximately double that of the other two sets.

Mid Logs

109 individual logs were included in the Mid log sawing study. Degrade by random defects was higher than in the other logs types but still only moderate - 8% of timber volume being downgraded from B to G grade. The prime causes of degrade by proportion were dark fleck 39%, brown heart 32%, brown streak 21%, wet wood 6% and resin streak 2%.

Various combinations of the measured log variables (Cown and Park, 2007) were regressed against total conversion to sawn timber but, as has been found previously on other species, CP proved the most appropriate.

Three dimensional models were constructed with timber grades or clearwood recovery as the dependent variable and CP and w/m as the independent variables. The most useful and practical expression of nodal habit was found to be the number of whorls per metre of log (Whorls/m).

The families of relationships were used to construct preliminary Mid Log Value Models. Those models are in the same form as the Pruned Log Model with the only difference in user input being PLI is replaced by whorls/m.

Top Logs

Wood from the small top logs was virtually free of random defects, and although almost half the boards contained pith, the remainder were of higher quality than expected. In Study 1 the Top logs were sawn as a batch to provide ‘the balance’ of recoverable wood from the tree; but it was subsequently agreed that these small sawlogs (15 to 20 cm SED) would have been better represented as the tail end of the mid log distribution. That option was to be tested in Stage 2.

Detailed information on log characteristics, conversions, grade recovery and the relationships derived for Study 1 is contained in Cown and Park (2007).

Conclusions from Stage 1 (Derived from the Milestone Report and subsequent Workshop at Gympie, Jan/Feb 2007)

Results and models from the first studies were presented to sawmillers and forest owners at a workshop in Gympie in January 2007. Recoveries and log values were shown first by Yarraman Mill timber grades and by recoverable clear lengths (Clearwood 2 option) in a simplified emulation of the functions performed by the Woodeye defecting machine. Separate Log Value models were demonstrated for each of the Pruned butts, the Unpruned butts, the Mid logs and the Top logs. The combination of the suite of models into an overall model for predicting whole tree value was shown to accurately replicate the values realised in actual sawing.

Summary:

- The Baseline Sawing Study Method proved to be highly suitable for the task of valuing logs.
- Total conversions to sawn timber from all three of the more valuable log types were related to log size and shape variables (from log profile measurements) combined into a sub index known as Conversion Potential factor (CP).
- Pruned Log Index (PLI) was shown to relate well to grade and clearwood recoveries from the Pruned logs, and explain differences in value between individual logs and sites.
- The most useful expression of internodal habit in the Unpruned logs was found to be whorls per metre (whorls/m). For both the Mid logs and the Unpruned butts whorls/m was combined with CP to derive three dimensional models predicting grade and clearwood recoveries.
- The Unpruned butts were an enigma. Being a transition between Pruned butts and mid logs. 40% of the boards were in clean Clears and Cuttings grades and, from the provisional models, log values were very similar to Mid logs. At this stage it would be imprudent to combine Unpruned butts and mid logs. Further sampling and analyses on the Unpruned butts, to expand the data base and increase the understanding, was recommended for Stage 2.
- The Top logs proved to be better than expected in terms of clearwood components.
- Families of relationships derived per log type were used to construct provisional Log Value Models driven by PLI and CP for the Pruned butts; and whorls/m and CP for the Unpruned log types. Starting values for the models were established using a relative timber pricelist based on information supplied by Yarraman and Hyne sawmills.
- It was suggested and agreed that in Stage 2, the Mid and Top logs would be combined into a single group – Upper Logs.
- While the provisional models developed explained the overall interactions between log characteristics and value well, some of the collaborators expressed an interest in a simpler method of displaying the relationships between individual variables.

- All results from this first stage were treated as provisional - with the intent that the second set of studies would expand the database and validate or rework these initial basic relationships and Log Value Models.

While Pruned Log Index was readily accepted as an appropriate measure of quality for Pruned Araucaria butt logs, feedback from the workshop indicated that some of the inputs and modelling, particularly the 3-dimensional relationships derived for the mid logs and Unpruned butts, were difficult concepts to grasp and perhaps more complicated than necessary. This was to be addressed in Stage 2.

Stage 2:

All results from Stage 1 were treated as provisional. Objectives of the Stage 2 studies were:

- To expand the database, treating Top logs as an extension of Mid logs,
- Validate or rework the initial basic relationships, and
- Provide improved Log Value Models based on relationships between log properties and value.

Samples were selected from logging sites in each of Mary Valley, Central Ranges and Yarraman Regions. Selection of 72 butts, 90 mid logs and 24 top logs provided a total of 186 logs for sawing studies all carried out at the individual log level. In this study Mid logs and Top logs were combined into a single group (Upper logs). Apart from a few logs too heavily debarked in the extraction and delivery process, it was found that whorl positions and depths could be accurately determined by external measurements on all log types. As in Study 1, all logs were sawn at the Yarraman sawmill and the lumber graded green with and without defects to under two criteria (Yarraman grades and the Clearwood 2 option – Appendix 2a). Sampling in Stage 2 intentionally differed from Study 1 in that logs were not sampled as standing stems, no whole trees were sampled, log length was allowed to vary and the full range of allowable sweep was included.

At each site, the SED range was established by measuring the minimum and maximum SED in each of the four log categories and then dividing the difference into 6 approximately equal size classes for sampling. Only two classes were used for the top log category due to the small variation.

The intention in sampling 72 butts was to provide matched samples of 36 Pruned and 36 Unpruned butt logs. In-field verification of pruning by cross-cutting the top pruned whorl in Study 1 ensured correct allocation of Pruned and Unpruned butts for that study but masked a major and on-going problem with the Araucaria resource. Pruning in this case was not verified by cross-cutting at the top whorl, but rather all butts were classified by external visual assessment conducted jointly by FPQ and an industry representative. The sawing study[7] confirmed that several logs were misclassified. Only after sawing and then 'rebuilding' log centres could study personnel accurately define which logs had been completely pruned. The original visual assessments proved incorrect on 12 of the 'pruned' and 5 of the 'Unpruned' butts. After reclassification, there were actually 29 Pruned and 43 Unpruned butts with a good spread of sizes and qualities in each set so the main study objectives were not compromised.

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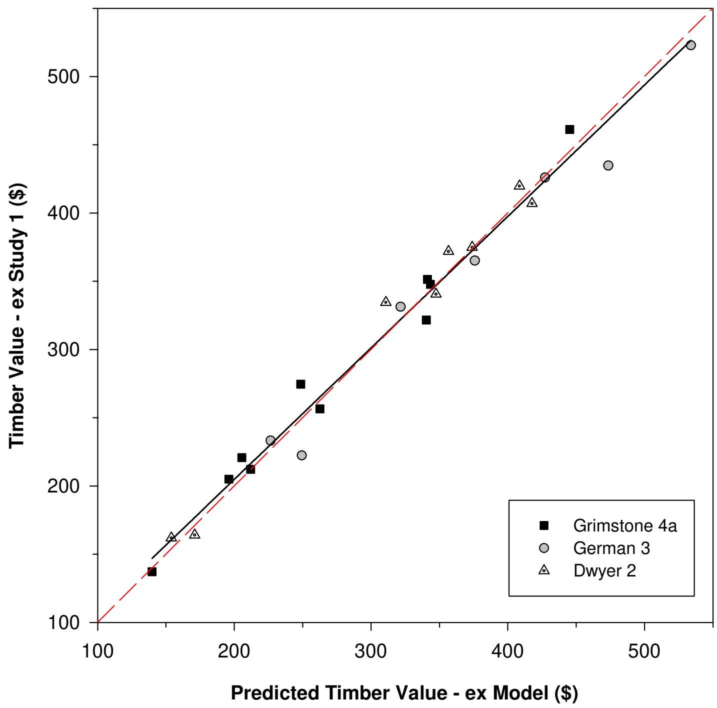
[7] Different machine operators and some changes to sawing approach resulted in an improved conversion standard in this second study. The differences were significant enough to prevent pooling of all data from both studies; so the complete database that has been created should also be considered as two parts. Due to the Baseline Study methods used the recovery differences were immediately recognised, could be accurately quantified by further analyses augmented by sawing simulation if required, and have assisted rather than hindered satisfactory validation of the indices used and the value models developed.

Before analysing data from this second study, data from the mid logs in previous Study 1 were reworked to derive a Clear Components Index (CCI) for predicting clears and clear-cuttings recovery and defining quality from branched Araucaria logs.

Clear Components Index (CCI) = SED/(3 + whorls/m) * (60 - %sweep)/10

The provisional Log Value Models for all branched logs from Study 1 were reworked to include CCI as a major driver to be automatically calculated in the program from inputs of SED, Whorls/m and %sweep. In the interests of compatibility the Pruned Log Value Models were also revised and the sub index CP was replaced with inputs of SED and %sweep. All the revised Log Value Models were combined into an overall Tree Value Model. A comparison of actual versus predicted timber value per tree using the Tree Value Model (Clearwood 2 option) is shown in Fig. 3. These results indicate the quality measures adopted and the models constructed from relationships derived from these Study 1 sample logs accurately reflect the actual values recovered from them.

Fig. 3: Actual and Predicted Value by Clearwood 2 Option



*Y = 12.22 + 0.9632*X   r2 = .98   se = 15.0   n = 25*

Preliminary Analyses

Statistics of important log variables are given in Appendix 3 by study and site. Important features are:

- Stems and logs were not selected randomly, so they cannot be assumed to be representative of the resource. However, as neither whorl count nor defect core was known when selecting the logs, the means of these variables may be reasonably representative of the sampled stands.
- Pruned log defect core was very similar across sites and studies, averaging about 200 mm, but was significantly lower for the Mary Valley site in Study 2 (Tables A3.1, A3.2). There was a very weak positive relationship between defect core and log diameter. The correlation between defect core and SED for the pooled data across both studies was r = 0.31.
- Whorl count in upper logs averaged around one whorl per metre, and differed very little between sites or studies (Table A3.2). The average whorl count did not vary with log height class except for a higher count in the unpruned but logs (Table A3.3). However, there was a large variation between individual logs, particularly above the butt log.

