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Standing tree measurement of acoustic velocity as a predictor of kraft pulp yield in *E. nitens* across 2 sites

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Standing tree measurement of acoustic velocity as a predictor of kraft pulp yield in *E. nitens* across 2 sites

Prepared for

Forest and Wood Products Australia

by

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Executive summary

Key objective

To validate or discard the use of standing tree and/or log acoustics as a tool for predicting Kraft pulp yield (KPY).

Key results

The major results of the study were:

- Acoustic velocity in both standing and felled trees was significantly correlated with Kraft pulp yield in over 700 trees sampled across 2 sites in northern Tasmania.
- The variance explained in pulp yield was only 25% (standing tree) and 18% (felled stem) by acoustic data
- Standing tree acoustic velocity measurements explained approximately 50-60% of the variance in felled stem measurements taken from the lower 70% of stem length
- The variance in kraft pulp yield explained by standing tree acoustic measurements is probably too small for commercial application.

Application of results

Standing tree acoustic measurements are quick and easy to obtain, and similar to previous studies, explain more variance in KPY than do measurements from felled stems. However, the low level of variance explained is unlikely to provide any major commercial incentive to acoustically screen sites or genotypes for Kraft pulp yield. However, in the absence of other data, acoustic measurements explain a statistically significant proportion of the variance in pulp yield.

Recommendations and conclusions

The correlation between standing-tree acoustic velocity and felled stem acoustic velocity was slightly lower than expected based on previous studies. The large number of trees studied and the consistency in relationships between the two sites indicated that the results are realistic and a true representation of the relationship in the population. It is possible that more extreme sites (drier with more limited growth) may increase the range of AWV and KPY within a site, which may strengthen the correlations relative to those identified here.

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Introduction

Previous studies have shown that Near Infra Red Spectroscopy (NIR) can be used to predict Kraft pulp yield (KPY) and basic density (BD) from woodmeal and woodchips (Downes et al 2005, Schimleck et al 2007). In particular, NIR spectra from the latter have been shown to provide good predictions of KPY when collected from moving conveyor belt systems (r^2 prediction > 0.75). Previous studies have also shown that acoustic wave velocity (AWV) measurements from standing trees and felled logs can provide predictions of KPY (Downes et al 2005), however some doubt remains as to the robustness of the relationship, particularly between sites. This study is intended to validate or refute the potential to use standing tree and log acoustic measurements to predict whole-tree KPY across 2 sites in Tasmania.

In an initial study, the relationship between AWV and KPY had been identified using measurements on felled logs (Wright *et al*. 2002). This study, based on 20 logs from a single site, indicated a reasonably strong relationship between AWV and KPY, thus raising the possibility of using AWV measurements as a non-destructive evaluation (NDE) assessment method for KPY. As a consequence this was investigated further in a subsequent project (Downes et al 2005).

In the latter study, based on standing tree AWV of a larger population obtained prior to felling, trees were selected across the range of AWV and felled for Kraft pulp yield assessment from three sites (15 trees per site) of varying site quality. In these trees a single standing tree AWV (ST 300) measurement from the north aspect accounted for 60% of the variance in the velocity measured in the stem (HM 200) between 0-70% tree height (Figure 1). Correlations were stronger within sites.

