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Project No. PN04.2002

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Species and treatment corrections for hand-held moisture meters with radiata and slash pine

Prepared for the

Forest & Wood Products Research & Development Corporation

by

P. Blakemore, A. Morrow, W. Liew, M. Muruganathan & R. Luff

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EXECUTIVE SUMMARY

Objectives

The research aims to:

- Generate new species and CCA preservative treatment (to H3 level) corrections for *P. radiata* (radiata pine) and *P. elliottii* (slash pine).
- Determine the overall reliability, or uncertainty, of the new species and CCA corrections.
- Assess the effect of between board density variation on capacitance-type meter readings.

Key Results

New *P. radiata* and *P. elliottii* species and CCA (oxide type) treatment corrections for the Deltron DCR22 were generated using simple linear regressions on the log transformed meter readings and oven-dry moisture content measurements.

The new species, CCA treatment and thickness corrections for the Wagner L612 and Brookhuis FMW were generated by using multiple regression. In this instance only the meter readings were log transformed.

The Deltron DCR22 can be used on CCA treated timber of both *P. radiata* and *P. elliottii* with similar levels of accuracy or confidence as on untreated timber.

- When used on timber with a MC in the range of 8-15%, the expected accuracy on both CCA treated and untreated timber is for 95% of individual meter readings to be within ±1.0% (meter readings close to 8%) up to ±3.0% (meter readings close to 15%) of the actual oven dry moisture content.

Similarly, CCA treatment showed little impact on the expected accuracy of the new corrections for use on both *P. radiata* and *P. elliottii*, the Wagner L612 and Brookhuis FMW.

- When used on timber with a MC in the range of 8-15%, the expected accuracy on both CCA treated and untreated timber is for 95% of individual meter readings to be within ±3.0% to ±4.0% of the actual oven dry moisture content.

The implications of these levels of uncertainty are discussed with regard to the importance of interpreting the variation of a number of meter readings from a pack or stack of timber as suggested in AS/NZS 4787 (2001).

As an example of the effect of between board density variation on the capacitance-type meters - density explained about half of the remaining uncertainty in the Wagner L612 corrections for untreated *P. radiata*.

Application of Results

The treatment and species corrections developed in this project should be included in a revision of AS/NZS 1080.1 (1997). Provided that accuracy limits are given with the species corrections, capacitance-type meters such as the Wagner L612 can be included in this revised standard for appropriate situations. In the case of the capacitance-type meters, thickness corrections should also be included.

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INTRODUCTION

Hand-held moisture meters, and in particular the Wagner (capacitance-type) moisture meters, are used extensively throughout the exotic softwood processing industry in Australia. While their use is widely accepted, one uncertainty is their use on CCA treated timber. This research aims to address that uncertainty, and focuses on two commercially important exotic softwood species in Australia: *Pinus radiata* D. Don (radiata pine) and *P. elliottii* Engelm var. *elliottii* (slash pine). For the treatment corrections generated to be meaningful, it is also important that control corrections were generated on matching untreated material.

The untreated species corrections generated in this project are of interest in their own right, especially with the capacitance-type meters. By and large, industry has either directly used the meter supplied (usually electronically inbuilt) density based corrections, or modified their use of these density based corrections over time in various ways. However, as discussed in Blakemore (2003), the inbuilt density based corrections are only intended as a first approximation in the absence of a specific species correction. There have been no species corrections previously published for use with either *P. radiata* or *P. elliottii* for either the Wagner L612 or Brookhuis FMW meter to verify the appropriateness of the density based corrections. Hence, the new species corrections on the matching control material is the first time that data has been publicly available to assess the density based corrections with *P. radiata* and *P. elliottii*.

A general summary of the literature on how resistance and capacitance-type meters function, and the various sources of variability with their use, can be found in Blakemore (2003).

MATERIALS AND METHODS

Sample Material

To cover the full range of density in both *P. radiata* and *P. elliottii*, sample material was obtained from the following companies and geographic regions:

P. radiata

- Carter Holt Harvey, Mt.Gambier
- French Enterprises, Scottsdale
- Carter Holt Harvey, New Zealand

P. elliottii

- Weyerhaeuser, Caboolture
- Hyne & Son, Tuan
- Allied Timber Products, Burpengary

Co-operating mills were requested to supply, as best possible, boards to cover the range of density, growth ring patterns and heartwood/sapwood contents that occur with their material. Fifteen boards of each of 3 thicknesses (25, 40 and 50 mm) were obtained from each of the co-operating mills. The only exceptions were that neither Weyerhaeuser nor Allied Timber Products cut 50 mm thick material. The supplied boards were nominally 100 mm wide and 3.6 m long (Allied Timber Products were only able to supply 3.1 m lengths). All boards supplied had been kiln dried.

Each board was cut in half, with one half being used as a control board and the other half treated to H3 specifications with CCA. It was originally intended that the 1.8 m long treated boards would be treated by CSIRO staff using a pilot scale treatment plant at Clayton. Unfortunately, delays in obtaining sample material meant that the treatment could not be scheduled in a reasonable timeframe and the material was treated commercially by 'Davids Timber' in Dandenong South.

Five 200 mm long sample boards were cut from each 1.8 m long board (Figure 1). Sections, 20 mm long were cut from the ends of, and between each 200 mm long sample board to determine basic density. The excess length in the 1.8m long boards enabled knots and other possible defects to be avoided in the 200 mm long sample boards.

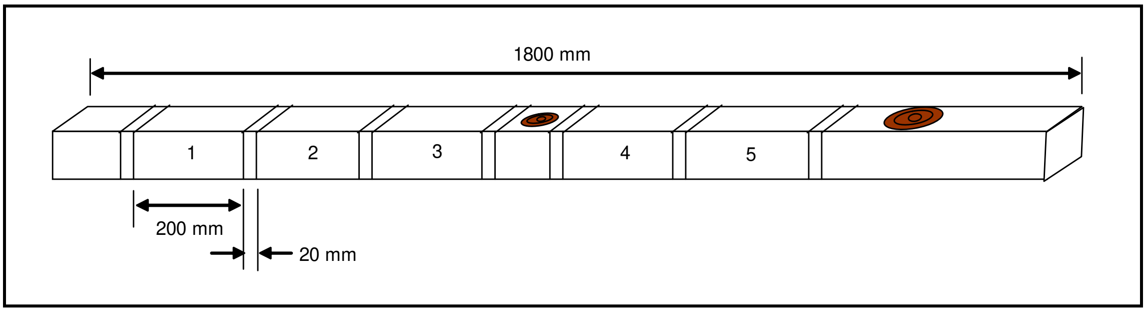


Figure 1: Diagram showing how the five sample boards and basic density sections were cut from each 1.8m long board.

As dried boards were supplied, the basic density of the 20 mm thick sections were calculated using the saturation or maximum-moisture method (Smith, 1955).
Matched control and treated pairs of sample boards were equilibrated concurrently at CSIRO in controlled environment rooms in the following Equilibrium Moisture Content (EMC) conditions:

Table 1: EMC, temperature and relative humidity of the various conditioning rooms used

EMC (%)	Temperature (°C)	Relative Humidty (%)
25	25	98
20	25	90
17	30	83
12	30	66
5	30	25

The sample boards were left in the controlled environment rooms until their masses had stabilized, a process that generally took a minimum of eight weeks. After a few weeks of conditioning, mould became apparent on both the CCA treated and control boards in the 25% EMC room. After discussions with CSIRO preservative chemists[1] it was decided that it was safe to wash the sample boards from this room in a dilute (4%) solution of ANTIBLU Select (Koppers Arch) without it being likely to have a discernible effect on the meter readings. The sample boards were not measured for at least 5 weeks after washing, by which time their effect on preventing mould was expected to have ended. The alternatives were to wash the sample boards repeatedly in water closer to the measurements being taken (and risk causing MC gradient problems) or trying to take measurements on mouldy boards (which apart from being an occupational health and safety issue may also have affected the meter readings).

Moisture Meters

Table 2 shows the type, brand and model of meters that were included in this study, as well as the supplying company. The Wagner L612 meter was the specific meter targeted for this project, given its prevalence within the Australian and New Zealand softwood industry. The Brookhuis FMW meter was chosen as an alternative to provide a comparison with a least one other capacitance-type meter.
The Deltron DCR22 meter was included as the representative resistance-type meter because it is known to be calibrated to the Australian Douglas-fir calibration, as described in AS/NZS 1080.1. Hence, the corrections for this meter should be applicable to most resistance meters that are similarly calibrated. If a meter with a different calibration is used, then corrections can still be used provided that the meters Douglas-fir calibration can be mathematically related to the AS/NZS 1080.1 Australian Douglas-fir calibration.

[1] Pers. Com. (2004) David Humphrey and Joely Taylor, research scientists, ensis – a joint venture of CSIRO and Forest Research.

Table 2: List of meters supplied for inclusion in this project

Meter Brand	Model	Type	Supplier/Distributor
Wagner	L 612	Capacitance	The Moisture Meter Company Pty Ltd
Deltron	DCR22	Resistance	Deltron Moisture Meters
Brookhuis	FMW	Capacitance	John Fogarty Ltd (NZ)

Calibration of meters

The calibration of the resistance-type meter was checked on a CSIRO built calibration box. The box (Figure 2) consists of a set of resistors that correspond to resistances for Douglas-fir from 6 to 40% moisture content (MC) as described in AS/NZS 1080.1. The calibration check data for this project are shown in Appendix A.

For the two capacitance-type meters, the supplying companies were asked to check the calibration of their meters before they were shipped and after they were returned at the completion of measurements. To give a general indication of their calibration during the project, two calibration plates (not specifically supplied with the meters) were used. While there are some anomalous readings shown, for reasons explained in the appendix it is felt that these were more likely errors in the process of checking the calibration, on those particular days, than an actual problem with the meter calibration. In general, the calibration checks were reasonably consistent over the period of the project and the suppliers verified that meters were still in calibration at the end of the measurements being taken.

Figure 2: Calibration box for resistance meters

Sampling procedure

Once equalised, the sample boards were brought out of the conditioning rooms in sets of 5-10 sample boards and then were weighed and their thickness measured. Thickness was measured in the middle of the face, directly under where the capacitance-type meters were placed. Boards were measured with each of the capacitance-type meters first and then with the resistance-type meter. Measurements were taken on both sides of each sample board with all meters.

For both of the capacitance-type meters, the sample boards were supported on timber blocks or boards at either end to provide an air gap under the boards. The minimum depth of the air gap under each sample board was 80 mm. All meters were placed on the sample boards in line or parallel with the long axis or length of each sample board. Light hand pressure (approximately 1.5 kg) was applied to the meters for each measurement. For the capacitance-type meters, density settings of 0.46 for the *P. radiata*, and 0.54 for the *P. elliottii* were used. These density settings were as specified by the industry representatives involved in this project.

The insulated pins of the resistance meter were driven into the sample boards so that the uninsulated tips were approximately at $^1/_3$ the depth of the sample boards. This is in accordance with AS/NZS 4787 (2001) for measuring the mean MC of the board using a resistance-type moisture meter. All measurements were taken with the pins aligned with the grain. There is some uncertainty about whether previous Australian species corrections were generated along or across the grain (Blakemore, 2003). However, as discussed in Blakemore (2003) the difference between measurements taken along or across the grain is likely to be negligible on material with a MC below 15%. Even though it is likely that most of the older Australian species corrections were generated across the grain, measurements in this case were taken along the grain as this appears to be the more common current practice.

The temperature of the laboratory where measurements were taken was controlled to about 22°C. Given the small number of sample boards (5-10 at a time), meter readings were generally taken well within 5-10 minutes of being removed from the conditioning rooms. As such, it was assumed that at the time of measurement with the resistance meter, the temperature of the sample boards were still at the conditioning room temperature of either 25°C or 30°C (see Table 1). In this way, the appropriate temperature correction was applied to the resistance meter measurements in accordance with AS/NZS 1080.1. The assumption about the temperature of the sample boards appears reasonable, especially given that the resistance meter measurements are taken at $^1/_3$ thickness depth, where the decline in wood temperature was unlikely to be significant within the 5-10 minute timeframe. No temperature corrections were supplied for either of the capacitance-type meters, and hence, no temperature corrections were applied to them.

Calculating new corrections and accuracy limits

The procedures and statistics used here are consistent with those used by Blakemore (2003). Extensive details for these procedures can be found in Blakemore (2003) and are not repeated here. The only difference here is that because the variance in the Deltron DCR22 meter readings were essentially proportional to the MC, a log (base 10) transformation of the variables was undertaken before calculating the linear regressions. For both the Wagner L612 and Brookhuis FMW a log (base 10) transformation of the meter reading only was used to try to better fit the curvilinear nature of the relationship.

RESULTS AND DISCUSSION

Species Properties

Table 3 shows the estimated basic density of all the sample boards included in this project. This table suggests that most of the CCA treated sample boards had a basic density 20 to 50 kg m^{-3} greater than the untreated sample boards. The large retentions of preservative suggested by these measurements are unlikely to be real as AS 1604.1 (2000) requires a minimum retention of only 0.38% (mass/mass basis) for H3 classification. It is most likely that the higher basic densities of the CCA treated boards in Table 3 are inaccurate and are an anomaly of the "maximum saturation" method used to determine density in this instance. The method is highly dependent on being able to obtain the mass of the fully saturated samples. In this case, it appears that the CCA treatment has reduced the ability of the samples to absorb water, beyond just the reduction in water that is displaced by the CCA.

Table 3: Estimated basic density of sample boards (kg m^{-3}). Number in bold is the mean value, lower left number is the SD and the lower right number indicates the number of boards included in the estimate of the mean value.