Sequentially fitted multiple regression analyses were undertaken to reveal the log quality drivers of value in the database created by the two studies[8]. The dependent variable used was the value of timber cut from each log divided by total log volume giving a value in $\$/m^3$. Timber was valued using both the timber grading options (Clearwood 1 and 2) and the price lists given in Appendix 2. Because these price lists only give relative values, and because no account was taken of processing costs or residue values, these regressions only show the relative importance of the different log variables and cannot be used to predict true log value. The sequential regressions were fitted separately for each study and log type, and the best regression models were then fitted to the combined data using separate intercepts for each study. The data were also combined for an overall analysis. The results are presented in Appendix 4, and summarized as follows:

Pruned Logs

- Visual log characteristics (SED and sweep) explained between 62% and 79% of the overall variation in log value.
- The addition of defect core information increased the ability to explain differences in value in both studies (76% to 87% respectively) and reduced the residual errors by about 20%.

Unpruned Butt Logs

- SED was the major driver of value, followed by sweep. Together they accounted for between 37% and 57% of the variation in log value.

Upper Logs

- SED was the major driver of value, followed by whorls/m. Together they accounted for between 56% and 78% of the variation in log value.

[8] The results for Study 1 showed consistent small but significant site effects which were not apparent in Study 2. For reasons explained elsewhere, the Study 2 results are considered to be more robust.

Pruned Butt Logs (Study 2)

After the re-classification of the delivered butt logs the target sample size of 36 Pruned butts was reduced to the total of 29. This did not adversely affect the derivation of robust relationships from the full Pruned log set but, because logs were unevenly distributed by stand of origin, examinations of differences in pruned log quality from each of the sampling points were not as useful or conclusive as they might have been.

As in Study 1, the quality of each Pruned butt log was defined by Pruned Log Index (PLI) which is derived from measurements of log size, log shape and the size of the defect core. To provide for that, the log profile measurements were complemented by measurements of the defect core size achieved by 'rebuilding' the log centres and mapping the extensions of pruned branch stubs and occlusion scars.

The relevance and effectiveness of PLI in defining the quality of pruned Araucaria was demonstrated in Study 1. The strength of PLI is further demonstrated here on these samples. Fig. 4 shows the relationship between PLI and recovery in the clears and clearcuttings that are a direct result of pruning, i.e. S18 + S11 + S7 grades (Appendix 2a).

Fig 4: Conversion to Clears and Long Clear-cuttings

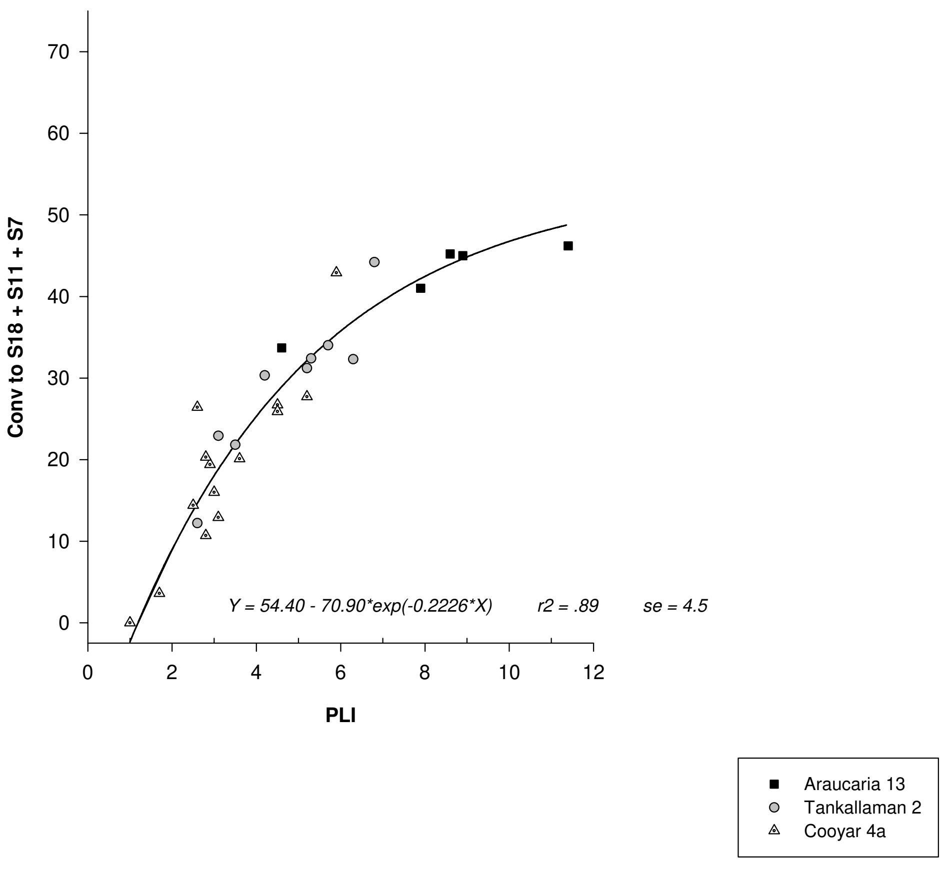


Figure 5 shows the relationship between PLI and Gross Log Values achieved under the same Clearwood 2 Option (data points have been differentiated by stand of origin).

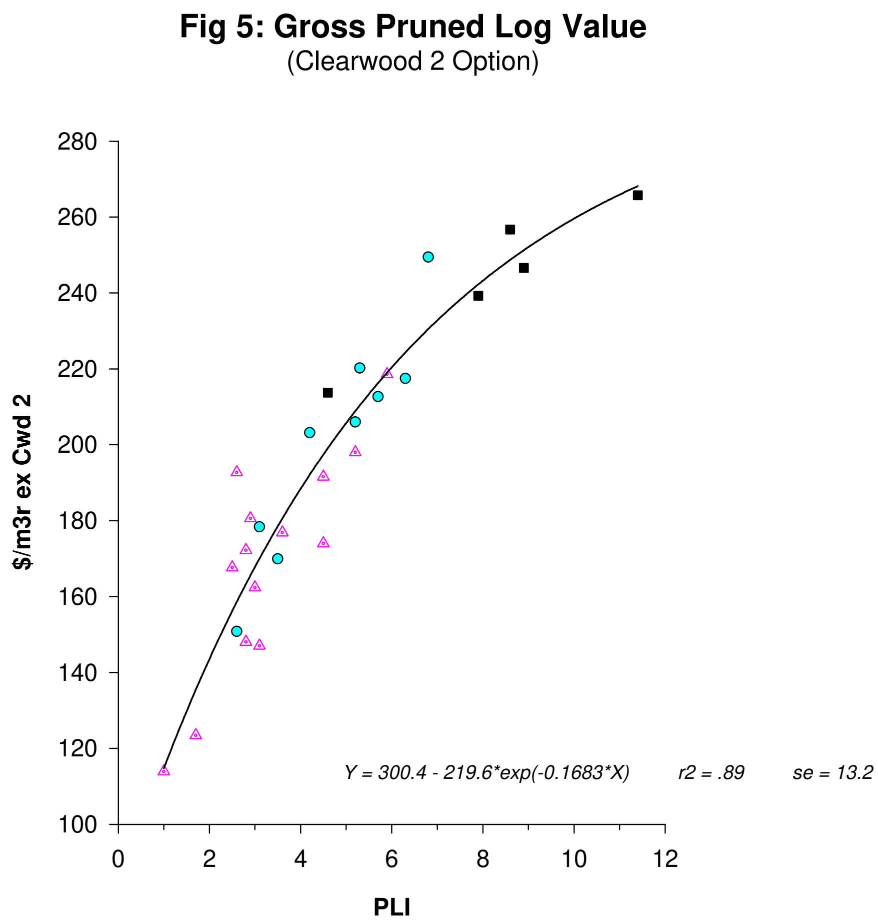


Fig. 5 demonstrates that under the relative pricelist applied there is a large range of values per cubic metre of log and that volume for volume the best Pruned logs are worth more than twice as much as the poorest.

Families of relationships between PLI and cumulative conversions, to both Clearwood options, were derived to provide for Pruned log value modelling. The three log quality inputs to the models are SED, % Sweep and PLI. All grade recoveries except for C Grade (pith in) were related to PLI. Three dimensional models using SED and % Sweep were used to predict C Grade and both nominal and green total conversions. The other user inputs to the model include timber prices, values for residues, sawing and processing costs and a nominated profit margin.

The form and appearance of the Pruned Log Value Model is shown in Fig. 6.

Fig. 6: Pruned Log Value Model - Example

PRUNED LOG SAWING MODELS: Yarraman Sawmill - Clearwood 2 | Araucaria

SET 2

Log Quality | SEDmm 450 (Min = 250 Max = 450) | Sweep 6.0 (Min = 0 Max = 25) | PLI 8.0 (Min = 3 Max = 12)

	S18	S11	S7	S2	G	C	Sub Tot	Dockings	Chips	Sawdust	O/cut	Tot
Pricelist $/m³	500	386	355	324	238	191		28	28	6		
Conversion												
% sawn	64.4	4.4	5.6	9.1	4.4	12.0	100.0					
% of log volume	36.7	2.5	3.2	5.2	2.5	6.8	57.0	5.0	17.6	9.9	10.5	100.0
Value												
$/m³ log processed	183.62	9.70	11.42	16.86	6.00	13.04	240.6	1.40	4.92	0.59	$/m³r	246.15
% value	74.6	3.9	4.6	6.9	2.4	5.3			2.0	0.2		100.0
Costs $												
Sawing	40.0	40.0	40.0	40.0	40.0	40.0						
	168.93	8.69	10.13	14.78	4.99	10.31		1.40	4.92	0.59		224.76
Processing	35.0	35.0	35.0	35.0	20.0	7.0						
	156.08	7.81	9.01	12.96	4.48	9.83		1.40	4.92	0.59		207.09
Profit %	25.0	25.0	25.0	25.0	25.0	25.0						
	117.06	5.86	6.76	9.72	3.36	7.37		1.40	4.92	0.59		157.05

Net Return $/m3 log 50.04

The Pruned Log Value Model can be used to generate relationships between log characteristics, but because the principle driver is PLI, a two-stage process is required. An example investigating the relative influences of log size and defect core size is given in Table 3 below.

