Assessing the Bending and Density Properties of six Eucalypt Species

Authors: Doug Gaunt, Dean Satchell, John Moore

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FOREST GROWERS RESEARCH

EXECUTIVE SUMMARY

Small clear bending strength samples were cut from the following 16 year old trees that had already been felled for an earlier SWP durability study.

- E. bosistoana
- E. quadrangulata
- E. pilularis
- E. sphaerocarpa
- E. globoidea
- E. muelleriana

331 small clears were prepared and then tested for bending stiffness/strength and measured for density.

<u>When comparing by Species (Figures 1 - 4)</u>
Similar trends were observed between density at test, nominal density and bending stiffness with the ranking (highest to lowest) being:

E. bosistoana, E. sphaerocarpa, E. quadrangulata, E. pilularis, E. globoidea & E. muelleriana

In terms of bending strength the ranking (highest to lowest) was:

E. bosistoana, E. quadrangulata, E. pilularis, E. sphaerocarpa, E. globoidea & E. muelleriana

<u>When comparing by inner/outer cut positions (Figures 5 - 8)</u>
A trend of inner properties being lower than outer properties was observed for the variables density at test, nominal density, bending stiffness and bending strength for;

E. quadrangulata, E. pilularis, E. sphaerocarpa, E. globoidea & E. muelleriana. E. bosistoana did not show this trend for density and bending stiffness and the trend was weak for *E. sphaerocarpa*.

<u>When comparing by log position (Figures 9 - 12)</u>

There was a general trend observed for density, bending strength and stiffness to increase with height in tree for all species.

Comparing the six species as 16 year old trees against New Zealand grown radiata pine small clear values showed that:

- *E. bosistoana, E. quadrangulata, E. pilularis* and *E. sphaerocarpa* all had higher small clear bending strength and stiffness properties than the highest density radiata pine;
- Stiffness and bending strength of young Northland *E. globoidea & E. muelleriana* is comparable to radiata pine with a nominal density of around 550kg/m^3.

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INTRODUCTION

The mechanical properties of wood are known to vary between site, between trees, across the tree (radially pith to bark) and vertically up the tree, tree age etc. This type of investigation is done using a ‘small clear (ASTM D143)’ approach rather than using a full in-grade (actual structural sizes) study.

For this study we tested timber from 16 year old trees already felled from an earlier SWP durability study, this being from 4 trees from each of the following species

- E. bosistoana
- E. quadrangulata
- E. pilularis
- E. sphaerocarpa
- E. globoidea
- E. muelleriana

A series of small clear specimens (20mm x 20mm x 500mm) were cut from four vertical positions and two radial positions in the trees, each representative of wood from thinned trees or the very inner wood in boards or veneer cut from a mature tree. These were cut to avoid knots, sloping grain and other strength reducing defects from up to four logs from each tree.

METHODS

Small clear sample selection and processing – Dean Satchell

All trees were harvested from one site at Purerua, Northland. Trees were 16 years old and were selected to represent a cross section of the population in terms of tree size and at an age that the stand required thinning for residual trees to grow to diameters suitable for sawmilling. The site was clay with low fertility and growth rates slow to moderate.

Four trees of each species were included in the trial.

All logs were cut as 3m lengths. Logs 1 to 4 were tested but because insufficient heartwood was available for *E. quadrangulata* and *E. bosistoana* only three log positions were tested for these species. Only three log positions were tested for *E. muelleriana*. Sawn timber was not available for testing from tree 3 log 1, tree 13 log 2 and tree 22 log 4.

Log 1 for all trees was sawn soon after felling in 2016. Buttlogs were halved, turned 90 degrees and sawn into 25mm slabs. This material was fillet stacked and air-dried under cover immediately after sawing.

Logs 2 and above were left on the ground for two years between harvesting and sawing into boards. This caused issues, in particular:

- Considerable decay in sapwood and severe end splitting of logs;
- Incipient decay on end splits and in some cases corewood near log ends;
- *E. bosistoana* and to a lesser extent *E. quadrangulata* incurred some borer damage in both heartwood and sapwood;
- Internal checking was evident in some *E. globoidea* logs, which caused downgrade in the sawn boards and stakes (i.e. cracking rendering the stakes unsuitable for mechanical testing);
- Browning of wood on the boundary between heart and sap. This was up to 5 mm deep, sometimes evident, sometimes not.

Other issues and notable features with the species included:
E. bosistoana was the most difficult to saw and dress, with some chattering and chipping of grain when machining. *E. bosistoana* and *E. sphaerocarpa* appeared to be more dense than the other species but *E. sphaerocarpa* machined well. *E. bosistoana* had a wide sapwood band, an interlocked grain and also had the most sloping grain, likely because the trees were not straight. *E. bosistoana* varied in colour considerably, from light yellow-brown to brown.

E. muelleriana, E. pilularis, E. globoidea and *E. quadrangulata* heartwood were similar colour (light pinkish yellow) and density and virtually indistinguishable apart from the wide sap band in *E. quadrangulata*.

E. sphaerocarpa was more yellowy-brown, sometimes with a distinctive ribbon feature in the grain, which was interlocked and notably greasy.

E. muelleriana and *E. pilularis* sawed the best, with low tension and movement off the saw. *E quadrangulata* also had low levels of movement but low heartwood recoveries because of the wide sapwood band. *E. globodea* and *E. bosistoana* had medium levels of movement off the saw and some *E. sphaerocarpa* logs had high levels of movement off the saw. *E. globoidea* had the highest levels of collapse.

Slabs were dried to between 12% and 15% moisture content, then ripped into 25 mm x 25 mm stakes. These were then dressed to 20 mm x 20 mm stakes and marked for cutting into test samples. Where possible samples were cut as near as possible to the mid-section of the log and no samples were cut any closer than 0.5 m to the end of the log.

All samples were heartwood as determined visually.

Inner samples (marked "I") were sawn as close to the pith as possible without actually including pith. Because the samples were required to be clearwood and also representative of timber that could be included in commercially sawn appearance structural timber, where possible discolouration caused by incipient decay that emanated from the pith was excluded and because of abundant small knots near to the pith, samples were sometimes selected adjacent to, but not right beside the pith. Not all “inner” samples were clearwood. Where insufficient clearwood was available samples were included with some sloping grain (around but excluding adjacent knots) and sometimes included small green knots.

Outer samples (marked "O") were taken from heartwood immediately adjacent to the sapwood, but from log 2 upward (because these logs had been left on the ground for two years) heartwood samples were often taken close to, but not including the 5mm thick brown heart/sap interface assumed to be a narrow band of intermediate wood. Samples from log 1 were taken no closer than approximately 5 mm from the sapwood interface. Within the limitations of ripping straight stakes from boards that did not have a straight heart/sap interface, where possible the samples were selected that were as close to the heart/sap interface as practicable.

Where possible, samples were selected to have the growth rings perpendicular to the end face rather than sloping across it (i.e. growth parallel to one face).

All specimens were be numbered such that they could be linked back to the species, the tree, the specimen height and the radial position.

Each sample was photographed to record any defect. Approximately 320 specimens were supplied to Scion for testing, covering the four species.