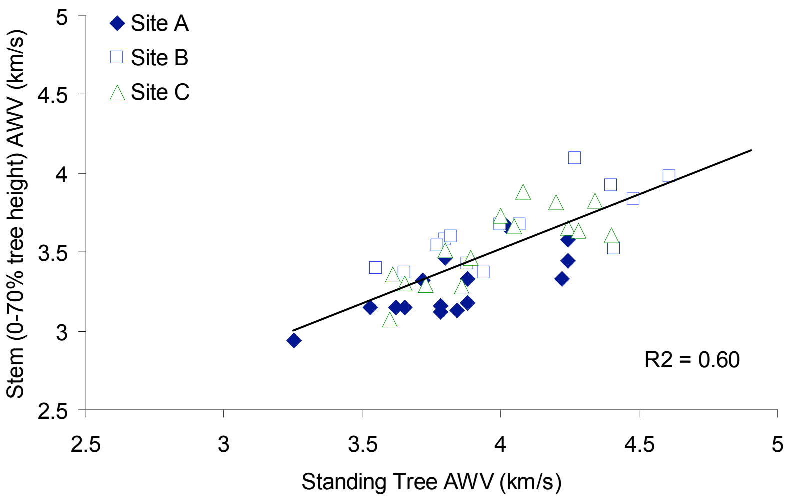


Figure 1. Relationship between standing tree acoustic velocity at breast height and stem velocity (0-70% tree height). One outlier was removed from the site B data (from Downes *et al.* 2005).

The relationship between standing tree AWV and KPY (Figure 2) was weakly positive when considered among trees combining all three sites. Correlations within sites were stronger but variable. These data suggest that AWV may be a reasonable predictor of KPY within a site but a robust relationship across sites is unlikely.

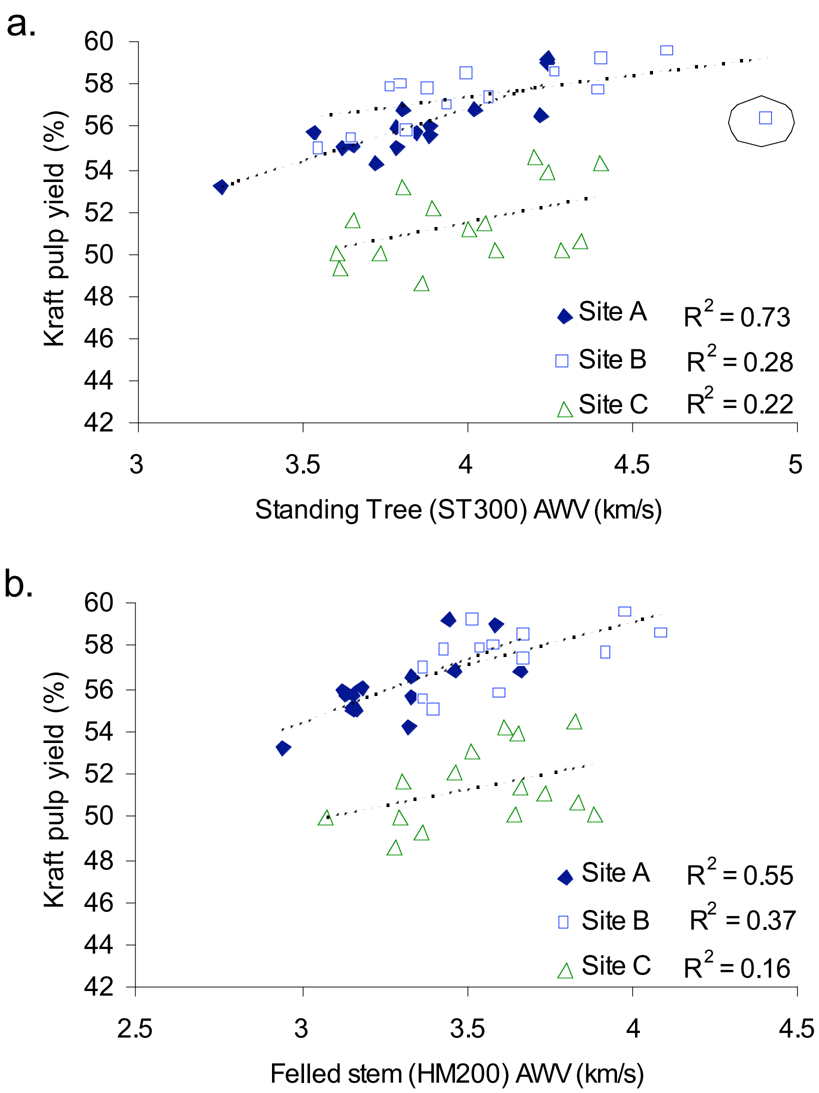


Figure 2. The relationship between standing tree and felled stem acoustic velocity with KPY for each of 3 sites. (nb the removal of one outlier (circled) from site B in (a) improved the r^2 from 0.28 to 0.68)

Correlations using data obtained using the standing tree tool (ST 300) were generally stronger than those obtained using the HM200. There was no relationship between DBH and KPY.