Table 3: Example of Use of Pruned Log Model

Araucaria PLI and Gross Log Value Matrices Assuming:

Log Length = 4.9m   Sweep = 10%   Taper = 5mm/m   Cvol/Lvol = 0.80

Section A: PLI Matrix

SED	250	275	300	325	350	375	400	425	450	*Range*
D1.3	*268*	*293*	*318*	*343*	*368*	*393*	*418*	*443*	*468*	
Defect Core										
150	4.3	5.2	6.1	7.0	8.0	9.0	10.1	11.2	12.3	*8.0*
160	3.9	4.7	5.5	6.4	7.3	8.3	9.3	10.3	11.4	*7.5*
170	3.5	4.2	5.0	5.9	6.7	7.6	8.6	9.5	10.5	*7.1*
180	3.1	3.8	4.6	5.4	6.2	7.1	7.9	8.8	9.8	*6.7*
190	2.8	3.5	4.2	4.9	5.7	6.5	7.4	8.2	9.1	*6.3*
200	2.4	3.1	3.8	4.5	5.3	6.0	6.8	7.6	8.5	*6.0*
210	2.2	2.8	3.5	4.2	4.9	5.6	6.4	7.1	7.9	*5.8*
220	1.9	2.5	3.2	3.8	4.5	5.2	5.9	6.7	7.4	*5.5*
230	1.6	2.2	2.9	3.5	4.2	4.8	5.5	6.2	6.9	*5.4*
240	1.3	2.0	2.6	3.2	3.8	4.5	5.1	5.8	6.5	*5.2*
Range	*3.0*	*3.2*	*3.5*	*3.8*	*4.2*	*4.6*	*5.0*	*5.4*	*5.8*	

Section B: Gross Values from Pruned Log Value model

SED	250	275	300	325	350	375	400	425	450	*Range*	*%*
Defect Core											
150	202.35	216.41	228.17	238.16	247.53	255.61	263.21	269.87	275.79	*73.44*	*36.3*
160	195.77	209.69	221.47	232.58	242.09	251.03	258.78	265.60	272.12	*76.35*	*39.0*
170	188.50	202.93	215.19	227.40	236.83	245.87	254.43	261.31	267.97	*79.47*	*42.2*
180	180.43	195.39	209.62	221.64	231.95	241.77	249.53	257.10	264.36	*83.93*	*46.5*
190	173.78	189.87	203.51	215.22	226.54	236.30	245.65	253.08	260.33	*86.55*	*49.8*
200	164.01	181.80	196.76	209.52	221.78	231.22	240.49	248.62	256.51	*92.50*	*56.4*
210	158.69	175.15	191.24	204.88	216.59	226.76	236.70	244.51	252.28	*93.59*	*59.0*
220	150.10	167.93	185.27	198.13	210.89	221.90	231.51	240.94	248.39	*98.29*	*65.5*
230	141.62	160.06	178.80	192.61	206.25	216.58	226.96	236.06	244.13	*102.51*	*72.4*
240	140.14	154.42	171.77	186.64	199.51	212.26	221.99	231.78	240.42	*100.28*	*71.6*
Range	*62.21*	*61.99*	*56.40*	*51.52*	*48.02*	*43.35*	*41.22*	*38.09*	*35.37*		
%	*44.4*	*40.1*	*32.8*	*27.6*	*24.1*	*20.4*	*18.6*	*16.4*	*14.7*		

NB: % is percentage increase from lowest to highest Gross Log Value

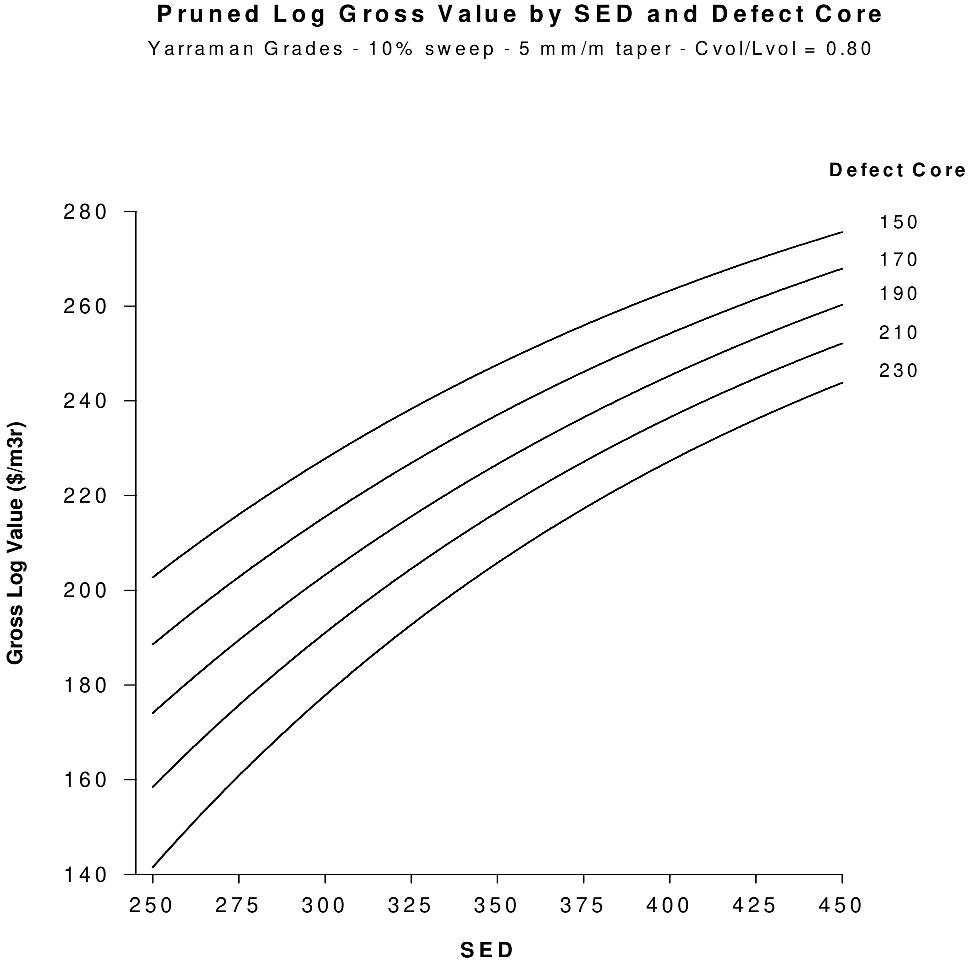
In the example the log shape variables have been fixed from averages found from the study samples. These were sweep 10%, taper 5 mm/m and the Cvol/Lvol ratio 0.80. Log length has also been fixed at 4.9m. Using those assumed shape variables and by applying the PLI formula a matrix of PLI by log size (SED) and defect core size was calculated and is presented as Section A of the table. In the second stage sweep was again held constant at 10% and the SED/PLI combinations from Section A were input to the model to derive the matrix of gross log values under the relative pricelist. That value matrix is shown as Section B.

Across the bottom of Section B of the table, from left to right, is the difference in gross value from smallest to largest defect core by each diameter class; first by dollar and then by percentage increase, lowest to highest value. Down the right side of the table is the equivalent difference in value from smallest to largest diameter class by each increment of defect core size. At mid diameter range of 350 mm SED there is a 24.1% difference in value from 150 to 240 mm defect core. At mid defect core range of 190mm there is a 49.8 increase in gross value from 250 to 450 mm SED. The table shows, under the pricelist used, at mid range log size has twice the influence of defect core size but the latter remains very important because it contributes to one third of the range in values.

These relationships are illustrated in Fig. 7.

The influence of defect core (and PLI) on Gross Log Value is also very sensitive to the pricing structure. The wider the price differentials between the Clears, Clearcuttings and Packaging grades the greater the influence of defect core. Conversely, if price differentials among timber grades are diminished the influence of defect core size also reduced.

Fig. 7: Impact of SED and Defect Core on Gross Log Value



Defect Core

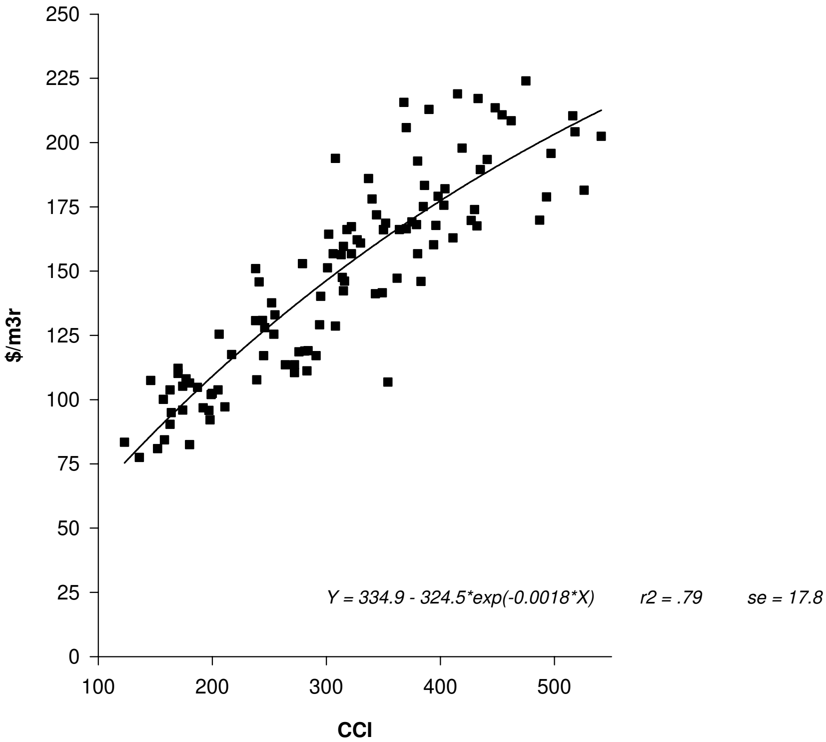
150	$/m3r = 321.9 - 388.8*exp(-0.0047*SED)
170	$/m3r = 321.9 - 412.7*exp(-0.0045*SED)
190	$/m3r = 320.2 - 509.8*exp(-0.0045*SED)
210	$/m3r = 308.5 - 509.8*exp(-0.0049*SED)
230	$/m3r = 298.8 - 584.9*exp(-0.0053*SED)

Upper Logs

In Study 2, all logs above the butt log were taken as the natural extension at the lower end of the Mid log size distribution and classed as Upper logs. Study 2 included 114 Upper logs[9].