		25 mm				40 mm				50 mm				CCA Treated Total		Untreated Total		Total	
		CCA Treated		Untreated		CCA Treated		Untreated		CCA Treated		Untreated							
P. radiata	Carter Holt Harvey, Mt Gambier	506		484		520		508		524		504		517		499		508	
		26	75	23	75	35	80	34	75	51	75	58	75	39	230	42	225	42	455
	Carter Holt Harvey, NZ	443		420		492		445		468		427		468		430		449	
		31	75	31	75	46	75	57	73	48	75	55	74	47	225	50	222	52	447
	French Enterprises Scottsdale	450		405		448		417		464		429		454		417		436	
		35	75	35	75	38	70	49	70	40	74	45	75	38	219	44	220	45	439
	Total	466		436		488		459		486		454		480		449		465	
		42	225	46	225	50	225	61	218	54	224	64	224	50	674	58	667	56	1341
P. elliotii	Allied Timbers, Burpengary	513		511		528		506						521		509		515	
		51	70	52	75	55	79	51	75					54	149	51	150	53	299
	Hyne & Son,	576		544		522		493		505		494		535		510		522	
		75	75	71	75	58	75	62	75	57	74	73	75	70	224	73	225	73	449
	Weyerhauser, Caboolture	549		500		568		525						558		512		535	
		65	75	48	76	73	75	67	75					70	150	59	151	68	301
	Total	547		518		539		508		505		494		538		511		524	
		70	220	61	226	65	229	62	225	57	74	73	75	67	523	64	526	67	1049

Species corrections

A statistical test of the meter readings showed little difference between the readings taken on the outer face (face closest to the bark in the standing tree) and inner face (face closest to the pith in the standing tree) of each board. While there were some significantly large differences in readings between faces on individual boards (especially at higher MCs), neither the outer nor inner face was consistently higher or lower overall. The main reason for differences between the inner and outer face is usually because of the presence of a mixture of heartwood and sapwood in back-sawn boards. In this project a majority of the material supplied was sapwood. Most heartwood that was present occurred in the thicker dimensions boards where the pith was more commonly found running down the middle of the board. As there was no consistent difference between the outer and inner face readings, the meter readings from each face of each board have been treated separately as averaging the readings from both faces marginally reduced the overall variation in the meter readings.

Figures 3&4 and Tables 4&5 show the new corrections for the Deltron DCR22. Scatter-plots of the actual meter readings against oven-dry MC are in Appendix B (Figures 14 to Figure 17). It is worth noting that all readings less than 6% and greater than 37% (the upper scale on the meter goes to 40%, but 37% was felt by the authors to be the highest reliable reading when using the meter) were excluded from the data set as they were considered unreliable. The figures in Appendix B clearly show the increasing variation in meter readings with increasing oven-dry MC and hence the necessity for the log transformation of the data. The figures also show, that while not the main reason for applying the transformation, a related gain was that the line fitted is in a sense 'curvilinear' and follows the curvature in the relationship. The expected accuracy of these new corrections is about ±1% for low readings (6-8%), to around ±3% for mid range readings (15%) and up to more than ±6 % for higher readings (25% and above).
Comparing the new and the old (untreated) species corrections (Tables 4&5), there are some apparent differences. The most obvious reason for this is simply due to random variation in the sampled population and how well the sampling size and selection procedures represented that variation. The different corrections are also specific to different regional resources or sub-populations. The curvilinear (log transformed) regression fitted in this study are also likely to have contributed to the differences between the new and older corrections. Also, it is likely that the earlier corrections were possibly based on across the grain measurements (see Blakemore (2003) for more detail on the differences between measurements taken along or across the grain) rather than the along the grain measurements used here.
Previously, CCA treatment correction factors (for resistance meters) were available for *P. radiata*, but not for *P. elliottii* (AS/NZS 1080.1). It is important to be careful as to which type of CCA is being used. Historically, CCA salts (with copper sulphate and sodium dichromate) were most commonly used, while in more recent times CCA oxide (with copper oxide and chromium trioxide) has become predominant. This change was in part made because of the lower conductance properties of the CCA oxide[2] for applications such as power poles. This difference in conductance can be seen in the corrections required, for example, for NZ grown sapwood (Table 4) the corrections , relative to the matched untreated material, are greater for tanalith (CCA salt) than for

[2] Pers. Com. (2004) David Humphrey and Kevin McCarthy, research scientists, ensis – a joint venture of CSIRO and Forest Research.

boliden (CCA oxide). A similar result is apparent here where the relative corrections for the CCA oxide treatment used in this study are less than for the older CSIRO corrections for salt type CCA.

Looking at Appendix B, it appears that the CCA treatment both raised the EMC of the treated timber and reduced the spread in EMC values. This would appear to support the previous observation that the increased estimates of basic densities (with treatment) observed in Table 3 were not real, but relate to the changed interaction of water with the treated timber.

Tables 6 to 14 and Figures 5 to 8 show the corrections for the Wagner L612 and Brookhuis FMW. Scatter-plots of the meter readings against oven-dry MC (for all thicknesses) are also shown in Appendix B (Figures 18 to 25). Again it is worth noting that for the Wagner L612 an upper measurement limit on the meter was encountered, because of the uncertainty as to how much higher the readings may have been; all such readings on the upper limit were excluded from the data set.

Unexpectedly, Appendix B shows a similar problem with the capacitance–type meters in that a curvilinear relationship, as occurred in the Deltron meter readings, is apparent. This was unexpected, as the capacitance-type meters are theoretically meant to have fewer problems with meter readings around the Fibre Saturation Point (FSP) (25-35%) than resistance-type meters (James, 1988). While previous studies have shown significantly increased variation in the meter readings at higher MCs and a slight tendency for a curvilinear relationship, the pattern appears more noticeable (cf. Milota, 1994) in this instance. Admittedly, not many of the previous studies extend the range of MCs included in the calibration beyond 20% (e.g. Milota, 1996, Milota & Gupta, 1996, Gillis *et al.*, 2001 and Shupe *et al.*, 2002) so the phenomena may well occur with other species and meters.

One other possibility is that against expectations, the treatment of the sample boards, from the 25% EMC room with the anti-sapstain treatment may have been partly responsible for some of the curvilinear nature of the relationship between the meter readings against oven-dry MC for both the capacitance and resistance-type meters (Appendix B). However, many of these sapstain treated sample boards were excluded from the analysis as the readings were on the upper limit of the meters' scale and in a number of cases the curvilinear trend is also already readily apparent in the data for the boards from 20% EMC room. As such, it is felt that the use of the anti-saptain treatment on the boards from the 25% EMC room was unlikely to have been a significant issue in this project.

Unfortunately the log transformation of all the data as used with the Deltron DCR22 is not as applicable with the capacitance-type meters. One reason is that, on a theoretical basis multiple regression on log transformed data is more complicated than for the simple linear regression, in that it implies that the predictor variables have a multiplicative, rather than additive effect.

i.e.

If the multiple regression model of the transformed data is:

$$\text{Log(MC\%)} = M_1 \times \text{Log(MR)} + M_2 \times \text{Log(Thickness)} + M_3 \times \text{Log(MR x Thickness)} + C$$

Where: M_1 = partial regression coefficient for Log(Meter Reading (MR))

M_2 = partial regression coefficient for Log(Thickness)

M_3 = partial regression coefficient for Log(MR x Thickness)

C = Y intercept

This imples that:

$$\text{MC\%} = (\text{MR})^{M_1} \times (\text{Thickness})^{M_2} \times (\text{MRThickness})^{M_3} \times 10^{C}$$

Also, the log transformation of both the meter reading and oven-dry MC did not appear to have an appreciable effect on the curvilinear relationship, and hence is not used here. Instead, the best fit for the curvilinear relationship in the multiple regression was obtained using the log transformation of the meter readings only. The appropriateness or otherwise of this fit can be observed from the scatter–plots in Appendix B.

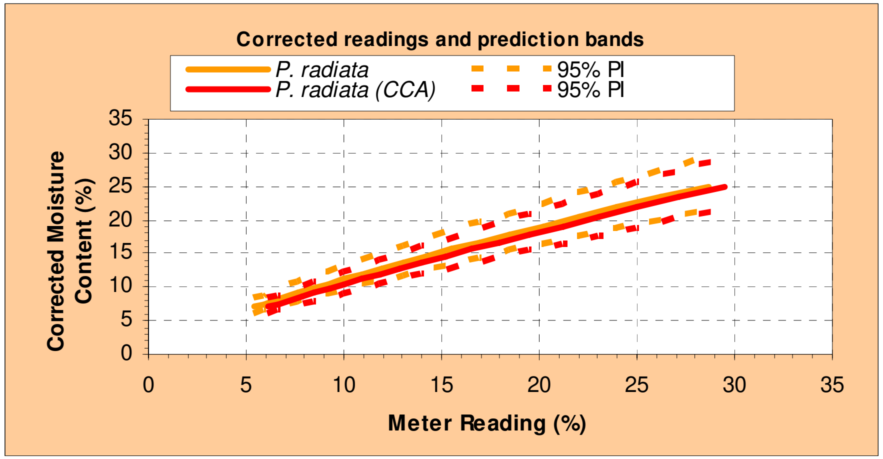
The confidence intervals, or accuracy, of the corrections with the meter readings vary slightly with timber thickness, hence Figures 5 to 8 are nominally for boards 40 mm thick. The confidence intervals do not change greatly for boards within the range of 25 to 50 mm (see Appendix B) and hence the intervals for 40 mm boards give a good indication of the accuracy that can be expected with these corrections. Generally, the expected accuracy of these new corrections is between ±3% to ±4%.

The new species corrections presented here suggests that there is some benefit in using a thickness correction with both the Wagner L612 and Brookhuis FMW. Assumedly, neither the Wagner L612 nor Brookhuis FMW provide a thickness correction because most of the effect gets lost in the more significant effect of between board density variation. The effect of density variation on meter readings is demonstrated and discussed in more detail later. Accepting that density variation does have a significant effect, a quick look at Table 3 would suggest that some of the thickness effect, for the *P. radiata* at least, may have been due to differences in the mean density of the different thicknesses. Regardless, assuming that sampling here is representative of the resource (in this case, the difference between 25 mm and 40 mm thick *P. radiata* was reasonably consistent across the 3 mills), applying the thickness corrections should still be of some benefit.

Taking the corrections for 40 mm thick material as an average species correction without regard to thickness, it would appear that the density setting of 0.46 for *P. radiata* was slightly out, especially for the Wagner L612; while the value of 0.54 for *P. elliottii* was more consistently out for both the Wagner L612 and the Brookhuis FMW. The differences are due to two possible reasons. The first is that the density based corrections might be inaccurate and the second is that an inappropriate density was used. Looking at the density setting issue first, Table 3 shows that for the material used here the overall untreated mean density was ~ 450 kg m^{-3} for *P. radiata* and ~510 kg m^{-3} for *P. elliottii*. If one uses the approximate conversion from ASTM D 2395-93 for the appropriate specific gravity to be used with the Wagner L612 (oven dry mass and volume at 12%), the suggested figures based on the density of this sample material would be ~0.49 and ~0.56. As these values are slightly higher than the standard industry values used in this project, using them may have resulted in less of a discrepancy being apparent. But the more important consideration is that as stated earlier and discussed in more detail in Blakemore (2003), the density based corrections are only intended as a first approximation in the absence of specific species correction. Providing the sampling here is representative of the resource for both species (and it should be reasonably representative providing the supplying mills chose a random sample that covered their range of material), the new species corrections generated here should be more accurate across the full range of MCs than the density based corrections, whichever density value is used. The choice of density setting the meter is set to when generating a new species correction is arbitrary, but once chosen, the new corrections are only applicable when the meter is set on the density. In this case, the new species and treatment corrections presented here are only applicable when the meter is set to 0.46 for *P. radiata* and 0.54 for *P. elliottii*.

Resistance meters

P. radiata



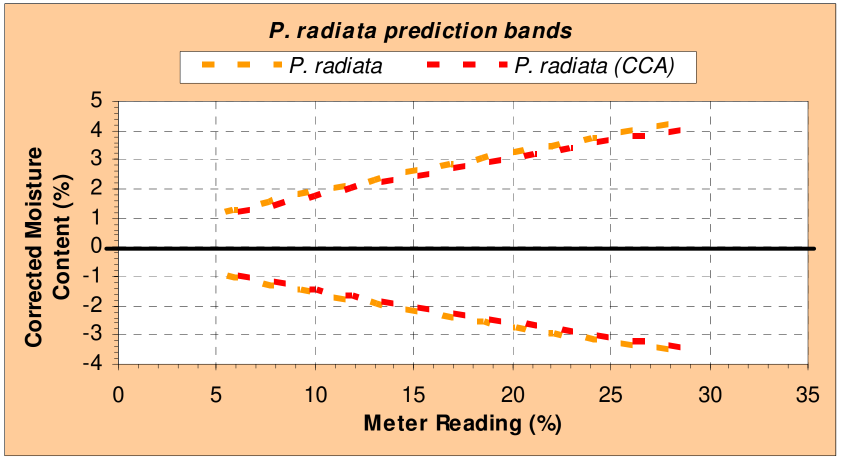


Figure 3: 95% prediction or confidence intervals for single corrected meter readings using the Deltron DCR22 moisture meter on *P. radiata*.

Table 4: Existing (AS/NZS 1080.1 1997, CSIRO 1974) and new species corrections for treated and untreated *P. radiata* with a resistance-type moisture meter.

Meter Readings(%)	m	c	r^2	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1080.1 (Vic)	1	-2		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1080.1 (S.A.)	0.982	-2.060		8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	26	27
1080.1 (N.Z.)	0.820	1.192		6	7	8	10	11	12	13	14	16	17	18	19	21	22	23	24	25	27	28
1080.1 (NZ – Sapwood – untreated)	0.975	1.492						12	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1080.1 (NZ – Sapwood – tanalith)	0.775	2.225						10	11	12	12	13	14	14	15	16	17	18	19	19	20	21
1080.1 (NZ – Sapwood – boliden)	0.904	2.239						11	12	13	14	15	16	17	18	19	19	20	21	22	23	24
CSIRO (CCA - relates to Vic)	1.113	-0.305		6	7	7	8	9	10	11	12	13	14	15	16	16	17	18	19	20	21	22
P. radiata*	1.308	-0.371	95.55%	8	9	9	10	11	12	13	14	14	15	16	17	18	18	19	20	20	21	22
P. radiata (CCA - H3)*	1.239	-0.261	97.18%	7	8	9	10	10	11	12	13	13	14	15	16	16	17	18	19	19	20	21

* Regression co-efficients apply to $\log_{10}$ transformed data

P. elliottii

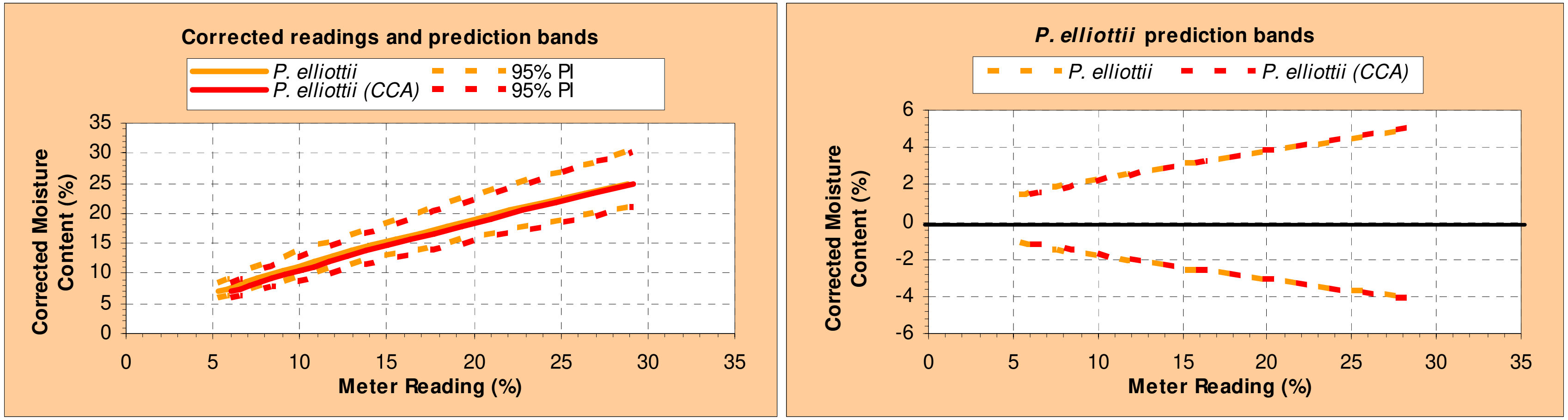


Figure 4: 95% prediction or confidence intervals for single corrected meter readings using the Deltron DCR22 meter on *P. elliottii*

Table 5: Existing (AS/NZS 1080.1 1997, CSIRO 1974) and new species corrections for treated and untreated *P. elliottii* with a resistance-type moisture meter

Meter Readings(%)	m	c	r^2	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1080.1 (Qld)	1.081	- 1.839		7	8	9	10	11	12	13	14	15	16	17	17	18	19	20	21	22	23	24
1080.1 (Immature)	0.763	2.112		5	6	8	9	10	12	13	14	16	17	18	20	21	22	23	25	26	27	29
P. elliottii*	1.330	- 0.399	93.87%	8	9	10	10	11	12	13	14	15	15	16	17	18	18	19	20	20	21	22
P. elliottii (CCA - H3)*	1.239	- 0.266	95.68%	7	8	9	10	11	11	12	13	14	15	15	16	17	18	18	19	20	21	21

* Regression co-efficients apply to $\log_{10}$ transformed data

Capacitance meters

Table 6: Multiple regression coefficients for Wagner L612 and Brookhuis FMW corrections.