Due to inconclusive results and small sample numbers from these previous studies, the current study was initiated to determine, on a large sample set, the true correlation between KPY and AWV utilising the availability of a larger sample set.

Materials and methods

Two eucalypt sites of the same species (Table 1) in Tasmania were selected, in which large numbers of trees were to be destructively sampled and assessed for Kraft pulp yield. Trees with poor form such as butt sweep, double stems or swelling were excluded from the sampling where possible.

Table 1. Available site details

Site	Altitude (m)	Previous land use	Age	Number of trees sampled	Average DBHOB (mm)
1	610	Ex-native forest	12	330	163
2	510	2nd Rotation	10	420	188

At each site, trees were labelled and standing-tree acoustic measurements made using the ST 300 instrument on opposing diameters (north and south). The ST300 measured acoustic speed (Time of Flight); the speed it takes for a sound wave to move through the stem from one probe to another. The probes were inserted into the stem approximately 0.5 to 1.5m above ground (Figure 3) and the distance between them determined automatically. The lower probe is struck with a hammer to generate an acoustic pulse.

Figure 3. Acoustic velocity measurements were taken from opposing diameters from each tree. Log values were taken using the HM 200 on felled stems

Each tree was then felled and the stem acoustic velocity value measured between 0% and 70% of merchantable height. This was done in contrast to using the whole stem length, because of difficulty in obtaining a reliable acoustic reading. Data from the stems was obtained using the Director HM200 which uses the resonance of sound in wood, and is highly correlated with time of flight. It measures the frequency of vibration rather than velocity, and can be used from one end of a stem or log, without requiring a probe at both ends. The length of the log or stem must be measured to correct the resonance value obtained. Log acoustic data was collected between 0 and 21 days after the standing tree measurements.

Representative samples from each tree were prepared and sent to for Kraft Pulp Evaluation.

Kraft pulp analysis

Cross-sectional discs from each tree were obtained and chipped to provide an appropriately weighted, representative sample of each tree. Chips were thoroughly riffled to ensure adequate mixing prior to sub-sampling for testing. All samples were stored in sealed plastic bags. Laboratory pulping properties were measured using a Haato 12 autoclave air pulping digester and associated equipment. Pulping conditions are given in Table 2.

Table 2. Pulping conditions used

Nominal time to/at temperature	90/90 min
Cook temperature	170°C
Liquor ratio	3.5:1
Sulphidity	25%
%NaOH charge	variable to give kappa 18
'H' factor	2865
Activation energy	147.5 kj mole^{-1}
Wood charge	300 o.d. equiva lent

Results and discussion

Sonic relationships

Both sites had a similar average standing-tree (3.4 km/sec) and stem (3.0 km/sec) acoustic velocities (Table 3).

Table 3. Comparison of acoustic velocity measurements across sites

		Site 1	Site 2
HM200 (Ave Velocity - km/sec)		3.00	3.03
	(sd)	0.23	0.18
	Max	3.59	3.79
	Min	1.94	2.50
	Range	1.65	1.29
ST300 (Ave Velocity - km/sec)		3.43	3.44
	(sd)	0.18	0.15
	Max	3.96	3.95
	Min	2.90	2.93
	Range	1.07	1.03

ST 300 measurements were significantly correlated with the Director HM 200 measurements made from the felled log. The variance explained was 45% (site 1) and 55% (site 2, Figure 4). If outliers (circled values in Figure 4) were removed, the variance explained increased to 56% and 64% respectively. Combining the two standing tree measurements (opposing diameters) improved the variance explained marginally, compared with using either south or north aspects alone. There were no significant differences between sites in terms of the average standing tree or log acoustic values obtained.