The Clear Components Index (CCI) derived from the Study 1 logs was calculated for all upper logs in this study. The relationship between CCI and gross log values under the Clearwood 2 option is shown in Fig 8. While the fit of points about this CCI-based curve for the Upper logs is not as tight as the PLI relationships for the Pruned logs, (Fig. 5), the relationship is strong and demonstrates how well the new index derived from Study 1 logs has performed on this different set of Upper logs from Study 2.

Fig 8: Upper Logs - Gross Value
(Clearwood 2 Option)



Families of relationships between CCI and cumulative conversions were derived to develop the ‘finalised” Upper Log Value Model. All grade recoveries except for C Grade (pith in) were related to CCI. The three log quality inputs to the models are SED, %sweep and whorls/m. Other user inputs to the models include timber prices, values for residues, sawing and processing costs and a nominated profit margin. The form and appearance the Upper Log Value Model is shown in Fig 9.

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[9] Details are included in Interim Report 2 – Park, cown and Kimberley, June 2007

Fig 9: Example of Revised Upper Log Value Model

Set 1 MID LOG SAWING MODELS: Yarraman Sawmill - **Timber Grades** **Araucaria** *INTERFACE 30.04.07*

Log Quality	SED	Whorls/ m	% Sweep	CCI
	350	0.50	10.0	500
	Min = 150 Max = 400	Min = 0.20 Max = 1.70	Min = 0 Max = 25	Min = 180 Max = 600

	A	A2	B	FJ	G	C	Sub Tot	Chips	Sawdust	O/cut	Tot	
Pricelist $/m³	500	432	299	265	238	191		28	6			
Conversion % sawn	2.2	0.6	80.5	1.4	4.0	11.2	100.0					
% of log volume	1.3	0.3	45.1	0.8	2.2	6.3	56.0	25.4	9.9	8.7	100.0	
Value $/m³ log processed	6.27	1.35	134.81	2.11	5.31	12.03	161.88	7.11	0.59	$/m³r	169.59	Gross
% value	3.7	0.8	79.5	1.2	3.1	7.1		4.2	0.4		100.0	
Costs $ Sawing	40.0	40.0	40.0	40.0	40.0	40.0						
	5.77	1.23	116.77	1.80	4.42	9.51		7.11	0.59		147.20	
Processing	35.0	35.0	35.0	35.0	20.0	7.0						
	5.33	1.12	100.99	1.52	3.98	9.07		7.11	0.59		129.70	Break Even
Profit %	25.0	25.0	25.0	25.0	25.0	25.0						
	4.00	0.84	75.74	1.14	2.98	6.80		7.11	0.59		99.20	Residual
										Net Return $/m3 log	30.50	

The Upper Log Value Model can be used to generate a matrix of Gross Log Values (relative values) by key variables. The examples in Tables 4 and 5 show the interactions of SED, Whorls/m and % Sweep. This demonstrates that SED exerts the most influence on log value but that whorls/m is highly significant and contributes about 25% of the variation. In Table 4 Whorls/m has been held at a constant mid-range value of 1.25 to allow and examination of the relative influences of log size (SED) and % sweep. SED is again shown to be the dominant variable but sweep at a given SED can contribute significantly to the observed variation.

Table 4: Relative Gross Log Values:

Mid Logs Gross Log Value Matrix From Araucaria Upper Logs Model

Yarraman Grades - Relative Pricelist ex Interim Reports - Whorls/m held constant at 1.25

SED	200	225	250	275	300	325	350	375	400	425	*Range*	*%*
% sweep												
0	132.24	141.41	150.17	158.54	166.57	174.27	181.69	188.85	196.34	203.66	*71.42*	*39.3*
3	128.05	137.12	145.81	154.12	162.11	169.80	177.20	184.36	191.37	198.65	*70.60*	*39.8*
6	123.78	132.75	141.34	149.59	157.53	165.19	172.58	179.72	186.64	193.51	*69.73*	*40.4*
9	119.43	128.28	136.77	144.95	152.83	160.44	167.80	174.93	181.85	188.56	*69.13*	*41.2*
12	115.01	123.71	132.09	140.18	147.99	155.55	162.87	169.97	176.87	183.58	*68.57*	*42.1*
15	110.49	119.04	127.30	135.28	143.01	150.50	157.77	164.84	171.71	178.41	*67.92*	*43.1*
18	105.95	114.27	122.38	130.24	137.87	145.29	152.49	159.51	166.35	173.02	*67.07*	*44.0*
21	101.36	109.38	117.34	125.06	132.58	139.90	147.03	153.98	160.77	167.40	*66.04*	*44.9*
25	95.34	102.85	110.40	117.92	125.25	132.42	139.41	146.26	152.95	159.51	*64.17*	*46.0*
Range	*36.90*	*38.56*	*39.77*	*40.62*	*41.32*	*41.85*	*42.28*	*42.59*	*43.39*	*44.15*		
%	*27.9*	*27.3*	*26.5*	*25.6*	*24.8*	*24.0*	*23.3*	*22.6*	*22.1*	*21.7*		

Table 5: Relative Gross Log Values:
Mid Logs Gross Log Value Matrix From Araucaria Upper Logs Model

Yarraman Grades - Relative Pricelist ex Interim Reports - Sweep held constant at 5%

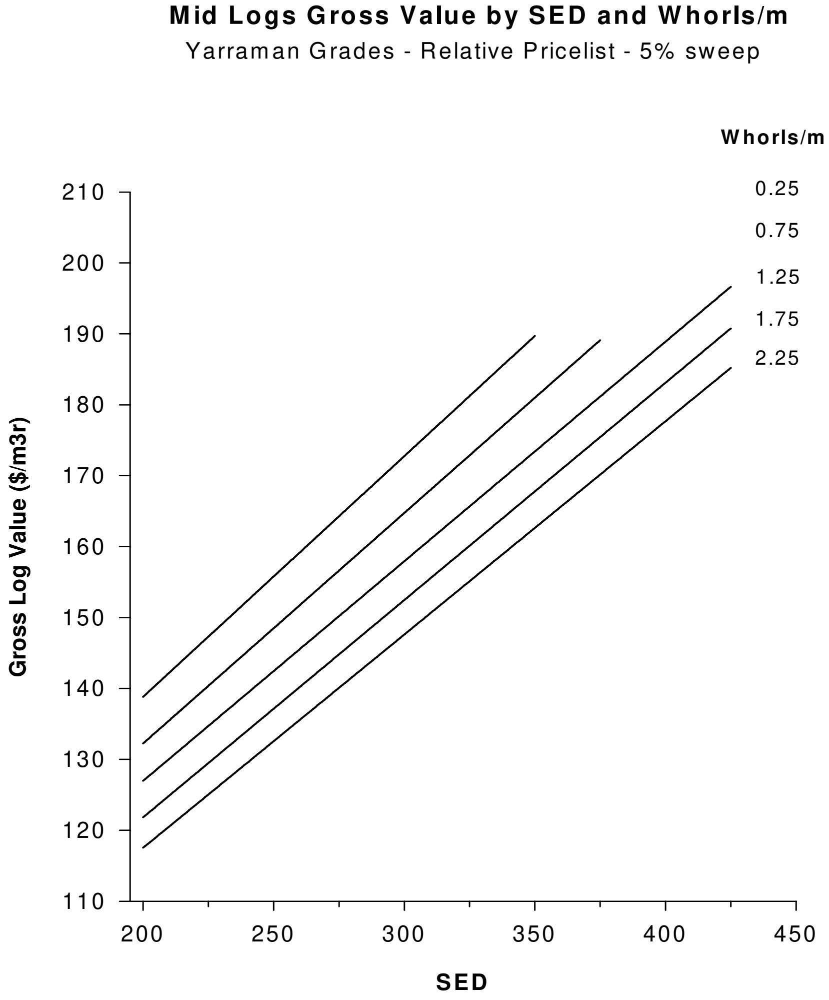
SED / Whorls/m	200	225	250	275	300	325	350	375	400	425	*Range*	*%*
0.25	137.96	147.43	156.39	164.90	172.99	181.04	189.18	*no data*	*no data*	*no data*	*51.22*	*37.1*
0.50	134.33	143.69	152.58	161.04	169.12	176.85	184.59	192.41	*no data*	*no data*	*58.08*	*43.2*
0.75	131.02	140.26	149.07	157.48	165.53	173.25	180.67	188.14	195.69	*no data*	*64.67*	*49.4*
1.00	127.99	137.12	145.83	154.18	162.19	169.88	177.30	184.45	191.69	198.99	*71.00*	*55.5*
1.25	125.21	134.20	142.84	151.12	159.07	166.74	174.13	181.28	188.21	195.24	*70.03*	*55.9*
1.50	122.66	131.54	140.07	148.27	156.17	163.79	171.16	178.30	185.22	191.94	*69.28*	*56.5*
1.75	120.30	129.06	137.49	145.61	153.45	161.04	168.37	175.49	182.40	189.71	*69.41*	*57.7*
2.00	118.11	126.76	135.09	143.13	150.91	158.44	165.75	172.84	179.73	186.43	*68.32*	*57.8*
2.25	116.09	124.61	132.85	140.81	148.53	156.01	163.27	170.33	177.20	183.89	*67.80*	*58.4*
Range	*21.87*	*22.82*	*23.54*	*24.09*	*24.46*	*25.03*	*25.91*	*22.08*	*18.49*	*15.10*		
%	*18.8*	*18.3*	*17.7*	*17.1*	*16.5*	*16.0*	*15.9*	*13.0*	*10.4*	*8.2*		

NB: % is percentage increase from lowest to highest Gross log Value

Log values based on SED alone inherently make assumptions about the numbers of branch whorls and sweep. Results here indicate that sweep has a greater effect than whorls/m but in terms of the forest resource, the relative impacts of these variables will depend on distributions of these features in the stems. Resource information is incomplete, but the indications are that nodal habit is much more variable than the straightness of the mid logs. These examples illustrate the power of models and the need for good resource data.