	P. radiata (Meter must be set to a density of 0.46)				P. elliottii (Meter must be set to a density of 0.54)			
	Wagner L612		Brookhuis FMW		Wagner L612		Brookhuis FMW	
		CCA		CCA		CCA		CCA
(m_1) Log (MR)	38.1694	37.3465	40.0224	35.5072	32.4632	32.5634	34.3449	32.1810
(m_2) Thickness	0.0964	0.1053	0.1386	0.0632	0.0849	0.1034	0.1394	0.0916
(m_3) Log(MR) x Thick	-0.1310	-0.1341	-0.1605	-0.0784	-0.0823	-0.1026	-0.1135	-0.0558
c	-26.2848	-25.8551	-30.3249	-26.2209	-20.1913	-20.4897	-24.4820	-22.7074
R^2	92.97%	93.90%	91.38%	94.76%	89.93%	90.70%	87.62%	91.27%

P. radiata

Table 7: Wagner L612 correction table for *P. radiata* (meter must be set to a density of 0.46).

	Meter Readings (%)																											
Thickness (mm)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
20						8	10	11	13	14	15	16	17	18	19	20	21	22	23	23	24	25						
25						8	9	11	12	14	15	16	17	18	19	20	21	22	22	23	24	24	25					
30						8	9	11	12	14	15	16	17	18	19	20	20	21	22	23	23	24	24					
35						7	9	11	12	13	15	16	17	18	18	19	20	21	21	22	23	23	24	25				
40						7	9	11	12	13	14	15	16	17	18	19	20	20	21	22	22	23	24	24	25			
45						7	9	10	12	13	14	15	16	17	18	19	19	20	21	21	22	23	23	24	24	25		
50						7	9	10	11	13	14	15	16	17	17	18	19	20	20	21	22	22	23	23	24	24	25	
55							9	10	11	12	14	15	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25

Table 8: Wagner L612 correction table for treated (CCA – H3) *P. radiata* (meter must be set to a density of 0.46).

	Meter Readings (%)																												
Thickness (mm)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
20						8	9	11	12	14	15	16	17	18	19	20	21	21	22	23	23	24	25						
25						7	9	11	12	13	15	16	17	18	19	19	20	21	22	22	23	24	24	25					
30						7	9	11	12	13	14	15	16	17	18	19	20	21	21	22	23	23	24	24					
35						7	9	10	12	13	14	15	16	17	18	19	20	20	21	22	22	23	23	24	25				
40						7	9	10	12	13	14	15	16	17	18	19	19	20	21	21	22	23	23	24	24	25			
45						7	9	10	11	13	14	15	16	17	17	18	19	20	20	21	22	22	23	23	24	24	25		
50						7	9	10	11	12	14	15	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25	
55						7	9	10	11	12	13	14	15	16	17	18	18	19	20	20	21	21	22	22	23	23	24	24	25

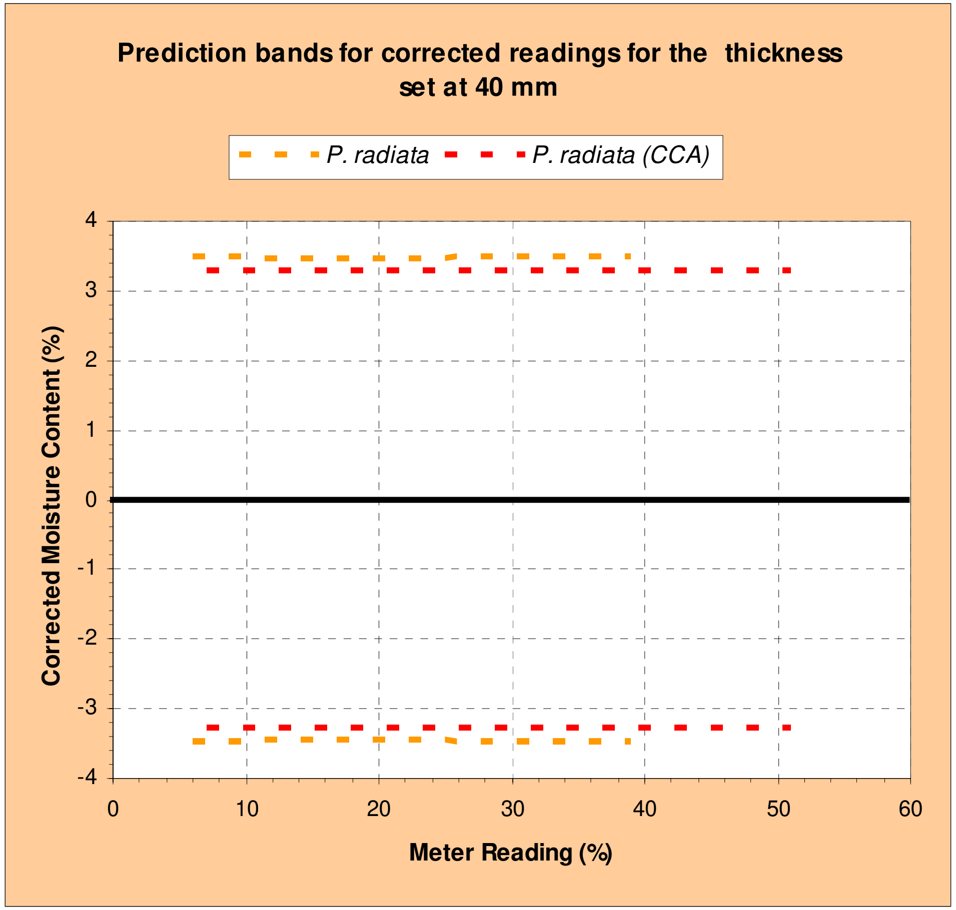


Figure 5: 95% prediction or confidence intervals for single corrected meter readings using the Wagner L612 on 40 mm thick *P. radiata*.

Table 9: Brookhuis FMW correction table for *P. radiata* (meter must be set to a density of 0.46).

Thickness (mm)	Meter Readings (%)																														
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
20							8	9	11	12	13	15	16	17	18	19	20	20	21	22	23	23	24	25							
25							8	9	11	12	13	14	15	16	17	18	19	20	21	21	22	23	23	24	25						
30							7	9	10	12	13	14	15	16	17	18	19	20	20	21	22	22	23	24	24	25					
35							7	9	10	12	13	14	15	16	17	18	19	19	20	21	21	22	23	23	24	24	25				
40							7	9	10	11	13	14	15	16	17	17	18	19	20	20	21	22	22	23	23	24	24	25			
45							7	9	10	11	12	14	14	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25		
50							7	9	10	11	12	13	14	15	16	17	18	18	19	20	20	21	21	22	22	23	23	24	24	25	
55							7	8	10	11	12	13	14	15	16	16	17	18	19	19	20	20	21	21	22	22	23	23	24	24	25

Table 10: Brookhuis FMW correction table for treated (CCA) *P. radiata* (meter must be set to a density of 0.46).

Thickness (mm)	Meter Readings (%)																														
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
20							7	9	10	12	13	14	15	16	17	18	18	19	20	21	21	22	22	23	24	24	25				
25							7	9	10	12	13	14	15	16	17	17	18	19	20	20	21	22	22	23	23	24	24	25			
30							7	9	10	11	13	14	15	16	16	17	18	19	20	20	21	21	22	23	23	24	24	25			
35							7	9	10	11	12	14	15	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25		
40							7	9	10	11	12	13	14	15	16	17	18	18	19	20	20	21	22	22	23	23	24	24	25		
45							7	9	10	11	12	13	14	15	16	17	18	18	19	20	20	21	21	22	22	23	23	24	24	25	
50							7	9	10	11	12	13	14	15	16	17	17	18	19	19	20	21	21	22	22	23	23	24	24	24	25
55							7	8	10	11	12	13	14	15	16	16	17	18	18	19	20	20	21	21	22	22	23	23	24	24	25

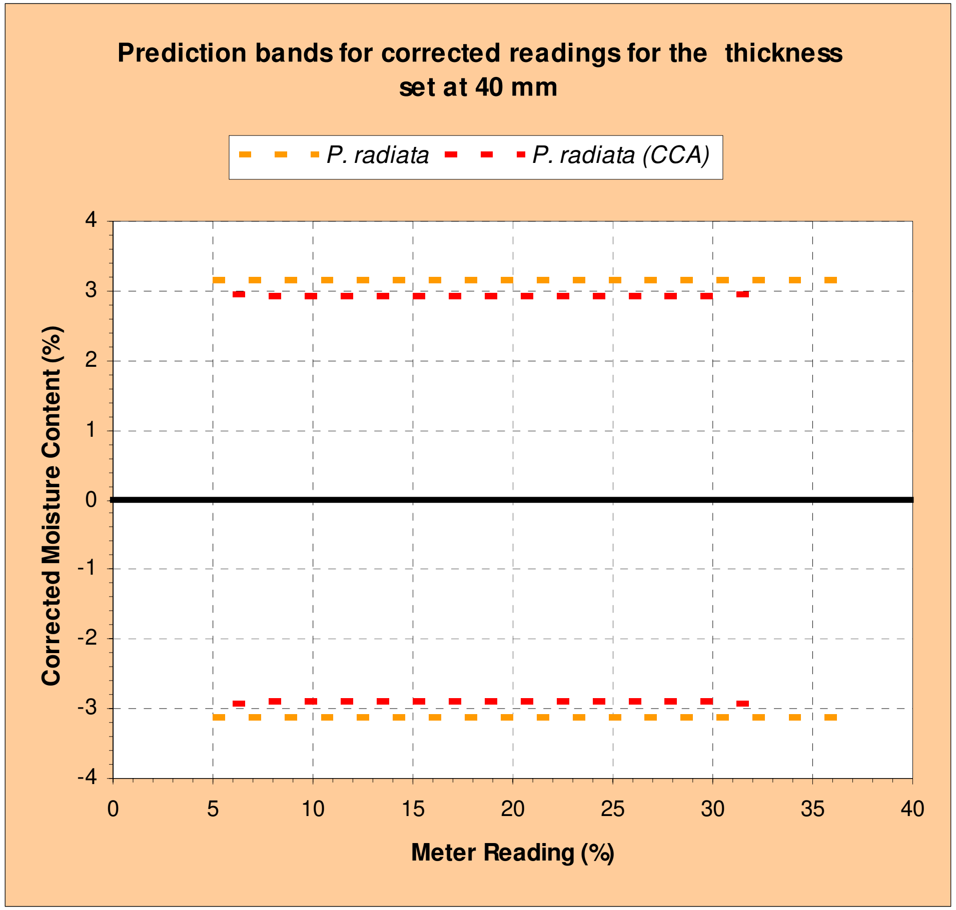


Figure 6: 95% prediction or confidence intervals for single corrected meter readings using the Brookhuis FMW on 40 mm thick *P. radiata.*

P. elliottii

Table 11: Wagner L612 correction table for *P. elliottii* (meter must be set to a density of 0.54).

		Meter Readings (%)																											
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Thickness (mm)	20					8	9	11	12	14	15	16	17	18	19	19	20	21	22	22	23	23	24	25					
	25					8	9	11	12	14	15	16	17	18	19	19	20	21	21	22	23	23	24	24	25				
	30					8	9	11	12	14	15	16	17	18	18	19	20	21	21	22	23	23	24	24	25				
	35					8	9	11	12	14	15	16	17	18	18	19	20	21	21	22	22	23	24	24	25				
	40					8	10	11	12	14	15	16	17	18	18	19	20	21	21	22	22	23	23	24	24	25			
	45					8	10	11	12	14	15	16	17	17	18	19	20	20	21	22	22	23	23	24	24	25			
	50					8	10	11	12	14	15	16	17	17	18	19	20	20	21	22	22	23	23	24	24	25			
	55					8	10	11	12	14	15	16	16	17	18	19	20	20	21	21	22	23	23	24	24	24	25		

Table 12: Wagner L612 correction table for treated (CCA) *P. elliottii* (meter must be set to a density of 0.54).