Small clear testing – Scion

On receipt of the specimens they were placed in fillets in our conditioning room (20^{O}C and 65% relative humidity). Several specimens from each species were weighed regularly. When the weights stop changing the timber was considered ready for testing.

The specimens were cut down to 300mm long trying to select the clear straight grained material, all the offcuts had the reference numbers transferred to them and these were held in the conditioning room as references.

Prior to testing the specimens were measured for length, width, depth and weight

Then the 20mm x 20mm x 300mm specimens were tested for bending strength and stiffness in accordance with ASTM D143 with an assessment made of the failure mode.

Following the testing for bending strength and stiffness testing the specimens were oven dried to determine moisture content and nominal density measurement.

Analysis of data – Scion

A linear mixed effects model was used to examine the effect of position in the stem (i.e. log height class and radial position) on density, MOE and MOR. Nested random effects of tree and log within tree were included in these models to account for the fact that multiple samples were collected from each log and multiple logs were sampled from each tree.

RESULTS

The data collected is summarised for density at test nominal density, bending strength and bending stiffness by:

1. Species, in Figures 1 – 4 and Tables 1 – 6
2. Species and inner/outer cut positions in Figures 5 – 8 and Tables 7 – 12
3. Species and log position in Figures 9 – 12 and Tables 13 – 18.

No analysis for the failure modes has been undertaken for this report.

Definitions

MC – Oven dry Moisture content

Dt – Density at test, (test weight/volume at test)

DN – Nominal density (oven dry weight/volume at test). *This density is a measure of the actual amount of wood substance in a definable volume of material and is known as the nominal density at 12% moisture content for the dry timber.*

MoR – Modulus of rupture, bending strength at failure

MoE – Modulus of Elasticity

Failure mode – Small Clear bending test failure mode refer to Appendix A.

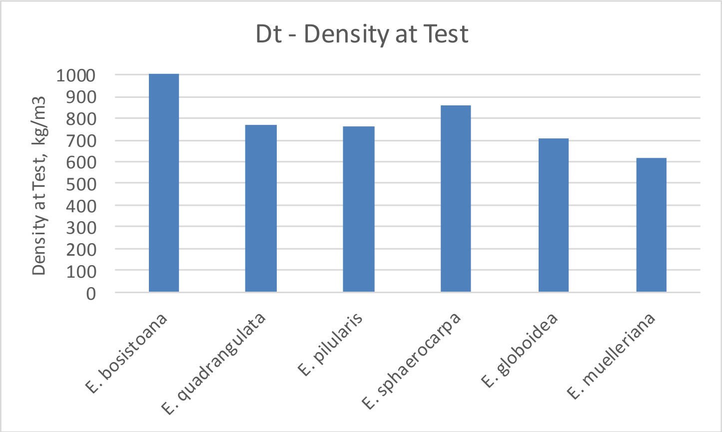

Figure 1: *Density at Test – All data*

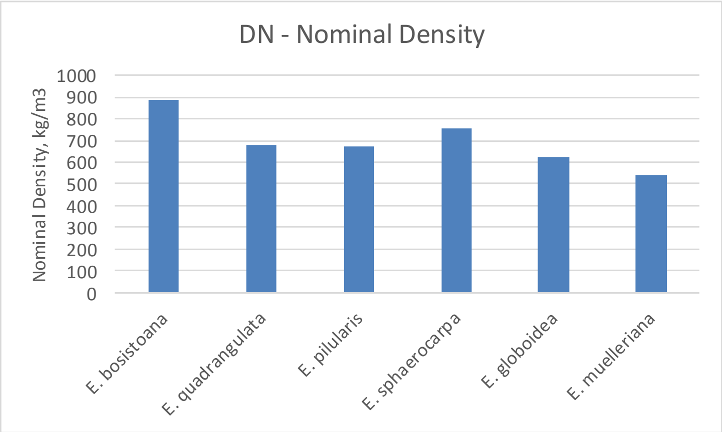

Figure 2: *Nominal Density – All data*

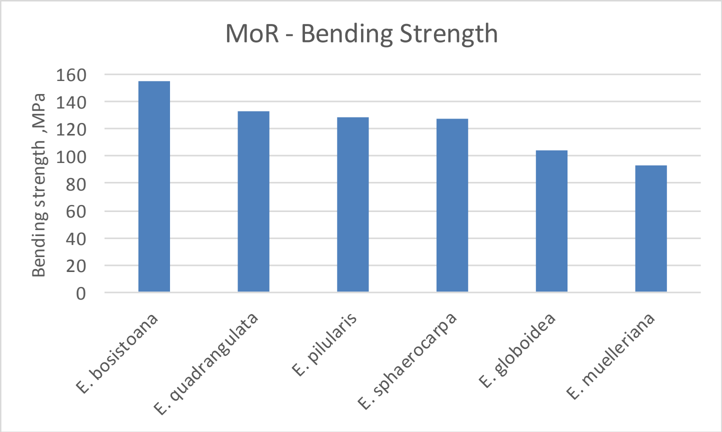

Figure 3: *Bending strength – All data*

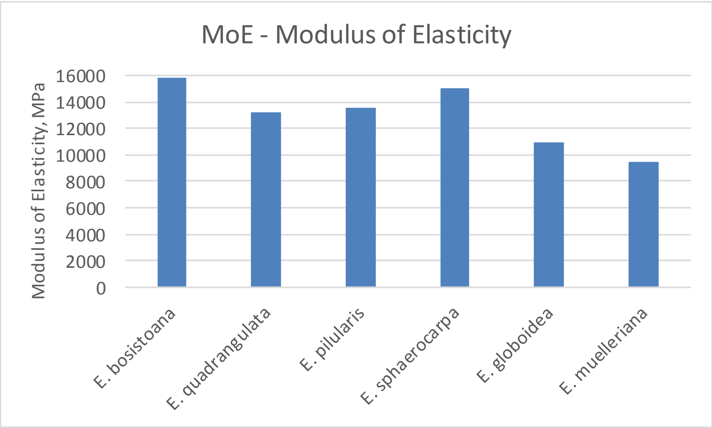

Figure 4: *Modulus of Elasticity – All data*

Table 1: *E. bosistoana – All data*

	MC (%)	Dt (kg/m3)	DN (kg/m3)	MoR (MPa)	MoE (MPa)	Fail Mode
Average	13.1	1004	888	155	15886	d
Minimum	12.6	864	763	113	12902	
Maximum	14.0	1082	959	181	20087	
Range	1.5	218	196	69	7185	
STDev	0.35	60.9	54.2	16.6	1863.4	
CoV%	2.7%	6.1%	6.1%	10.7%	11.7%	
Count	24	24	24	24	24	24

Table 2: *E. quadrangulata – All data*

	MC (%)	Dt (kg/m3)	DN (kg/m3)	MoR (MPa)	MoE (MPa)	Fail Mode
Average	13.2	766	677	133	13198	d
Minimum	12.7	621	549	89	8153	
Maximum	14.6	877	778	170	19341	
Range	2.0	256	229	81	11188	
STDev	0.49	62.6	55.3	17.7	2476.0	
CoV%	3.7%	8.2%	8.2%	13.3%	18.8%	
Count	38	38	38	38	38	