The influence of the log variables in these examples is also dependent on the relativities between product values assigned in the price list used. This illustrates the value of models based on timber grade recoveries and log potential (expressed by log variables or indices) which can accommodate user inputs on lumber prices and production costs. Fig. 10 shows the influence of whorls/m on values realised by log size (SED) under the relative price list used to generate the above table. (Fig. 10 was generated directly from the Table 5).

Fig 10: Relationships Derived from Upper Log Value Model -



Whorls/m

0.25	$/m3r = 70.97 + 0.3393*SED
0.75	$/m3r = 67.24 + 0.3250*SED
1.25	$/m3r = 65.04 + 0.3096*SED
1.75	$/m3r = 60.54 + 0.3064*SED
2.25	$/m3r = 57.37 + 0.3007*SED

Unpruned Butt Logs

After reclassification of the butt logs there was a total of 43 Unpruned butts. Log characteristics and grade recoveries per log, both as volume and percentage of round log volume, are presented in Interim Report 2 (Park, Cown and Kimberley, 2007).

The Unpruned butts are highly variable due to unpredictable variations in brown heart centres and various and erratic levels of both natural and artificial pruning. While those features could have been defined for each of these samples from data acquired during the log 'rebuilding' phase there was little point because such improved information would have no practical application. As a consequence it was first considered that log size alone would be as good as any other indicator of Unpruned butt log quality. However, the whorl positions were recognisable on the bark and CCI derived from SED, % sweep and external measurements of internodes proved a significantly better indicator of grade and value than log size alone. CCI has been adopted as a practical method of *approximating* the quality of Unpruned butts (Figs. 11, 12). As there are so many major differences between Unpruned butts and the upper logs separate interpretations of CCI and separate families of relationships will always be required for each of the two log types.

Fig 11: Conversion to all Clears and Clear-cuttings

Study 2 – Unpruned Butt Logs

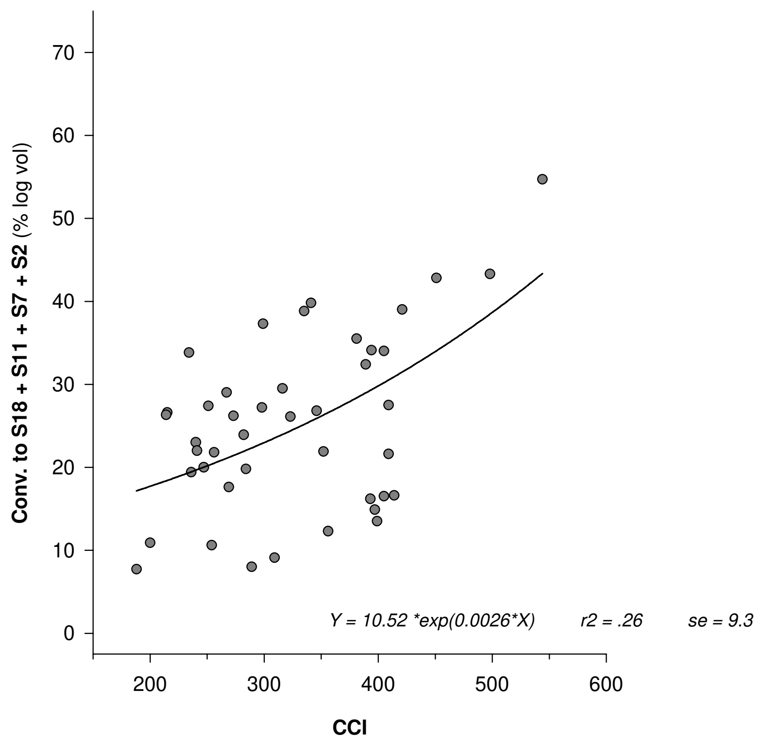
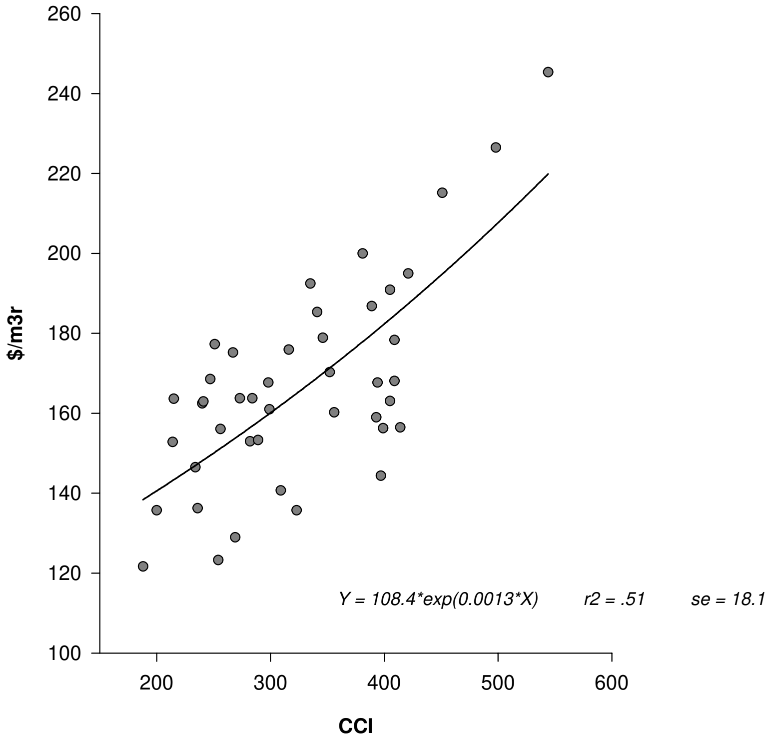


Fig 12: Butt Logs - Gross Value

(Clearwood 2 Option)



Tree Value Model

The finalised Log Value Models for Pruned butts, Unpruned butts and Upper logs were combined into an overall Tree Value Model (Fig.13). User inputs are in two screens. The secondary screen (not shown) provides for user inputs on timber values and processing costs.

User inputs to the main screen include grading type (Clearwood 1 or Clearwood 2), log volume, butt log type, SED, % Sweep, Whorls/m and PLI. (CCI is automatically calculated in the program.)The model calculates the gross and residual values for each log type and, using the input log volumes, converts those to actual log values and actual residual values. The 'actual' values by logs are then accumulated to give the total value per tree. Depending on how the secondary screen is set up, values may be timber only or may include residues. In the following validation exercise the model was set to predict timber value only.

Fig 13: Example of Main Screen – Araucaria Tree Value Model

Set 2 **ARAUCARIA TREE VALUE MODEL - Yarraman Sawing April 2007**

Type G / C	Log Class	Log Volume (m3)	Butt P / U	Sed (mm)	Swp %	W/m	CCI	PLI	Gross Log Value ($/m3r)	Residual Log Value ($/m3)	Actual Log Value ($)	Actual Residual Value ($)
C	Butt	0.689	P	397	9.2			7.3	236.38	142.89	162.87	*98.45*
C	2nd	0.549		356	8.0	0.82	485		199.97	117.98	109.78	*64.77*
C	3rd	0.450		318	0.0	0.82	499		203.66	120.11	91.65	*54.05*
C	4th	0.336		284	0.0	0.61	472		197.79	116.15	66.46	*39.03*
C	5th	0.224		221	11.8	1.02	265		135.33	78.99	30.31	*17.69*
C	6th								0.00	0.00	0.00	*0.00*
Totals		2.248									461.07	*273.99*
Vol/wtd Means									205.10	*121.88*		

Butt Log Range	Sed = 200 - 450	Swp = 0 - 25	w/m = 0.8 - 2.1	PLI = 3.0 - 12.0
Mid Log Range	Sed = 120 - 425	Swp = 0 - 25	w/m = 0.2 - 2.4	CCI = 100 - 600

Type	G = Yarraman Grades	C = Clearwood 2 Option
Butt	P = Pruned	U = unpruned

Validation

A test of the indices and models developed from Study 2 was undertaken by predicting the values actually realised from the Study 1 trees. However, it has been shown that conversion and grade recovery were somewhat better in Study 2. Consequently, an accurate model derived from Study 2 logs only and applied to Study 1 trees should predict higher values than were actually realised.

