WQI BENCHMARKING STUDY

UTILISATION STUDY – GOLDEN DOWNS AND KAINGAROA FORESTS

A Report Prepared for WQI Ltd
by

DAVE COWN, GEOFF DOWNES, RUSSELL MCKINLEY, MARK KIMBERLEY, JOHN TURNER, JOHN LEE, GRANT HOLDEN

REPORT NO. RES 26
DATE: NOVEMBER 2004

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

REPORT INFORMATION SHEET

Report Title	Utilisation Study – Golden Downs and Kaingaroa
Authors	Dave Cown, Geoff Downes, Russell McKinley, Mark Kimberley, John Turner, John Lee, & Grant Holden (ensis)
Contributors	Trevor Jones, Pat Hodgkiss & John Sole (ensis) Don McConchie (Wood Quality Focus)
Report No	RES 26
WQI Objective	RES Resource Characterisation
WQI Project	2 Benchmarking
WQI Task	4 Utilisation Studies
WQI Milestone	8, 16 Report on Golden Downs, Kaingaroa
Signed off by	Graeme Young
Date:	November 2004
Confidentiality requirement	This is a Report prepared for WQI Ltd. Information contained in this report is restricted to shareholders of WQI Ltd. This Report may not be copied or distributed except amongst shareholders.
Intellectual Property	There are no intellectual property issues associated with this report. All information contained in this report has been derived from the public domain.

EXECUTIVE SUMMARY

UTILISATION STUDY - GOLDEN DOWNS AND KAINGAROA FORESTS

DAVE COWN, GEOFF DOWNES, RUSSELL MCKINLEY, MARK KIMBERLEY, JOHN TURNER, JOHN LEE, & GRANT HOLDEN

REPORT NO. RES 26 ***DATE: NOVEMBER 2004***

A large WQI Utilisation Study was planned and executed to provide a source of well-documented material for studies of the regional stiffness, strength and stability characteristics of mature radiata pine. It was designed to complement the detailed wood properties collected in the 1978 Genetic Gains Benchmarking Studies and yield information on both the average stem and lumber properties and the range of behaviour to be expected from "normal" stands in two major forest areas.

Two stands from a 1979 Genetic Gains trial were selected, belonging to WQI members (Kaingaroa Timberlands and Weyerhaeuser NZ). Each stand was visited and a sample of 25 stems selected for a sawing study on the basis of their acoustic properties (IML Hammer). Long logs (11m – lower 5m pruned) were shipped to the TITC Sawmill at Rotorua where they were assessed for external and internal wood properties (increment cores, wood discs, sonic resonance, SilviScan samples), reduced to 4.9m sawlogs and sawn to structural dimensions (200mm cant). The lumber was HT dried in main 200x40mm size, measured, and after about 3 weeks split to 100x40mm before being re-assessed for dimensional stability and tested for mechanical properties (static and dynamic tests).

The stands were shown to be very similar in wood properties – Golden Downs had a larger DBH and slightly lower wood density than Kaingaroa. Increment core estimates of log density showed good correlations with stem density (r^2 = 76%), but disappointing relationships to stem IML readings. There were also poor correlations between wood density and the Director HM200. This was possibly due to the use of inexperienced operators, but also points to a lack of knowledge of the real relationships involved and the lack of benchmarking of log measures in the log yard (almost 25% of the values were thought to be "suspect" in retrospect).

"Normal" patterns of wood properties (density, spiral grain, microfibril angle, shrinkage) were reported for the wood disc and SilviScan samples. Compression wood distribution seemed to be more variable in the Golden Downs logs.

Very strong pith-to-bark lumber stiffness trends were observed, and analyses showed then to be most closely related to wood density (63%) and MFA (42%). Together, these two variables accounted for 78% of the variation in lumber stiffness. Grain orientation (flat-sawn vs. quarter-sawn) also had a smaller but significant effect on stiffness.

Both the IML Hammer and Director HM200 were able to predict average lumber stiffness to some extent (r = 0.5 to 0.6), although some operational issues arose in the course of the study. At this stage it is felt that the tools can be used to compare stands but are not accurate enough to give good data on individual stems (this will be controversial!). On the other hand, sonic lumber values were very highly related to actual stiffness (r = 0.96 to 0.99). A very high correlation was found between stress grade MoE and lumber sonic MoE (separate WQI report by Doug Gaunt). Variable results have been found for the standing tree assessments, some of which may be related to operator experience. Outerwood density also gave high correlations with lumber stiffness, particularly for the Golden Downs stand (r = 0.82).

Overall, the sawing and drying were well implemented and there was minimal lumber distortion[1] (less than 1% overall). When stricter allowances were applied (based on past FR customer research) both twist and crook became more significant. The driving variables were found to be:

1. Log height class – lumber from butt logs was more prone to distortion (twist and crook).
2. Spiral grain and longitudinal shrinkage were related to twist – strongly associated with inner juvenile wood rings.
3. Crook: No strong wood properties were found to be associated. The suspicion that compression wood is a driver was not confirmed with these data.

[1] The "two-out splitting" approach was used both for convenience and to enable further study of the wood properties associated with distortion. In this case, there was minimal distortion, presumably because the drying was done to a high standard and a holding period (3 weeks) was used to enable the green lumber properties to be assessed.

BACKGROUND

One of the objectives of WQI is to provide good information on the biological factors influencing the behaviour of wood and wood-based materials in the market place. In order to document the material performance characteristics of radiata pine, it is essential to cover a wide range of within-tree and between-tree properties to be expected from the current resource and provide information to breeders for future generations of trees.

Most of the sawing studies carried out in the past (e.g. the Conversion Planning Project in the 1970's) were done to develop relationships between visible log properties (SED, sweep, branching) and lumber grade yield. The only study following stem wood properties through to market performance was the Value Recovery 10-clone study (1990's). This demonstrated a high degree of variation in wood and log properties and clear links to product performance (structural lumber, remanufacturing grades, veneer recovery). Unfortunately, the material consisted of aged clones from a single site.

Several WQI studies in the planning stages require material for mechanical and stability tests for the purposes of documenting relationships and preparing material performance models. The most efficient and effective means of achieving this is to focus on a well-documented source of material (known genotype and silviculture).

The current study was planned to provide well-documented material from two contrasting forests, selected for a range of stiffness and stability studies to enable regional variation to be investigated and existing wood property/performance models validated and possibly improved. In order to reduce the "noise" on the datasets, material was selected from trial areas in two major forest regions, containing well-documented genetic material of harvest age.

MATERIALS AND METHODS

The 1979 Genetic Gains Trial was selected as the source of documented material for this trial, and Seedlot FRI 78/2300 (GF 14) was selected at two forests:

Golden Downs Cpt. 26	(Weyerhaeuser NZ)
Kaingaroa Cpt. 1218	(Kaingaroa Timberlands)

The sample plots were located and 100 stems pre-screened at each site with the IML Hammer. (This was considered to be a faster and more cost-effective than increment cores[2]). This enabled the selection of 25 trees at each site, covering a range of breast height diameter, sound velocity and branching characteristics. These stems were selected to represent the mean and range of stiffness and diameter at each site. The 50 sample trees were numbered and extracted (11m logs: butt – pruned; second log - unpruned), and subsequently transported to the Waiariki Institute of Technology (TITC) sawmill in Rotorua for processing[3].

[2] In retrospect, cores would have given additional confidence in the sample selection

[3] The assistance of Weyerhaeuser and Kaingaroa Timberlands is gratefully acknowledged.

At the TITC sawmill log yard, outerwood cores were collected from the breast height (BH) position in the stems, and all were labelled to indicate forest, tree and log nos. Log characteristics (including SED, LED, sweep, branch index (BIX), internode index (IIX), visible compression wood, and dynamic stiffness – Director HM200[4]) were documented. After debarking the full length logs and reducing to separate 4.9m logs, discs (70 mm) removed from butt, 5m and 10m for wood property assessments and all individual logs again assessed with the Director HM200. The log ends were painted to identify log no., site and height class, and prepared for sawing to structural sizes. All logs were sawn (200 mm cant) to maximise 200x40 mm boards for later splitting to 100x40 mm. Sawing patterns were recorded at the headrig for individual logs to enable boards to be positioned later with respect to log features. Only full-length boards were retained and marked in the mill with both log and board nos. Visible compression wood was noted on the green lumber.

All lumber was dried with a High Temperature schedule ($110/70^{0}$C with restraint - 24hr; 3 hr. reconditioning). Moisture content and shape stability (distortion) and were assessed after drying. The lumber was held for 3 weeks then machined and split to yield 100x40 mm dressed lumber. All dry boards were re-assessed for shape stability and mechanical properties using a Plessey Machine Grader.
At Forest Research the discs underwent standard processing to yield 5-ring block samples from the pith for a series of tests to generate log values for:

- Wood density
- Spiral Grain
- Shrinkage to 12% MC (L,R,T)
- Heartwood Diameter
- Compression wood (assessed by quartiles)
- Juvenile Wood Diameter (10 rings)

In addition, from each of the 50 stems, three radial strips (butt, 5m and 10m) were prepared for SilviScan analyses (density, mfa and SS stiffness). SilviScan wood properties were subsequently ascribed to all individual boards on the basis of their distance from the pith. A subset of 14 (7/site @ 5.5m) were reserved for cross-sectional fibre dimensions.

The lumber was extensively tested at Forest Research for stiffness, strength and stability[5]. Radial distance from pith to the centre of each board (r) was estimated using a template. The angle of the board in relation to the pith ( ) was also estimated. Radial distances from board centres were converted into ring numbers using ring widths from Silviscan. For each board, ring numbers were then used to assign wood properties from Silviscan, averaging the two ends. Properties obtained from discs in 5-ring samples (shrinkage and spiral grain), were also assigned to each board by fitting smoothing-spline functions between the each property and ring number for each tree at each height. These functions were then used to estimate the property using the appropriate ring number for each board.

Relationships between MoE and stability (both assessed on the dry gauged boards) and wood properties were then explored. Correlations and regressions between wood properties, MoE and stability were calculated using tree means for each stand, and pooled across both stands. Similar analyses were also performed for individual boards using wood properties estimated for each board derived from the r,   values.

[4] Thanks to Fibre-gen
[5] More detail of mechanical studies is reported under Str 4.1.3

RESULTS

Stem Properties

The sample trees were chosen to represent both the averages and ranges of the two stands. In addition, pragmatic decisions had to be made to select trees which were both accessible for extraction and not included in permanent sample plots. The diameters and sonic velocities of the selected stems are given in Table 1, along with the basic density values from the log increment cores. Also given are the stand values for the 100 trees assessed prior to sample selection. Appendix 1 shows the distribution of samples within the stand parameters.

The sample stems turned out to have mean properties very close to the stand averages. Since increment cores were not deemed necessary from the crop standing trees, no comparable data are available for wood density. As for site comparisons, the Golden Downs sample stems were about 10% larger in DBH and 10% lower in outerwood density. (By comparison, the other Kaingaroa Benchmarking samples – cpts. 222 and 1210 (Seedlot WN/72/2 GF 14) – were also about 10% lower than this site.

Log and Wood Properties

Acoustic data was collected from the 11 m log from each tree, and subsequently from the separate 4.9 m logs, using the Director HM200, and wood properties later allocated using information from the wood discs and SilviScan samples (butt, 5 and 10m). Individual log sonic data are given in Appendix 2. There were some anomalies in the acoustic data – in a number of trees there were clear inconsistencies between the 11 m and 4.9 m logs, or between the butt and 2nd logs which could only be possible if one or more log measurements were erroneous. Subsequent investigation suggested that a programming error may have caused data contamination. This problem was only identified and corrected later when inconsistent measurements on boards were noticed. Unfortunately, it was then too late to reassess the logs. Because of this, the acoustic measurements of logs in this trial must be treated as suspect. For the purposes of the analysis several trees with clearly inconsistent results in one or more logs were discarded from subsequent analysis (trees 2, 13, 16, 67, 106, 111, 115, 122, 123), but it is likely that there are other unidentified remaining data errors.

Discs recovered from the log ends provided samples for detailed wood analyses. Some measures were taken on the complete discs before wood samples were prepared. (Table 2 & Appendix 2).

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

Table 1: Standing Tree Assessments

Tree No.	IML (m/sec)	DBHOB (mm)	Outerwood Density* (kg/m^3)	Tree No.	IML (m/sec)	DBHOB (mm)	Outerwood Density* (kg/m^3)
Kaingaroa				Golden Downs			
2	2282	563	387	62	2616	570	437
3	2441	541	399	63	2675	518	474
4	2751	508	414	64	2609	412	388
5	2676	502	485	65	2656	458	406
6	2905	388	468	66	2435	590	406
7	2715	373	442	67	2524	444	443
8	2851	384	483	71	2307	528	403
9	2865	320	471	80	2507	690	378
10	2632	493	418	95	2578	340	414
11	2708	495	443	106	2555	587	422
12	2709	463	441	109	2530	567	377
13	2426	517	432	111	2311	662	402
14	2679	520	469	112	2363	655	424
15	2604	478	412	113	2718	577	395
16	2392	575	406	114	2583	537	388
17	2669	515	486	115	2569	580	402
18	2803	475	413	116	2328	516	429
19	2604	499	413	117	2291	467	418
20	2621	475	429	118	2731	465	424
21	2620	515	469	119	2741	549	438
22	2815	454	477	120	2594	353	444
23	2449	504	405	121	2861	397	450
25	2764	525	437	122	2744	530	411
26	2621	494	447	123	2482	542	352
27	3078	392	452	124	2667	511	439
Mean	**2667**	**479**	**440**	**Mean**	**2559**	**522**	**414**
Min.	2282	320	387	Min.	2291	340	352
Max.	3078	575	486	Max.	2861	690	474
SD	178	62	30	SD	154	90	27
Site	**2710**	**475**			**2560**	**498**	
Comparison:							
Kaingaroa 222		480	404				
Kaingaroa 1210		511	415				

* Basic density - assessed later from log BH increment core samples

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

Table 2: Average Disc Properties By Sampling Height

Disc Ht. (m)	DIB (mm)	Total Rings	Heart Wood Rings	Heart Wood (%)*	Juv Wood (%)*	Compression wood by Quartile**				
						1 (%)	2 (%)	3 (%)	4 (%)	Disc (%)
Kaingaroa										
0	467	24	7	16	29	4	4	4	4	4
5	381	20	6	25	43	4	4	5	5	4
10	353	18	6	26	51	3	3	5	5	4
Golden Downs										
0	506	23	6	11	30	1	1	5	6	3
5	420	19	5	17	45	3	4	8	10	6
10	383	17	5	20	51	2	4	7	8	5

* Area based ** No direction inferred

Differences in average stem parameters between forests were generally small. An observation is that compression wood seemed to be uniformly distributed within and between the Kaingaroa stems, whereas the Golden Downs values were much more variable both by height in the stem and disk sector.

Sectors were marked along a chosen diameter, and 5-ring blocks removed for assessment of a range of wood properties.

Means, standard deviations and ranges of wood properties from the two stands are shown in Table 3.