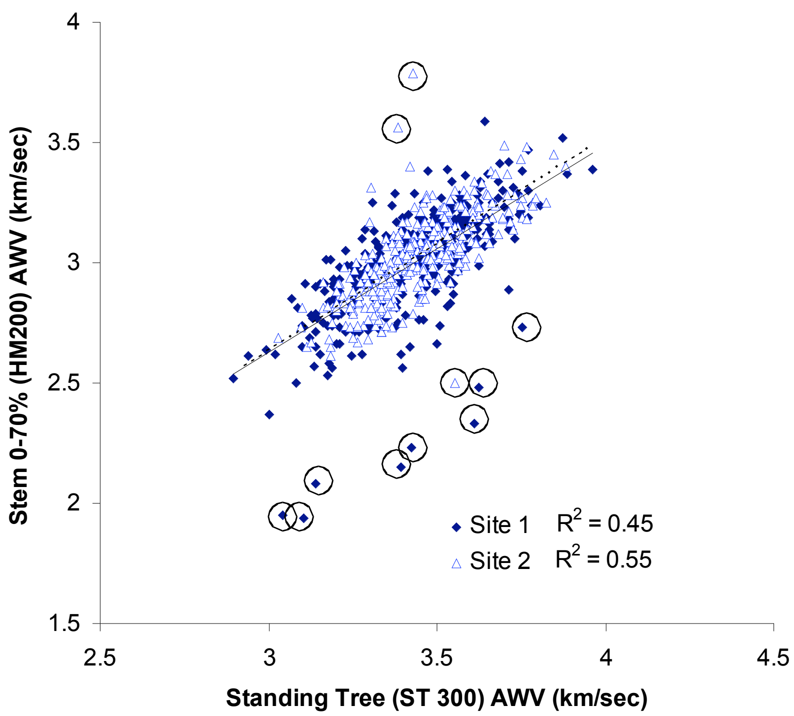


Figure 4. Relationship between standing tree and stem acoustic velocity. If outliers (circled values) were removed the r^2 increased to 0.56 (site 1) and 0.64 (site 2).

Contribution of circumferential variation

Averaged over all trees there was little difference between north and south measurements. However, comparing the absolute difference between the readings indicated the opposing diameters could differ up to 0.38 km/sec at Site 1 and 0.56 km/sec at Site 2 (Table 4). At Site 1 the variation in standing tree acoustic velocity (ST 300) measurements on one side of the tree (north) explained 68% of the variance (Figure 5a) in the measurements on the opposing diameter (south). At site 2 the variance explained was 64% (Figure 5b).

Table 4. Comparison of ST300 readings from north and south aspects

Site 1

	Acoustic velocity (North)	Acoustic velocity (South)	Absolute Difference
Average	3.42	3.43	0.09
Stdev	(0.20)	(0.19)	(0.07)
Max	3.95	3.97	0.38
Min	2.80	2.92	0.00
Range	1.15	1.05	0.38

Site 2

	Acoustic velocity (North)	Acoustic velocity (South)	Absolute Difference
Average	3.43	3.45	0.08
Stdev	(0.17)	(0.16)	(0.07)
Max	3.98	3.93	0.56
Min	2.80	3.00	0.00
Range	1.18	0.93	0.56

To explore this further, measurements from three trees at Site 1 were examined at 4 directions (Table 5) and on one tree at 8 directions (Figure 6). These data indicate that there is considerable variation, and the west – southwest aspect tended to have higher readings. This is the direction of the prevailing wind on the site.

Table 5. Three trees were examined for circumferential variation at four points around the circumference. In all 3 trees the western aspect produced high readings. Standard deviations are shown in parentheses.