Table 3: *E. pilularis – All data*

	MC (%)	Dt (kg/m3)	DN (kg/m3)	MoR (MPa)	MoE (MPa)	Fail Mode
Average	13.3	764	674	128	13608	d
Minimum	12.7	629	555	101	9558	
Maximum	14.4	916	808	156	17517	
Range	1.7	287	252	54	7959	
STDev	0.36	67.2	59.2	14.4	1781.3	
CoV%	2.7%	8.8%	8.8%	11.2%	13.1%	
Count	72	72	72	72	72	

Table 4: *E. sphaerocarpa– All data*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Average	13.5	861	758	128	15098	c
Minimum	8.8	640	563	63	8817	
Maximum	19.3	1008	886	176	21306	
Range	10.5	368	323	113	12490	
STDev	1.03	85.3	75.6	30.5	2945.2	
CoV%	7.6%	9.9%	10.0%	23.9%	19.5%	
Count	61	61	61	61	61	

Table 5: *E. globoidea – All data*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Average	13.5	705	621	105	10918	c
Minimum	12.9	542	474	55	5770	
Maximum	15.4	866	763	138	15959	
Range	2.4	325	289	83	10189	
STDev	0.41	73.3	63.8	17.4	2212.7	
CoV%	3.0%	10.4%	10.3%	16.7%	20.3%	
Count	72	72	72	72	72	

Table 6: *E. muelleriana– All data*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Average	13.6	619	545	93	9460	c
Minimum	13.2	546	482	68	5893	
Maximum	14.3	683	600	117	12907	
Range	1.1	137	118	49	7014	
STDev	0.25	35.2	30.8	11.0	1250.0	
CoV%	1.8%	5.7%	5.7%	11.8%	13.2%	
Count	62	62	62	62	62	

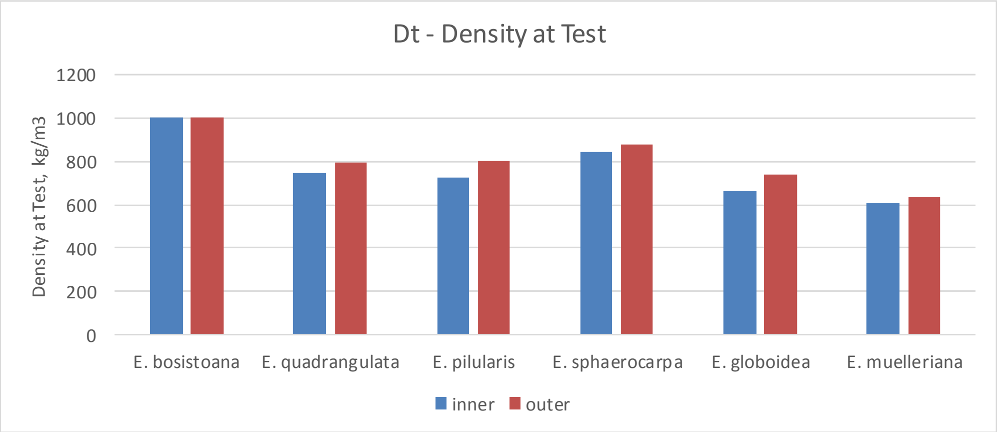

***Figure 5**: Density at Test – Inner vs Outer*

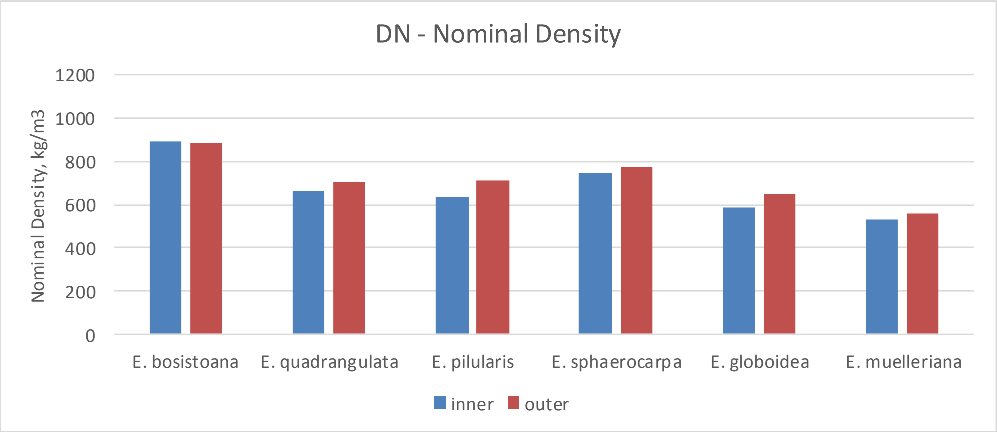

***Figure 6**: Nominal Density at Test – Inner vs Outer*

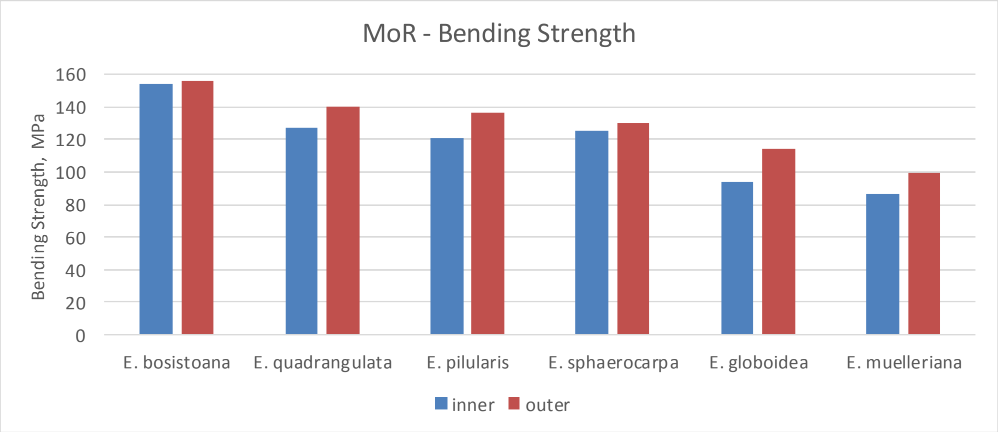

***Figure 7**: Bending Strength – Inner vs Outer*

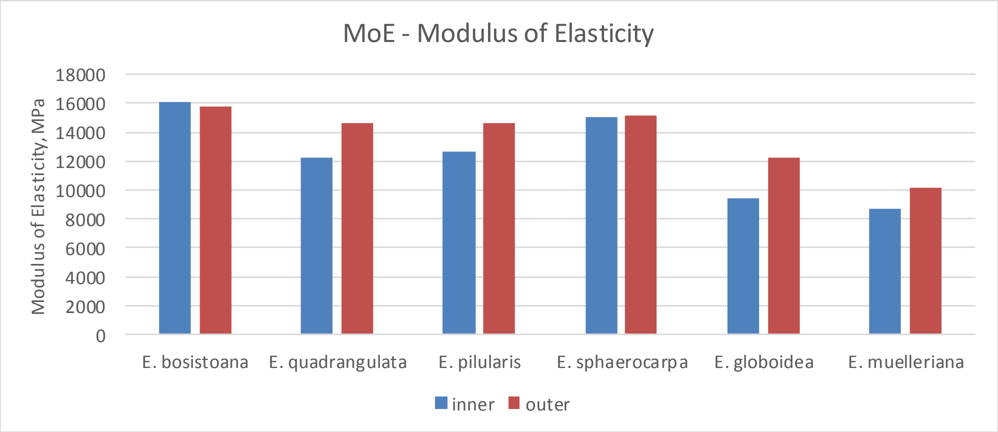

***Figure 8**: Modulus of Elasticity – Inner vs Outer*

Table 7: *E. bosistoana – Inner/Outer*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Inner Average	13.21	1006	888	154	16134	d
Outer Average	13.09	1003	887	156	15737	d
Inner Count	9	9	9	9	9	
Outer count	15	15	15	15	15	