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

Table 3: Summary Statistics for Tree-Level (Logs 1 & 2) Variables in Each Stand

Property	Mean		Range		Std dev	
	G Downs	Kaingaroa	G Downs	Kaingaroa	G Downs	Kaingaroa
DBH (mm)	522	479	340 - 690	320 - 575	90	62
Basic density (kg/m^3)	389	402	335 - 427	356 - 437	22	22
Outerwood density (kg/m^3)	415	440	352 - 474	387 - 486	27	30
SS density (kg/m^3)[1]	467	495	403 - 524	409 - 544	30	35
MFA (degrees)[1]	19.2	17.0	14.7 - 23.0	13.0 - 19.8	1.8	1.9
SS MoE (Gpa)[1]	10.8	12.9	8.4 - 13.1	9.3 - 16.1	1.2	1.7
Timber MoE (Gpa)[2]	7.4	8.6	6.1 - 9.0	6.4 - 11.1	0.7	1.2
Timber sonic MoE (kg/m^3)[2]	8.50	9.77	6.9 - 10.2	7.2 - 12.3	0.84	1.41
Stem sonic velocity (km/s)[3]	2.56	2.67	2.29 - 2.86	2.28 - 3.08	0.15	0.18
Log sonic velocity (km/s)[4]	3.21	3.31	2.94 - 3.61	3.05 - 3.67	0.20	0.18
Longitudinal shrinkage (%)[5]	-0.08	-0.04	-0.23 - 0.05	-0.10 - 0.06	0.06	0.04
Radial shrinkage (%)[5]	1.56	1.90	1.1 - 2.1	1.3 - 2.6	0.27	0.31
Tangential shrinkage (%)[5]	3.92	3.98	3.3 - 4.5	3.0 - 4.7	0.33	0.43
Compression wood (%)[1]	4.8	4.0	0 - 15	0 - 9	3.5	2.0
Grain angle (degrees)[5]	3.8	3.8	1.4 - 8.0	1.8 - 7.0	1.9	1.5
Internode index	0.31	0.18	0 - 0.71	0 - 0.62	0.22	0.19
Branch index (cm)	4.5	3.8	2.6 - 7.2	2.3 - 5.6	1.2	0.9
Largest branch (cm)	5.5	4.4	3.0 - 9.5	2.5 - 6.0	1.6	1.0

[1] area-weighted averages
[2] mean of dry gauged 100x40 boards
[3] standing-tree sonic velocity assessed using IML tool
[4] sonic velocity in 11 m log assessed using Director, excludes 9 outliers
[5] average of 5-ring samples

Wood Density (Blocks)
Density values (unextracted) by 5-ring groups from the pith are given in Table 4 and Fig. 1).

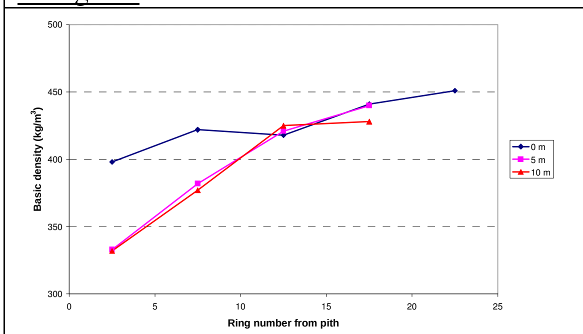
Table 4: Pith-To-Bark Basic Density Trends By Sampling Height

Disc Ht. (m)	Basic density (kg/m^3) by ring group from pith 1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	Basic density (kg/m^3) Juv. Wood Rings 1-10	Outer	Disc
Kaingaroa								
0	398	422	418	441	451	414	435	426
5	333	382	421	440		358	431	391
10	332	377	425	428		354	429	383
Average Stem Density: 402 kg/m^3		Range: 356 – 437 kg/m^3						
Golden Downs								
0	414	394	387	412	430	400	405	403
5	350	363	398	428		357	414	382
10	357	362	410	419		359	412	381
Average Stem Density: 389 kg/m^3		Range: 335 – 427 kg/m^3						

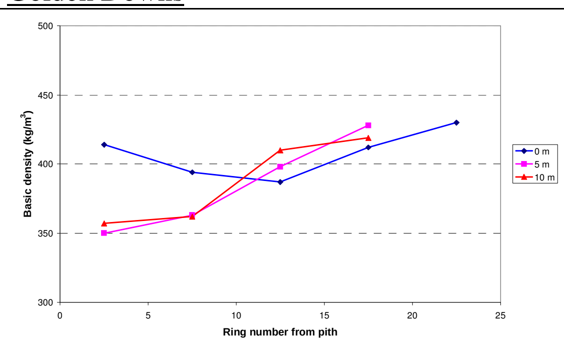
The values for juvenile wood (rings 1-10) are almost identical between the sites, emphasising that most of the difference is in the outerwood portion of the stem. It is a long established fact that climatic and site effects are more strongly expressed in the outerwood (Cown *et al*. 1991).

Fig. 1: Basic Density Patterns

Kaingaroa



Golden Downs



Wood density patterns conformed to expectations:

1. Increase from pith to bark by around $100 kg/m^3$.
2. Heartwood rings increase the apparent density of the inner two sample positions (rings 1-5 and 6-10) due to the accumulation of extractives (resin).
3. Identical patterns at each height within sites (allowing for heartwood formation).

Both sites showed values corresponding to the upper 50% of Benchmarking sites documented in WQI studies to date (Cown et *al.* 2004).

Shrinkage
Average shrinkage values (radial, tangential, longitudinal) are given in Table 5 for tree heights across sites and in Fig. 2 (and Appendix 4) for pith-to-bark patterns across sites and stem heights. As in all other WQI studies (Benchmarking site reports) the patterns are consistent:

1. Radial shrinkage increases from pith to bark - from around 1.0 - 1.5% to about 2.0 - 2.5%. Values for Kaingaroa are slightly greater – possibly related to the higher wood density.

2. Tangential shrinkage also increases from pith to bark - from around 3.0 – 3.5% to about 4.0 – 5.5%. Values for Kaingaroa and Golden Downs are similar.
3. Longitudinal shrinkage always shows high values for the inner rings at the base of the stem (in this case in the butt disc). Values for both stands (inner 5 rings) are significantly greater than elsewhere and may seem small (0.2% and 0.4%), but are likely to contribute significantly to distortion. *N.B. The negative values are a normal phenomenon when assessing small blocks and may in fact indicate some slight expansion of the samples. As with the other benchmarking studies, there is a slight tendency for higher extreme values in the lower-density site (Cown et al. 2004).*

The values recorded here are similar to those found in other benchmarking studies for similar stem heights, but slightly higher than those published (Cown 1991) because of the greater focus on the lower stem in this study.

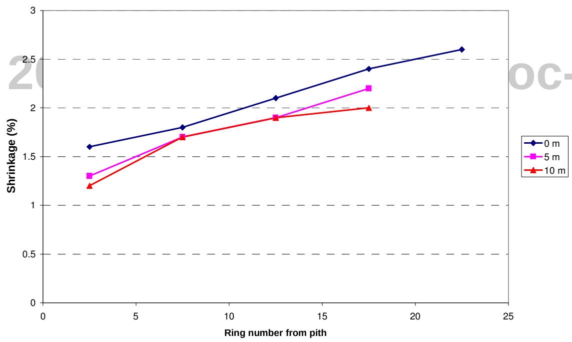
Table 5: Average Air-Dry Block Shrinkage By Sampling Height

Disc height (m)	Air-dry shrinkage* (%) Longitudinal	Radial	Tangential
Kaingaroa			
0	-0.01	2.1	4.4
5	-0.06	1.8	3.8
10	-0.05	1.7	3.5
Golden Downs			
0	-0.03	1.9	4.5
5	-0.12	1.5	3.7
10	-0.08	1.3	3.4

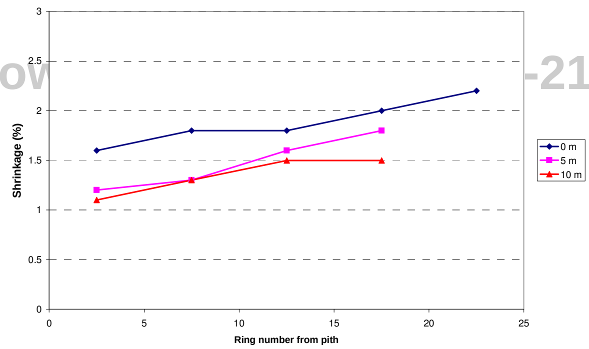
* Adjusted to 12% m.c.

Fig. 2: Dimensional Shrinkages For Sites And Stem Heights

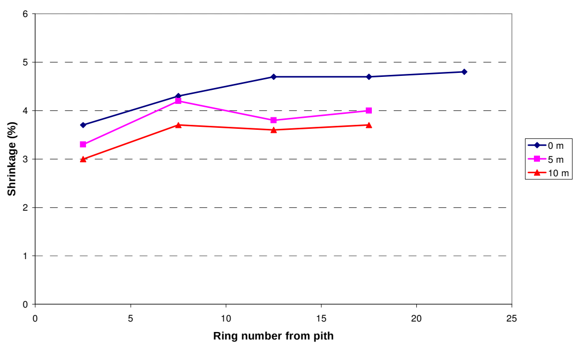
Radial – Kaingaroa



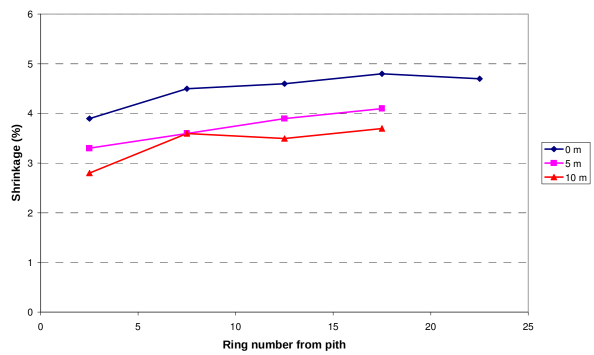
Radial – Golden Downs



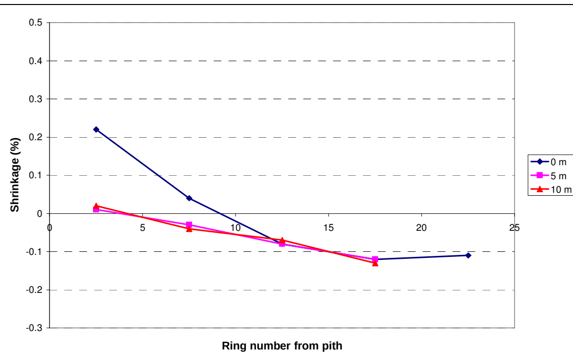
Tangential – Kaingaroa



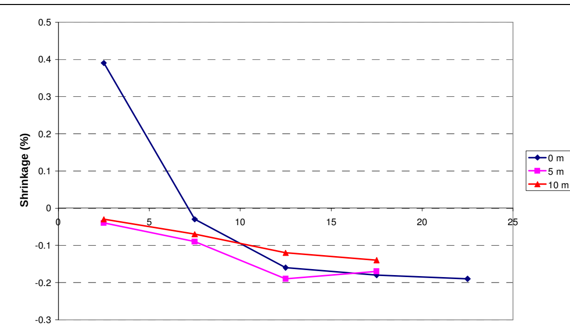
Tangential – Golden Downs



Longitudinal – Kaingaroa



Longitudinal – Golden Downs



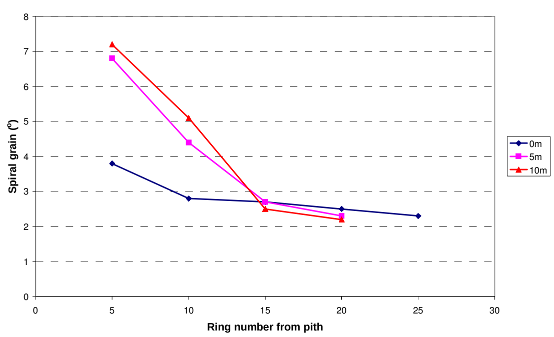
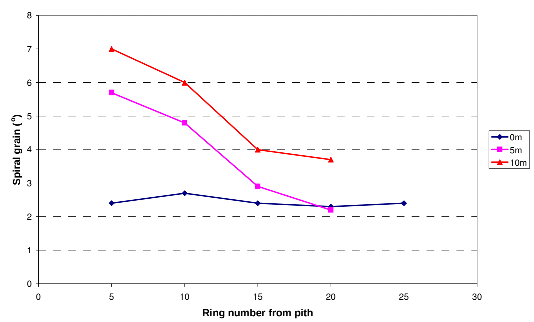
Spiral Grain

Values for spiral grain as assessed on the outer faces of the 5-ring block samples are given in Table 6 and Fig. 3 for sites and disc heights.

Table 6: Average Pith-To-Bark Spiral Grain Patterns By Sampling Height

Disc ht. (m)	Spiral grain (°) by ring number from pith				
	5	10	15	20	25
Kaingaroa					
0	3.8	2.8	2.7	2.5	2.3
5	6.8	4.4	2.7	2.3	
10	7.2	5.1	2.5	2.2	
Golden Downs					
0	2.4	2.7	2.4	2.3	2.4
5	5.7	4.8	2.9	2.2	
10	7.0	6.0	4.0	3.7	

Fig. 3: Spiral Grain Patterns – 2 Sites

Kaingaroa	Golden Downs
	

The average values recorded for both sites conform to the normal pattern of increase up the stem, particularly in the inner (juvenile wood) growth rings (from around 2.5^0 in the butt to 7^0 at 10m) and are well within the range recorded for the other Benchmarking studies (Cown *et al.* 2004).

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

SilviScan Data

SilviScan wood property averages were determined in samples from each disc and allocated to each individual log and stem (logs 1 & 2) using volume-weighted annual ring averages calculated from analyses of radii from the three sampling heights (0, 5 and 10m – Appendices 5,6). A summary of the data allocated to discs and summarised as individual logs is given in Table 7.