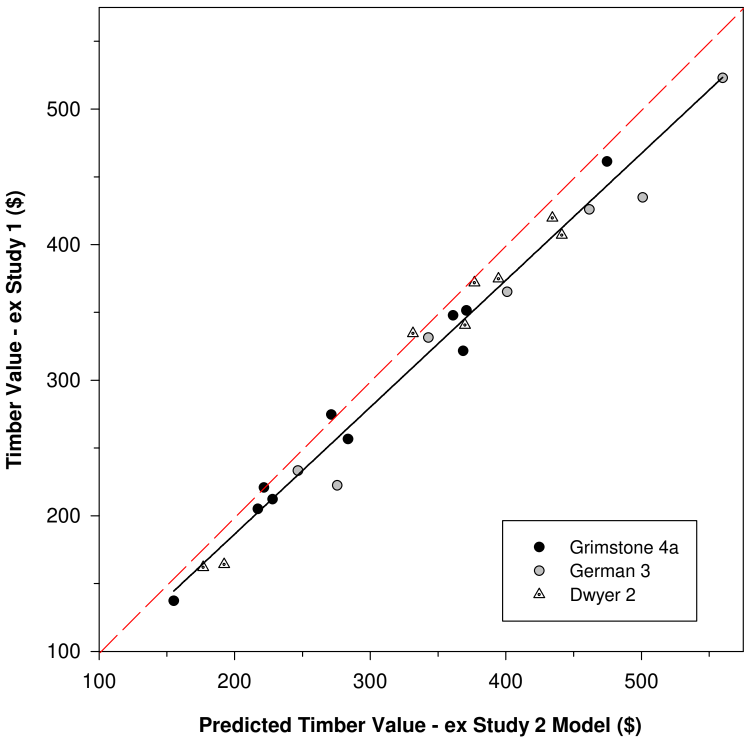
Comparisons of actual versus predicted timber value per tree with timber values from the Clearwood 2 Option are presented in Fig. 14. The fit of points is tight and the (r^2 = 0.98). These results are very similar to those achieved from the Study 1 model (Fig. 3), and the final model from Study 2 correctly predicts higher values. The strength of the regression shows the model to be reliable and the results in Fig 14 can be used to quantify the improvement in sawing practice in terms of the timber pricelist used. Under the Clearwood 2 option there has been a 7% increase in value across the range[10].

[10] A similar result (6%) was found for the Yarraman grades (Interim Report 2 - (Park, Cown and Kimberley, 2007).

Fig 14: Validation of Final Tree Value Model

Timber Value ex Study 1 Vs Predicted Value ex Study 2 Model

(Clearwood 2 Option)



*Y = -0.7211 + 0.9361*X   r2 = .98   se = 16.0*

Results presented in Fig 14 constitute a satisfactory validation of the Tree and Log Value Models and also confirm that PLI and CCI are effective and appropriate[11]. The finalised models recommended for general use are derived from Study 2 data only.

[11] The original intention was to combine all data from both studies into a final model. This was attempted, and while the differences in conversion standards between studies were not huge, they were large enough to create an unwelcome increase in variation and produce weaker relationships than either of the sets listed for Study 1 and Study 2 alone. The outcome is that two sets of models exist - one for each conversion standard. Sawing in the second study was more consistent and the equations derived are generally more robust. The finalised models recommended for general use are derived from Study 2 data only.

Discussion and Recommendations

Results of Study 2 confirmed the draft conclusions from Study 1 and showed while SED alone may be the single most important driver of quality, there is still a lot of residual variation in value which could potentially be captured by better log allocation. The quality and relative value of the Pruned logs and the Upper logs in particular can be predicted and modelled from additional basic data which is not difficult to acquire. Quality predictions on the Unpruned butts are much less reliable and more approximate; but that may not be a serious drawback if the distributions by log types in the three stands these logs were drawn from are typical. From data supplied by FPQ, the indication is that the percentage Unpruned log volume may represent somewhere between 10 to 15% of the totals, and this was confirmed in the sampled stands[12]. There remain difficulties in guaranteeing individual logs as Pruned.

Analyses of Study 2 drew attention to subtle differences in sawing approach and to the distributions of sizes sawn from each log type. Those differences, probably augmented by other unmeasured improvements such as better placed opening cuts, resulted in a more consistent performance with a slightly higher conversion standard and improved grade recovery in the Study 2[13]. The differences were significant enough to prevent pooling of all data for all analyses. The complete database created should be considered as two separate parts. On the other hand, the models derived from the data can be used to derive relative values for a wide range of situations.

Results from these studies confirmed that the relative size of the defect core is a major factor affecting Pruned log value and that some measure, such as Pruned Log Index (PLI) is an appropriate approach for defining the quality and value of Pruned Araucaria butt logs. Log inputs to the finalised Pruned Log Value Models are SED, % Sweep and PLI.

The two sets of sawing studies have provided a database on Araucaria sawlogs, and allowed the development of models for determining relative value by log types and whole stems. Although the application of the models developed in this project is reasonably straightforward, the limitation is a shortage of relevant information on the resource. In addition to data currently available, to derive a better indication of crop values at the stand, block or stratum level using these tools it will also be beneficial to acquire:

- Data on PLI (or at least DOS) for the Pruned butt logs
- Confirmation of the % Pruned (from stand records)
- Information on distributions of Whorls/m.

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[12] This is in no way a “validation” of the % Pruned in the Araucaria resource. That would require formal inventory methods.

[13] This effect is well known in wood processing. There is sufficient data from each of the studies to fully explain the differences. That, however, is beyond the scope of this report. The purpose in identifying the differences is to create the awareness that models derived from each of the data sets are slightly different and to demonstrate how indices such as PLI and CCI can be used to identify and measure critical differences in conversion standards both within and between sawmills.

Information on the defect core (PLI) data can be acquired by physical sampling of DOS at the time of pruning. Once that is achieved, PLI can be derived through prediction accompanied by minimal sample data to verify or adjust predictions (as is now the case with most pruned radiata in New Zealand).

Distributions of Whorls/m may be acquired by external observations and measurements which, with modern technology, can be accurately made on standing trees. This could also be collected at the time of final pruning for several log height classes and used for stand comparisons.

The studies confirmed the importance of several stem characteristics - size straightness, internode length – which have been the subject of genetic improvement programmes for over 50 years (Dieters *et al.* 2007). If significant breeding efforts continue, these characteristics should continue to be emphasized. However, management of pruning is probably the critical factor influencing individual tree and crop value.

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Stand sampling, marking of the logs and delivery to the sawmill was very competently undertaken by Geoff Pearce of FPQ using the sample designs supplied by Jim Park. His attention to detail is much appreciated and helped ensure the success of these studies. We are equally grateful for the positive attitudes and total co-operation received from Steve Wyvill and Chris Windley and their staff at Yarraman Sawmill which also was critical to the achievement of all study objectives. Thanks are also due to Ian Last and Richard Jackson of FPQ for their assistance with communications and logistics on the forest side and to Jim Burgess of Timber Queensland for similar organisation with the Araucaria Processing Group. Chris Goulding of Ensis provided insights in to the mensurational and forest management aspects of this report.

APPENDIX 1a

Pruned Sawlog Indices: Conversion Potential (CP) and Pruned Log index (PLI)

The clearwood potential of a pruned sawlog depends on log size, log shape, and the size of the defect core. (The defect core, a description of the pruned knotty core applicable to sawlogs only, is the 'cylinder' inside the log which contains the pith, pruned branch stubs and occlusion scars. The size of this core is expressed by its diameter.) Those measurable log variables are combined in Pruned Log Index (PLI) which is a single expression of pruned sawlog potential to produce clears grade timber 'off the saw' i.e. without grade enhancement by docking or defecting.

Conversion of pruned sawlogs has two important aspects. The first is total conversion to sawn timber (all grades); and the second conversion to clears grades alone. While the second is part of the first, the ratio of one to the other, and hence clears grades percentages of sawn outturn, can vary markedly depending on the mill, the sizes produced and the overall sawing strategy. Therefore PLI is calculated in two stages, the first of which produces a sub-index known as Conversion Potential factor (CP).

CP relates directly to total conversion to sawn timber and is derived from measurements of log size and log shape only (Appendix 1b). Log size is expressed by diameter underbark 1.3 m from the butt end which relates well to log volume for a given length, in butt logs is virtually the same point as DBH, and is common to pruned logs of all lengths. All the variables influencing log shape are collectively expressed by reducing the log to two basic components - wood which is common to the whole length of the log and wood which is not. Measurements of log profiles in two planes at right angles, either manually or by twin axis scanner, provide for the calculation of a column from four quarter ellipses. The semi-axes for these ellipses are the minimum radii measured from the central or Z axis of a log in both the X and Y planes. The volume of this column of 'common wood' is divided by the log volume to derive a reduction factor to be applied to the diameter.

$$\text{Conversion Potential factor (CP)} = (D_{1.3})^{0.2} \times (\text{Cvol}/\text{Lvol})^{0.5}$$

where $D_{1.3}$ = diameter (mm) under bark 1.3 m from the butt end of a log
Cvol = volume of common wood (m^3)
Lvol = under bark log volume (m^3)

The log size and shape variables, used to calculate CP, are then combined with defect core size to derive PLI.