Table 8: *E. quadrangulata– Inner/Outer*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Inner Average	13.18	747	660	127	12190	d
Outer Average	13.21	794	701	140	14584	d
Inner Count	22	22	22	22	22	22
Outer count	16	16	16	16	16	16

Table 9: *E. pilularis– Inner/Outer*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Inner Average	13.39	723	637	121	12606	d
Outer Average	13.31	805	710	136	14609	d
Inner Count	36	36	36	36	36	
Outer count	36	36	36	36	36	

Table 10: *E. sphaerocarpa– Inner/Outer*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Inner Average	13.46	843	743	125	15023	c
Outer Average	13.59	881	775	130	15180	3
Inner Count	32	32	32	32	32	
Outer count	29	29	29	29	29	

Table 11: *E. globoidea– Inner/Outer*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Inner Average	13.41	666	587	94	9439	c
Outer Average	13.57	739	651	115	12241	c
Inner Count	34	34	34	34	34	
Outer count	38	38	38	38	38	

Table 12: *E. muelleriana– Inner/Outer*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Inner Average	13.66	604	531	87	8743	c
Outer Average	13.60	634	558	100	10177	d
Inner Count	31	31	31	31	31	
Outer count	31	31	31	31	31	

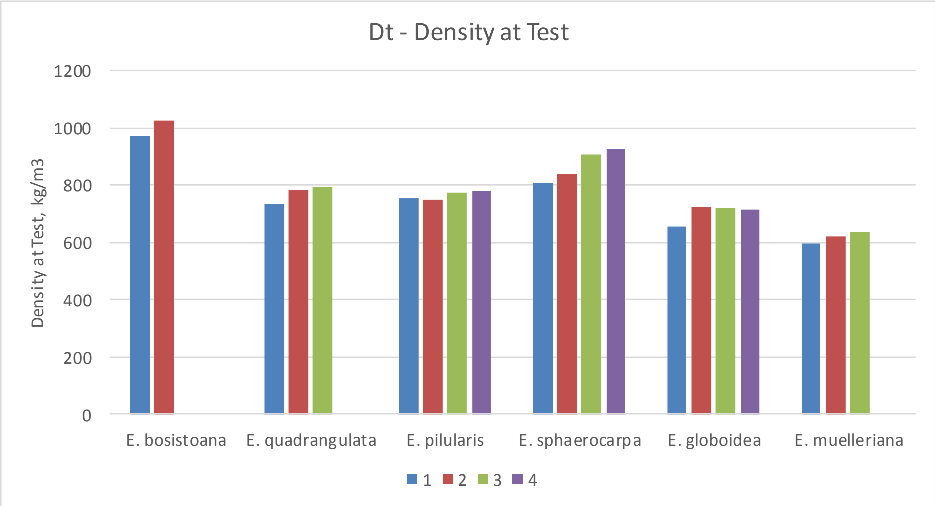

Figure 9: *Density at Test – Log*

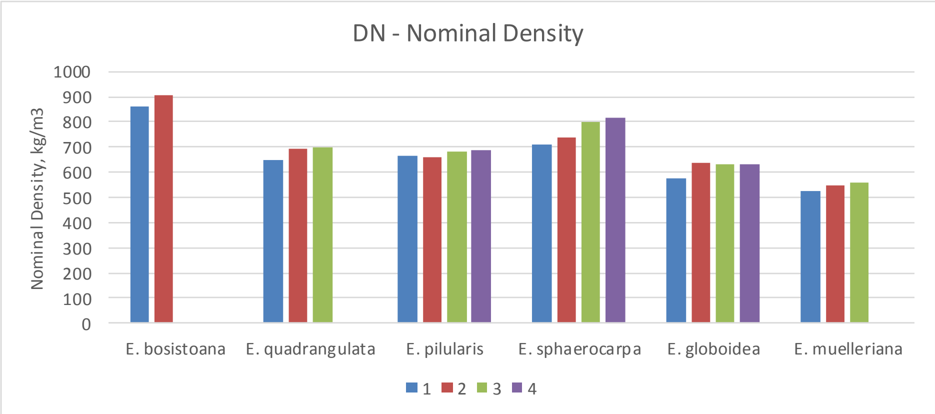

Figure 10: *Nominal Density – Log*

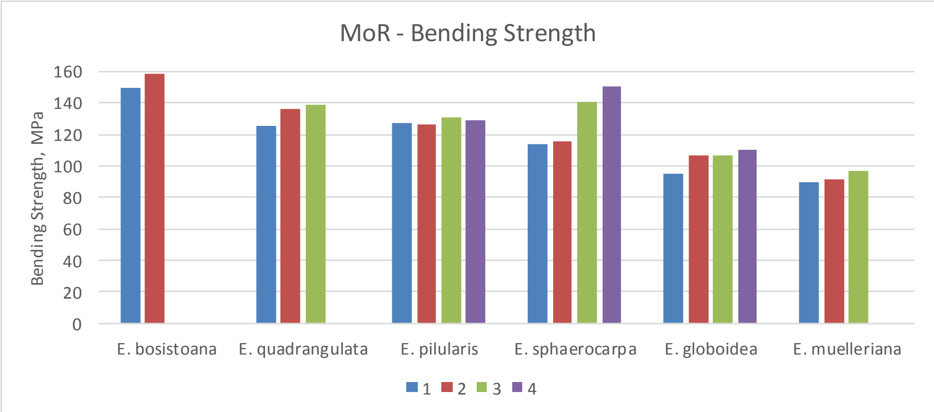

Figure 11: *Bending Strength – Log*

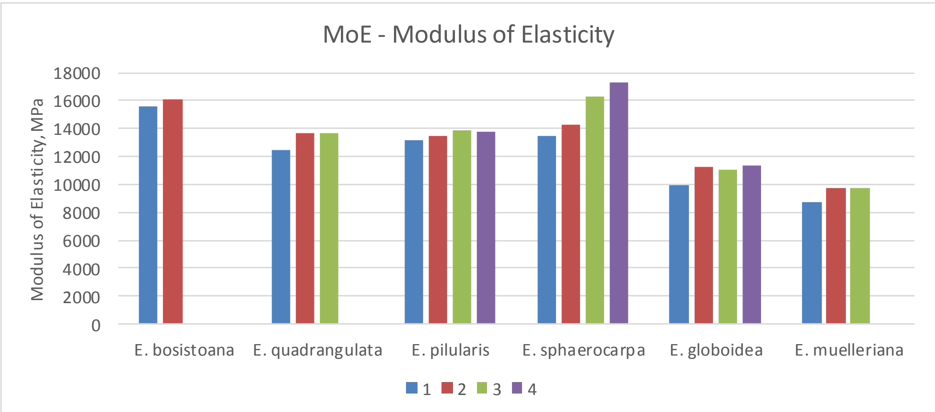

Figure 12: *Modulus of Elasticity – Log*

Table 13: *E. bosistoana – Log*

	MC (%)	Dt (kg/m³)	DN (kg/m³)	MoR (MPa)	MoE (MPa)	Fail Mode
Log 1 Average	12.97	973	862	150	15581	d
Log 2 Average	13.24	1026	906	159	16104	d
Log 3 Average						
Log 4 Average						
Log 1 Count	10	10	10	10	10	
Log 2 Count	14	14	14	14	14	
Log 3 Count						
Log 4 Count						

Table 14: *E. quadrangulata – Log*

	MC (%)	Dt (kg/m³)	DN (kg/m³)	MoR (MPa)	MoE (MPa)	Fail Mode
Log 1 Average	13.04	736	651	126	12515	d
Log 2 Average	13.45	786	693	136	13672	d
Log 3 Average	13.12	793	701	139	13723	d
Log 4 Average						
Log 1 Count	16	16	16	16	16	
Log 2 Count	12	12	12	12	12	
Log 3 Count	10	10	10	10	10	
Log 4 Count						

Table 15: *E. pilularis – Log*

	MC (%)	Dt (kg/m³)	DN (kg/m³)	MoR (MPa)	MoE (MPa)	Fail Mode
Log 1 Average	13.23	752	664	127	13193	d
Log 2 Average	13.67	749	659	126	13456	d
Log 3 Average	13.28	774	684	131	13911	d
Log 4 Average	13.24	776	685	129	13816	d
Log 1 Count	17	17	17	17	17	
Log 2 Count	17	17	17	17	17	
Log 3 Count	18	18	18	18	18	
Log 4 Count	20	20	20	20	20	

Table 16: *E. sphaerocarpa – Log*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Log 1 Average	13.54	807	711	114	13458	c
Log 2 Average	13.66	839	738	116	14333	c
Log 3 Average	13.47	907	800	140	16344	c
Log 4 Average	13.40	925	816	150	17325	c
Log 1 Count	21	21	21	21	21	
Log 2 Count	14	14	14	14	14	
Log 3 Count	13	13	13	13	13	
Log 4 Count	13	13	13	13	13	

Table 17: *E. globoidea – Log*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Log 1 Average	13.62	653	575	95	9934	c
Log 2 Average	13.52	726	640	107	11231	c
Log 3 Average	13.41	718	633	106	11091	c
Log 4 Average	13.43	717	632	110	11359	c