Table 7: Individual Log SilviScan Averages - Data From Three Heights (Butt, 5 And 10m)

Kaingaroa							**Golden Downs**						
	Log 1			**Log 2**				**Log 1**			**Log 2**		
	Density (a-d)	**MFA**	**MOEss**	**Density**	**MFA**	**MOEss**		**Density (a-d)**	**MFA**	**MOEss**	**Density**	**MFA**	**MOEss**
Mean	**505**	**18**	**12.6**	**482**	**15**	**13.3**		**472**	**21**	**10.4**	**458**	**17**	**11.4**
Min	413	14	8.9	403	11	9.8		410	16	8.4	392	13	7.9
Max	560	22	15.8	529	18	16.6		528	25	12.6	519	24	14.0
SD	36	2	1.71	33	2	1.75		32	2	1.26	29	2	1.43

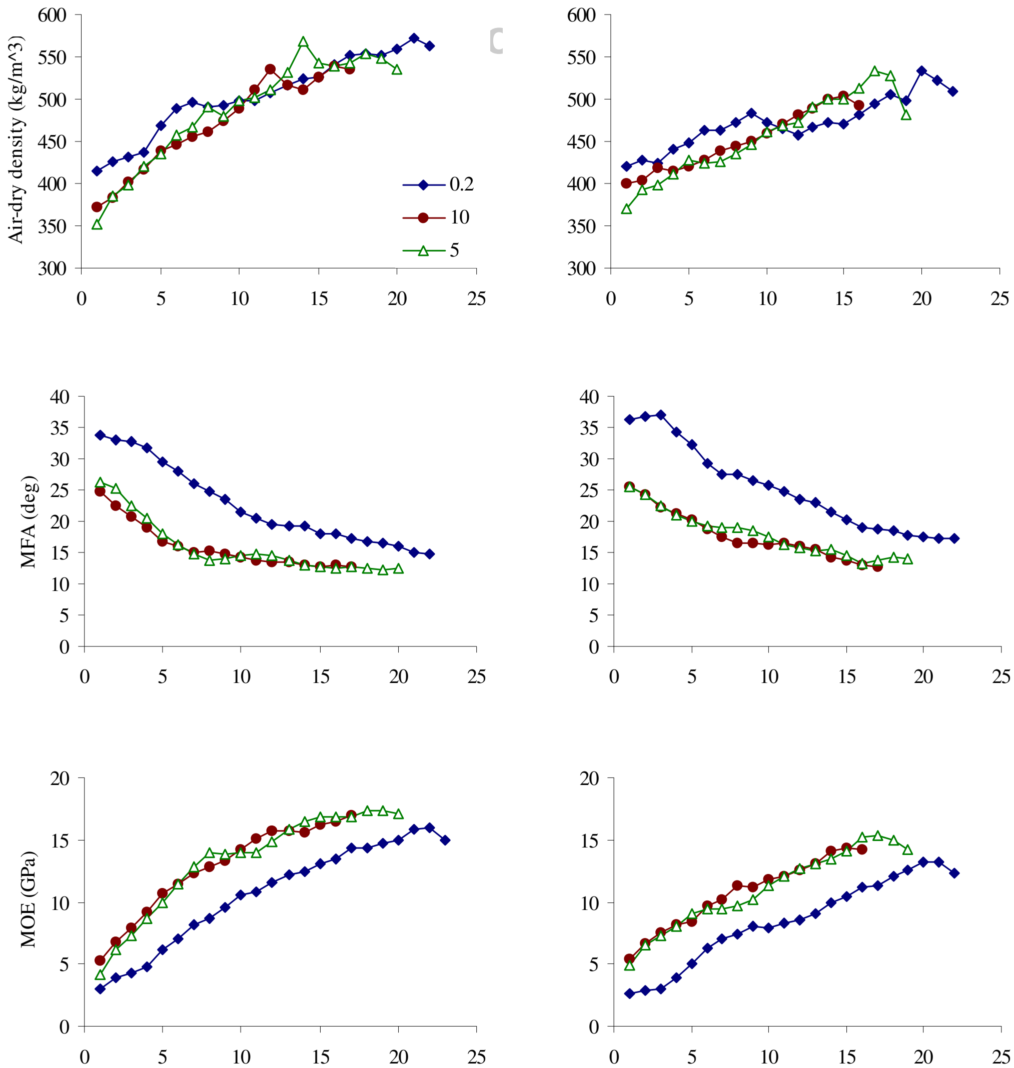
N.B. The density values from SilviScan are expressed as resin-extracted air-dry density, and are generally higher than the basic densities commonly used for stems, logs and lumber. This does not affect the analyses substantially, and has some advantages in eliminating the variable effects of resin of the results.

Radial variation in SilviScan measured properties

Annual ring averages were calculated for each of the SilviScan samples and the average radial profiles for each sampling height at each site calculated (Fig. 4).

Fig. 4: Variation in Density, MFA and MOEss across sites: Radial x Height Patterns

Kaingaroa **Golden Downs**



The trends are similar to those seen at many other WQI sites:

a) Density increases regularly from pith to bark – juvenile wood values at the base of the stem tend to be higher because of the resin-enriched heartwood.
b) Microfibril angles (MFA) decrease (by around 50%) from pith to bark – butt values are much higher than further up the stem.

MoE_{SS} increases steadily from pith to bark in line with both the increasing density and decreasing MFA. *N.B. This is a fundamental prediction, independent of the influence of knots.*

SilviScan Fibre Dimensions

A sub-sample of 7 trees was selected from each site to give detailed data on wood cell dimensions (Fibre Wall Thickness; Radial and Tangential Cell Diameters; Coarseness) for later reference, if necessary to help explain any anomalous results. A summary of the data is given in Appendix 7. The differences in the mean results appear small and will not be further discussed in this report.

Allocation of Properties to Logs and Lumber

The wood properties assessed on the discs and SilviScan samples were assigned to individual lumber boards on the basis of the measured distance from the pith and growth ring orientation. Overall averages are given in Appendix 8.

Lumber Properties

Green Lumber Characteristics

The predominant size cut in the sawmill was 200x40mm. As expected, the green lumber in this dimension showed minimal distortion, with average crook values well below 2 mm in the 4.9 m lengths (Appendix 9).

Dry Lumber Characteristics

After drying the MC distribution was measured and found to be acceptable (Appendix 4). Summaries of all the board twist and crook data are given in Table 8 in relation to two levels of grade allowances:

1. (NZS 3631: 1988 – Tables 3 and 5), and
2. Customer expectations (Bayne *et al*. 1998)

Table 8: Summary of Distortion (dry, dressed)

Twist

Forest	Height Class	Samples	Mean mm	% over 15 mm*	% over 10 mm**
Kaingaroa	1	480	0.9	0.0	0.8
	2	409	1.8	0.7	3.9
Golden Downs	1	597	1.2	0.0	1.0
	2	502	1.5	0.0	1.1

Crook

Forest	Height Class	Samples	Mean mm	% over 30 mm*	% over 15 mm**
Kaingaroa	1	480	3.9	0.2	7.0
	2	409	2.5	0.0	1.0
Golden Downs	1	597	4.9	0.5	10
	2	502	3.7	0.0	5.0

* - NZS 3631 allowance for 4.8m lengths of 100x40mm. ** - Customer preference, based on an FRI study (Bayne *et al.* 1998).

STATISTICAL ANALYSES

Timber stiffness relationships with time of flight measurements and wood properties

Correlations between MoE of the dry gauged 100x40 mm boards obtained using a Plessey machine stress grader averaged for each tree, and velocities, resonance measurements and sonic MoEs measured at various stages in the study are given in Table 9. The correlations between stress graded MoE and sonic MoEs of boards, both green and dry, were extremely high, and verify that sonic MoE is a reliable method of measuring bending stiffness in boards. There were moderate correlations with sonic velocity measured in standing trees and resonance measurements obtained using Director from logs. The Golden Downs stand had lower correlations (not quite statistically significant) than the Kaingaroa stand. The poor correlations between the IML hammer and MoE data at the Golden Downs site were unexpected given the strength of the relationships at Kaingaroa. The reduced range in stiffness values at Golden Downs (8 – 13) compared to Kaingaroa (9 – 16) may explain this in part, although the density and MFA ranges would not support this.

Table 9: Correlations (r) between average tree MoE, sonic velocity and sonic MoE.

Property	Golden Downs		Kaingaroa		Pooled	
Velocity Standing Tree	0.28		0.74	**	0.57	**
Sonic resonance 11m log+	0.30		0.70	**	0.53	**
Average sonic resonance in 5 m logs+	0.37		0.72	**	0.59	**
Sonic MoE green 200x40 boards	0.96	**	0.97	**	0.96	**
Sonic MoE dry 200x40 boards	0.95	**	0.98	**	0.97	**
Sonic MoE dry 100x40 boards	0.99	**	0.98	**	0.99	**

+ omitting nine outliers
* significant at p=0.05
** significant at p=0.01

The relationship between velocity measured in standing trees using the IML hammer and timber MoE were comparable to results from two West Coast stands sampled in a previous WQI project (Fig. 5). The general conclusion from the earlier study which is verified by this study is that standing-tree velocities are useful for ranking stands or grouping trees into broad stiffness classes, but are not accurate enough to predict stiffness reliably in individual trees.

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

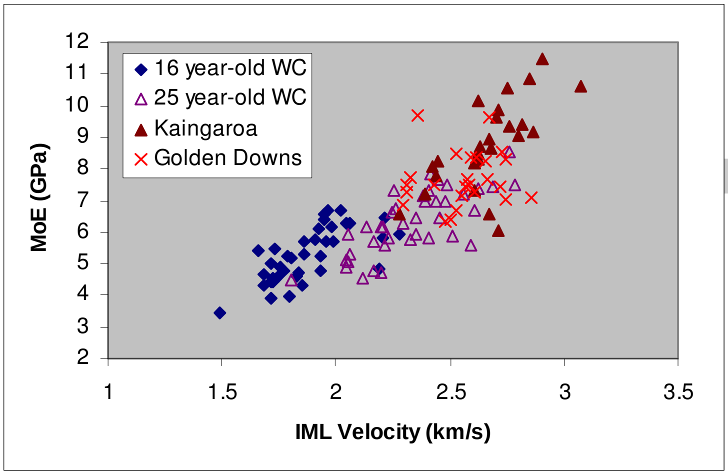


Fig. 5: Relationship between butt log average MoE from four stands and IML velocity in standing trees

In the West Coast study, resonance values measured in logs using the Hitman tool gave better correlations than velocities measured in standing trees using the IML tool. However, in this study, correlations with log resonance measurements were no better than with standing-tree velocity, even after discarding nine trees with clearly erroneous values (Table 10). Overall, the relationship between sonic velocity measured in logs using Director, and stiffness of timber cut from those logs, was poorer than the results achieved in the earlier study, possibly due to data contamination (Fig. 6).

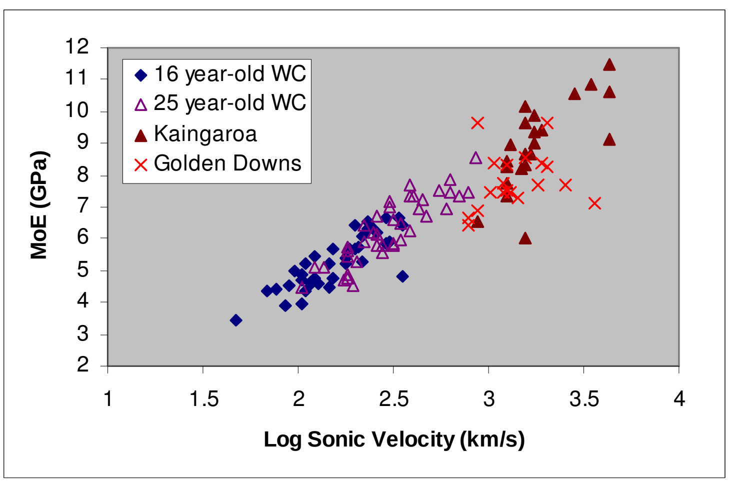


Fig. 6: Relationship between butt log average MoE from four stands and log resonance. Nine trees from the current study are omitted as outliers

Correlations between mean lumber MoE from the butt log and various methods of assessing stiffness in standing trees are given in Table 10 for the two stands from this study, and the two West Coast stands. Overall as expected, density was positively correlated with stiffness - Silviscan density having a higher correlation (pooled r=0.56) than outerwood density (pooled r=0.44). Also, as expected, there was a negative correlation with MFA (pooled r=-0.60). The ratio Density/MFA, and Silviscan MoE, were both significantly better correlated than Density or MFA alone. The pooled correlation for sonic velocity assessed using the IML Hammer was higher than outerwood density, but lower than Silviscan MoE. However, results differed somewhat between stands. In the Golden Downs stand, there was a high correlation with density but a low correlation with standing-tree velocity and MFA. In the Kaingaroa stand, the correlations with density and MFA were of a similar absolute order. In the two West Coast stands, correlations with MFA were higher than with density.

Table 10: Correlations between mean lumber MoE from the butt log and measurements on standing trees from various tools in the Utilisation Study and West Coast Study stands.

Stand	Velocity standing tree	Outerwood Density	Silviscan Density	Silviscan MFA	Silviscan Density/MFA	Silviscan MoE
Golden Downs	0.13*	0.70	0.75	-0.13	0.53	0.49
Kaingaroa	0.67	0.40	0.66	-0.56	0.71	0.68
Westcoast 16 year	0.69	0.33	0.46	-0.78	0.81	0.80
Westcoast 25 year	0.60	0.43	0.48	-0.74	0.74	0.78
Pooled within-stand	0.54	0.44	0.56	-0.60	0.71	0.71

* Inexperienced operator

Correlations between MoE of dry gauged 100x40 mm boards averaged for each tree, and various tree properties are shown in Table 11 (tree 7 was omitted as an apparent outlier). Correlations are shown separately for each stand, and as pooled within-stand correlations. Wood density, radial and tangential shrinkage and to a lesser extent MFA were most strongly correlated with lumber stiffness. There were also negative correlations with grain angle and tree diameter, with larger diameter trees generally having lower stiffness than smaller diameter trees.

Table 11: Correlations between average timber MoE and tree variables.

Property	Golden Downs		Kaingaroa		Pooled	
Basic Density	0.76	**	0.59	**	0.64	**
Outerwood Density	0.82	**	0.48	*	0.59	**
Silviscan Density	0.81	**	0.73	**	0.75	**
MFA	-0.32		-0.65	**	-0.52	**
Grain Angle	-0.55	**	-0.15		-0.31	*
Branch Index	-0.17		-0.29		-0.22	
Largest Branch	-0.03		-0.39		-0.18	
Internode Index	-0.26		0.55	**	0.19	
DBH	-0.26		-0.59	**	-0.39	**
Compression Wood	-0.10		-0.19		-0.13	
Longitudinal Shrinkage	-0.18		-0.39		-0.27	
Radial Shrinkage	0.50	*	0.54	**	0.52	**
Tangential Shrinkage	0.45	*	0.74	**	0.64	**
Silviscan MoE	0.68	**	0.79	**	0.76	**
Density/MFA	0.69	**	0.80	**	0.78	**

* significant at p=0.05
** significant at p=0.01

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

Multiple regressions were fitted to the combined data using timber stiffness as the dependent variable, with one outlier (tree 7) excluded. Fitted separately, density (Silviscan) explained 63% of the variation in stiffness (Fig. 7), and MFA explained 42% (Fig. 8). In combination, they explained 78% of the variation. The combined effect of density and MFA was less than the sum of individual effects because across the combined data set, density was negatively correlated with MFA (r = -0.37). Once density and MFA were included in the regression, there was no significant benefit in including tangential or radial shrinkage or any other variable. The regression equation is as follows:

MoE = 1.46 + 0.0206 Density - 0.188 MFA **R^2 = 0.78, RMSE = 0.54**
(1.78) (0.0027) (0.045)

(figures in parentheses are standard errors of coefficients)

There was also a good relationship between stiffness and the ratio of Density to MFA (Fig. 9), explaining 71% of the variation:

MoE = 2.60 + 0.201 Density/MFA **R^2 = 0.71, RMSE = 0.61**
(0.51) (0.019)