	N	E	S	W
Tree 1	3.28	3.30	3.35	3.40
	(0.02)	(0.04)	(0.07)	(0.03)
Tree 2	3.16	3.16	3.14	3.31
	(0.02)	(0.03)	(0.03)	(0.04)
Tree 3	3.75	3.72	3.57	4.05
	(0.04)	(0.05)	(0.05)	(0.06)

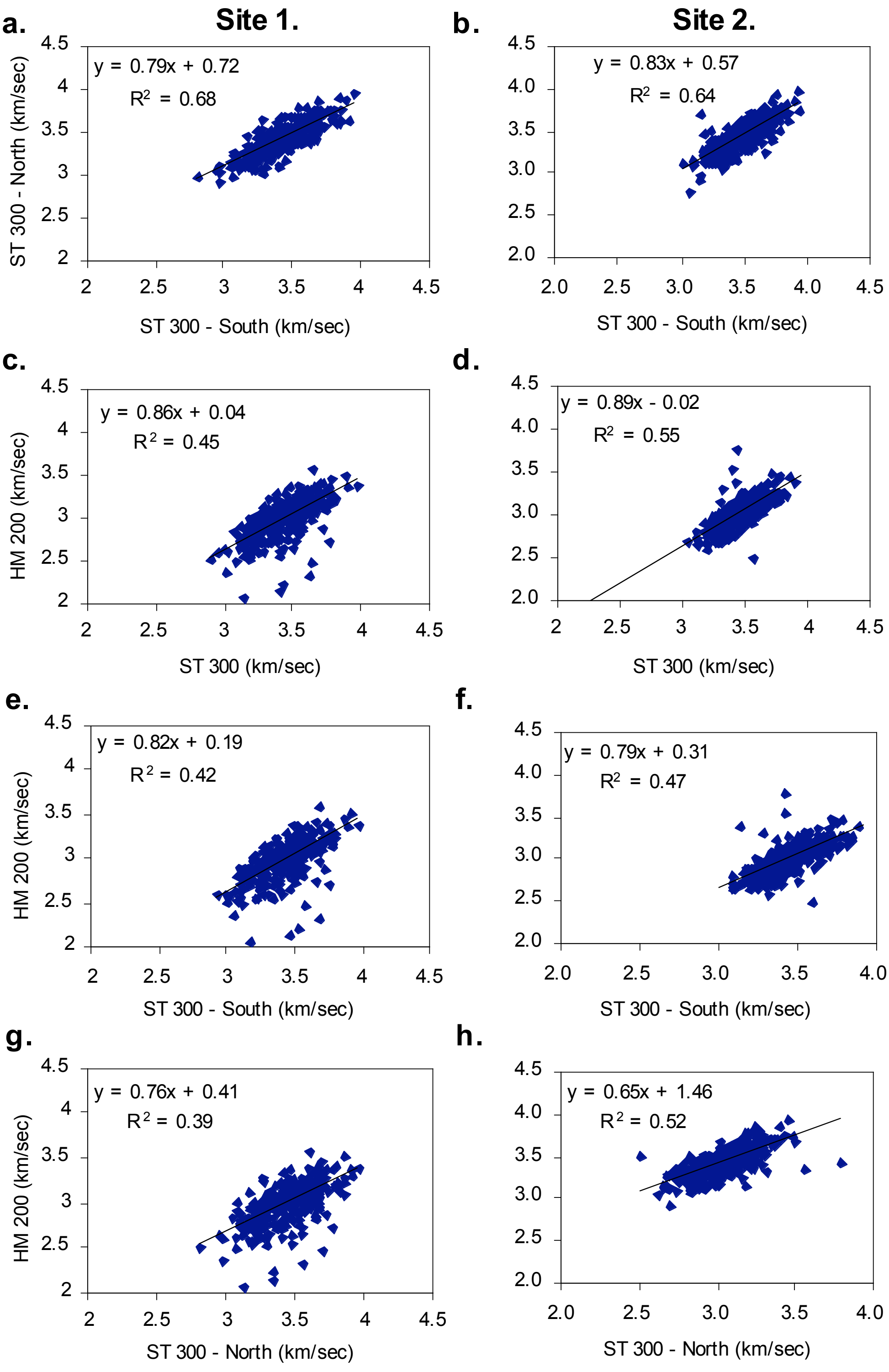


Figure 5. Relationship at each of the two sites between (a,b) standing tree acoustic measurements (ST 300) from opposing diameters (c,d) average standing tree value and log acoustic resonance (HM 200) (e,f) ST 300 measurements from south aspect and log acoustic resonance (g,h) ST 300 measurements from north aspect and log acoustic resonance.