		Meter Readings (%)																											
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Thickness (mm)	20					7	9	11	12	13	15	16	17	17	18	19	20	21	21	22	23	23	24	24	25				
	25					7	9	11	12	13	14	16	16	17	18	19	20	20	21	22	22	23	23	24	25				
	30					8	9	11	12	13	14	15	16	17	18	19	20	20	21	22	22	23	23	24	24	25			
	35					8	9	11	12	13	14	15	16	17	18	19	19	20	21	21	22	23	23	24	24	25			
	40					8	9	11	12	13	14	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25		
	45					8	9	11	12	13	14	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25		
	50					8	9	11	12	13	14	15	16	17	18	18	19	20	20	21	22	22	23	23	23	24	24	25	
	55					8	10	11	12	13	14	15	16	17	18	18	19	20	20	21	21	22	22	23	23	24	24	25	25

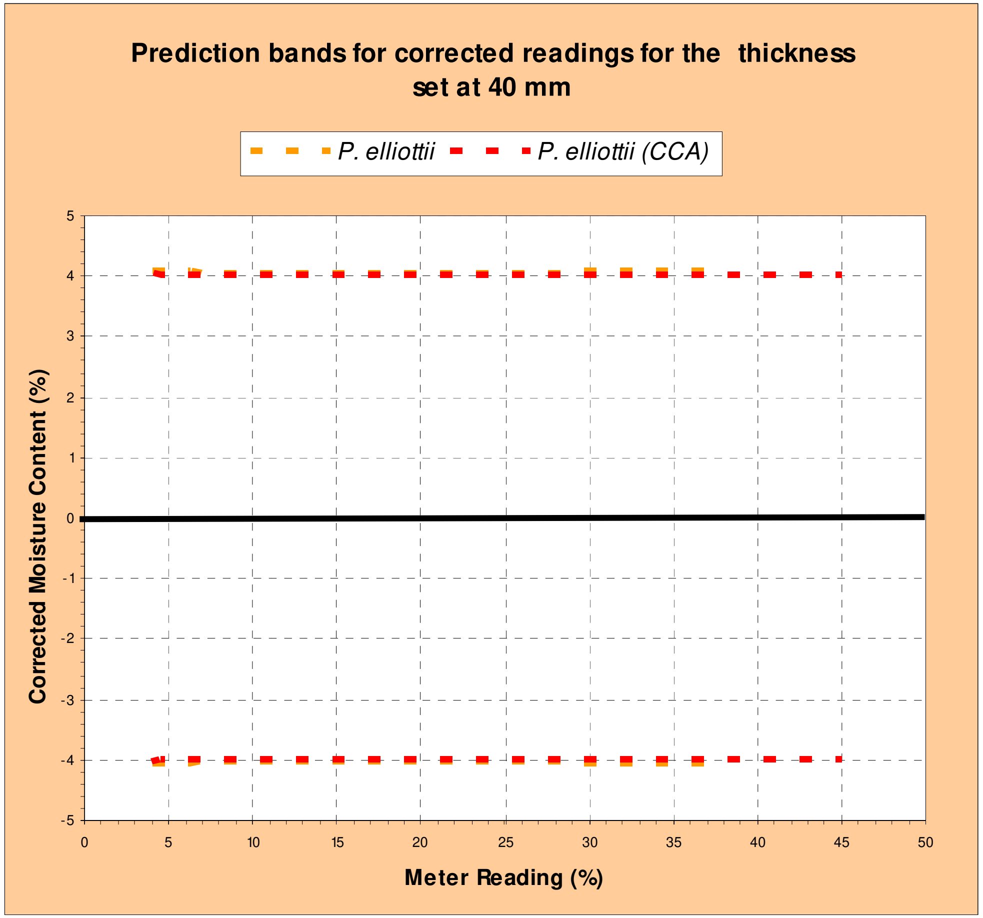


Figure 7: 95% prediction or confidence intervals for single corrected meter readings using the Wagner 612 on 40 mm thick *P. elliottii*.

Table 13: Brookhuis FMW correction table for *P. elliottii* (meter must be set to a density of 0.54).

	Meter Readings (%)																											
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
20						7	9	10	12	13	14	15	16	17	18	19	19	20	21	21	22	23	23	24	24	25		
25						7	9	11	12	13	14	15	16	17	18	19	19	20	21	21	22	22	23	24	24	25		
30						8	9	11	12	13	14	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25	
35						8	9	11	12	13	14	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25	
40						8	10	11	12	13	14	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25	
45						8	10	11	12	13	14	15	16	17	18	18	19	20	20	21	22	22	23	23	24	24	25	25
50						8	10	11	12	13	14	15	16	17	18	18	19	20	20	21	22	22	23	23	24	24	24	25
55						9	10	11	12	14	14	15	16	17	18	18	19	20	20	21	21	22	22	23	23	24	24	25

Table 14: Brookhuis FMW correction table for treated (CCA) *P. elliottii* (meter must be set to a density of 0.54).

	Meter Readings (%)																											
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
20						7	9	10	11	13	14	15	16	17	17	18	19	20	20	21	21	22	23	23	24	24	25	
25						7	9	10	12	13	14	15	16	17	17	18	19	20	20	21	22	22	23	23	24	24	25	
30						8	9	11	12	13	14	15	16	17	18	18	19	20	20	21	22	22	23	23	24	24	25	
35						8	9	11	12	13	14	15	16	17	18	18	19	20	20	21	22	22	23	23	24	24	25	
40						8	10	11	12	13	14	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25	
45						8	10	11	12	13	14	15	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25	
50						8	10	11	12	14	15	16	16	17	18	19	19	20	21	21	22	22	23	23	24	24	25	
55						9	10	11	13	14	15	16	17	17	18	19	20	20	21	21	22	23	23	24	24	24	25	

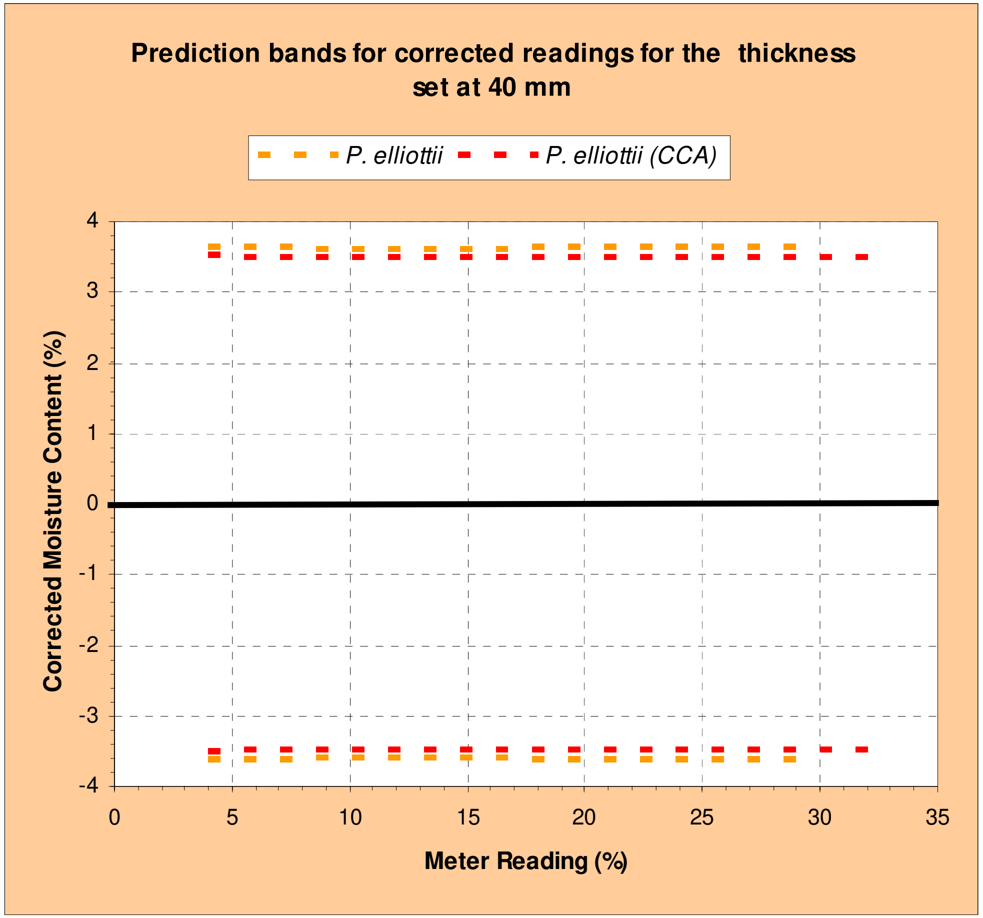


Figure 8: 95% prediction or confidence intervals for single corrected meter readings using the Brookhuis FMW on 40 mm thick *P. elliotti*.

Practical implications of measured accuracy levels.

The main question that arises from the measurements of the accuracy of the different moisture meters with *P. radiata* and *P. elliottii* is: how can operators use electrical moisture meters to measure whether or not boards meet the expected product requirements of standards such as AS/NZS 1748 (1997) or AS 4785.1 (2002)? For example, AS/NZS 1748 specifies a MC range of 8 to 15%, AS 4785.1 specifies a range of 9-14% for products such as strip flooring or joinery or moulding products, and AS 4785.3 specifies a range of 10±2% for furniture components. These ranges are for the MC as determined using AS/NZS 1080.1 (1997) which ultimately means it is as determined by the oven-dry method (Preface, paragragh 2).
The difficulties with moisture meters arise when meter readings are close to the limits of the ranges specified above. For example, the oven-dried determined MC of a board that has a meter reading of 14% (given a 95% confidence interval of ±1.5%) could actually be as low as 12.5% or as high as 15.5%. For meters with a confidence interval of ±4.0%, the actual oven-dry MC could be as low 10% or as high as 18%. This means that depending on the confidence limits for the meter, a certain percentage of boards with an acceptable oven-dry MC would be rejected, and alternatively, a certain percentage of boards with an unacceptable oven-dry MC would be accepted. The only way of ensuring that the oven-dry MC of boards was within the acceptable range of 8-15%, as measured with a moisture meter with say a given level of accuracy of ±1.5%, would be to only accept boards with readings in the range from 10-13%. However, this very conservative approach could result in a high percentage of boards with an acceptable oven-dry MC being rejected.
To help illustrate this discussion, Figure 9 shows the distribution of the oven-dry MC of 1000 fictional structural pine boards. Figures 10 to Figure 12 show the distribution of meter readings (rounded off to nearest 0.5%) for a meter with a 95% confidence interval of ±1.5%, ±3.0% and ±4.0% on these 1000 boards. Given the acceptable moisture content range for structural boards is 8-15%, 5 of the boards shown in Figure 9 should be rejected because their mean moisture content is too high. In this example though, if boards with meter readings outside the 8-15% range are rejected, then 20 boards would be rejected for the meter with a ±1.5% confidence interval, 72 boards with the ±3.0% confidence interval, or 125 boards with the ±4.0% confidence interval. This example only shows the problem with rejecting boards whose MC was actually acceptable simply because of the inherent inaccuracy of the meter. Nevertheless, it is easy to visualise how for example, for a pack of timber slightly over-dried there would be a large number of boards with too low a MC that could be wrongly accepted.

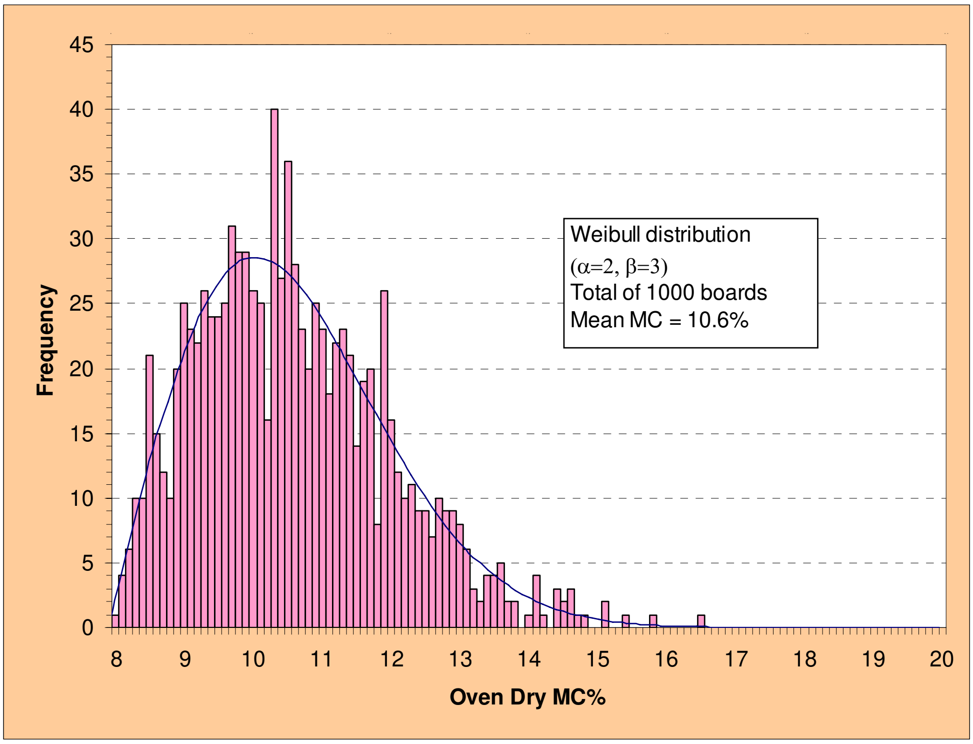


Figure 9: An attempt at generating a 'typical' distribution of the oven-dry MC of 1000 structural boards based with an intended MC of between 8 -15%, the distribution was generated on a spreadsheet using a Weibull distribution.

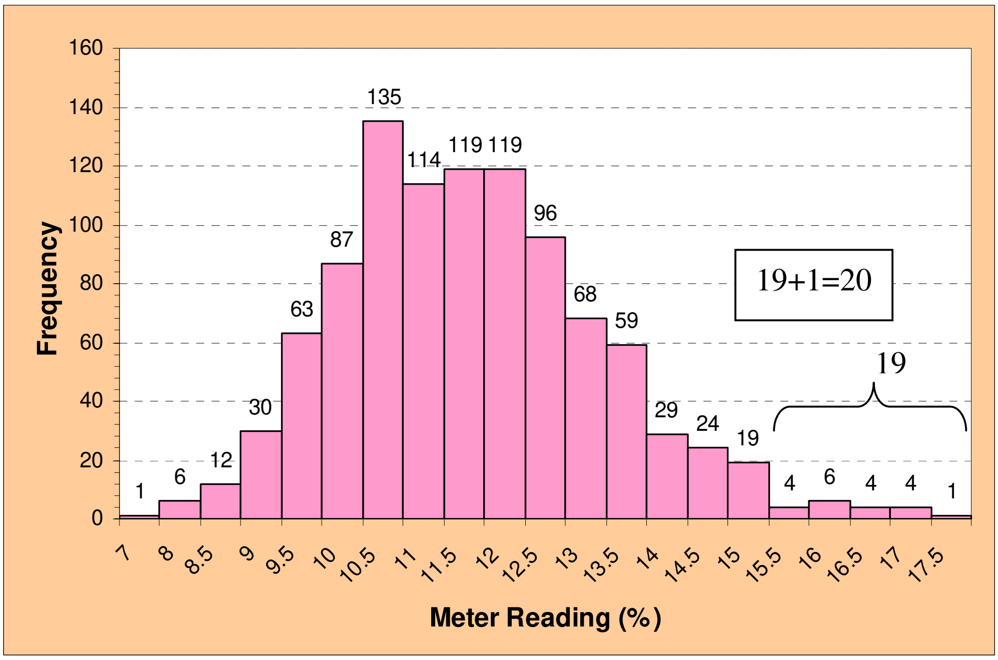


Figure 10: Distribution of meter readings rounded off to the nearest 0.5% in accordance with AS/NZS 1080.1 (1997). The meter readings were normally distributed around each oven-dry MC shown in Figure 9 so that 95% of the meter readings are within ±1.5% of the actual oven-dry MC.