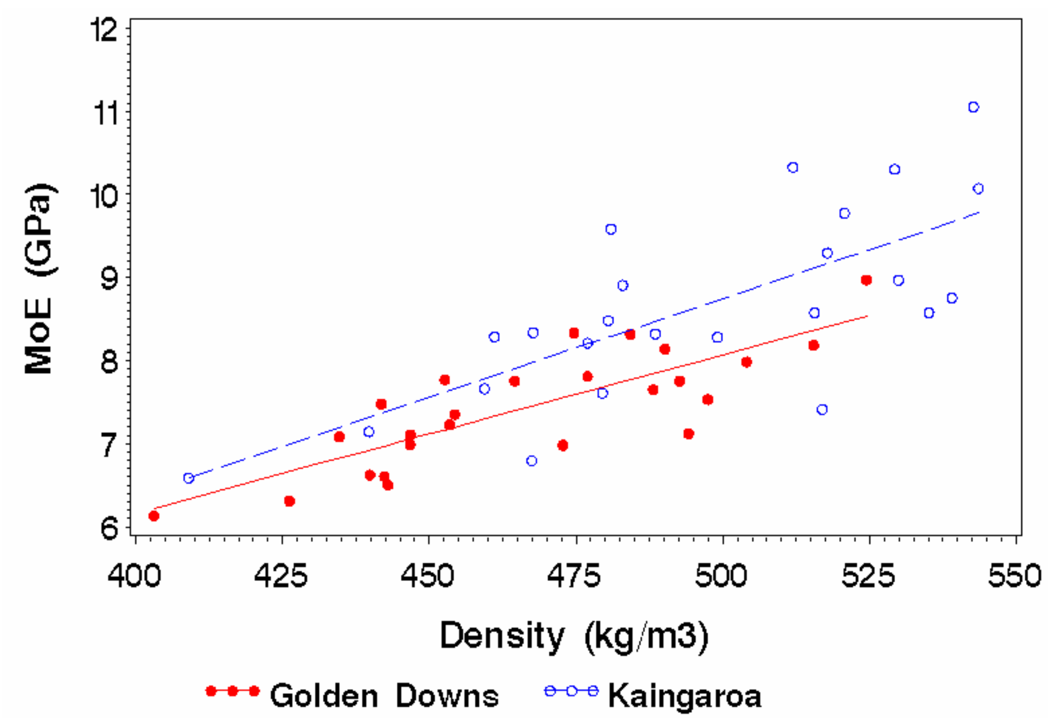


Fig. 7: Relationship Between Stem Moe (Dry Gauged Boards) And Ss Density

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

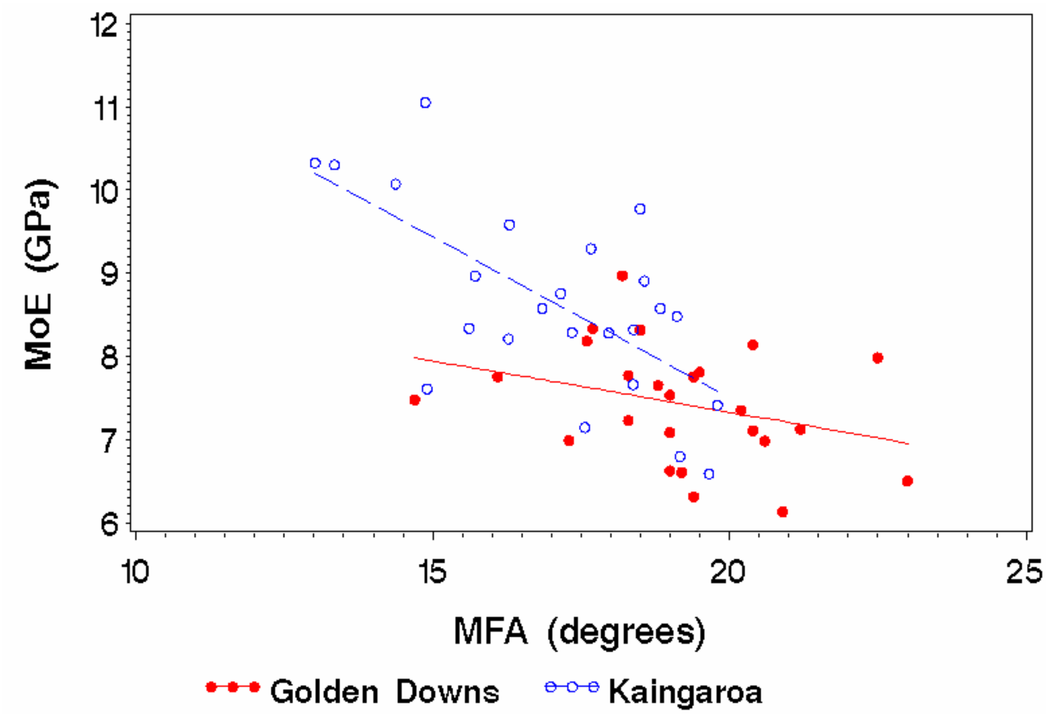


Fig. 8: Relationship Between Stem Moe (Dry Gauged Boards) And MfA

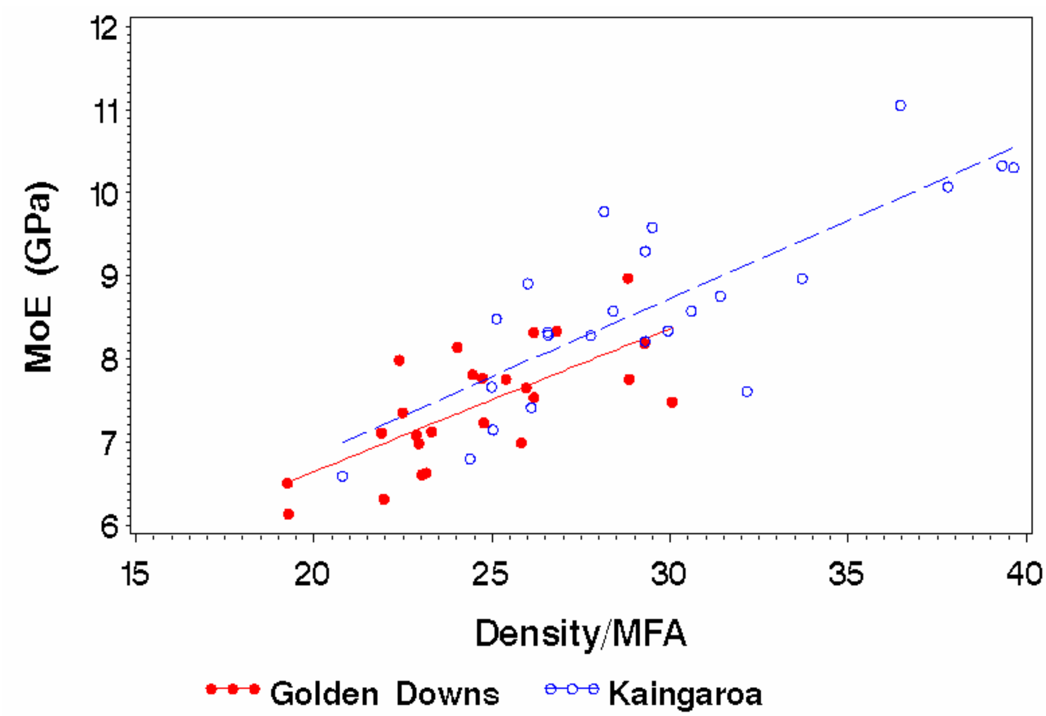


Fig. 9. Relationship Between Stem Moe (Dry Gauged Boards) And Density/Mfa

Relationships similar to those noted for tree means were also found to apply for log means. For example, mean timber MoE from each log correlated positively with mean density and negatively with mean MFA, where both variables were calculated using area-weighted averages from Silviscan samples taken at each end of the log. However, timber from the unpruned 2nd logs was significantly less stiff than timber from the pruned butt logs for an equivalent density and MFA (Fig. 10).

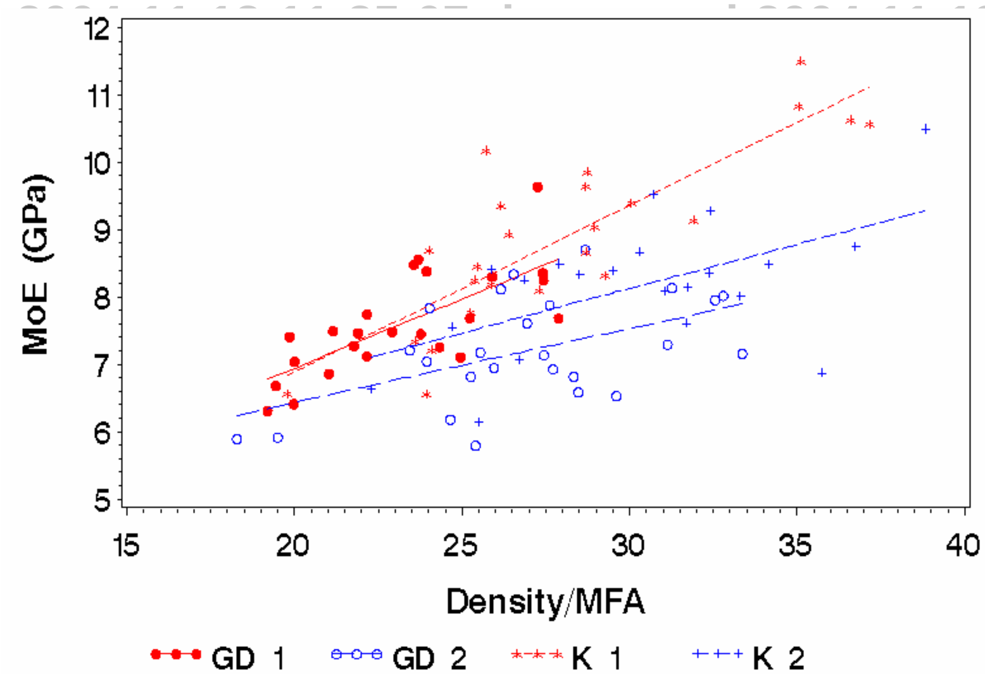


Fig. 10: Relationship between MoE in dry gauged boards and Density/MFA using log means for 1st and 2nd logs from Golden Downs (GD1 and GD2) and Kaingaroa (K1 and K2)

The following regression equations were fitted to the combined data (figures in parentheses are standard errors of coefficients) for each log height class:

Butt logs: **MoE = 3.60 + 0.0195 Density - 0.253 MFA** **R^2 = 0.77, RMSE = 0.61**
(1.81) (0.0025) (0.046)

2nd logs: **MoE = 2.63 + 0.0172 Density - 0.181 MFA** **R^2 = 0.57, RMSE = 0.74**
(2.10) (0.0035) (0.050)

Butt logs: **MoE = 1.98 + 0.244 Density/MFA** **R^2 = 0.74, RMSE = 0.64**
(0.55) (0.021)

2nd logs: **MoE = 3.55 + 0.143 Density/MFA** **R^2 = 0.51, RMSE = 0.77**
(0.61) (0.020)

Stiffness in individual boards was also analysed in terms of the position of each board within the log. Mean stiffness in individual boards is plotted against ring number in Fig. 11. For a given ring number, timber from Kaingaroa was stiffer than timber from Golden Downs. This was expected given the slightly higher density and lower MFA in the Kaingaroa stand (Table 1). Also in both stands, beyond ring 5 the timber from the 2nd log was lower in stiffness than the timber from the butt log for the equivalent ring. This is despite the fact that for an equivalent ring, density did not vary with height, but MFA was greater at the 0.2 m height (Fig. 4). Based on density and MFA alone, stiffness of timber from the butt log would have been expected to be lower than from the 2nd log. It can be concluded that the higher stiffness in butt log timber is related to the knot-free nature of these boards. When individual board stiffness was compared with the Density/MFA ratio, similar trends noted with log means were apparent (Fig. 12). For a given Density/MFA ratio, both stands produced timber of the same stiffness, but 2nd logs produced higher stiffness timber than butt logs.

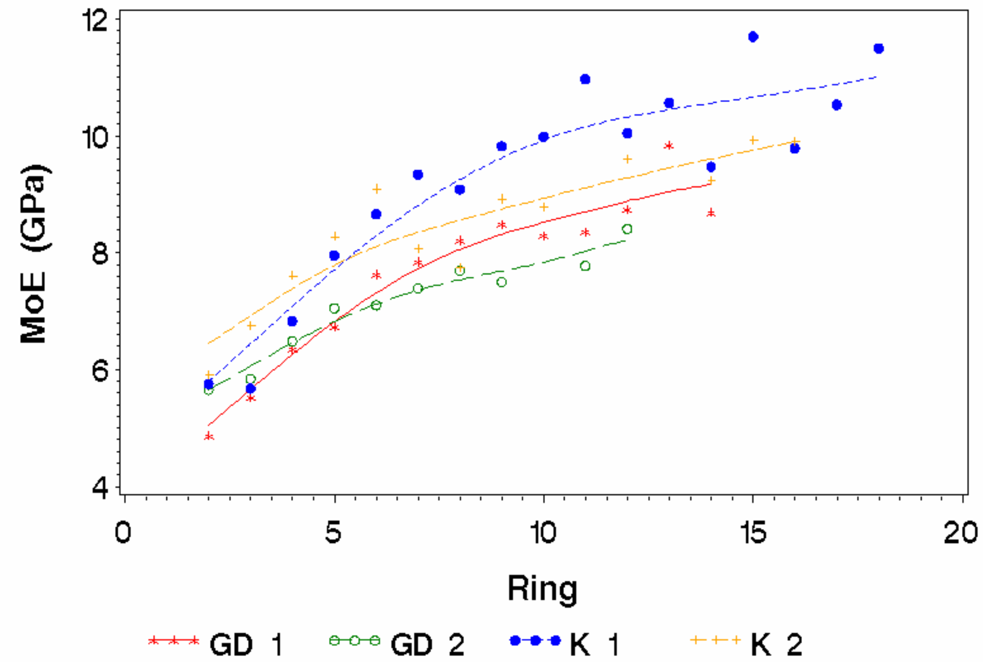


Fig. 11: Average timber MoE in each ring by height class and stand.