Log 1 Count	17	17	17	17	17	
Log 2 Count	19	19	19	19	19	
Log 3 Count	19	19	19	19	19	
Log 4 Count	17	17	17	17	17	

Table 18: *E. muelleriana– Log*

	MC (%)	Dt (kg/m^3)	DN (kg/m^3)	MoR (MPa)	MoE (MPa)	Fail Mode
Log 1 Average	13.70	595	523	90	8715	c
Log 2 Average	13.58	621	547	92	9731	c
Log 3 Average	13.62	635	559	96	9784	d
Log 4 Average						
Log 1 Count	18	18	18	18	18	
Log 2 Count	22	22	22	22	22	
Log 3 Count	18	18	18	18	18	
Log 4 Count						

Observations

By Species (Figures 1 - 4)

Similar trends were observed between density at test, nominal density and bending stiffness with the ranking (highest to lowest) being:

E. bosistoana, E. sphaerocarpa, E. quadrangulata, E. pilularis, E. globoidea & E. muelleriana

In terms of bending strength the ranking (highest to lowest) was:

E. bosistoana, E. quadrangulata, E. pilularis, E. sphaerocarpa, E. globoidea & E. muelleriana

By inner/outer cut positions (Figures 5 - 8)

A trend of inner properties being lower than outer properties was observed for the variables density at test, nominal density, bending stiffness and bending strength for;

E. quadrangulata, E. pilularis, E. sphaerocarpa, E. globoidea & E. muelleriana. E. bosistoana did not show this trend for density and bending stiffness and the trend was weak for *E. sphaerocarpa*.

By log position (Figures 9 - 12)

There was a general trend observed for density, bending strength and stiffness to increase with height in tree for all species.

It should be noted that is not possible to infer structural grades from small testing, as structural timbers are affected by their larger size, knots, sloping grain.

With reference to the Forest Research Bulletin 41 Strength Properties of Small Clear Specimens of New Zealand-Grown Timbers, H. Bier revised by R. A. J. Britton, 1999, the following information has been extracted (Table 19) and shown for reference only.

Table 19: *Average pith to bark values*

Properties at 12% M.C.	Nominal density at 12%M.C (kg/m^3)	Bending stiffness (MPa)	Bending strength (MPa)	Number of tests	Source
E. pilularis	738	13400	114	44	? 1963
E. globoidea	726	14600	132	85	Tauranga 1980
E. muelleriana	599	11200	110	25	Athenree 1984
Pinus radiata Nom. den. above 550 kg/m^3	572	11680	114	174	Nationwide
Pinus radiata Nom. den. 500 - 550 kg/m^3	529	11150	108	222	Nationwide
Pinus radiata Nom. den. 450 - 500 kg/m^3	472	9510	94	518	Nationwide
Pinus radiata Nom. den. 400 - 450 kg/m^3	425	7790	79	971	Nationwide
Pinus radiata Nom. den. Below 400 kg/m^3	362	5365	63	93	Nationwide

Note: It is not possible in this report to extract the history of this test data

Comparing the six species against New Zealand grown radiata pine small clear values showed that:

- *E. bosistoana, E. quadrangulata, E. pilularis* and *E. sphaerocarpa* all had higher small clear bending strength and stiffness properties than the highest density radiata pine.
- Stiffness and bending strength of young Northland *E. globoidea & E. muelleriana* is comparable to radiata pine with a nominal density of around 550kg/m^3.