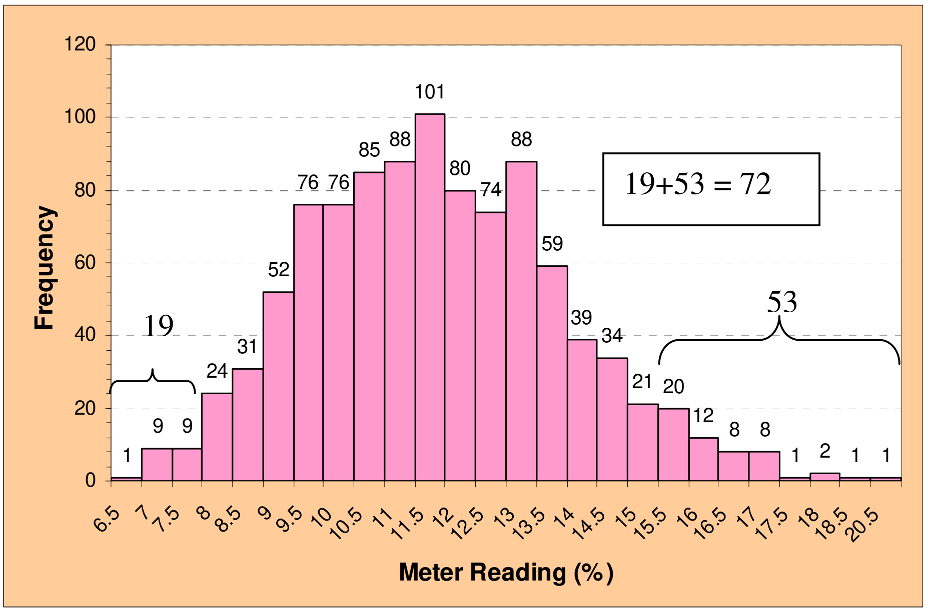


Figure 11: Distribution of meter readings rounded off to the nearest 0.5% in accordance with AS/NZS 1080.1 (1997). The meter readings were normally distributed around each oven-dry MC shown in Figure 9 so that 95% of the meter readings are within ±3.0% of the actual oven-dry MC.

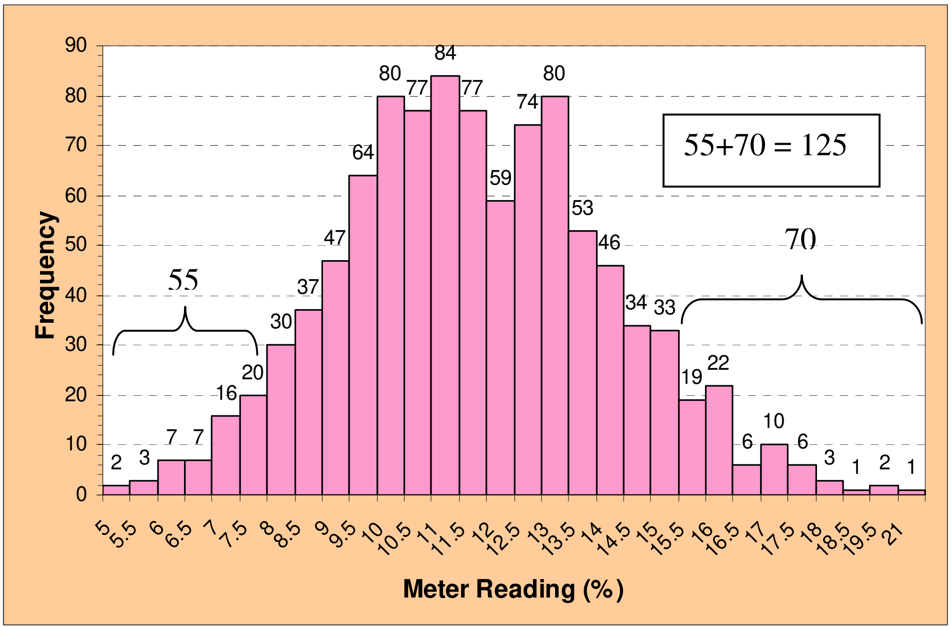


Figure 12: Distribution of meter readings rounded off to the nearest 0.5% in accordance with AS/NZS 1080.1 (1997). The meter readings were normally distributed around each oven-dry MC shown in Figure 9 so that 95% of the meter readings are within ±4.0% of the actual oven-dry MC.

An alternative that overcomes the difficulty of using moisture meters to determine if boards fall within a set range is provided in AS/NZS 4787 (2001) (actually, the approach used in AS/NZS 4787 (2001) is briefly discussed in Appendix F of AS/NZS 1080.1 (1997)). This standard specifies allowable ranges for 90% of meter readings for a given quality class and target MC_t as shown in Table 15. This approach of setting allowable ranges for meter readings appears to be far more practical than the MC limits specified in AS/NZS 1748, AS 4785.1 or AS 4785.3. The compromise that has to be made with this approach is the assumption that the odd board outside of the specified range is unlikely to be a major problem if included with a large number of boards with an acceptable MC. For example, if instead of requiring every board to be within the 8-15% range, the target MC for structural boards was specified as Class C with a mean of 11%, then the range for 90% of the readings is again 8-15%. Therefore, for the distribution shown in Figures 9, 10 & 11, a meter with a 95% confidence interval of at least ±3.0%, could satisfactorily determine that this sample of timber was acceptable. For a meter with a confidence interval of ±4.0%, either a lower drying class would need to be specified, or the drying improved to reduce the variation of the underlying oven-dry MCs from what is shown in Figure 9. As the example used for the above discussion is purely fictional, industry would still need to determine what target MC_t and drying class, as measured with a meter of a known accuracy, is needed to avoid any MC related problems with structural grade, or other grades of timber.

Table 15: Allowable range for 90% of all moisture content ($MC_{1/3}$)[3] readings around the target moisture content (MC_t) (AS/NZS 4787: 2001)

Quality Class	Allowable range for 90% of all $MC_{1/3}$ readings	Examples of ranges				
		Target moisture contents (MC_t), percent				
		8	10	12	14	18
A	MC_t - 0.1 MC_t MC_t + 0.2 MC_t	7-10	9-12	11-14	13-17	16-22
B	MC_t - 0.2 MC_t MC_t + 0.3 MC_t	6-10	8-13	10-16	11-18	14-23
C	MC_t - 0.3 MC_t MC_t + 0.4 MC_t	6-11	7-14	8-17	10-20	13-25
D	MC_t - 0.4 MC_t MC_t + 0.5 MC_t	5-12	6-15	7-18	8-21	11-27
E	MC_t - 0.5 MC_t MC_t + 0.6 MC_t	4-13	5-16	6-19	7-22	9-29

The importance of looking at a number of meter readings, and not placing too much significance on an individual reading, is already acknowledged and accepted by most people in industry. The question is simply how to interpret the significance of the meter readings obtained. As discussed above, AS/NZS 4787 (2001) is one approach, but it is not the only one. Anecdotally for example, there is already evidence that where mills are currently happy with their use of capacitance-type meters, it is on the basis of them having determined what is an acceptable mean and standard deviation of the sample meter readings when accessing the MC of a stack or pack of timber.

Effect of density on capacitance-type meters

Figure 13 is shown to demonstrate the effect of between board density variation on the meter readings of the capacitance-type meters. It plots the residuals from the multiple regression used to generate the species correction for the Wagner L612 on the untreated

[3] $MC_{1/3}$ -the moisture content measured by a resistance moisture meter, with insulated pins at one third of the thickness of the piece. This is intended to be a measure of the boards mean MC.

P. radiata. The residuals can be thought of as the unexplained variance or uncertainty in the model. The linear regression of these residuals against density shows that about half of the uncertainty ($R^2 \approx 0.5$) in the correction can be related to the effect of between board density variation on the meter readings.

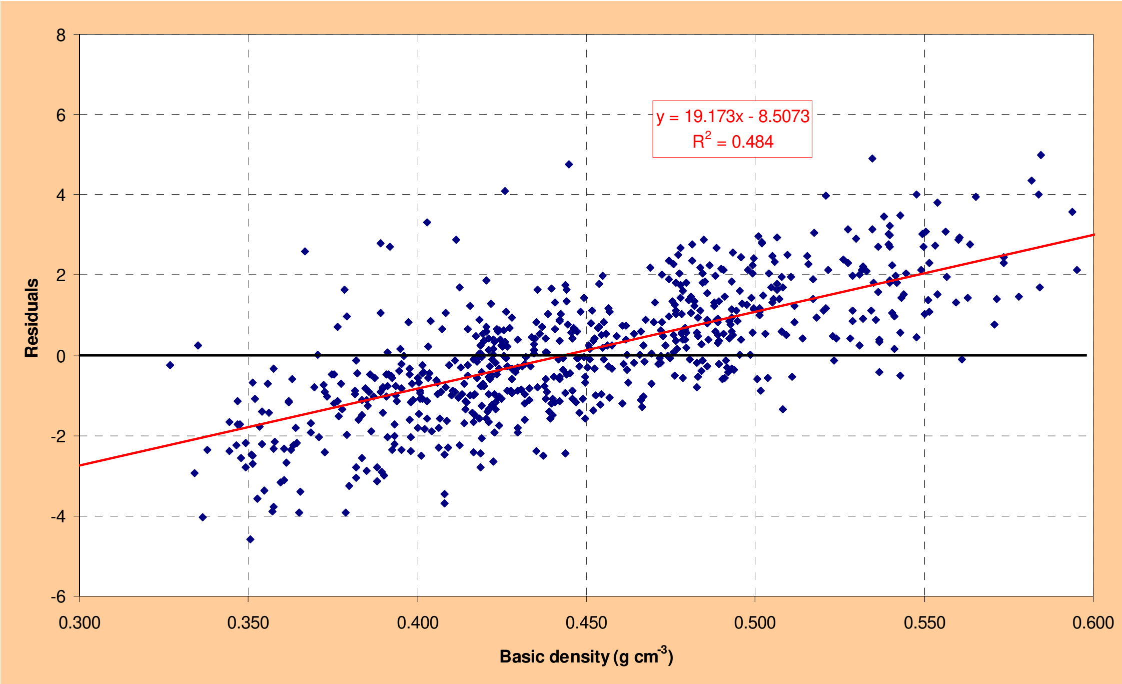


Figure 13: Scatter-plot of residuals from multiple regression (Wagner L612 meter) for untreated *P. radiata* against basic density.

CONCLUSIONS AND RECOMMENDATIONS

New species and CCA (oxide type, treated to H3 level) treatment corrections have been generated for both *P. radiata* and *P. elliottii*. The new corrections for the Deltron DCR22 differ in some respects from previously published corrections. This is most likely due to the new corrections being based on material from a range of geographic zones and based on measurements being taken along the grain. The new corrections are also based on a log transformation of the data, which in this instance better fitted the curvilinear relationship between the meter readings and oven-dry determined MC.

The expected accuracy of the CCA treatment corrections for the Deltron DCR22 ranged from ±1% at MCs between 6 and 8% up to ±6% at higher MCs closer to FSP (25% and above). Generally, the expected accuracy in the important range of 8-15% MC would be between ±1.0% to ±3%. The accuracy limits are similar for both untreated and treated (CCA H3) timber.

With the corrections for the Wagner L612 and Brookhuis FMW (for MC less than 20%) the expected accuracy is generally between ±3.0% to ±4.0%. Again the accuracy limits are similar for both untreated and treated (CCA H3) timber.

Given the lack of consistent difference in the accuracy of the CCA corrections compared with the untreated corrections, industry should be able to use the Wagner L612 and Brookhuis FMW on treated timber with as much confidence as on untreated timber.

The important practical consideration about the accuracy of moisture meters is that the uncertainty in any one individual reading can be high (especially with the capacitance-type meters) and for both types, they are best used on multiple boards to measure the mean MC and variation for a charge or pack of timber. Clearly, the better accuracy of the resistance meters as shown in this project are a distinct advantage, but provided the levels of accuracy are known, methods for using capacitance-type meters that use an approach consistent or similar to AS/NZS 4787 (2001) are still possible, with the advantage being that much larger samples of boards can be quickly measured.

ACKNOWLEDGMENTS

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REFERENCES

AS/NZS 1080.1. (1997) Timber-Methods of Test. Method 1: Moisture Content

AS 1604.1 (2000) Specification for preservative treatment. Part 1: Sawn and round timbers.

AS/NZS 1748 (1997) Timber—Stress-graded—Product requirements for mechanically stress-graded timber.

AS 4785.1 (2002) Timber—Softwood—Sawn and milled products. Part 1: Product Specification

AS 4785.3 (2002) Timber—Softwood—Sawn and milled products. Part 3: Timber for furniture components.

AS/NZS 4787 (2001) Timber-Assessment of drying quality

Blakemore P.A. (2003) The use of hand-held electrical moisture meters with commercially important Australian hardwoods. FWPRDC (PN01.1306).

CSIRO (1974) Testing Timber for Moisture Content. CSIRO Division of Building Research Special Report

ASTM D 2395-93 (1993) Standard Test Methods for Specific Gravity of Wood and Wood-Base Materials.

Gillis C.M., Stephens W.C., and Peralta P.N. (2001) Moisture Meter Correction Factors for Four Brazilian Wood Species. Forest Prod. J. 51(4): 83-86

James W.L. (1988) Electrical Moisture meters for Wood. USDA Forest Products Laboratory, General Technical Report FPL-GTR-6. 17 pp

Milota M.R. (1994) Specific gravity as a predictor of species correction factors for a capacitance-type moisture meter. Forest Prod. J. 44(3):63-68

Milota M.R. (1996) Calibration moisture meters for western hardwood species. Forest Prod. J. 46(1):39-42

Milota M.R. and Gupta R. (1996) Moisture meter correction factors for Dahurian Larch from the Russian far east. Forest Prod. J. 46(6):91-93

Shupe T.F., Wu, Q. and Hartley I.D. (2002) Calibration of moisture meters for southern hardwoods.For. Prod. J. 52 (7/8):59-62.