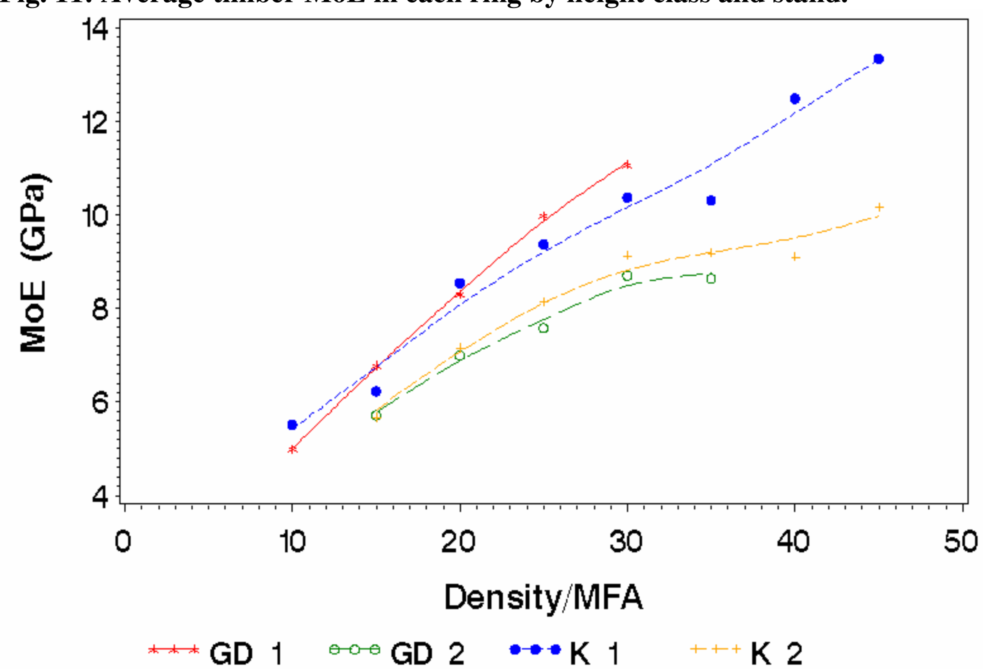
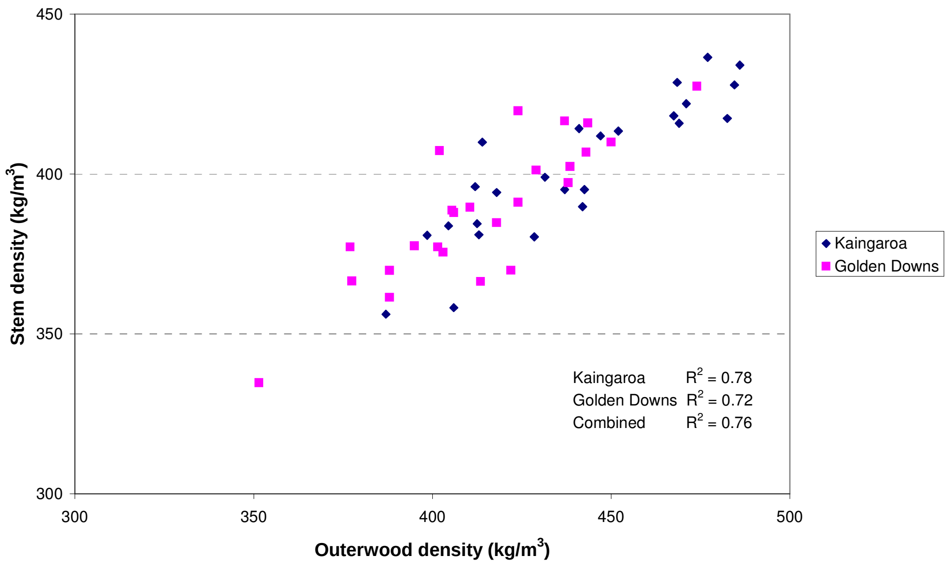


Fig. 12: Average timber MoE versus Density/MFA. For clarity, data has been averaged in 5 unit classes of the Density/MFA ratio.

Wood Density Relationships

Disc values were used to calculate log and stem (but and second log) weighted values and examined in relation to the outerwood values (Fig. 13). The individual correlations for the sites were good (r^2 = 0.78 and 0.72), as was the combined result – r^2 = 0.76. This confirmed the ability of breast height increment cores to predict stem densities reasonably well across the range encountered.

Fig. 13: Outerwood density: stem relationships



Wood Density/Time-of-flight relationships

The relationships between outerwood density and IML sound velocity were examined for all logs (Fig. 14). Overall, there was a trend for sound velocity and wood density to be positively related, with correlation coefficients r of 0.61 and 0.29 for Kaingaroa and Golden Downs respectively. These values are in line with other WQI studies which indicate that within-site correlations are typically of the order of 0.4 - 0.5 (McConchie, Kimberley & Lee, 2004). In an effort to elucidate relationships further, the Director data for 11 m logs were compared to the IML standing tree values. Even after discarding the obvious outlier trees, these correlations were only moderate at 0.76 and 0.56 for Kaingaroa and Golden Downs respectively, and generally lower than those achieved in other WQI studies. This probably reflects the Director data contamination problem alluded to earlier. Previous WQI studies with the Director have used small samples (10 trees/site) to generate reasonable correlations across sites (r for butt logs 0.79; second logs 0.76, Cown *et al.*, 2004).

Stem and Log Characteristics Driving Lumber Stability

Timber was assessed for stability (twist, bow and crook) at three stages: Green rough-sawn 200x40; Dry rough-sawn 200x40; and Dry gauged 100x40. There was very little bow or twist in the green timber and only minimal crook (Table 12), and the latter was not significantly correlated with any tree variable. Overall, there was very little rejection due to twist, even using the less stringent criteria of Bayne *et al.* (1998), but somewhat higher rejection due to crook (Table 13). Rejection due to both twist and crook was higher in butt than 2nd logs and higher in the Kaingaroa than the Golden Downs stands.

Fig. 14: Relationship between outerwood density and standing tree sound velocity (IML Hammer)

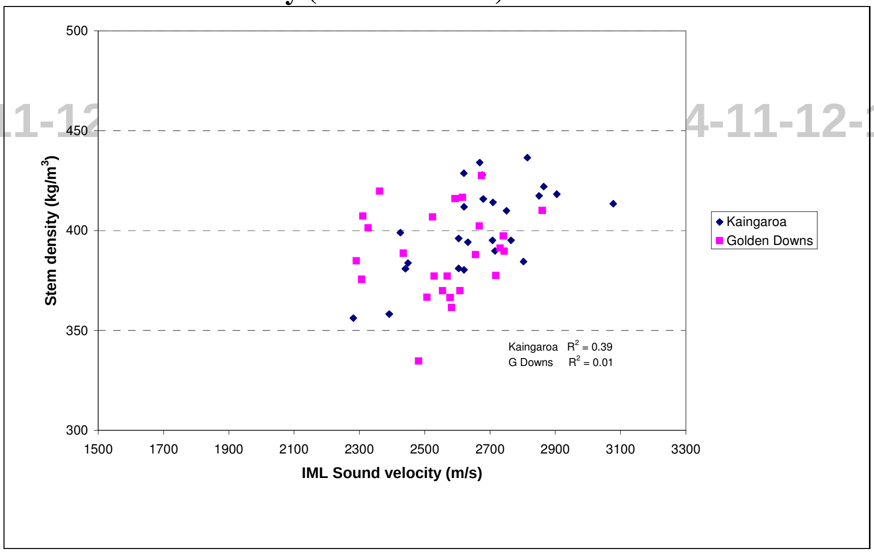


Table 12: Summary statistics of timber (100 x 40mm) stability tree means

ariable		Mean		Range		Std dev	
		G. Downs	Kaingaroa	G. Downs	Kaingaroa	G. Downs	Kaingaroa
Crook (mm)	Green	1.20	1.05	0 - 3.6	0 - 4.7	0.98	1.13
	Dry rough sawn	2.65	2.11	0.6 - 5.3	0 - 5.3	1.35	1.58
	Dry gauged	4.18	3.18	1.3 - 6.6	0.6 - 5.2	1.53	1.07
Bow (mm)	Dry rough sawn	0.70	0.10	0 - 2.5	0 - 1.9	0.81	0.38
	Dry gauged	11.36	10.07	6.7 - 16.9	3.1 - 20.0	2.88	3.44
Twist (mm)	Dry rough sawn	4.03	3.93	1.1 - 9.3	1.6 - 9.4	1.89	2.08
	Dry gauged	1.34	1.37	0.1 - 4.1	0 - 3.5	0.85	1.02

Table 13: Mean stability values after drying and gauging, and percentage rejection due to twist (≥ 10 mm) and crook (≥ 15 mm) by stand and log height class

Stand	Log height	Mean twist (mm)	Mean crook (mm)	Mean bow (mm)	Twist reject %	Crook reject %
Kaingaroa	Butt	1.18	4.9	11.1	1.1	10.0
	2^{nd} log	1.52	3.7	12.6	0.8	6.5
Golden Downs	Butt	0.87	3.8	10.9	0.9	6.4
	2^{nd} log	1.82	2.4	9.5	0.3	2.0

In dry gauged timber, twist was significantly correlated with spiral grain angle and longitudinal shrinkage (Table 14). Neither crook nor bow was strongly related to any property although there were some weak but statistically significant correlations, with, e.g., MFA and compression wood (Tables 15 and 16).

Table 14: Correlations between average twist per tree and tree variables

Property	Dry Rough Sawn 200x40			Dry Gauged 100x40		
	G. Downs	Kaingaroa	Pooled	G. Downs	Kaingaroa	Pooled
Basic Density	-0.19	-0.02	-0.10	-0.19	0.09	-0.04
Outerwood Density	-0.33	-0.12	-0.21	-0.22	0.02	-0.09
Silviscan Density	-0.20	0.06	-0.06	-0.14	0.16	0.03
MFA	0.29	-0.12	0.07	0.22	-0.15	0.01
Grain Angle	0.71 **	0.88 **	0.78 **	0.49 *	0.81 **	0.64 **
Branch Index	-0.14	-0.07	-0.10	-0.29	-0.07	-0.18
Largest Branch	-0.21	-0.03	-0.13	-0.30	-0.05	-0.18
Internode Index	-0.11	-0.02	-0.07	-0.23	0.06	-0.09
DBH	0.14	-0.02	0.07	-0.03	-0.26	-0.13
Compression Wood	0.03	0.14	0.07	0.05	0.00	0.03
Long. Shrinkage	0.41 *	0.65 **	0.50 **	0.30	0.63 **	0.44 **
Radial Shrinkage	-0.21	-0.18	-0.19	-0.12	0.04	-0.03
Tan. Shrinkage	-0.08	0.13	0.04	-0.07	0.19	0.08
Moisture Content (after drying)	0.13	-0.19	0.00	0.14	-0.19	0.01

* significant at p=0.05
** significant at p=0.01

Table 15: Correlations between average crook per tree and tree variables

Property	Dry Rough Sawn 200x40			Dry Gauged 100x40		
	G. Downs	Kaingaroa	Pooled	G. Downs	Kaingaroa	Pooled
Basic Density	0.14	-0.15	-0.02	-0.14	-0.14	-0.14
Outerwood Density	-0.10	-0.19	-0.15	-0.28	-0.12	-0.20
Silviscan Density	0.12	-0.16	-0.04	-0.20	-0.21	-0.20
MFA	0.21	-0.14	0.02	0.50 *	0.19	0.36 *
Grain Angle	-0.06	-0.33	-0.18	0.19	0.05	0.14
Branch Index	0.16	-0.02	0.08	0.14	0.20	0.16
Largest Branch	0.22	0.03	0.13	0.14	0.28	0.18
Internode Index	0.42 *	0.01	0.21	0.10	-0.11	0.03
DBH	0.25	0.08	0.17	0.54 **	0.35	0.48 **
Compression Wood	-0.04	0.15	0.03	0.60 **	0.21	0.48 **
Longitudinal Shrinkage	0.03	-0.07	-0.02	-0.06	0.15	0.01
Radial Shrinkage	-0.01	-0.13	-0.08	-0.59 **	-0.28	-0.44 **
Tangential Shrinkage	-0.13	-0.01	-0.06	-0.38	-0.02	-0.20
Moisture Content (after drying)	0.26	0.01	0.15	0.34	-0.02	0.24

* significant at p=0.05
** significant at p=0.01

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

Table 16: Correlations between average bow per tree and tree variables

Property	Dry Rough Sawn 200x40			Dry Gauged 100x40		
	G. Downs	Kaingaroa	Pooled	G. Downs	Kaingaroa	Pooled
Basic Density	-0.42 *	-0.16	-0.32 *	-0.17	-0.43 *	-0.31 *
Outerwood Density	-0.26	-0.17	-0.21	-0.31	-0.41 *	-0.37 *
Silviscan Density	-0.33	-0.16	-0.25	-0.22	-0.48 *	-0.37 *
MFA	-0.16	0.26	-0.02	0.39	0.33	0.36 *
Grain Angle	-0.03	0.09	0.01	0.34	0.41 *	0.37 *
Branch Index	-0.16	0.30	-0.04	0.04	0.18	0.10
Largest Branch	-0.05	0.23	0.01	0.00	0.29	0.11
Internode Index	0.13	-0.21	0.04	0.24	-0.37	-0.06
DBH	-0.27	0.08	-0.18	0.47 *	0.12	0.30 *
Compression Wood	0.35	0.14	0.31 *	0.44 *	0.19	0.32 *
Long. Shrinkage	0.01	0.14	0.04	0.09	0.43 *	0.23
Radial Shrinkage	-0.11	-0.18	-0.12	-0.55 **	-0.37	-0.45 **
Tan. Shrinkage	-0.04	-0.16	-0.07	-0.20	-0.41 *	-0.33 *
Moisture Content (after drying)	-0.05	-0.13	-0.07	0.25	--0.28	0.04

* significant at p=0.05
** significant at p=0.01

When stability measurements of individual boards were related to position within log, very strong pith-to bark trends were evident for twist in both stands (Fig. 15). In the Kaingaroa stand, there was more twist in timber from 2nd logs than butt logs but this was not so apparent in the Golden Downs stand. There was some elevation in crook in boards cut from the inner few rings (Fig. 16). However, bow did not vary greatly with ring number (Fig. 17).

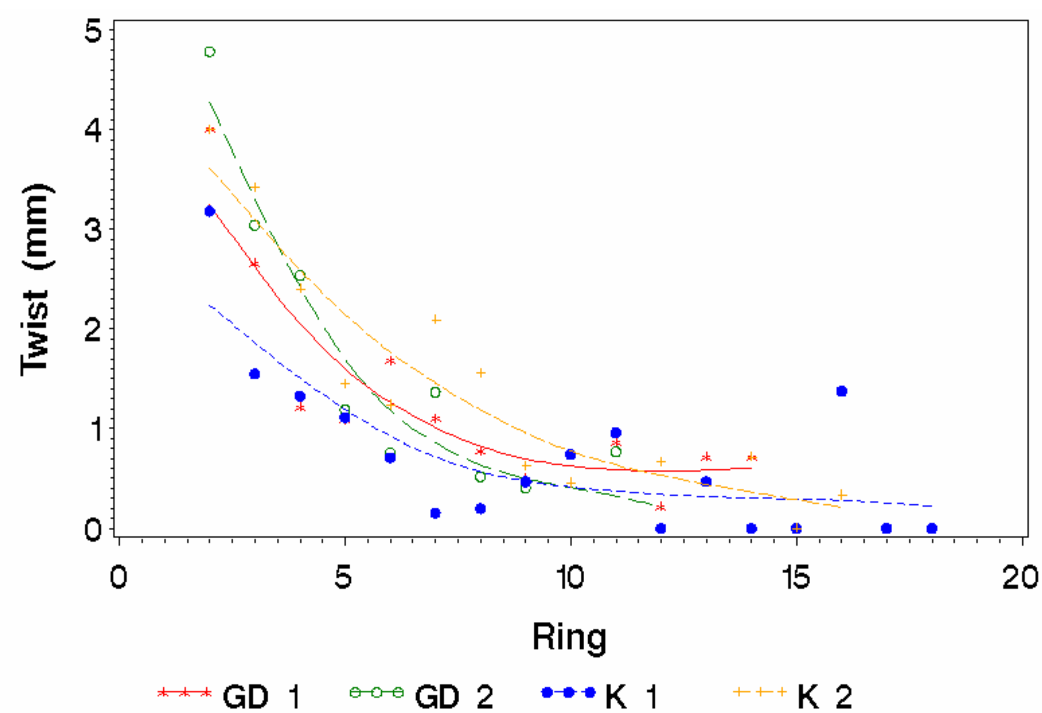


Fig. 15: Average Twist in each ring in Dry Gauged Boards by Stand and Log Height Class