The effects of position in the stem and species on density, MoE and MoR

Figure 13

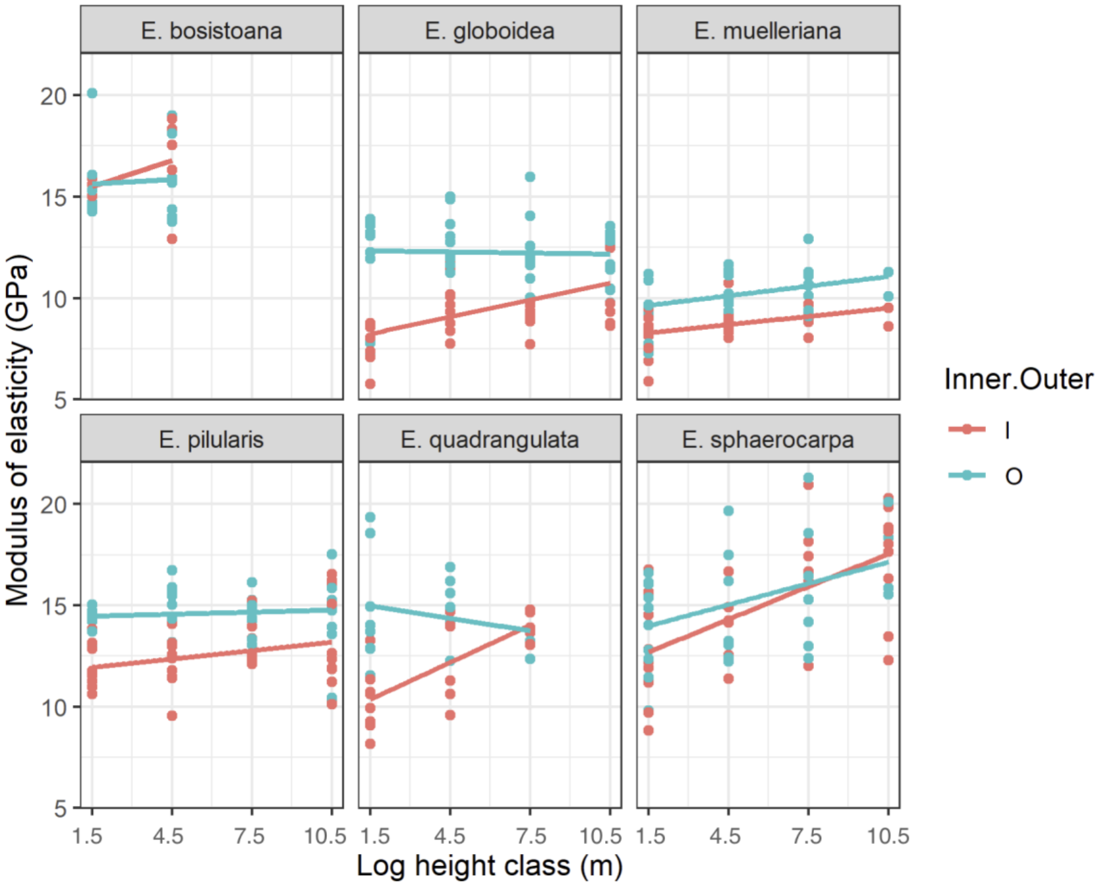

Figure 13: *MoE vs Log height*

	numDF	denDF	F-value	p-value
(Intercept)	1	238	1993.0768	<.0001
Species	5	18	12.0140	<.0001
LogHeight	1	48	45.9061	<.0001
Inner.Outer	1	238	145.9575	<.0001
Species:LogHeight	5	48	6.0401	0.0002
Species:Inner.Outer	5	238	8.5055	<.0001
LogHeight:Inner.Outer	1	238	16.4995	0.0001
Species:LogHeight:Inner.Outer	5	238	2.3822	0.0392

There was a significant effect of log height class and radial position on MoE. There were also significant different among species. For example, in *E. sphaerocarpa* MoE increases rapidly with log height but there is little effect on MoE by radial position. Conversely, the effect of log height is much less in *E pilularis* but there is a large difference in MoE between inner and outer samples.

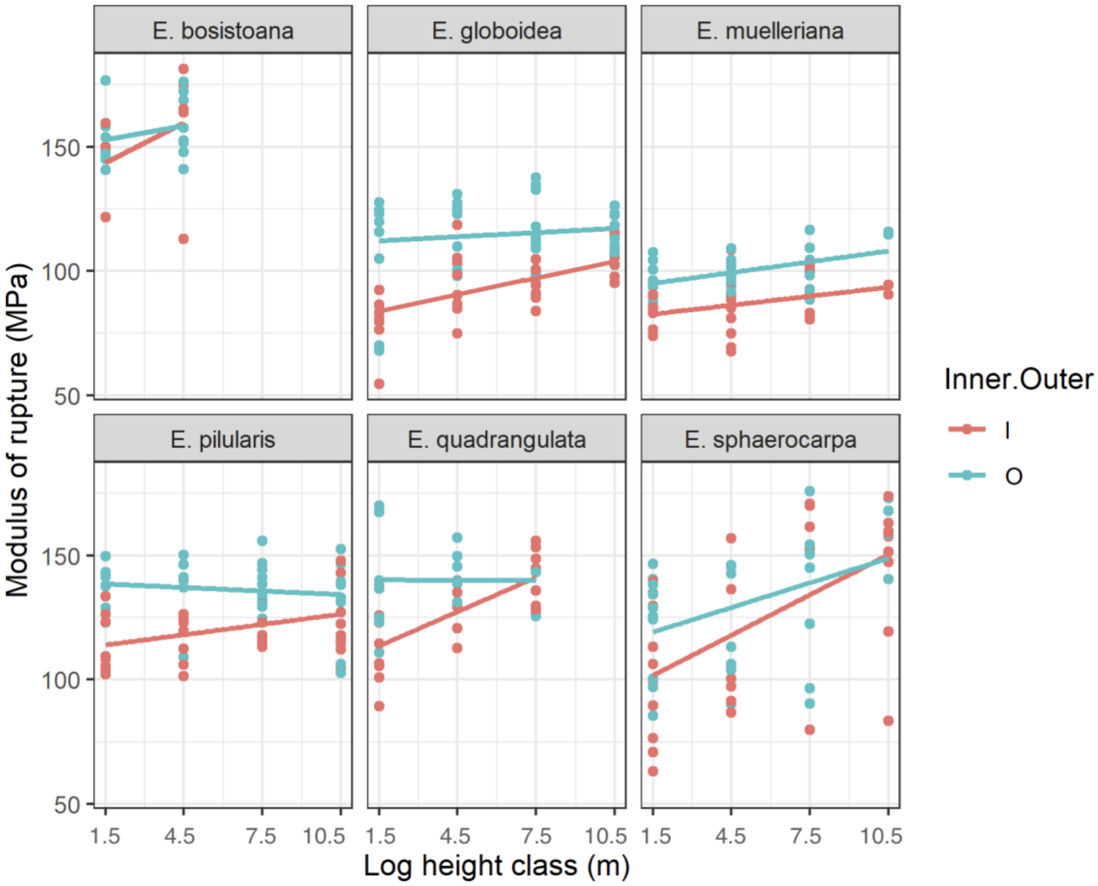

Figure 14: *MoR vs Log height*

	numDF	denDF	F-value	p-value
(Intercept)	1	238	2575.4621	<.0001
Species	5	18	12.8201	<.0001
LogHeight	1	48	48.8020	<.0001
Inner.Outer	1	238	102.8235	<.0001
Species:LogHeight	5	48	6.7687	0.0001
Species:Inner.Outer	5	238	2.1605	0.0592
LogHeight:Inner.Outer	1	238	12.8899	0.0004
Species:LogHeight:Inner.Outer	5	238	1.1692	0.3250

A similar pattern was observed for MoR. In this case the three-way interaction between Species, Log Height and Inner/Outer was not significant. Overall, the model was able to explain approximately 65% of the variation in MoR.