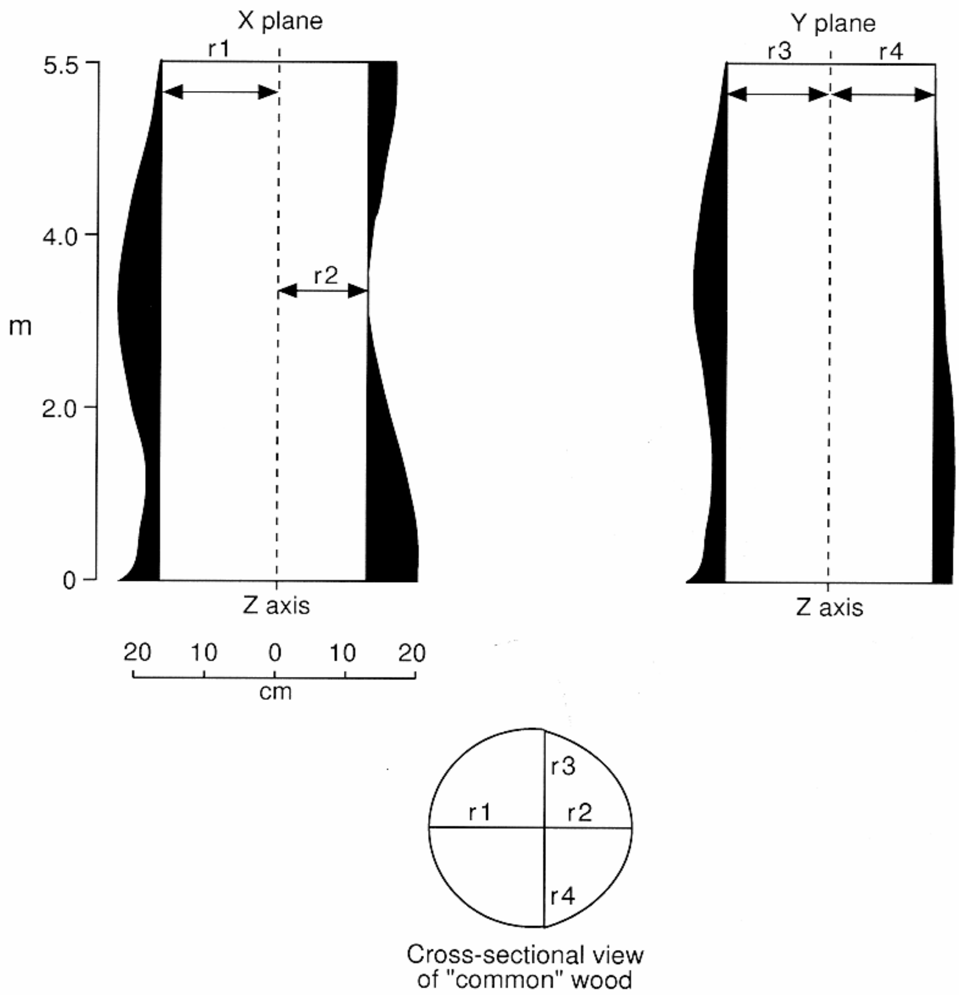
$$\text{Pruned Log Index (PLI)} = ((D_{1.3} - DC)/10)^{0.5} \times (D_{1.3}/DC) \times (\text{Cvol}/\text{Lvol})^{1.6}$$

where DC = defect core diameter (mm).

Note: PLI expresses basic pruned log quality and does not include randomly occurring defects such as resin pockets. These are accounted for by deriving grade reduction factors based on their frequency and size.

APPENDIX 1b

Illustration of "Common Wood"



"Common Wood" is defined as the column of wood common to the whole log length with a cross section derived from four quarter-ellipses. The semi-axes for these ellipses are the minimum radii measured from the central or *Z* axis in both the *X* and *Y* planes

Appendix 2a: Lumber Grades

All timber was assessed first with and then without randomly occurring defects such as needle fleck. Degrade caused by random defects thus was isolated and examined using batch results. The main results presented in this report exclude the potentially confounding influence of randomly occurring defects in the clearwood.

Clearwood 1:

Minimum length 1.8 m and the 6 grades recognised were:

A	Clear
A2	Clear one face and both edges
B	70% of the piece in clear-cuttings 400+ mm.
FJ	Finger Joint stock; 70% of the piece in clear-cuttings 200+ mm
G	General Utility grade excluding pith
C	Utility grade with pith in

At both Yarraman and Hyne Sawmills all wood qualifying for the top four grades above progresses to the remanufacturing plant for processing through the WoodEye defecting system. The second set of results, identified as the Clearwood 2 Option, emulated part of the functions of the WoodEye by reducing the top four grades above to the clears and clearcuttings they contained. The two lowest grades, G and C, were left unchanged. Four classes of clear components were recognised and the complete set of grades under the Clearwood 2 Option were as follows:

Clearwood 2:

S18	Completely clear random lengths 18+ dm long (ie Grade A above unchanged but renamed)
S11	Clear lengths 11 to 17 dm
S7	Clear lengths 7 to 10 dm
S2	Clear lengths 2 to 6 dm
G	General Utility grade excluding pith (unchanged)
C	Utility grade with pith in (unchanged)

Appendix 2b: Timber Values

The timber prices applied in both sawing studies are listed below. They are relative values derived from a composite of information supplied by Yarraman and Hyne Sawmills. The price for the most valuable product, full length clears, has been scaled down to $500/m3 and used as the base for all other relative prices.

A. Timber Grades – Clearwood 1

Grade	A	A2	B	FJ	G	C	Chip	S/dust
$/m3	500	432	299	265	238	191	28	6

B. Clearwood 2

Grade					G	C	Chip	S/dust
Clears	S18	S11	S7	S2				
Lth (dm)	18+	11-17	7-10	2-6				
$/m3	500	386	355	324	238	191	28	6

Appendix 3: Analysis of log variables

Summary statistics of important log variables across both studies are given in Table A4.1. The major log quality variables - pruned log defect core and upper log whorl count - are summarised by study and site in Table A4.2. As trees and logs were not selected randomly, they cannot be assumed to be representative of the resource. However, as neither whorl count nor defect core was known when selecting the logs, the means of these variables may be reasonably representative of the sampled stands. Pruned log defect core was very similar across sites and studies, averaging about 200 mm, but was significantly lower for the Mary Valley site in Study 2. There was a very weak relationship between defect core and log diameter, i.e., larger diameter logs tended to have a slightly larger defect cores. The correlation between defect core and SED for the pooled data across both studies was r = 0.31.

Whorl count in upper logs averaged around one whorl per metre, and differed very little between sites or studies (Table A4.2). The average whorl count did not vary with log height class except for a higher count in the unpruned but logs (Table A4.3). However, there was a large variation between individual logs, particularly above the butt log.

Table A3.1: Summary statistics of important log variables across both studies

Variable	Log type	Mean	Std dev	Min.	Max.
SED (mm)	Pruned butt	332	56	209	446
	Unpruned butt	338	60	214	508
	Upper	256	64	127	412
Defect Core (mm)	Pruned butt	191	27	136	247
Whorl Count (N/m)	Unpruned butt	1.7	0.4	0.8	2.8
	Upper	1.0	0.4	0.2.	2.5
Sweep (%)	Pruned butt	11.5	4.3	4	21
	Unpruned butt	11.8	5.0	4	29
	Upper	8.1	4.5	1	30

Table A.2: Means of important log quality variables by study and site. Within a column, values followed by the same letter are not significantly different (LSD test, α=0.05).

Site	Study	Defect Core (mm)	Upper log Whorl Count (N/m)
Yarraman	1	183 bc	0.93 b
	2	205 a	1.09 ab
Central Range	1	198 ab	1.04 ab
	2	198 ab	1.02 ab
Mary Valley	1	185 abc	0.94 b
	2	159 c	1.17 a

Table A3.3: Mean whorl count by log height class from Study 1 data. Values followed by the same letter are not significantly different (LSD test, α=0.05).

Log Height Class	Whorl Count (N/m)
Unpruned butt log	1.50 a
2nd log	0.97 b
3rd log	0.99 b
4th log	0.95 b
5th log	0.99 b

Appendix 4: Multiple Regression Analysis

Sequential multiple regressions were fitted separately for each study to identify the important drivers of log value. These are shown in Tables A3.1-A3.6. The dependent variable used in these regressions was the value of timber cut from the log per cubic metre of log volume, using the two timber grading options and price lists given in Appendix 2. The tables show the R^2 and root mean square error (RMSE) of each regression, and F-ratios and p-values for each variable as it was added sequentially. Tests of differences between the three sites represented in each study are also included as the last line in each table to demonstrate whether relationships differ between sites. Boldface type indicates statistically significant regressions (p=0.05).

These regressions show that SED is the most important single value driver followed by defect core in pruned logs, and whorl count in upper logs. Sweep is an important secondary variable but log taper is of little significance.

Although slightly better conversions were obtained for pruned butt logs in Study 2 than Study 1, Tables A3.1–A3.6 show that the relative importance of each log variable was very similar in both studies. Therefore, it was possible to fit general regression equations to the combined dataset with little loss of precision. Regressions fitted to the combined data are summarised in Tables A3.7–A3.9.

In Tables A3.10-A3.17, the coefficients of these regressions are given (with standard errors of slope coefficients in brackets).

Table A4.1: Fit statistics of regressions fitted separately to each study for pruned butt logs using Clearwood 1 grades.

	Study 1 (N = 34)				**Study 2 (N = 29)**			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**54**	**22.8**	**37.55**	**<.0001**	**70**	**22.9**	**62.06**	**<.0001**
+ Sweep	**62**	**21.0**	**6.49**	**0.016**	73	22.1	3.01	0.095
+ Taper	62	21.4	0.00	0.95	75	21.5	2.45	0.13
+ Site	69	20.1	2.93	0.070	76	22.0	0.42	0.66
SED	**54**	**22.8**	**37.55**	**<.0001**	**70**	**22.9**	**62.06**	**<.0001**
+ Defect Core	**74**	**17.4**	**23.66**	**<.0001**	**81**	**18.7**	**14.82**	**0.0007**
+ Sweep	**79**	**16.0**	**6.57**	**0.016**	82	18.3	1.96	0.17
+ Taper	79	16.3	0.01	0.94	82	18.7	0.08	0.78
+ Site	83	15.3	3.04	0.064	84	18.6	1.14	0.34

Table A4.2: Fit statistics of regressions fitted separately to each study for unpruned butt logs using Clearwood 1 grades.

	Study 1 (N = 36)				Study 2 (N = 43)			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**40**	**19.7**	**22.73**	**<.0001**	**30**	**17.3**	**17.60**	**0.0001**
+ Sweep	**51**	**18.1**	**7.15**	**0.012**	**37**	**16.6**	**4.71**	**0.036**
+ Taper	51	18.4	0.01	0.93	**48**	**15.2**	**8.33**	**0.0063**
+ Whorls/m	53	18.3	1.37	0.25	52	14.9	2.65	0.11
+ Site	**68**	**15.6**	**6.71**	**0.0040**	53	15.2	0.32	0.73

Table A4.3: Fit statistics of regressions fitted separately to each study for upper logs using Clearwood 1 grades.