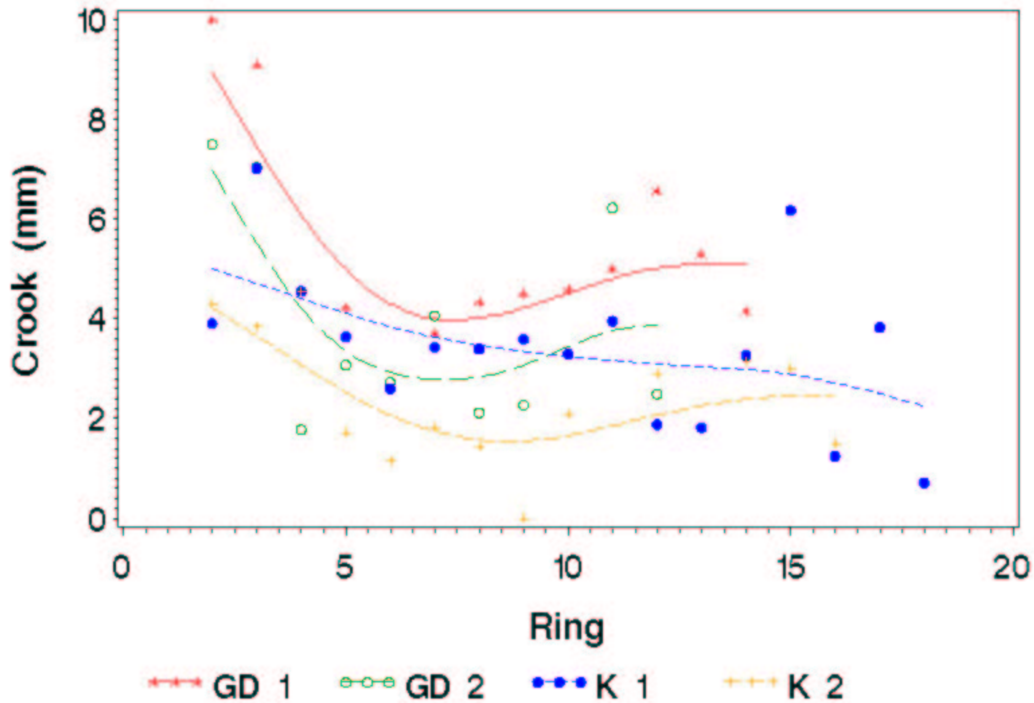


Fig. 16: Average Crook in each ring In Dry Gauged Boards by Stand and Log Height Class

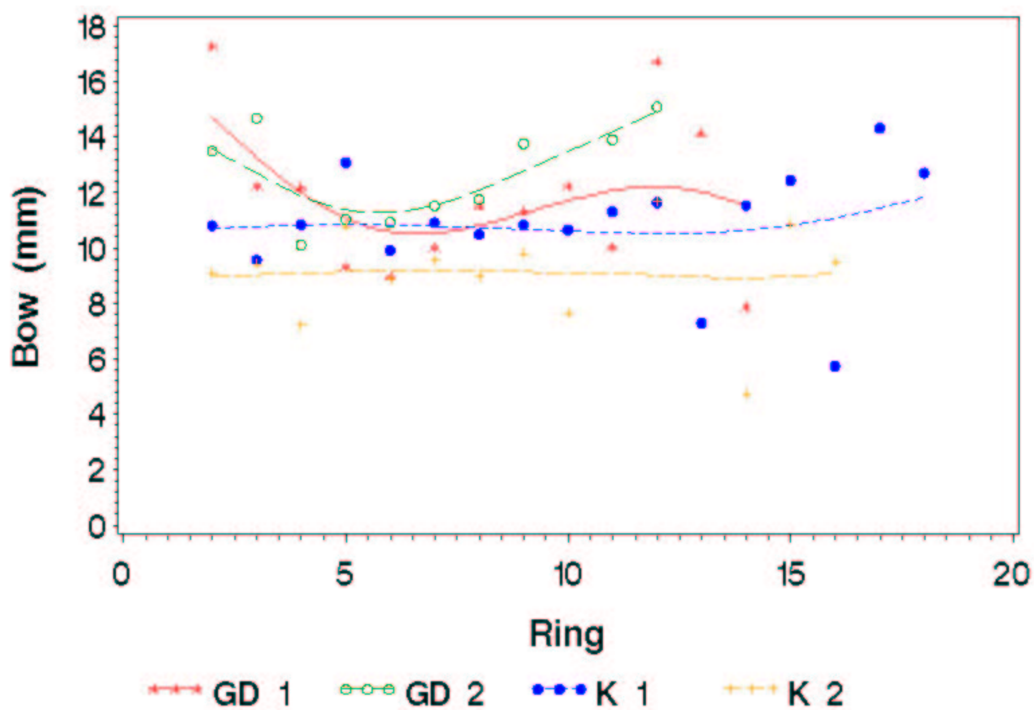


Fig. 17: Average Bow in each Ring in Dry Gauged Boards by Stand and Log Height Class

The strong trend of increasing twist with grain angle is shown in Fig. 18, which shows mean twist for boards averaged in 2º grain angle classes. At the individual board level, there was also a strong relationship between twist and moisture content after drying (Fig. 19). The tendency for crook to increase with MFA is shown in Fig. 20.

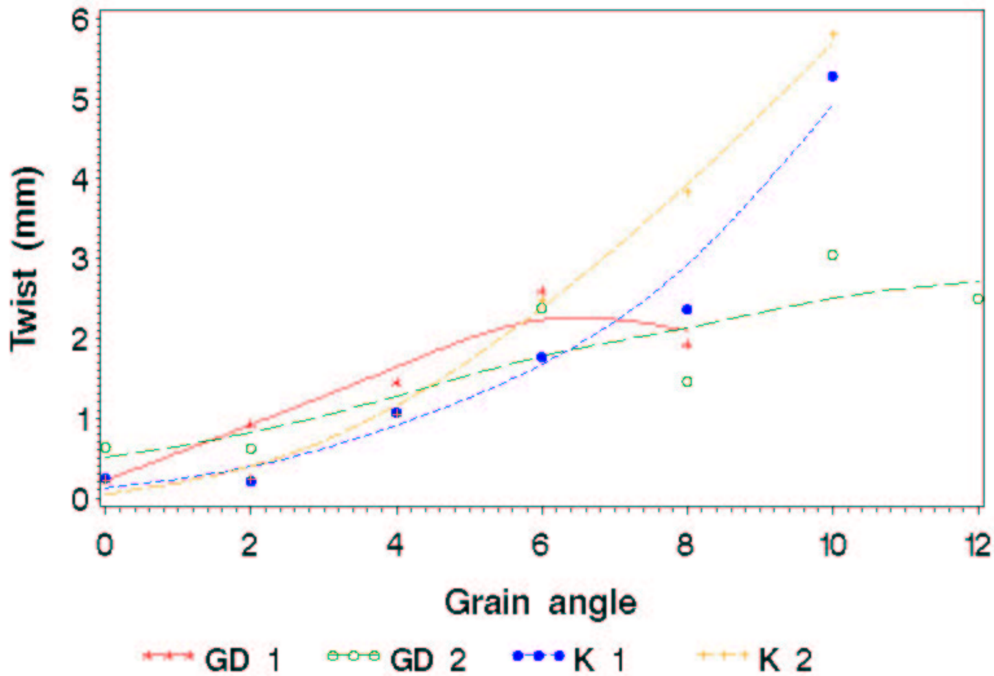


Fig. 18: Relationship Between Twist In Dry Gauged Boards And Spiral Grain Angle by Stand and Log Height Class. For clarity, data has been averaged in 2º Grain Angle classes.

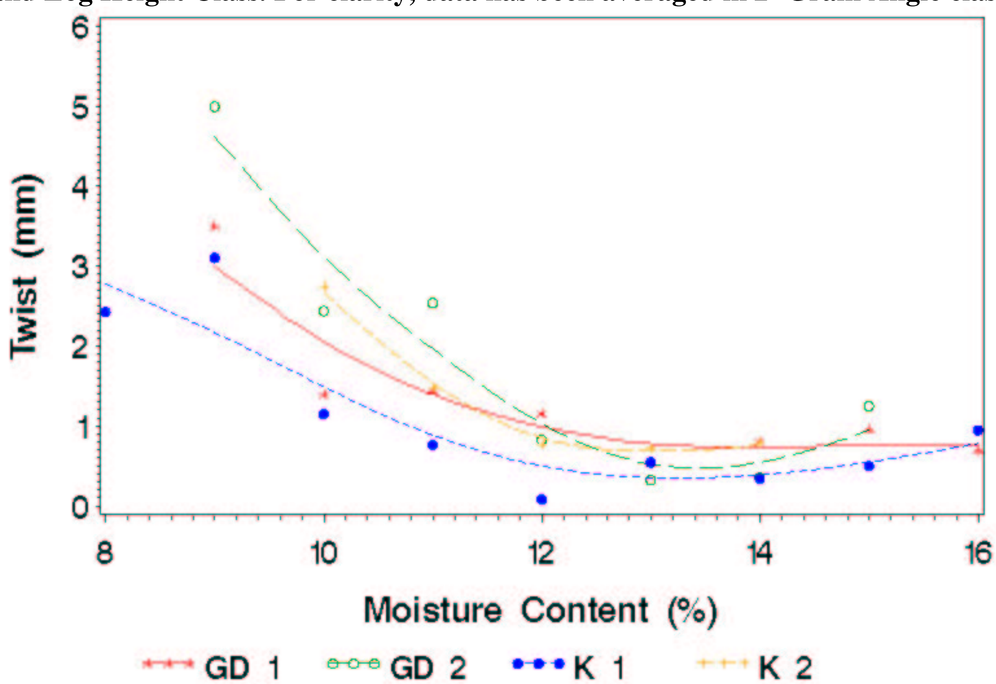


Fig. 19: Relationship Between Twist In Dry Gauged Boards and Moisture Content after Drying by Stand and Log Height Class. For clarity, data has been averaged in 2% Moisture Content classes.

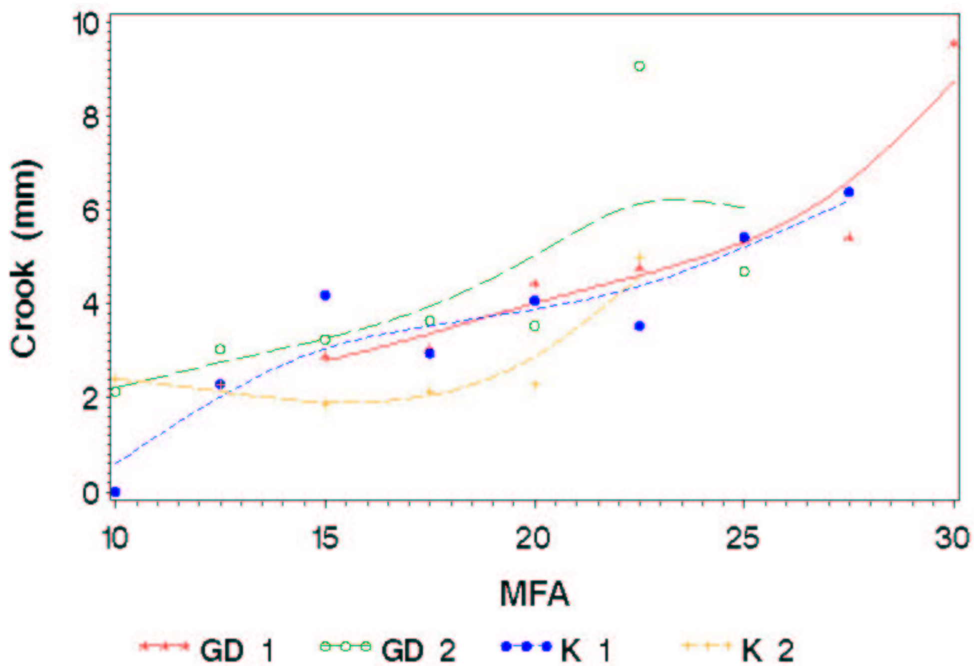


Fig. 20: Relationship Between Crook In Dry Gauged Boards and Mfa Obtained Using Silviscan by Stand and Log Height Class. For clarity, data has been averaged in 2º Mfa classes.

Mean wood properties of boards rejected due to excessive twist or crook were compared with means of acceptable boards to determine whether any wood property was strongly associated with board stability (Table 17). The number of standard deviations between the two means was calculated as a measure of the ability of each property to discriminate between rejected and accepted boards. For example, a discrimination value of three standard deviations would imply that there was almost no overlap between rejected and accepted boards, whilst a discrimination of less than one would imply that there was little difference between the two means.

For twist, there was reasonable discrimination for grain angle (1.43 standard deviations) and longitudinal shrinkage (1.07 standard deviations), and to a lesser extent ring number, distance from pith, ring orientation in the board, and moisture content. However, no wood property was strongly discriminating for crook, with the best property, MFA, having a value of only 0.78 standard deviations, followed by ring orientation with 0.71 standard deviations. Ring orientation ( ) was higher (i.e., generally more flat-sawn) in accepted boards than rejected boards (more generally quarter-sawn) for crook, and especially twist. However, because of the sawing pattern, boards from closer to the pith tended to have lower values, making it difficult to determine whether this differentiation due to board orientation was a genuine driving factor, or merely a secondary association.

In general, the analysis of individual boards confirms the correlation analysis based on tree means. For twist, grain angle was identified as the strongest driver, along with longitudinal shrinkage which is itself strongly associated with grain angle. However, no readily predictable wood property was strongly related to crook. The correlations based on tree means clearly showed that compression wood assessed on log-end discs was positively correlated with crook, especially in the Golden Downs stand (Table 15). However, in the analysis of individual board data, no correlation was found between crook and compression wood score assessed for each individual board (Table 17). This may be because of difficulties in assessing compression wood accurately in individual boards.

Table 17. Average wood properties in acceptable and reject boards.

	Crook			Twist		
	Acceptable	Rejected	Discrimination	Acceptable	Rejected	Discrimination
Number of boards	1345	104		1431	18	
Ring number	7.9	6.1	0.51	7.8	4.6	0.89
Distance from pith (r)	110.4	86.8	0.56	109.3	66.9	0.99
Ring orientation ( )	61.0	45.4	0.71	60.1	38.9	0.96
Density	462	449	0.30	461	440	0.49
MFA	20.3	23.7	0.78	20.6	23.4	0.66
Grain angle	4.7	4.8	0.02	4.7	8.2	1.43
Radial Shrinkage	1.5	1.4	0.35	1.5	1.4	0.33
Tangential Shrinkage	3.8	3.7	0.23	3.8	3.7	0.14
Long. Shrinkage	-0.035	0.017	0.50	-0.033	0.078	1.07
CW score[1]	0.48	0.60	0.18	0.49	0.44	0.07
CW length[2]	0.74	0.81	0.06	0.75	0.50	0.24
MC	12.0	11.4	0.30	12.0	10.3	0.87

[1] Compression wood severity score: 0=none; 1=slight; 2=moderate; 3=severe
[2] Length of board affected by compression wood: 0=none; 1=slight; 2=moderate; 3=entire length

Relationships among Wood Properties

Internal correlations among the tree properties are shown in Table 18. The two sites generally show very similar relationships between properties. In both stands, radial and tangential shrinkage were correlated positively to density and negatively to MFA. A number of other correlations were consistent in both stands. Tree diameter was positively related to branch diameter and MFA, and negatively related to tangential and radial shrinkage. Compression wood was negatively related to radial shrinkage. Grain angle was positively related to longitudinal shrinkage.