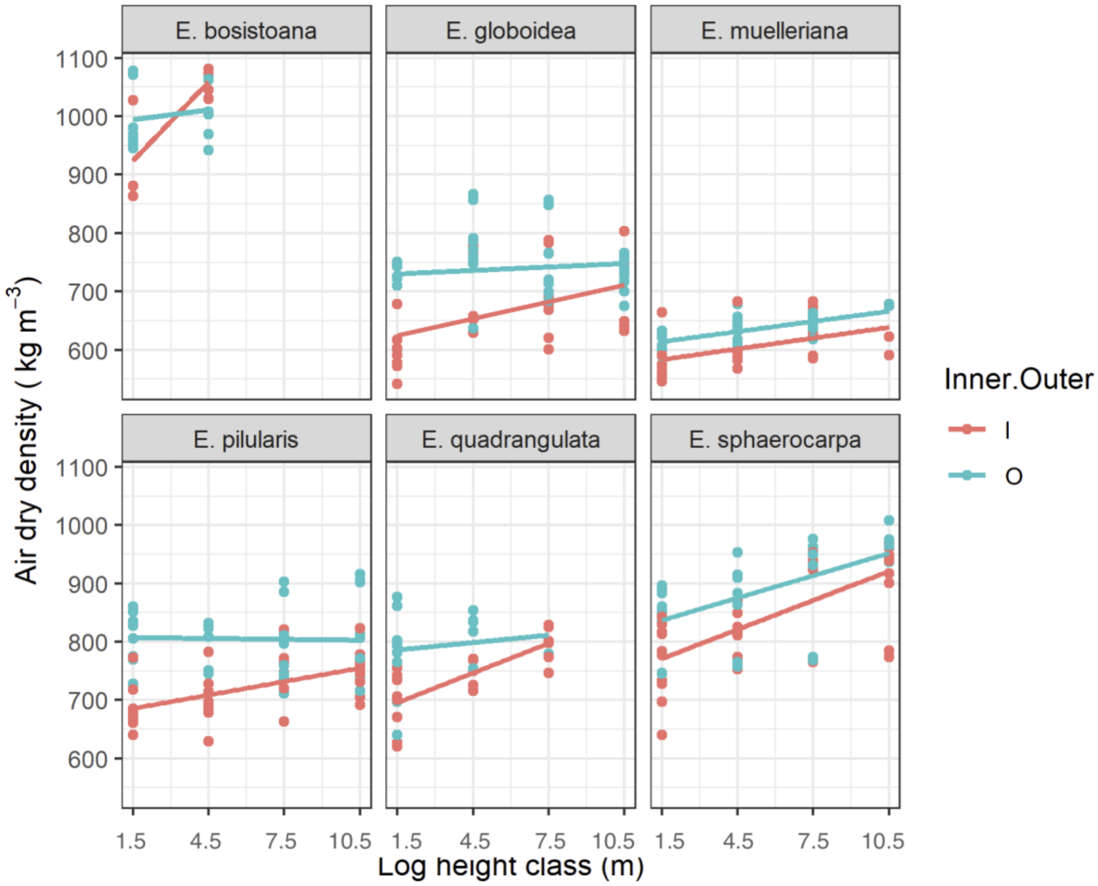

Figure 15: *Density vs Log height*

	numDF	denDF	F-value	p-value
(Intercept)	1	238	6606.214	<.0001
Species	5	18	30.310	<.0001
LogHeight	1	48	63.792	<.0001
Inner.Outer	1	238	201.128	<.0001
Species:LogHeight	5	48	4.878	0.0011
Species:Inner.Outer	5	238	7.023	<.0001
LogHeight:Inner.Outer	1	238	21.781	<.0001
Species:LogHeight:Inner.Outer	5	238	1.485	0.1954

Sample position and species were able to explain approximately 82% of the variation in air-dry density. There was a clear difference in density between radial positions across all species with the exception of *E bosistoana*.

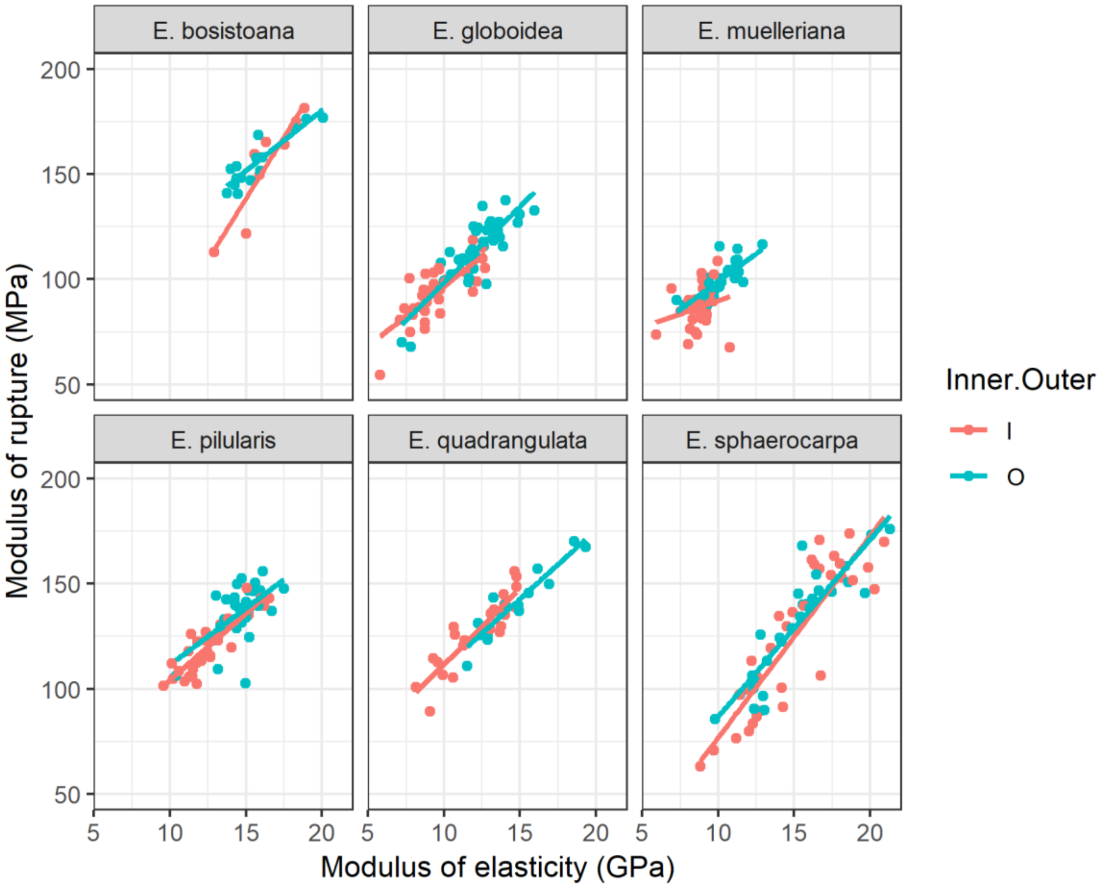

Figure 16: *MoR vs MoE by species*

There is a very strong relationship between MoE and MoR across the six species. The slope and intercept of this relationship differs by species. There is also some suggestion that the relationship between MoE and MoR differs between inner and outer samples (p=0.066). There was no interaction between radial position and log height class (p=0.327).