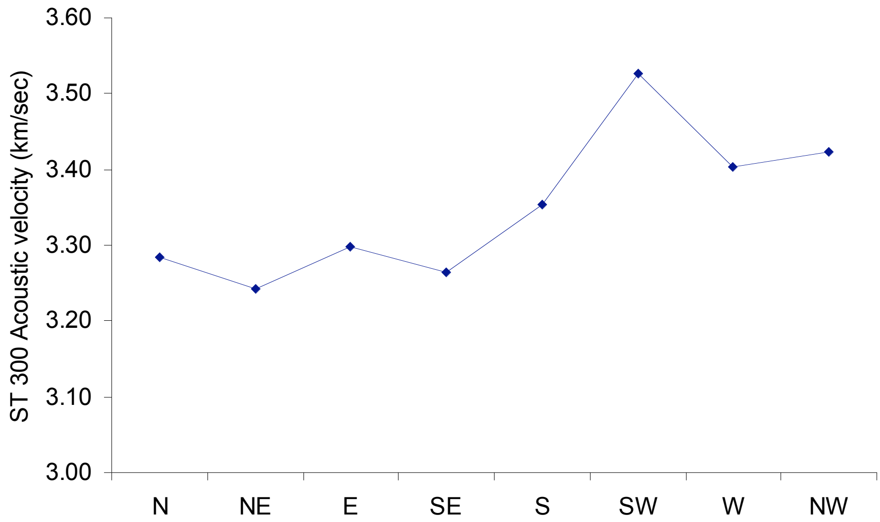


Figure 6. Circumferential variation in a single tree

Kraft pulp analyses

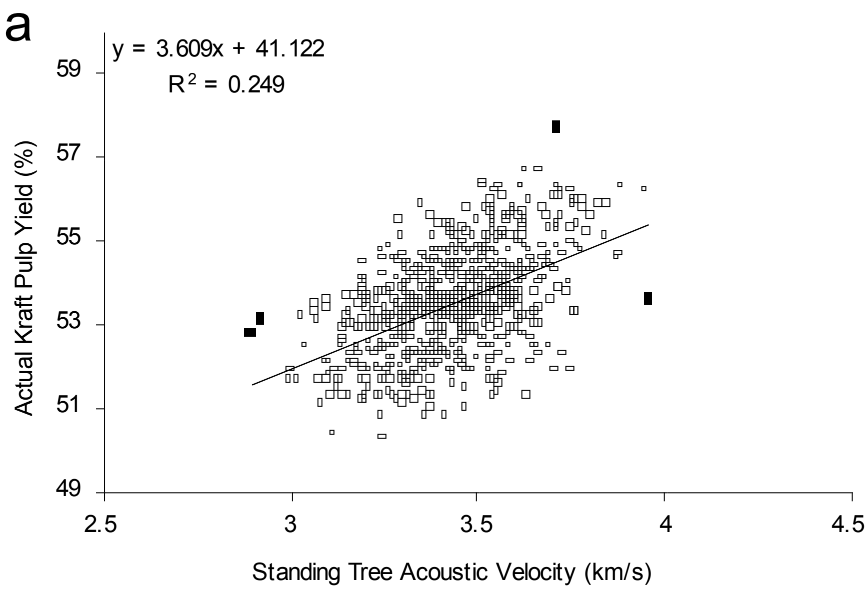
The average site pulp values were similar (Table 6) both in terms of the means, variance and range evident in the data. No significant effect of site was evident.