The correlations of radial and tangential shrinkage with density (positive) and MFA (negative) presumably explain their strong positive associations with lumber stiffness. The positive correlations between MFA and DBH of 0.62 and 0.58 respectively in the Kaingaroa and Golden Downs stands, explain why the larger diameter trees tended to produce lower stiffness lumber. In the Westcoast study, the correlations between MFA and DBH were also statistically significant in all stands, being 0.36, 0.23 and 0.40 in the 8, 16 and 25 year-old stands respectively.

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

Table 18: Correlations between Tree Properties. Values for Kaingaroa are above the diagonal (red) and values for Golden Downs are below the diagonal

	DBH	BIX	IIX	CW	Dens	MFA	Gr ang	L Shr	R Shr	T Shr
DBH		0.43*	-0.15	0.57**	-0.61**	0.58**	0.08	0.09	-0.71**	-0.48*
BIX	0.45*		0.19	0.32	-0.12	0.55**	0.02	0.01	-0.09	-0.3
IIX	0.27	0.31		-0.11	0.51**	-0.38	0.07	-0.17	0.28	0.37
Comp. Wd.	0.17	-0.04	0.25		-0.42*	0.25	0.20	-0.15	-0.54**	-0.26
SS Density	-0.20	-0.21	-0.13	-0.09		-0.38	0.01	-0.19	0.83**	0.84**
MFA	0.62**	0.32	0.29	0.38	0.00		0.05	0.17	-0.23	-0.42*
Grain angle	0.28	-0.01	0.17	-0.08	-0.27	0.36		0.68**	-0.24	0.01
Long. Shrink	-0.05	-0.29	0.01	0.22	0.05	0.42*	0.54**		-0.29	-0.21
Rad. Shrink	-0.65**	-0.12	-0.22	-0.47*	0.53**	-0.54**	-0.39	-0.19		0.64**
Tan. Shrink	-0.67**	-0.17	-0.27	-0.28	0.38	-0.45*	-0.28	0.03	0.66**	

* significant at p=0.05

** significant at p=0.01

In addition to the data above, cell property data was also determined from selected trees and sampling heights from each site. These are recorded in Appendix xxx.

DISCUSSION AND CONCLUSIONS

While the study met the objectives of supplying material for regional stiffness/strength and distortion studies, there were some limitations (due both to budget restrictions and the necessarily hasty implementation):

- Failure to collect increment cores for all stems in the pre-screening (budget)
- Pragmatic use of an inexperience operator for some of the stem sonic measures (haste)

On the other hand, the logging, transport, sawing and drying went smoothly. The anticipated issues with lumber distortion following "2-out splitting" did not in fact eventuate.

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

Stand and Sample Characteristics

The study set out to provide material for the study of stiffness, strength and stability in well-documented commercial forest stands in two major forest areas of New Zealand. Seedlot FRI 78/2300 (GF 14), planted and maintained in a 1979 Genetics Gains Trial, was selected at Kaingaora (cpt. 1218) and Golden Downs (cpt. 26). An attempt was made to select 25 comparable samples of stems at each site, representing the mean and range within each of the stands. This was done by pre-screening the stands using the IML Hammer. Normally in the past, when such a sampling approach is used, wood density cores would have been collected. As the first case where standing tree acoustics was used instead of increment cores, it was not entirely successful. There was a strong indication of some operator bias – an issue not well addressed to date. In retrospect, increment cores would have provided additional confidence in the sampling.

Wood density and Sonic Measures (logs and lumber)

Outerwood density cores were removed only from the sample logs, and they showed the normal relationship with average stem density (r^2 = 76%). This is a particularly good result considering the ease of collection and the length of stem considered (10m). On the other hand, relationships between core density and the standing tree sonic values (IML Hammer) proved disappointing (best correlation r^2 = 0.39 for Kaingaroa). Similarly, Director values proved troublesome (almost 25% of the 10m stems gave values exceeding both the individual log measures, and relationships to wood density were very poor). This can only partly be ascribed to inexperienced operators, as many of the "suspect" log values were checked immediately. These aspects need urgent attention. After "outliers" had been removed, log sonic measures (Director HM200) were found to be related to both wood density (r^2 = 35%) and MFA (r^2 = 57%).

Wood Properties

The disc data collected showed that the 2 stands at age 25 years were relatively similar in wood characteristics, despite the geographic separation. The Golden Downs sample stems showed slightly faster diameter growth (552mm vs. 479mm) and 10% lower outerwood density (414 kg/m^3 vs. 440 kg/m^3). Normal pith-to-bark wood density gradients were observed, and most of the wood density difference occurred in the mature wood. Kaingaroa sample discs showed average compression wood levels consistently around 5% for all stem heights and quartiles, whereas the Golden Downs sample averages ranged from 1% to 10%, seemingly concentrated in the same orientation (wind?). Heartwood was slightly more developed at Kaingaroa, but juvenile wood % (volume of inner 10 growth rings) the same.

Shrinkage (to 12%MC) was examined in detail on 5-ring pith-to-bark block samples and showed the following patterns:

1. Radial shrinkage (as reported in other FRI reports and WQI Benchmarking studies) increased from pith to bark - from around 1.0 - 1.5% to about 2.0 - 2.5%. Values for Kaingaroa were slightly greater – possibly related to the higher wood density.
2. Tangential shrinkage also increased from pith to bark - from around 3.0 – 3.5% to about 4.0 – 5.5%. Values for Kaingaroa and Golden Downs are similar.
3. Longitudinal shrinkage (considered the main contributing factor to lumber distortion) showed the normal high values for the inner rings at the base of the stem (in this case in the butt disc). The inner wood samples (rings 1-5) from Golden Downs averaged 0.4% compared to 0.2% for Kaingaroa. This property is the shrinkage dimension thought to contribute most to crook and bow.

Spiral grain was assessed on the 5-ring samples and showed similar overall patterns (common the WQI Benchmarking studies:

1. Large increase in juvenile wood grain angle with height from the butt.
2. Significant decrease in average angle from pith to bark (above the butt level) – from around 5^0 to 7^0 in the inner rings to between 2^0 and 4^0 in the outerwood.

SilviScan analyses gave detailed variations in a number of wood properties at the three heights (butt, 5m and 10m) in the sample stems:

1. Air-dry extracted density increased regularly from pith to bark on both sites (from 350 kg/m^3 to over 500 kg/m^3), as suggested by the wood blocks. Average trends at the three stem levels were similar (this time seen without the confounding effect of heartwood resin in the butt discs).
2. Microfibril angles decreased from pith to bark – upper stem values were virtually identical but significantly less than in the butt samples. This confirms that there is a steep vertical gradient in MFA within the lower part of stems – likely to affect wood performance in material from, say, the bottom 2m.
3. Predicted MoE_{ss} (based on density and MFA values) increased steadily from the pith to the bark at all levels. Trends in the upper levels were identical, and very significantly higher than the butt level with Kaingaroa showing values around 20% higher than Golden Downs.

Relationships between stem wood properties were examined in some detail.

Relationships between Stem Characteristics and wood Performance

All lumber was dried to 12% MC, dressed to dimension, machine graded and assessed for conformance with distortion allowances in the Grading Rules.

Stiffness & Strength

The stiffness and strength characteristics of the two stands will be reported separately (Str 4.1.3). This document covers the relationships uncovered between stiffness and the various log and lumber measures.

Overall, the standing tree sonic data (IML Hammer) was fairly well related to the average lumber stiffness (r^2 = 57%), as was the Director HM200 log data (r^2 = 59%). All relationships were significantly higher for the Kaingaroa stems (presumably a reflection of IML operator experience). The lumber sonic correlations (Director HM200) with measured stiffness were uniformly very high at both sites (r^2 = 0.96 – o.99%).

A very strong pith-to-bark trend was evident for MoE. The most important tree variables influencing average lumber stiffness across both sites were shown to be density and MFA, but stiffness was shown to be lower in quarter-sawn than flat-sawn boards. Density alone (SilviScan) explained 63% of the variation and MFA alone 42%. Together the two variables accounted for 78%. It was concluded that density is the most important log variable influencing stiffness, but that MFA has a significant secondary effect.

Other measured tree properties had little effect on timber stiffness. In contrast to earlier studies (Cown et al, 1987), branch diameter had little effect on stiffness. However, these earlier studies are not directly comparable to the current study, as timber grading was based on maximum deflection rather than average deflection, and boards were tested as planks rather than on edge.

Stability

The lumber was checked for compliance with NZS 3631. Negligible "out-of-grade" was recorded for twist and crook in this material. However, a Forest Research study of customer preferences (Bayne *et al.* 1998) indicated that the official levels are too lax and proposed more appropriate values. Even after these suggested grade limits were applied, rejection for twist was very low – generally around 1%, but up to about 4% in the upper logs from Kaingaroa. Crook was more of a problem – particularly in butt log material, with 7% from Kaingaroa and 10% from Golden Downs exceeding the limits. The process of drying in wide dimension (200x40 mm) and later splitting to 100x40 did not cause much problem in this study.

Strongest impact from compression wood at Golden Downs?

REFERENCES

Bayne, K., Roper, J., Turner, J.C.P. 1998: Customer perceptions of distortion in structural lumber. Wood Processing Newsletter 24.

Chauhan, S.S. and Walker, J. 2004: Associations between acoustic velocity, MOE and density. WQI Report No. STR 5: 32pp.

Cown D.J., Kimberley M.O., Whiteside I.D. 1987: Conversion and timber grade recoveries from radiata pine logs. In Proceedings of the Conversion Planning Conference, Kinimonth JA (ed), FRI Bulletin 128.

Cown, D.J, McKinley, R.B., Jones, T. 2004: Summary of Sites 1-6 (Aupouri, Kaingaroa, Southland, Athenree, Mohaka, Ruatoria). WQI Report RES 13: 43pp.

Cown, D.J. 1999: New Zealand radiata pine and Douglas fir: Suitability for processing. Ministry of Forestry, FRI Bulletin No. 216: 72pp.

Guenole, L., Huang, C-L., Kimberley, M.O., Lausberg, M., McConchie, D.L. 2003: Comparison of instruments for measuring sound velocity and wood density in standing trees. WQI Report STR 4: 37pp.

McConchie, D., Kimberley, M.O., Lee, J. 2004: Relationships between sound velocity measured on standing trees as a predictor of stiffness and outerwood density and diameter at breast height. WQI Report RES 17: 15pp.

NZS 3631:1988: New Zealand Timber Grading rules. Standards Assoc. of New Zealand: 112pp.

Wang, X., Ross, R.J., Bradshaw, B.K., Punches, J., R.J., Erickson, J.R., Forsman, J.W., Pellerin, R.F. 2004: Diameter effect on stress-wave evaluation of modulus of logs. Wood and Fiber Science 36(3): 368-377.

ACKNOWLEDGEMENTS

The study could not have been undertaken without the excellent cooperation of Weyerhaeuser NZ and Kaingaroa Timberlands, who made the stands available and assisted in the transport to TITC. Special thanks to Marion Hughes and Bob Boardman.

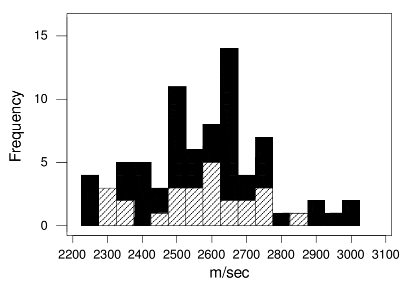
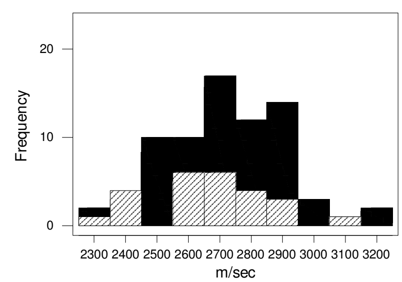
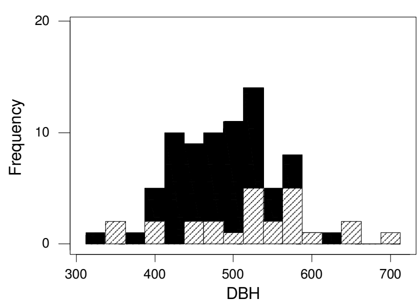
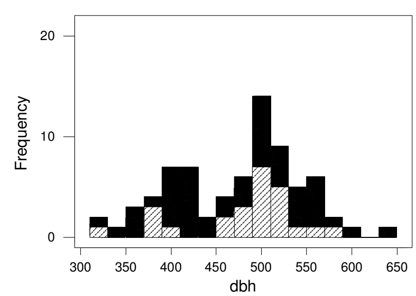
Other contributors were:
Trevor Jones, Pat Hodgkiss, John Sole (ensis)
Don McConchie (Wood Quality Focus)

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

APPENDICES

NO.	TITLE
1	Site and sample DBH and Sonic Characteristics
2	CHH Director HM200 Log And Stem Sonics
3	Site Outerwood Density Distributions
4	Lumber MC Distributions
5	Radial Shrinkage Trends By Sampling Height
6	Stem Average SS Values (Density, MFA, MoE)
7	Log Average SS Values (Density, MFA, MoE)
8	Average fibre dimensions (selected trees – 5m height)
9	Average Shape stability results for green dry and gauged lumber (200x40 and 100x40mm)

Appendix 1: Site DHB and acoustic characteristics

Golden Downs	Kaingaroa
	
	

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

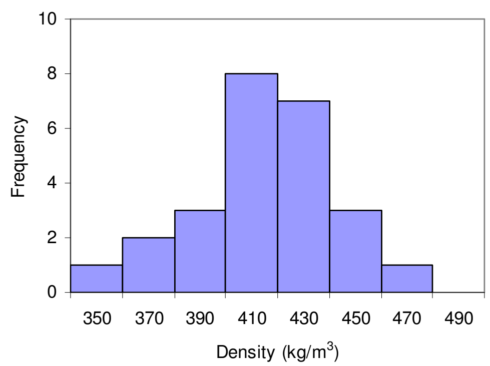
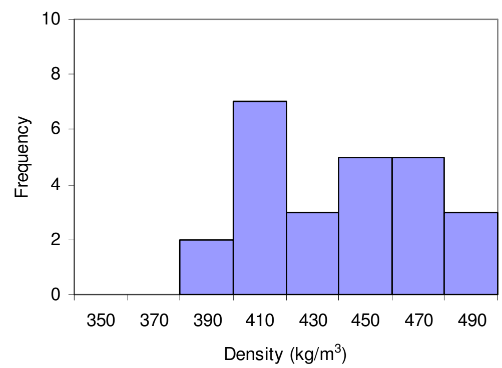
Appendix 2: CHH Director HM200 log and stem sonics