Smith D.M. (1955) A comparison of two methods for determining the specific gravity of small samples of second-growth Douglas-fir

APPENDIX A – Calibration data

Table 16 Deltron DCR22 calibration checks

	Day																					
Douglas-fir MC (%)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Mean
6	6.5	7	6	6.5	6.5	6	6.5	6	6.5	6.25	6.25	6.25	7	6.25	6.5	6	6	6	6.5	6	6	6.3
7	7.25	7.25	7.25	7.5	7.5	7	7.5	7	7.25	7.25	7.5	7.25	7.75	7.5	7.5	7.25	7.5	7.25	7.5	7	7.25	7.3
8	8.25	8.25	8	8	8.5	8	8.5	8	8	8.25	8.25	8.25	8.25	8.5	8.25	8.25	8.5	8.25	8	8	8.25	8.2
9	9	9	9	9	9.25	9	9.5	9	9	9.25	9	9	9.25	9.25	9.25	9	9.25	9.25	9	9.25	9.25	9.1
10	10.3	10	10	10.3	10.3	10.25	10.5	10.3	10	10.3	10	10.3	10.3	10.3	10	10.25	10	10.25	10	10.3	10.25	10.2
11	11	11	11	11.3	11	11.25	11.25	11	11	11.3	11	11	11	11	11	11.25	11	11.25	11	11.3	11.25	11.1
12	12.3	12	12	12.3	12	12.5	12.5	12	12	12.3	12.3	12.3	12	12.3	12	12.25	12	12.25	12	12.5	12.25	12.2
13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13.3	13	13.0
14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14.3	14	14.0
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15.3	15	15.0
16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16.3	16	16.0
17	17	17	17	17	17	17.25	17	17	17	17	17	17	17	17	17	17.25	17	17	17	17.3	17	17.0
18	18	18	18	18	18	18.25	18.25	18	18	18	18	18	18	18	18	18	18	18	18	18.3	18	18.0
19	19.3	19	19	19	19	19.25	19.5	19	19	19	19	19	19	19	19	19.25	19	19.25	19	19.5	19	19.1
20	20.3	20	20	20	20	20.5	20.5	20	20	20.3	20	20	20	20	20	20.5	20	20.25	20	20.5	20.25	20.1
21	21.3	21	21	21	21	21.5	21.5	21	21	21.3	21	21	21	21	21	21.5	21	21.25	21	21.5	21.25	20.2
22	22.3	22	22	22	22	22.25	22.25	22	22	22.3	22	22	22	22	22	22.25	22	22.25	22	22.5	22	22.1
23	23.3	23	23	23	23	24	23.25	23	23	23.5	23	23	23	23	23	23.25	23	23.4	23	23.5	23.25	23.2
24	26.5	26	25	24	25	25	26	25	25	25	24	24	24	24	25	26	25	25	24	27	25	25.0
26	28	28	27	27	27		28	26			26	27	26	26	26	28	26	27	26	28	28	26.9
28	29	30	29	29	29			30			29	29	29	29	29	30	29	30	28	30	30	29.3
30	31	31	30	31	30.5			30	30		31	30	30	30	30	32	31	32	30	32	31	30.7
32	33	33	32	33	32			32			32	32	31	32	32	34	32	34	31.5	34	33	32.5
34	35	35	34		34			34	35		34	34	34	34	34	36	35	35	34	36	35	34.6
36	36	37	36		36			36	36		36	36	36	36	36	37	35	37	36	37	36	36.2
38	38	38	38		38			38	38		38	38	38	38	38	38.5	38	38	38	38	38	38.0
40	39	39	39		39			39	40		39	39	39	39	39	39	38	39	39	39	39	39.0

Table 17 Wagner L612 and Brookhuis calibration checks

			Day																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Mean
Wagner	0.54	Plate 1	15.5	16.2	16.1	16.1	16.2	17.6	16.3	16.3	16.3	15.3	15.3	16.1	15.4	14.8	16.3	15.5	16.3	15.9	16.3	16.0
		Plate 2	16.3	16.9	15.8	11.6	16.9	17.2	16.9	16.9	16.5	15.5	16.6	16.3	16.3	15.3	16.8	15.3	16.7	16.3	16.9	16.2
	0.46	Plate 1	18.5	18.4	12.8	17.8	18.4	15.5	17.1	18.4	18.4	18.4	18.1	18.3	18.1	17.8	18.4	17.4	18.5	18.2	17.8	17.7
		Plate 2	20	19.1	17.7	13.3	18.9	15.6	19	19.1	18.5	18.9	18.4	19	18.4	18.3	19	17.2	19.5	18	18.7	18.2
Brookhuis	0.54	Plate 1	11.2	11	11.1		10.1	10.9	10.8	10.9	11.2	11	11	10.9	10.8	11.1	11	10.9	11	11	11.1	10.9
		Plate 2	12.2	11.8	11.8		11.5	11.9	11.7	11.6	12	11.8	11.7	11.6	11.8	11.8	11.9	11.8	12	11.8	12	11.8
	0.46	Plate 1	13.2	12.8	12.9		12.4	13	12.8	12.7	12.4	12.9	12.6	12.7	12.8	12.9	12.9	12.9	12.8	12.8	12.9	12.8
		Plate 2	14.2	13.7	13.7		13.3	13.8	13.8	13.8	13.9	13.7	13.5	13.5	13.7	13.7	13.7	13.7	13.7	13.7	13.6	13.7

NB: Not too much significance should be placed on the variation in the calibration checks shown for the capacitance-type meters. Unfortunately, the more anomalous readings on certain days are likely to be recording or other systematic errors (e.g. meter not centrally located on the testing plate or variation in hand pressure) that were not noticed at the time. Partly this was due to the capacitance-type meter calibration checks being recorded on the same sheet as the resistance meter, but unlike for the resistance meter where the expected reading were readily apparent on the recording sheet, the expected readings for the given density settings used were not on the recording sheet and if the meter appeared to be functioning OK, the discrepancies were not always immediately obvious to the recorder. In general though, the calibration checks were reasonably consistent over the period of the project and the suppliers were happy with the calibration of the returned meters. It is also important to note that batteries were changed immediately the meter indicated, or even if the operators felt they might be starting to go flat.

APPENDIX B – Meter reading against oven-dry MC plots

Deltron

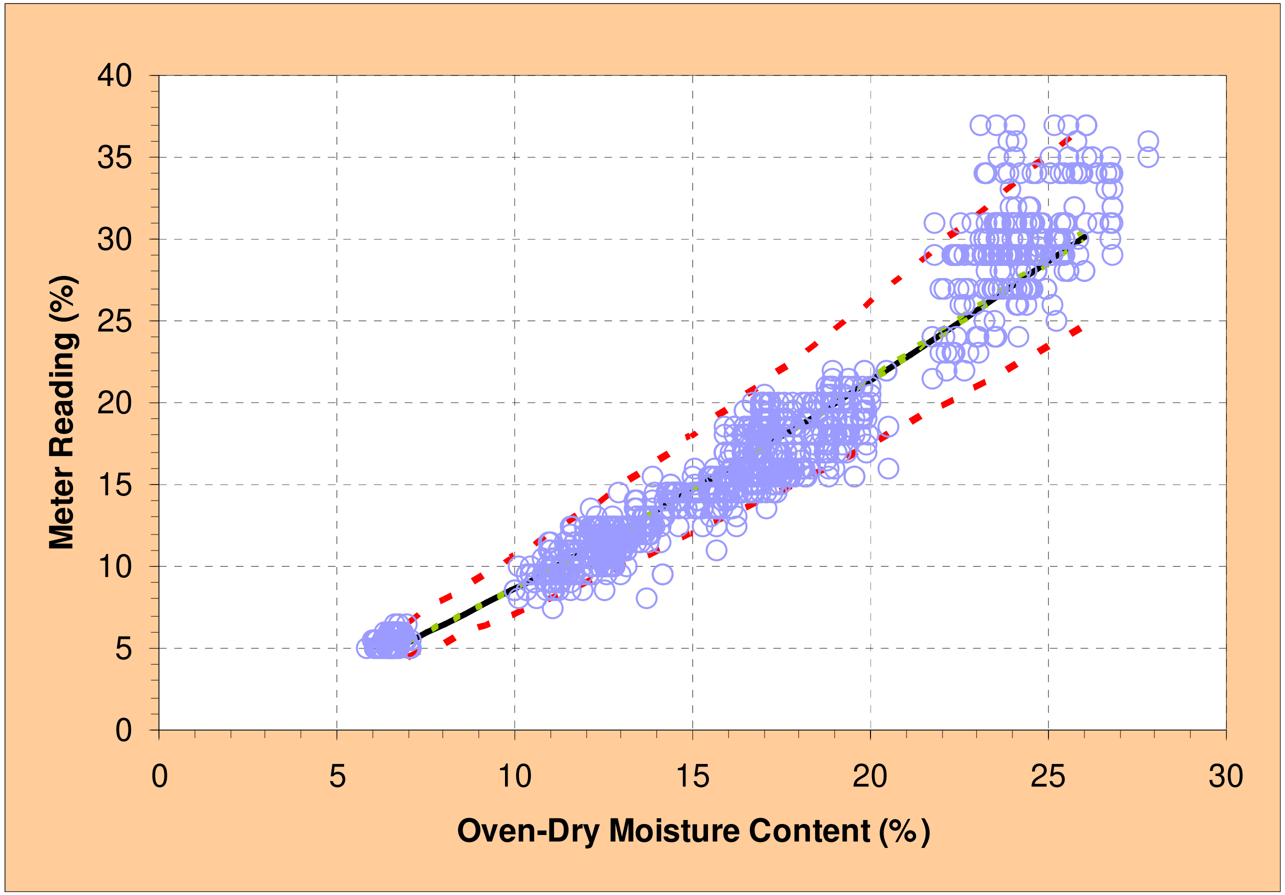

Figure 14: Scatter-plot of Deltron DCR22 meter readings against oven-dry MC for untreated *P. radiata* samples

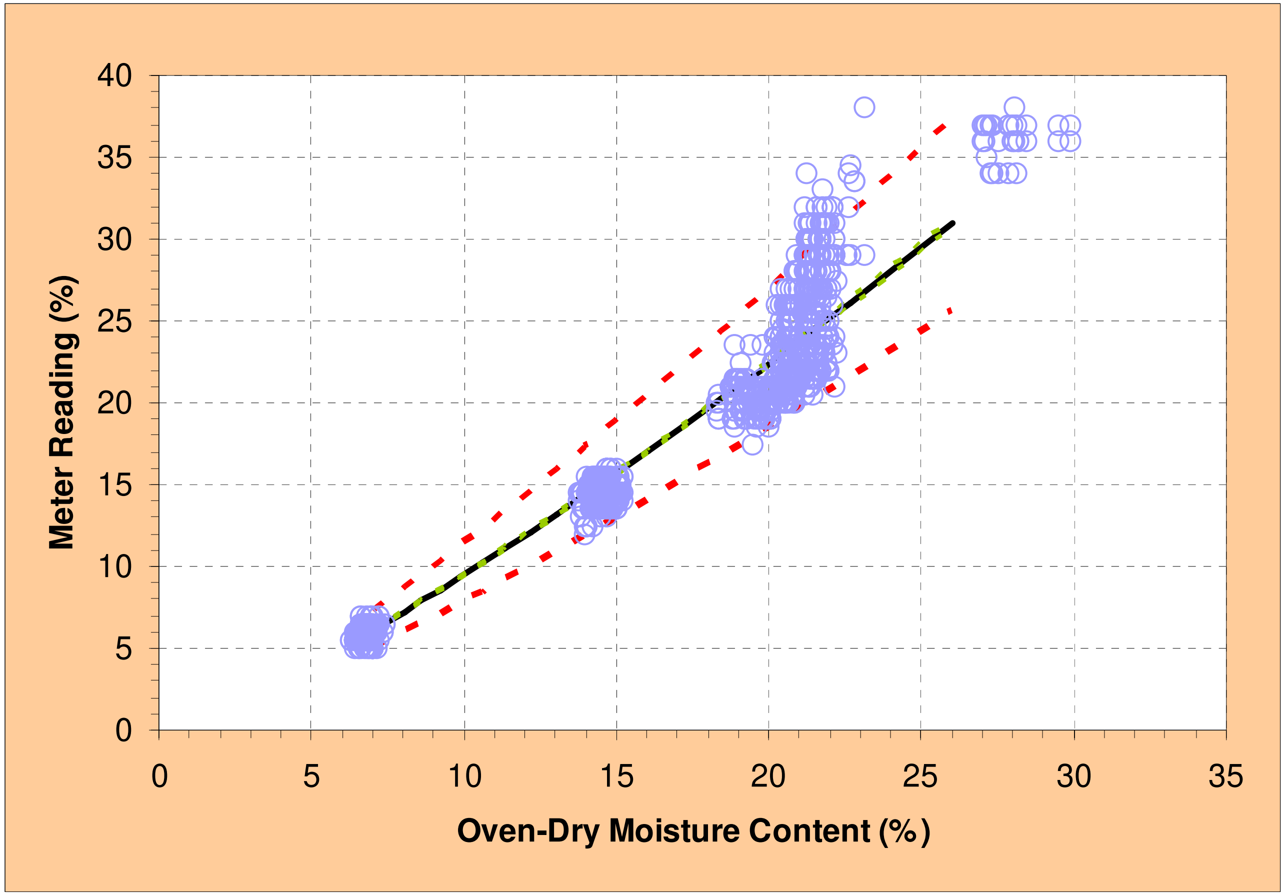

Figure 15: Scatter-plot of Deltron DCR22 meter readings against oven-dry MC for treated (CCA) *P. radiata* samples