	Study 1 (N = 108)				Study 2 (N = 110)			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**71**	**14.0**	**263**	**<.0001**	**75**	**16.7**	**324**	**<.0001**
+ Sweep	**73**	**13.7**	**6.75**	**0.011**	**78**	**15.8**	**14.54**	**0.0002**
+ Taper	73	13.7	0.11	0.75	78	15.8	1.01	0.32
+ Site	74	13.7	1.20	0.31	79	15.6	2.27	0.11
SED	**71**	**14.0**	**263**	**<.0001**	**75**	**16.7**	**324**	**<.0001**
+ Whorls/m	**75**	**13.2**	**14.90**	**0.0002**	**76**	**16.2**	**6.54**	**0.012**
+ Sweep	**76**	**12.9**	**5.30**	**0.023**	**79**	**15.4**	**12.98**	**0.0005**
+ Taper	76	12.9	0.73	0.39	79	15.4	0.90	0.35
+ Site	77	13.0	0.85	0.43	80	15.1	2.84	0.063

Table A4.4: Fit statistics of regressions fitted separately to each study for pruned butt logs using Clearwood 2 grades.

	Study 1 (N=34)				Study 2 (N = 29)			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**57**	**22.5**	**42.07**	**<.0001**	**76**	**20.8**	**84.02**	**<.0001**
+ Sweep	**62**	**21.4**	**4.33**	**0.046**	79	19.7	4.02	0.055
+ Taper	62	21.8	0.01	0.91	81	19.0	2.80	0.11
+ Site	**70**	**19.9**	**3.92**	**0.032**	84	18.3	2.09	0.15
SED	**57**	**22.5**	**42.07**	**<.0001**	**76**	**20.8**	**84.02**	**<.0001**
+ Defect Core	**73**	**18.0**	**19.25**	**0.0001**	**85**	**16.4**	**17.46**	**0.0003**
+ Sweep	76	17.2	3.63	0.066	87	15.8	3.02	0.095
+ Taper	76	17.5	0.02	0.89	87	16.1	0.09	0.76
+ Site	81	16.3	3.21	0.056	88	16.5	0.39	0.68

Table A4.5: Fit statistics of regressions fitted separately to each study for unpruned butt logs using Clearwood 2 grades.

	Study 1 (N = 35)				Study 2 (N = 43)			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**46**	**21.9**	**28.45**	**<.0001**	**46**	**19.6**	**34.35**	**<.0001**
+ Sweep	**57**	**20.0**	**7.69**	**0.0092**	47	19.5	1.28	0.26
+ Taper	57	20.2	0.41	0.53	**55**	**18.3**	**6.38**	**0.016**
+ Whorls/m	62	19.3	3.76	0.062	58	17.9	2.92	0.095
+ Site	**70**	**17.9**	**3.50**	**0.044**	61	17.7	1.39	0.26

Table A4.6: Fit statistics of regressions fitted separately to each study for upper logs using Clearwood 2 grades.

	Study 1 (N = 109)				Study 2 (N = 110)			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**53**	**24.5**	**120**	**<.0001**	**65**	**24.1**	**205**	**<.0001**
+ Sweep	**56**	**23.7**	**8.52**	**0.0043**	**68**	**23.2**	**9.43**	**0.0027**
+ Taper	57	23.8	0.39	0.53	68	23.2	0.66	0.42
+ Site	58	23.7	1.24	0.29	69	23.2	0.98	0.38
SED	**52**	**24.6**	**118**	**<.0001**	**65**	**24.1**	**205**	**<.0001**
+ Whorls/m	**75**	**17.8**	**96.26**	**<.0001**	**77**	**19.5**	**54.9**	**<.0001**
+ Sweep	**77**	**17.3**	**7.64**	**0.0067**	**79**	**18.8**	**9.30**	**0.0029**
+ Taper	**78**	**17.0**	**4.61**	**0.034**	79	18.8	0.90	0.34
+ Site	78	17.1	0.60	0.55	80	18.5	2.66	0.075

Table A4.7: Fit statistics of regressions fitted to the combined dataset for pruned butt logs (N = 63).

	Clearwood 1				Clearwood 2			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**62**	**23.1**	**97.7**	**<.0001**	**66**	**22.1**	**118**	**<.0001**
+ Sweep	**65**	**22.1**	**6.25**	**0.015**	**69**	**21.2**	**5.93**	**0.018**
+ Study	**68**	**21.4**	**5.18**	**0.027**	**72**	**20.5**	**5.36**	**0.024**
SED	**62**	**23.1**	**97.7**	**<.0001**	**66**	**22.1**	**118**	**<.0001**
+ Defect Core	**76**	**18.4**	**36.3**	**<.0001**	**79**	**17.6**	**35.4**	**<.0001**
+ Sweep	77	18.2	1.86	0.18	79	17.5	1.67	0.20
+ Study	**80**	**16.9**	**10.67**	**0.0018**	**82**	**16.2**	**10.91**	**0.0016**
PLI	**76**	**18.4**	**189**	**<.0001**	**77**	**18.3**	**200**	**<.0001**
+ Study	**78**	**17.6**	**6.78**	**0.012**	**79**	**17.5**	**6.60**	**0.013**

Table A4.8: Fit statistics of regressions fitted to the combined dataset for unpruned butt logs (N = 79).

	Clearwood 1				Clearwood 2			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**30**	**19.9**	**32.4**	**<.0001**	**42**	**21.6**	**56.1**	**<.0001**
+ Sweep	**34**	**19.4**	**4.94**	**0.029**	45	21.3	2.88	0.094
+ Whorls/m	34	19.5	0.36	0.55	45	21.4	0.06	0.81
+ Study	**50**	**17.1**	**23.26**	**<.0001**	**56**	**19.3**	**17.88**	**<.0001**
CCI	**28**	**20.0**	**30.7**	**<.0001**	**39**	**22.2**	**48.4**	**<.0001**
+ Study	**51**	**16.7**	**35.4**	**<.0001**	**56**	**18.9**	**30.5**	**<.0001**

Table A4.9: Fit statistics of regressions fitted to the combined dataset for upper logs (N = 218).

	Clearwood 1				Clearwood 2			
Model	**R^2**	**RMSE**	**F-ratio**	**p-value**	**R^2**	**RMSE**	**F-ratio**	**p-value**
SED	**74**	**15.4**	**607**	**<.0001**	**60**	**24.2**	**331**	**<.0001**
+ Sweep	**76**	**14.8**	**17.9**	**<.0001**	**63**	**23.4**	**15.5**	**0.0001**
+ Study	**76**	**14.7**	**4.58**	**0.034**	63	23.4	2.22	0.14
SED	**74**	**15.4**	**607**	**<.0001**	**60**	**24.2**	**331**	**<.0001**
+ Whorls/m	**76**	**14.8**	**17.5**	**<.0001**	**76**	**19.0**	**134**	**<.0001**
+ Sweep	**77**	**14.3**	**14.4**	**0.0002**	**77**	**18.6**	**10.9**	**0.0011**
+ Study	**78**	**14.2**	**6.02**	**0.015**	**78**	**18.2**	**8.54**	**0.0038**
CCI	**72**	**15.6**	**560**	**<.0001**	**76**	**18.8**	**678**	**<.0001**
+ Study	**74**	**15.4**	**11.0**	**0.0011**	**77**	**18.3**	**12.9**	**0.0004**

Table A4.10: Regression Coefficients - Pruned butt log value = *a* + *b* × SED

Coefficient	Clearwood 1	Clearwood 2
a	28.4	9.8
b	0.513 (0.052)	0.539 (0.050)
RMSE	23.1	22.1
R^2	62	66

Table A4.11: Regression Coefficients - Pruned butt log value = *a* + *b* × SED + *c* × Sweep

Coefficient	Clearwood 1	Clearwood 2
a	60.4	39.6
b	0.476 (0.052)	0.505 (0.050)
c	-1.71 (0.68)	-1.60 (0.066)
RMSE	22.1	21.2
R^2	65	69

Table A4.12: Regression Coefficients - Pruned butt log value = *a* + *b* × SED + *c* × Defect Core

Coefficient	Clearwood 1	Clearwood 2
a	103.8	81.4
b	0.594 (0.043)	0.616 (0.042)
c	-0.537 (0.089)	-0.510 (0.086)
RMSE	18.4	17.6
R^2	76	79

Table A4.13: Regression Coefficients - Unpruned butt log value = *a* + *b* × SED

Coefficient	Clearwood 1	Clearwood 2
a	76.3	49.9
b	0.213 (0.037)	0.307 (0.041)
RMSE	19.9	21.6
R^2	30	42

Table A4.14: Regression Coefficients - Unpruned butt log value = *a* + *b* × SED + c × Sweep

Coefficient	Clearwood 1	Clearwood 2
a	98.0	68.2
b	0.185 (0.039)	0.283 (0.043)
c	-1.03 (0.47)	-0.87 (0.51)
RMSE	19.4	21.6
R^2	34	45

Table A4.15: Regression Coefficients - Upper log value = *a* + *b* × SED

Coefficient	Clearwood 1	Clearwood 2
a	24.4	19.7
b	0.409 (0.017)	0.475 (0.026)
RMSE	15.4	24.2
R^2	74	60

Table A4.16: Regression Coefficients - Upper log value = *a* + *b* × SED + *c* × Sweep

Coefficient	Clearwood 1	Clearwood 2
a	40.8	43.7
b	0.379 (0.018)	0.431 (0.028)
c	-1.09 (0.26)	-1.60 (0.41)
RMSE	14.8	23.4
R^2	76	63

Table A4.17: Regression Coefficients - Upper log value = *a* + *b* × SED + *c* × Sweep + *d* × Whorls/m

Coefficient	Clearwood 1	Clearwood 2
a	48.8	73.6
b	0.380 (0.017)	0.439 (0.022)
c	-0.95 (0.25)	-1.07 (0.32)
d	-9.2 (2.4)	-35.5 (3.1)
RMSE	14.3	18.6
R^2	77	77