Tree No.	Acoustic data (km/s) Kaingaroa			Tree No.	Acoustic data (km/s) Golden Downs		
	Stem*	Log 1+	Log 2+		Stem*	Log 1+	Log 2+
2	4.23	3.72	2.94	62	3.07	3.03	3.01
3	3.22	3.10	3.22	63	3.33	3.31	3.19
4	3.58	3.45	3.63	64	3.40	3.15	3.22
5	3.12	3.12	3.10	65	3.35	3.31	3.19
6	3.67	3.63	3.70	66	3.15	3.08	3.10
7	3.40	3.19	3.42	67	3.22	3.22	3.61
8	3.49	3.54	3.54	71	3.20	3.12	3.03
9	3.58	3.63	3.58	80	2.99	2.89	2.94
10	3.24	3.22	3.26	95	3.61	3.40	3.33
11	3.27	3.19	3.22	106	2.99	2.96	3.35
12	3.25	3.24	3.24	109	2.96	2.89	3.01
13	3.19	3.80	3.19	111	2.94	3.31	2.99
14	3.27	3.19	3.33	112	2.94	2.94	2.89
15	3.24	3.17	3.26	113	3.09	3.01	3.05
16	4.37	4.18	2.94	114	3.09	3.10	2.96
17	3.09	2.94	3.19	115	4.23	2.89	3.63
18	3.22	3.24	3.22	116	3.15	3.08	3.08
19	3.05	3.10	3.03	117	2.99	2.94	2.99
20	3.17	3.19	3.17	118	3.35	3.19	3.15
21	3.30	3.19	3.28	119	3.22	3.10	3.12
22	3.38	3.28	3.35	120		3.28	3.45
23	3.15	3.10	3.12	121	3.61	3.56	3.61
25	3.27	3.24	3.19	122	3.04	2.94	4.32
26	3.17	3.10	3.22	123	3.61	4.09	4.16
27	3.63	3.63	3.67	124	3.30	3.26	3.10
Mean	3.38	3.34	3.28		3.24	3.16	3.26

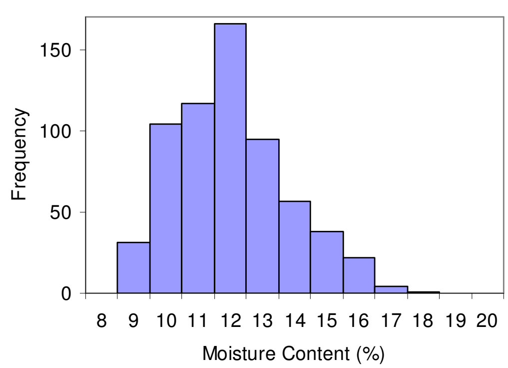
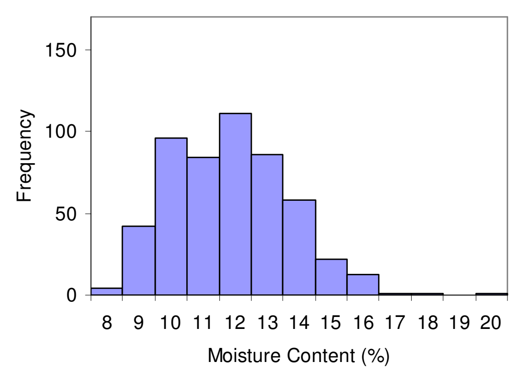
* 10m length + 5m length

N.B. The Kaingaroa values are consistently higher than the Golden Downs (in line with the standing tree IML and outerwood density results).

Appendix 3: Site Outerwood Density Distributions

<u>Golden Downs</u>	<u>Kaingaroa</u>
	

Appendix 4: Lumber MC Distributions

<u>Golden Downs</u>	<u>Kaingaroa</u>
	

Appendix 5: Radial Shrinkage Trends By Sampling Height

Disc	Air-dry shrinkage* (%) by ring group from pith									
ht. (m)	1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	1 to 5	6 to 10	11 to 15	16 to 20	21 to 25
	Kaingaroa					Golden Downs				
Radial										
0 m	1.6	1.8	2.1	2.4	2.6	1.6	1.8	1.8	2.0	2.2
5 m	1.3	1.7	1.9	2.2		1.2	1.3	1.6	1.8	
10 m	1.2	1.7	1.9	2.0		1.1	1.3	1.5	1.5	
Tangential										
0 m	3.7	4.3	4.7	4.7	4.8	3.9	4.5	4.6	4.8	4.7
5 m	3.3	4.2	3.8	4.0		3.3	3.6	3.9	4.1	
10 m	3.0	3.7	3.6	3.7		2.8	3.6	3.5	3.7	
Longitudinal										
0 m	0.22	0.04	-0.08	-0.12	-0.11	0.39	-0.03	-0.16	-0.18	-0.19
5 m	0.01	-0.03	-0.08	-0.12		-0.04	-0.09	-0.19	-0.17	
10 m	0.02	-0.04	-0.07	-0.13		-0.03	-0.07	-0.12	-0.14	

* Adjusted to 12% m.c.

Appendix 6: Stem Average SS Values (Density, MFA, MoE)

Tree No.	Volume	Density (air-dry)	MFA	MOEss	Tree No.	Volume	Density (air-dry)	MFA	MOEss
	(m^3)	(kg/m^3)	(deg)	(GPa)		(m^3)	(kg/m^3)	(deg)	(GPa)
Kaingaroa					Golden Downs		-		
2	1.41	409	19.66	9.28	62	1.28	490	20.4	10.8
3	1.36	459	18.38	11.20	63	1.20	525	18.2	12.6
4	0.99	512	13.02	14.99	64	0.72	447	17.3	11.5
5	1.21	535	18.84	12.94	65	0.95	465	16.1	12.0
6	0.83	543	14.88	15.96	66	1.70	454	20.2	9.8
7	0.58	487	15.80	13.73	67	0.74	493	19.4	11.2
8	0.53	544	14.38	15.53	71	1.37	453	18.3	11.2
9	0.41	530	15.72	15.42	80	2.28	426	19.4	9.7
10	1.08	481	19.12	11.61	95	0.57	442	14.7	13.0
11	1.06	481	16.30	12.58	106	1.52	435	19.0	10.1
12	0.91	518	17.67	12.98	109	1.30	442	19.2	10.3
13	1.34	477	16.28	12.52	111	2.28	494	21.2	10.2
14	1.07	516	16.85	13.71	112	1.67	504	22.5	9.8
15	1.09	489	18.39	12.52	113	1.54	453	18.3	10.7
16	1.68	440	17.57	11.01	114	1.55	440	19.0	10.3
17	1.31	517	19.80	12.10	115	1.84	447	20.4	9.9
18	1.04	468	15.62	12.87	116	1.21	477	19.5	10.6
19	1.23	467	19.17	11.29	117	1.13	473	20.6	10.1
20	1.04	480	14.91	13.28	118	1.08	475	17.7	11.9
21	0.99	521	18.50	12.07	119	1.44	484	18.5	11.4
22	1.08	539	17.16	13.66	120	0.54	516	17.6	13.1
23	1.07	461	17.35	11.57	121	0.80	497	19.0	12.4
25	1.40	483	18.57	11.70	122	1.41	443	23.0	8.4
26	1.14	499	17.97	12.39	123	1.43	403	20.9	8.5
27	0.57	529	13.35	16.14	124	1.27	488	18.8	10.9
Mean	**1.06**	**495.34**	**17.01**	**12.92**	**Mean**	**1.31**	**466.63**	**19.17**	**10.82**
Min.	0.41	409.04	13.02	9.28	Min.	0.54	403.08	14.70	8.36
Max.	1.68	543.60	19.80	16.14	Max.	2.28	524.52	23.05	13.14
SD	0.30	34.50	1.92	1.69	SD	0.46	29.97	1.83	1.25

Appendix 7: Log Average SS Values (Density, MFA, MoE)

Kaingaroa							Golden Downs					
	Log 1			Log 2				Log 1			Log 2	
Tree no.	Density	MFA	MOEss	Density	MFA	MOEss	Tree no.	Density	MFA	MOEss	Density	MFA	MOEss
2	414	20.9	8.9	403	18.1	9.8	62	508	21.2	10.9	466	19.4	10.7
3	467	18.5	11.3	449	18.2	11.0	63	529	19.4	12.3	519	16.6	13.1
4	521	14.0	14.7	501	11.7	15.4	64	453	18.6	11.1	439	15.4	12.1
5	544	20.6	12.2	524	16.5	13.9	65	483	17.6	11.8	442	14.2	12.1
6	555	15.8	15.8	524	13.5	16.2	66	464	21.2	9.6	441	18.8	10.0
7	496	17.0	13.5	475	14.2	14.0	67	502	21.3	10.6	482	17.0	11.9
8	561	16.0	15.0	524	12.5	16.1	71	463	20.2	10.8	441	15.9	11.7
9	549	17.2	15.1	503	13.7	15.8	80	424	21.2	9.1	429	17.4	10.5
10	493	20.5	11.2	464	17.3	12.2	95	452	16.2	12.6	431	12.9	13.5
11	496	17.3	12.6	461	15.0	12.6	106	443	20.0	9.9	424	17.7	10.3
12	529	18.4	13.0	503	16.6	12.9	109	432	22.2	8.8	456	15.4	12.3
13	478	17.5	12.0	476	14.7	13.2	111	499	22.9	9.6	488	18.8	11.0
14	523	18.2	13.3	505	14.8	14.3	112	508	24.6	9.0	498	19.5	10.8
15	505	19.5	12.5	466	16.7	12.5	113	459	19.3	10.6	445	17.0	11.0
16	448	18.6	10.8	427	16.0	11.3	114	440	20.8	9.8	440	17.3	10.9
17	524	21.9	11.4	507	17.2	12.9	115	441	22.2	9.0	455	18.0	11.1
18	484	16.7	12.7	447	14.1	13.1	116	481	21.7	9.7	472	17.1	11.6
19	472	20.0	11.1	461	18.1	11.6	117	480	22.8	9.4	461	16.8	11.4
20	480	16.4	12.5	479	13.4	14.1	118	479	20.2	10.9	469	14.3	13.3
21	527	20.5	11.	512	15.8	13.	11	497	19.2	11.	467	17.6	11.

			1			4	9			5			3
22	547	18.2	13.5	530	15.9	13.9	120	521	19.0	12.6	508	15.6	14.0
23	467	18.4	11.2	453	15.9	12.0	121	512	20.5	12.0	473	16.5	13.1
25	502	19.2	12.0	458	17.7	11.3	122	446	22.3	8.7	439	24.0	7.9
26	507	19.9	11.7	490	15.8	13.1	123	411	21.4	8.4	392	20.1	8.5
27	542	14.8	15.8	511	11.2	16.6	124	497	19.7	10.8	477	17.7	11.0
Mean	**505.2**	**18.2**	**12.6**	**482.1**	**15.4**	**13.3**		**472.9**	**20.6**	**10.4**	**458.2**	**17.2**	**11.4**
Min	413.8	14.0	8.9	403.3	11.2	9.8		410.9	16.2	8.4	392.1	12.9	7.9
Max	560.9	21.9	15.8	529.5	18.2	16.6		528.8	24.6	12.6	519.1	24.0	14.0
SD	36.38	1.99	1.71	33.05	1.99	1.75		32.39	1.81	1.26	28.59	2.22	1.43

Appendix 8: Average fibre dimensions (selected trees – 5m height)

Tree	Radial Cell Diameter (um)		Tangential Cell Diameter (um)		Fibre Coarseness (ug/m)		Fibre Wall thickness (um)	
Kaingaroa								
65	34.0	(4.9)	29.8	(2.2)	493.8	(116.9)	2.9	(0.9)
66	34.7	(6.0)	29.2	(2.0)	475.4	(125.7)	2.8	(1.0)
71	35.0	(6.0)	29.1	(2.2)	474.8	(110.3)	2.8	(0.9)
95	36.2	(5.2)	30.1	(2.4)	451.8	(103.3)	2.5	(0.7)
109	34.6	(6.3)	28.0	(2.5)	456.0	(113.6)	2.7	(0.9)
112	35.0	(5.5)	29.7	(3.1)	475.7	(124.3)	2.7	(0.8)
120	34.9	(5.5)	29.5	(2.5)	534.3	(135.2)	3.1	(1.0)
Mean	**34.9**		**29.4**		**480.3**		**2.8**	
Golden Downs								
65	37.7	(5.3)	30.9	(2.5)	494.1	(107.5)	2.6	(0.7)
66	37.7	(5.2)	30.1	(2.1)	478.4	(98.1)	2.6	(0.6)
67	35.2	(5.0)	27.3	(2.0)	439.7	(109.4)	2.6	(0.7)
112	33.6	(3.9)	27.7	(1.9)	455.3	(99.6)	2.2	(0.8)
117	34.8	(4.5)	26.6	(1.6)	407.0	(80.2)	2.4	(0.6)
118	36.2	(5.1)	31.0	(2.1)	490.4	(120.8)	2.7	(0.8)
120	32.4	(4.8)	27.9	(2.0)	416.5	(82.5)	2.6	(0.7)
Mean	**35.4**		**28.8**		**454.5**		**2.5**	

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21

Appendix 9: Mean properties by forest and log height class

Property	Golden Downs		Kaingaroa	
	Butt log	2nd log	Butt log	2nd log
Basic density (kg/m^3)	394	382	412	387
Silviscan density (kg/m^3)	473	458	505	482
MFA (degrees)	20.6	17.2	18.2	15.4
Silviscan MoE (Gpa)	10.4	11.4	12.6	13.3
Timber MoE (Gpa)	7.7	7.2	8.8	8.3
Timber sonic MoE (kg/m^3)	8.9	8.1	10.1	9.4
Log sonic velocity (km/s)	3.16	3.26	3.34	3.28
Longitudinal shrinkage (%)	-0.07	-0.10	-0.03	-0.05
Radial shrinkage (%)	1.70	1.39	1.99	1.74
Tangential shrinkage (%)	4.18	3.57	4.19	3.68
Compression wood (%)	4.48	5.56	4.04	4.08
Grain angle (degrees)	3.16	4.48	3.49	4.18
Crook (mm)	4.72	3.49	3.62	2.66
Bow (mm)	11.03	11.63	10.90	9.15
Twist (mm)	1.18	1.61	0.92	1.92

Appendix 9: Average Shape stability results for green dry and gauged lumber (200x40)

Green 200 x 40 mm

Forest	Log Height Class	Green Rough-sawn				Dry Rough-sawn				Dry Gauged			
		Crook mm	Bow mm	Twist mm	CW	Crook mm	Bow mm	Twist mm	MC %	Split mm	Crook mm	Bow mm	Twist mm
Kaingaroa	1	1.1	0.0	0.0	0.6	2.4	0.3	4.7	11.7	8.0	4.0	11.2	1.0
Kaingaroa	2	0.6	0.0	0.0	0.5	1.9	0.6	6.3	11.5	5.0	2.5	9.0	2.0
G. Downs	1	1.5	0.0	0.0	0.4	2.4	0.2	3.8	11.5	10.3	5.3	11.2	1.3
G. Downs	2	1.2	0.0	0.0	0.5	1.8	0.0	6.5	11.3	8.1	3.9	11.9	1.6

Green 100 x 40 mm

Forest	Log Height Class	Green Rough-sawn				Dry Rough-sawn				Dry Gauged			
		Crook mm	Bow mm	Twist mm	CW	Crook mm	Bow mm	Twist mm	MC %	Split mm	Crook mm	Bow mm	Twist mm
Kaingaroa	1	0.8	0.0	0.0	0.4	1.9	0.0	0.6	9.4	N.A	1.8	6.6	0.2
Kaingaroa	2	1.2	0.0	0.0	0.5	1.6	0.0	1.4	11.9	N.A	2.1	9.0	1.0
G. Downs	1	1.0	0.9	0.0	0.4	2.8	1.4	0.2	11.3	N.A	2.4	9.8	0.2
G. Downs	2	0.3	0.0	0.0	0.5	3.6	1.1	0.8	11.8	N.A	2.5	11.4	0.7

2004-11-12-11-25-07-doc-cownd-2004-11-12-13-36-21