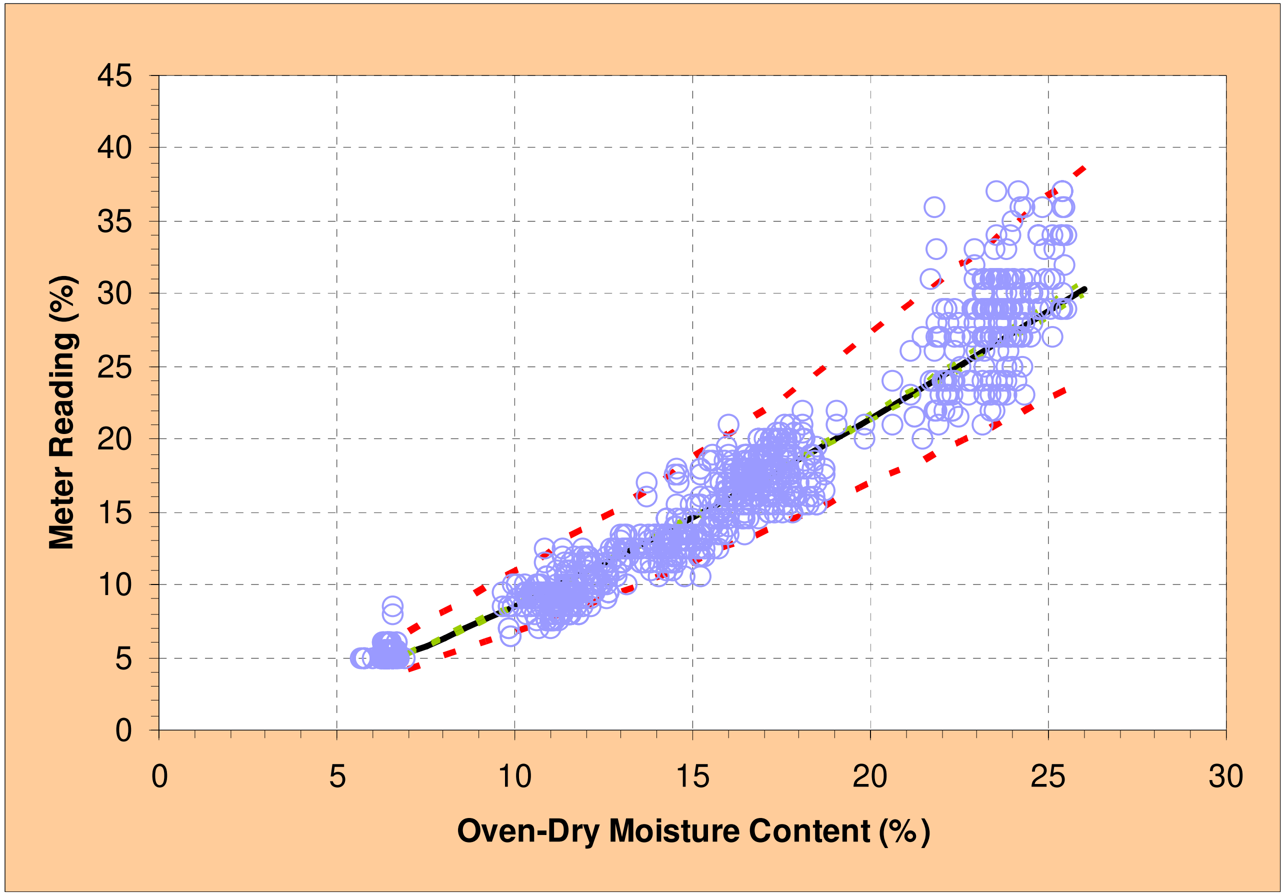

Figure 16: Scatter-plot of Deltron DCR22 meter readings against oven-dry MC for untreated *P. elliottii* samples

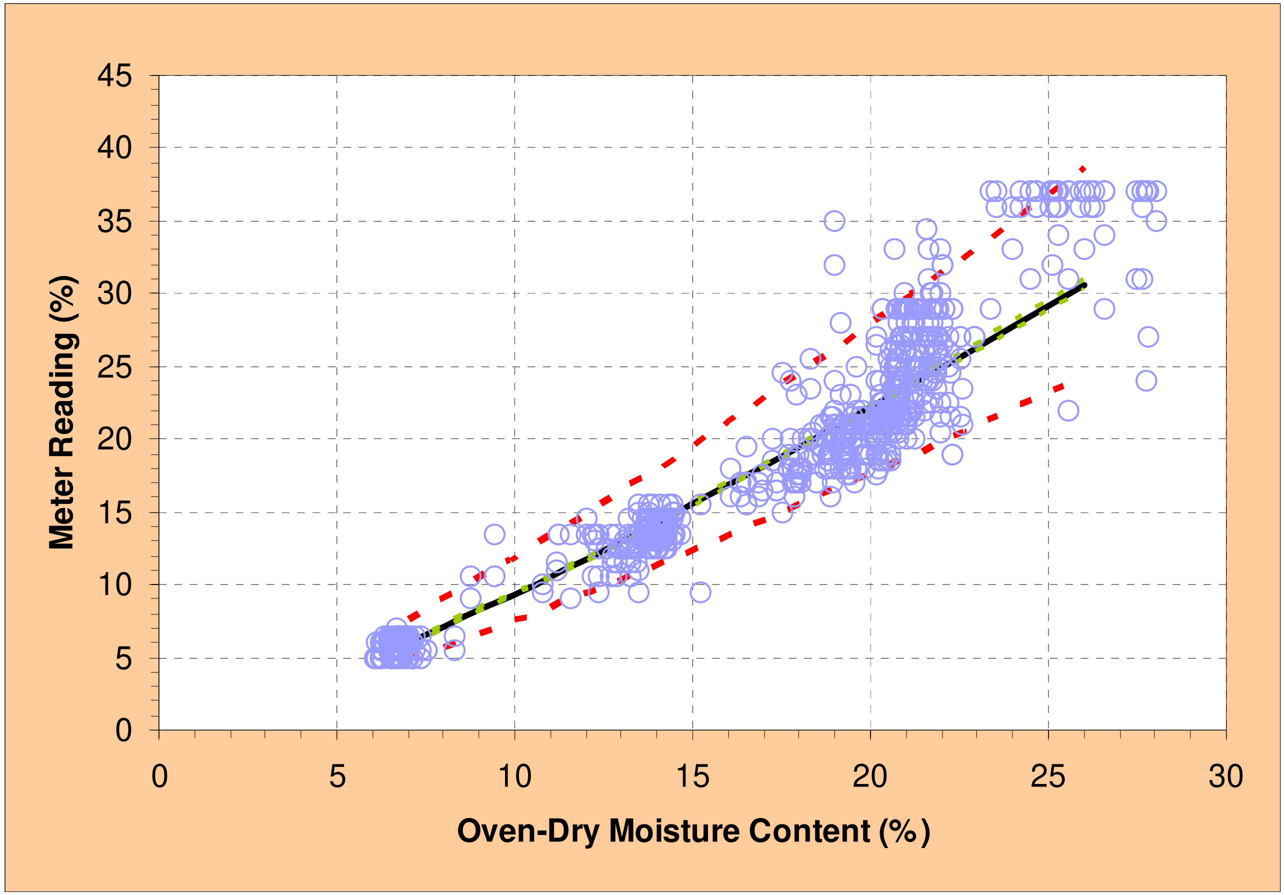

Figure 17: Scatter-plot of Deltron DCR22 meter readings against oven-dry MC for treated (CCA) *P. elliottii* samples

Wagner L612

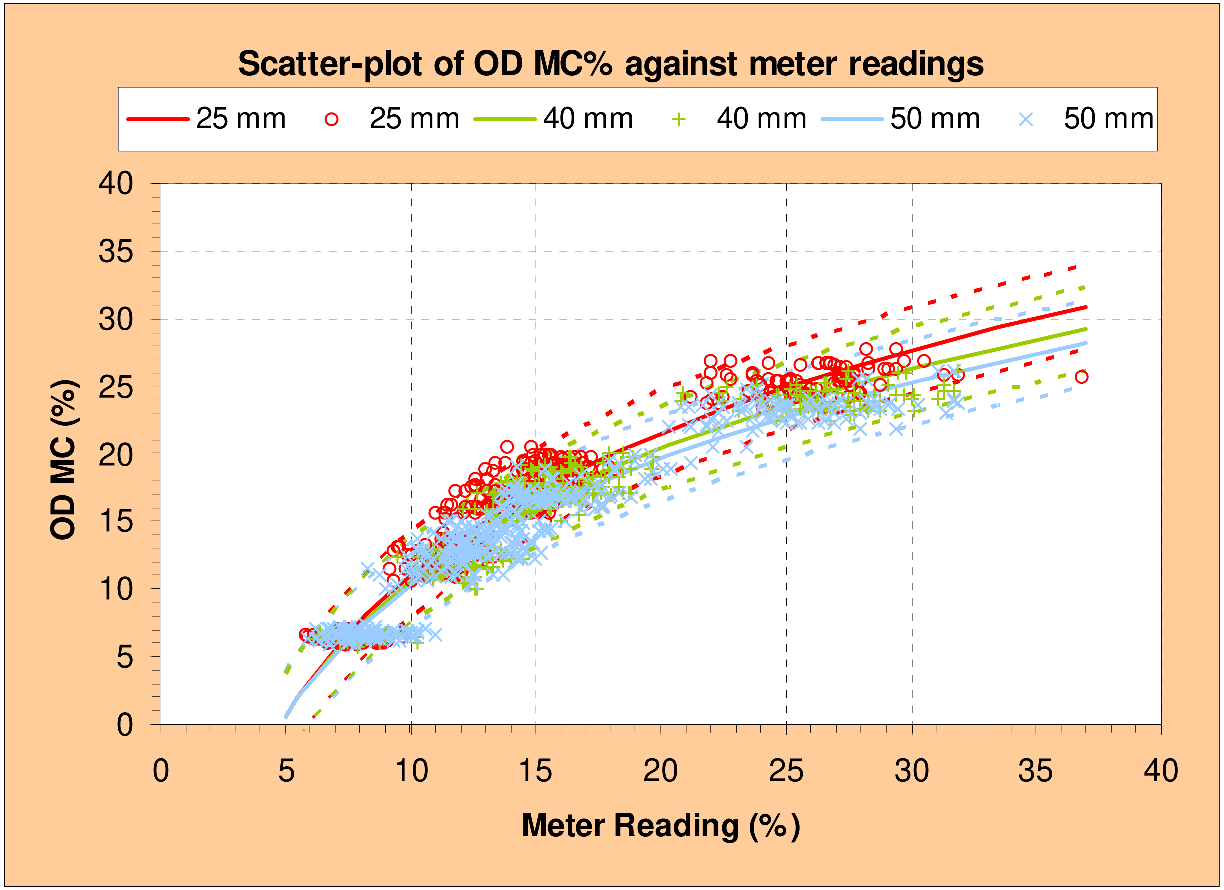

Figure 18: Scatter-plot of Wagner L612 oven-dry MC against meter readings (all thicknesses) for untreated *P. radiata* samples. Data-points are grouped by nominal thickness, fitted regression lines and confidence limits are for exactly 25, 40 & 50 mm thick boards.

Figure 19: Scatter-plot of Wagner L612 oven-dry MC against meter readings (all thicknesses) for treated (CCA) *P. radiata* samples. Data-points are grouped by nominal thickness, fitted regression lines and confidence limits are for exactly 25, 40 & 50 mm thick boards.

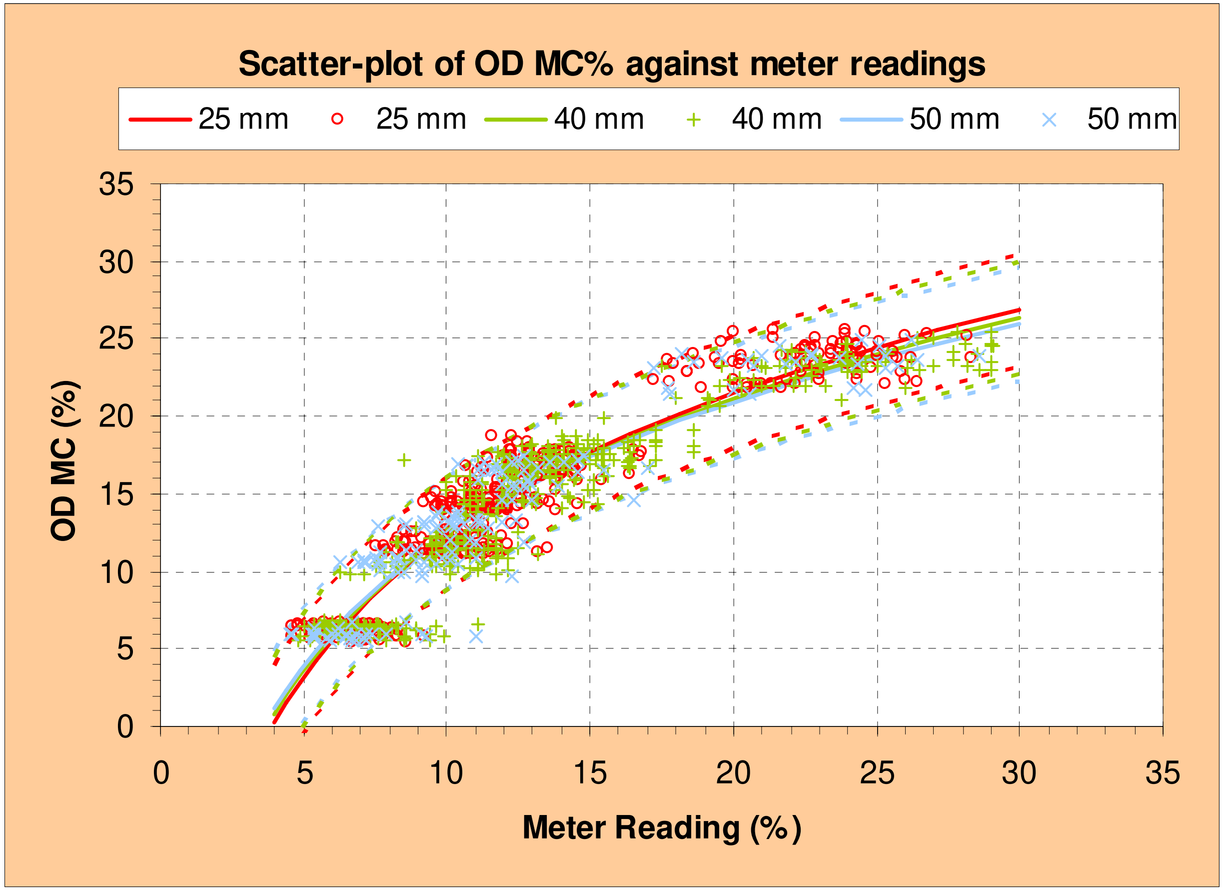

Figure 20: Scatter-plot of Wagner L612 oven-dry MC against meter readings (all thicknesses) for untreated *P. elliottii* samples. Data-points are grouped by nominal thickness, fitted regression lines and confidence limits are for exactly 25, 40 & 50 mm thick boards.

Figure 21: Scatter-plot of Wagner L612 oven-dry MC against meter readings (all thicknesses) for treated (CCA) *P. elliottii* samples. Data-points are grouped by nominal thickness, fitted regression lines and confidence limits are for exactly 25, 40 & 50 mm thick boards.