Table 6. Kraft Pulp Yield statistics by site (N = number of trees)

	Site 1	**Site 2**
Mean	53.5	53.5
Stdev	1.18	1.22
Max	57.7	56.7
Min	50.8	50.3
Range	6.9	6.4
N	330	420

Standing tree AWV was significantly correlated with KPY within and across both sites (Figure 7). Combining all data from both sites the correlation coefficient ($r=0.5$) was highly significant ($P<0.0001$). Standing tree AWV was a better predictor than log AWV explaining 7 % more of the variance (25% vs 18%). This was also true if the standing tree data collected only from the northern aspect was used, in contrast to the average of the north and south values.

However the variance explained was relatively small (markedly less than 50%) and probably of little use in a commercial screening context, except possibly in the broadest sense of removing low velocity (KPY) individuals from a population.



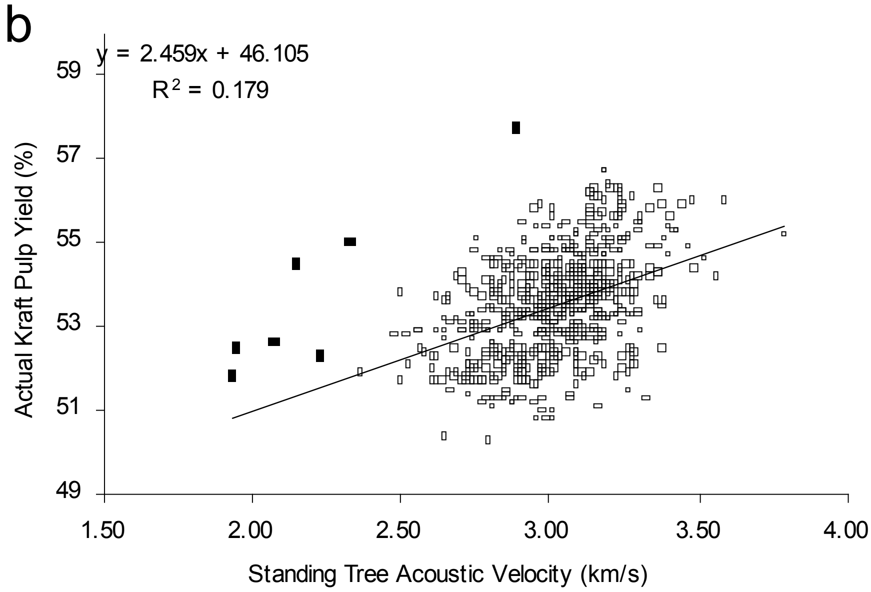


Figure 7. Correlation between (a) standing tree and (b) felled stem AWV for each of the two sites studied. Points with solid fill are considered outliers.

Within sites, trends were similar, with the standing tree AWV consistently explaining 7-9% more variance than the felled stem AWV. This is a similar finding to that made in the smaller data set from the previous study (Downes et al. 2005). It is evident from Figure 7 that some data points were evident outliers (filled points). Removing these from the data set, improved the variance explained marginally by 0.3% for the ST300 and 3.2% for the HM 200.

Conclusions

The correlation between standing-tree acoustic velocity and felled stem acoustic velocity was slightly lower than expected based on the previous study. The large number of trees studied and the consistency in relationships between the two sites indicated that the results are realistic and a true reflection of the population. It is possible that more extreme sites (drier with more limited growth) may increase the range of AWV and KPY within a site which may strengthen correlations relative to those identified here. However this is not expected to explain additional, commercially-significant variation.

The major results and recommendations of the study were:

- Acoustic velocity in both standing and felled trees was significantly correlated with Kraft pulp yield in over 700 trees sampled across 2 sites in northern Tasmania.
- The variance explained in pulp yield by acoustic data was only 25% (standing tree) and 18% (felled stem)
- Standing tree acoustic velocity measurements explained approximately 50-60% of the variance in felled stem measurements taken from the lower 70% of stem length
- Acoustic wave velocity on either standing-tree or felled stem may allow some degree of segregation of low velocity trees (and hence low pulp yield trees) from a breeding population
- Acoustic wave velocity does not provide sufficient resolution to predict Kraft pulp yield of an individual tree, with acceptable accuracy.

Acknowlegements

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