Brookhuis FMW

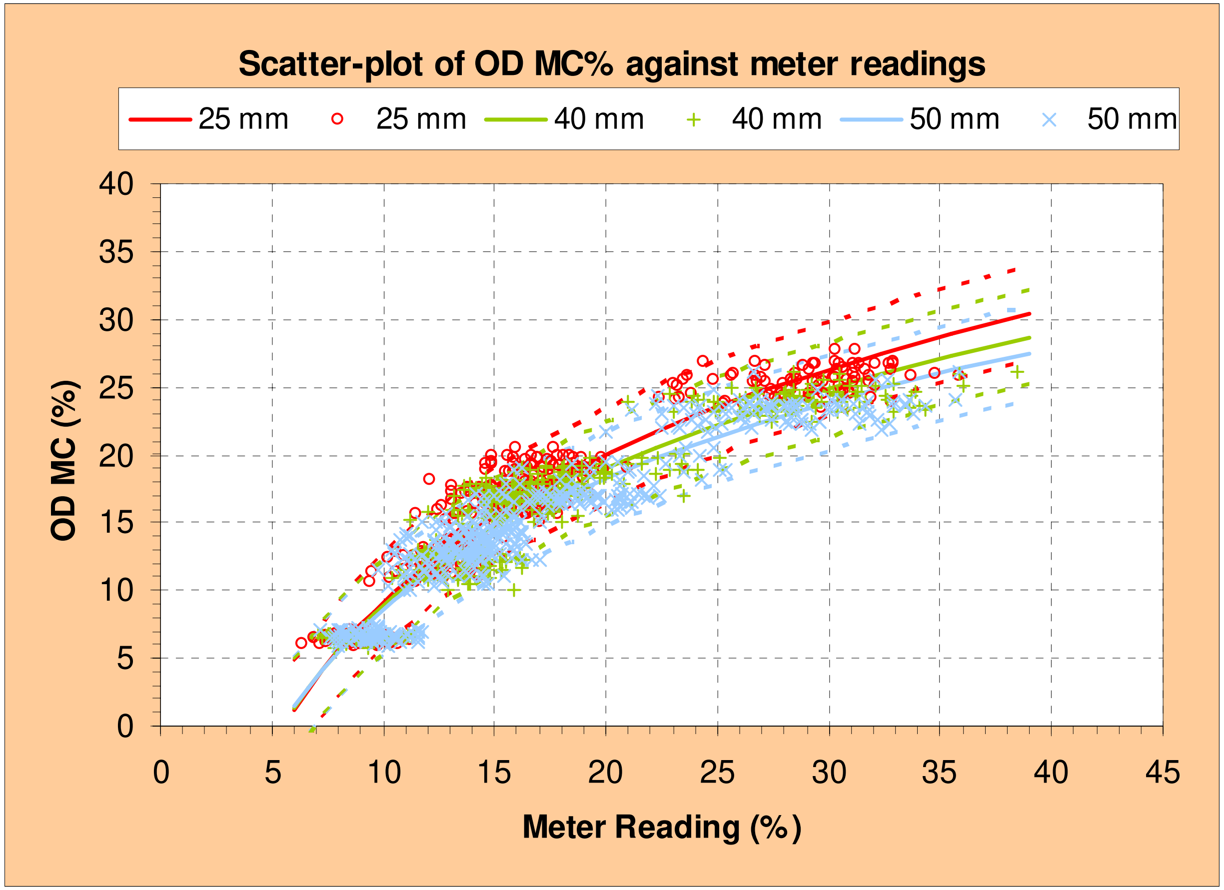

Figure 22: Scatter-plot of Brookhuis oven-dry MC against meter readings (all thicknesses) for untreated *P. radiata* samples. Data-points are grouped by nominal thickness, fitted regression lines and confidence limits are for exactly 25, 40 & 50 mm thick boards.

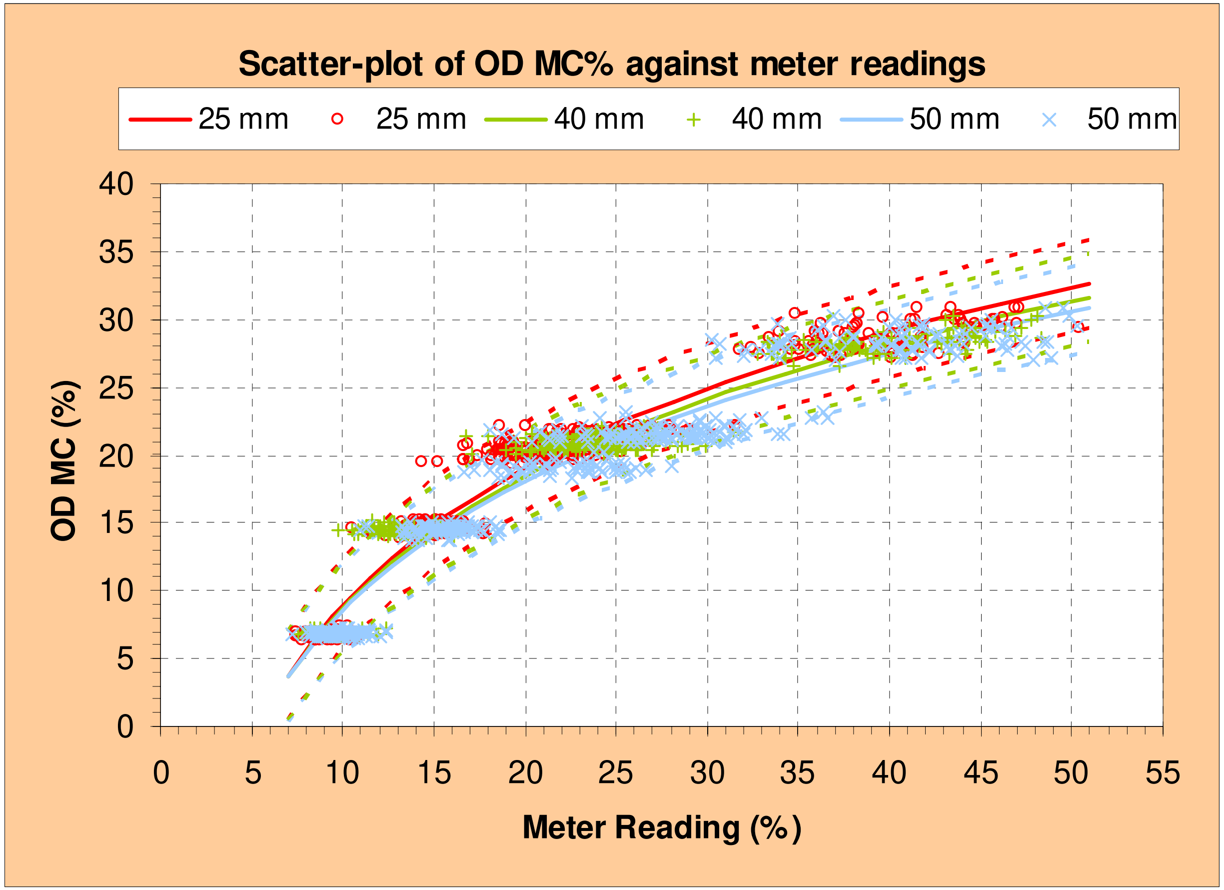

Figure 23: Scatter-plot of Brookhuis oven-dry MC against meter readings (all thicknesses) for treated (CCA) *P. radiata* samples. Data-points are grouped by nominal thickness, fitted regression lines and confidence limits are for exactly 25, 40 & 50 mm thick boards.

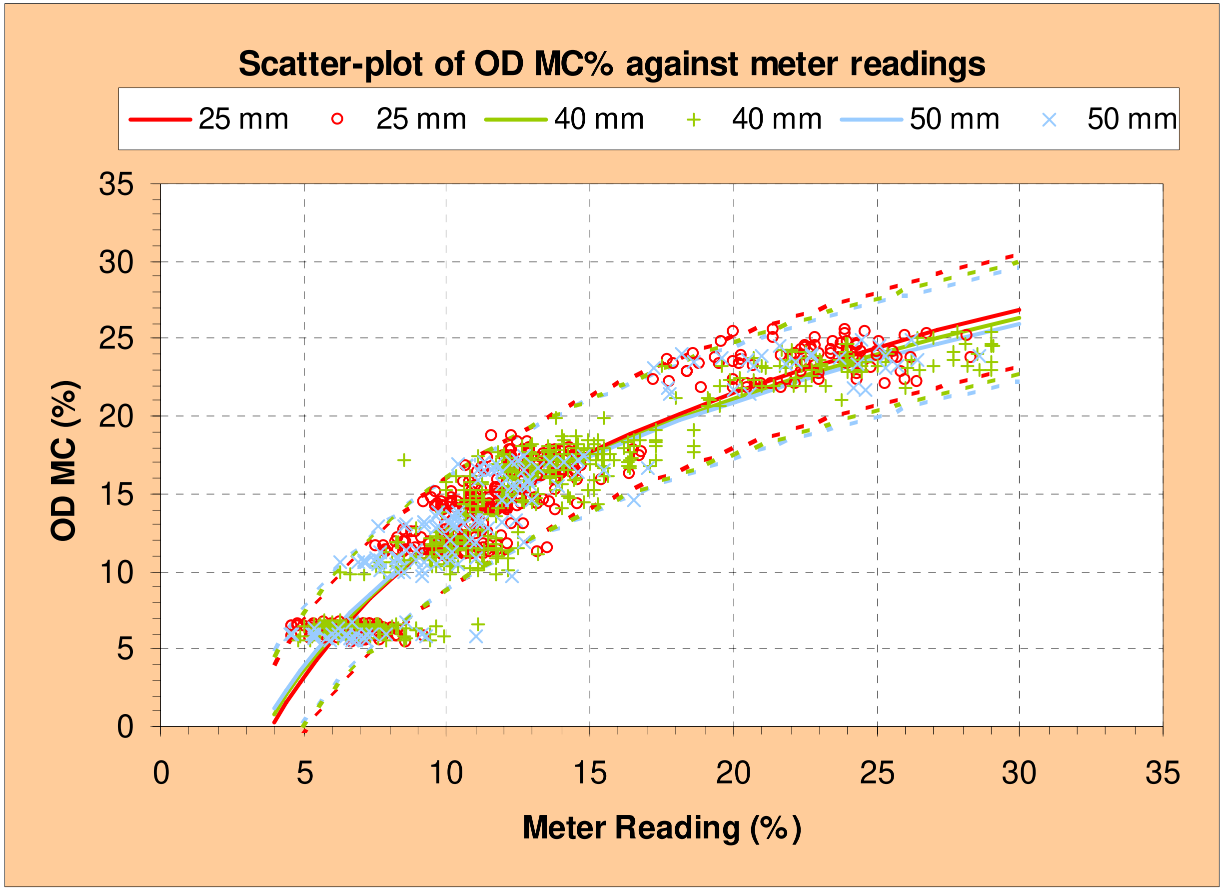

Figure 24: Scatter-plot of Brookhuis oven-dry MC against meter readings (all thicknesses) for untreated *P. elliottii* samples. Data-points are grouped by nominal thickness, fitted regression lines and confidence limits are for exactly 25, 40 & 50 mm thick boards.

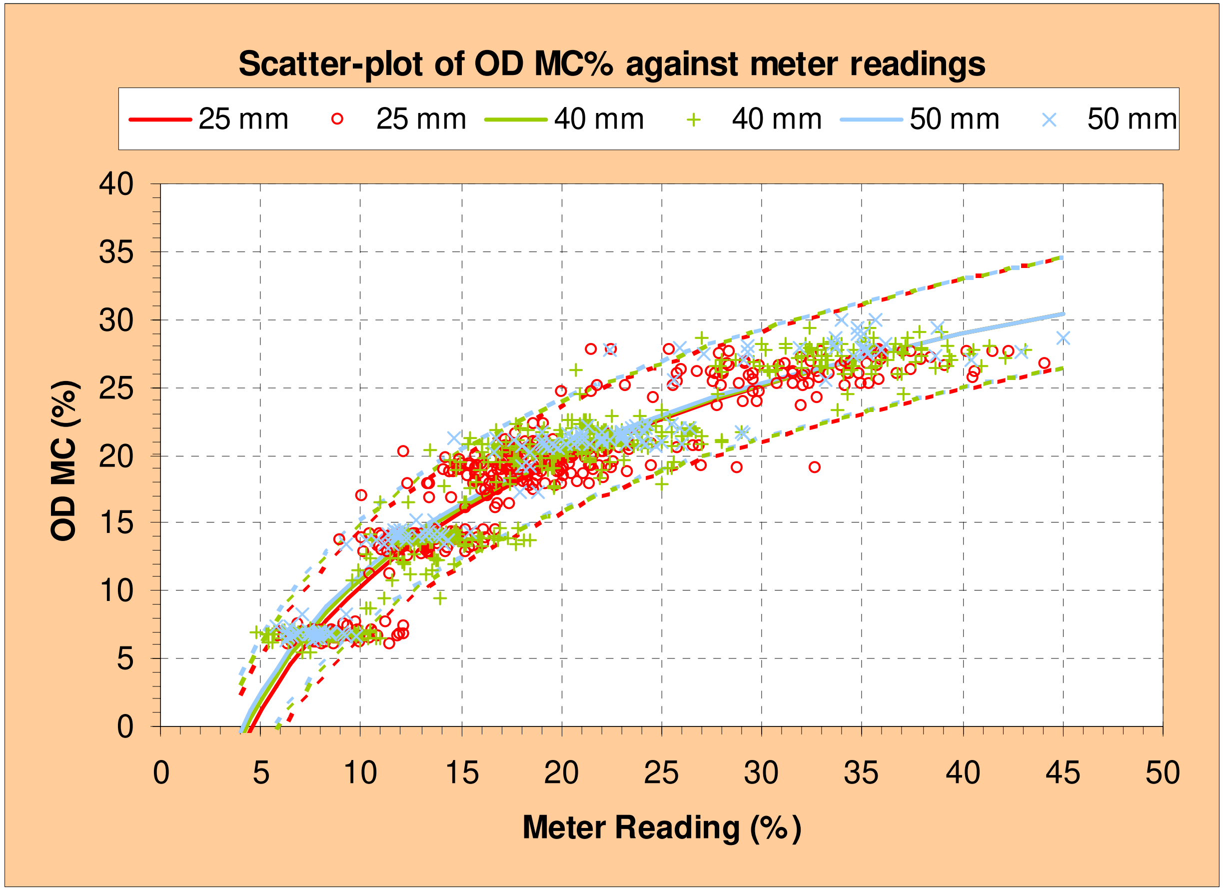

Figure 25: Scatter-plot of Brookhuis oven-dry MC against meter readings (all thicknesses) for treated (CCA) *P. elliottii* samples. Data-points are grouped by nominal thickness, fitted regression lines and confidence limits are for exactly 25, 40 & 50 mm thick boards.

Disclaimer