	numDF	denDF	F-value	p-value
(Intercept)	1	243	11708.740	<.0001
MOE	1	243	1132.171	<.0001
Species	5	18	7.715	0.0005
LogHeight	1	53	4.808	0.0327
Inner.Outer	1	243	3.409	0.0660
MOE:Species	5	243	5.272	0.0001

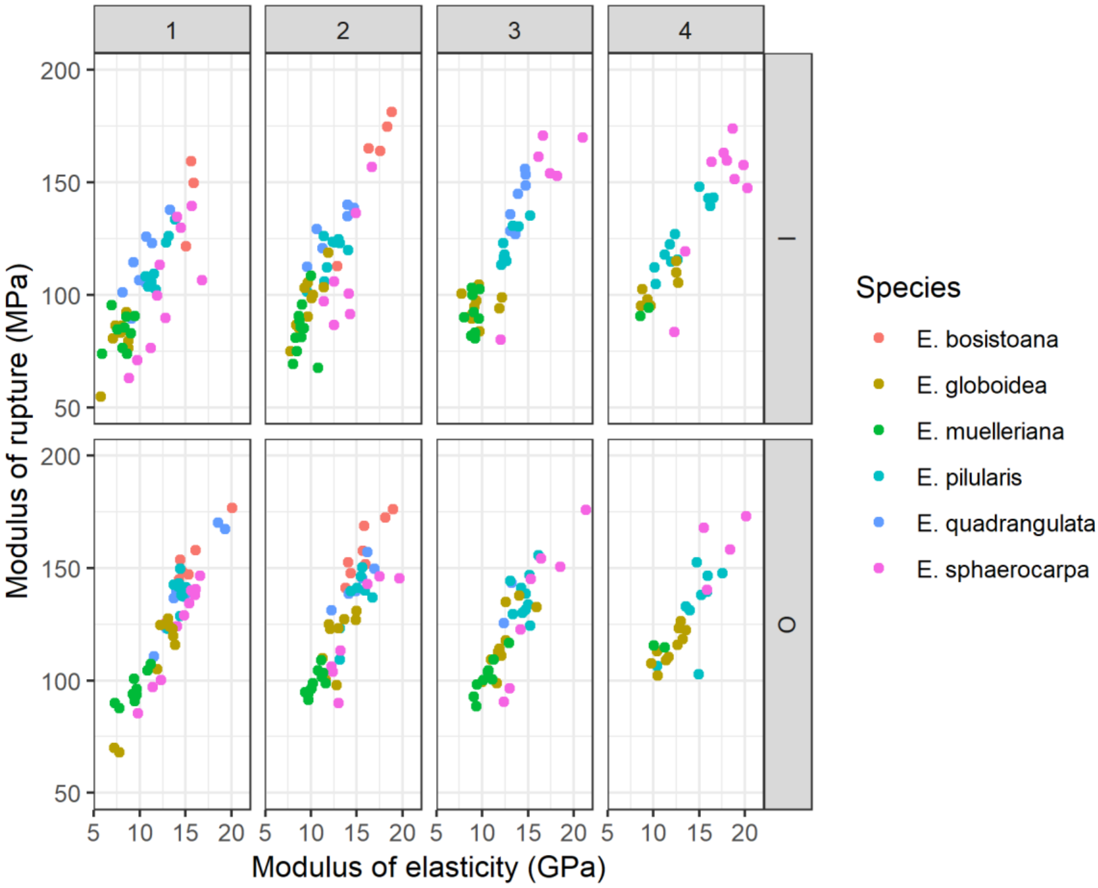

Figure 17: *MoR vs MoE by species according to position in tree Logs 1-4, I (inner heartwood) and O (outer heartwood)*

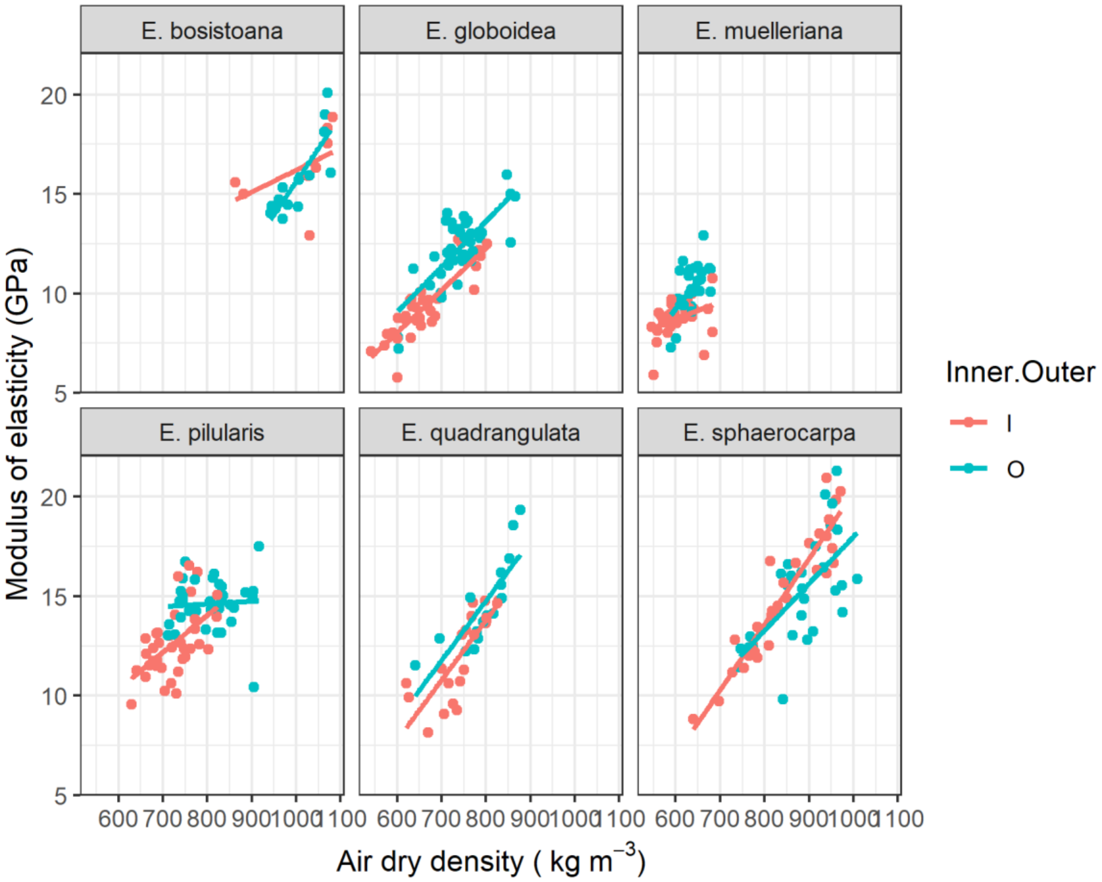

Figure 18: *MoE vs density*

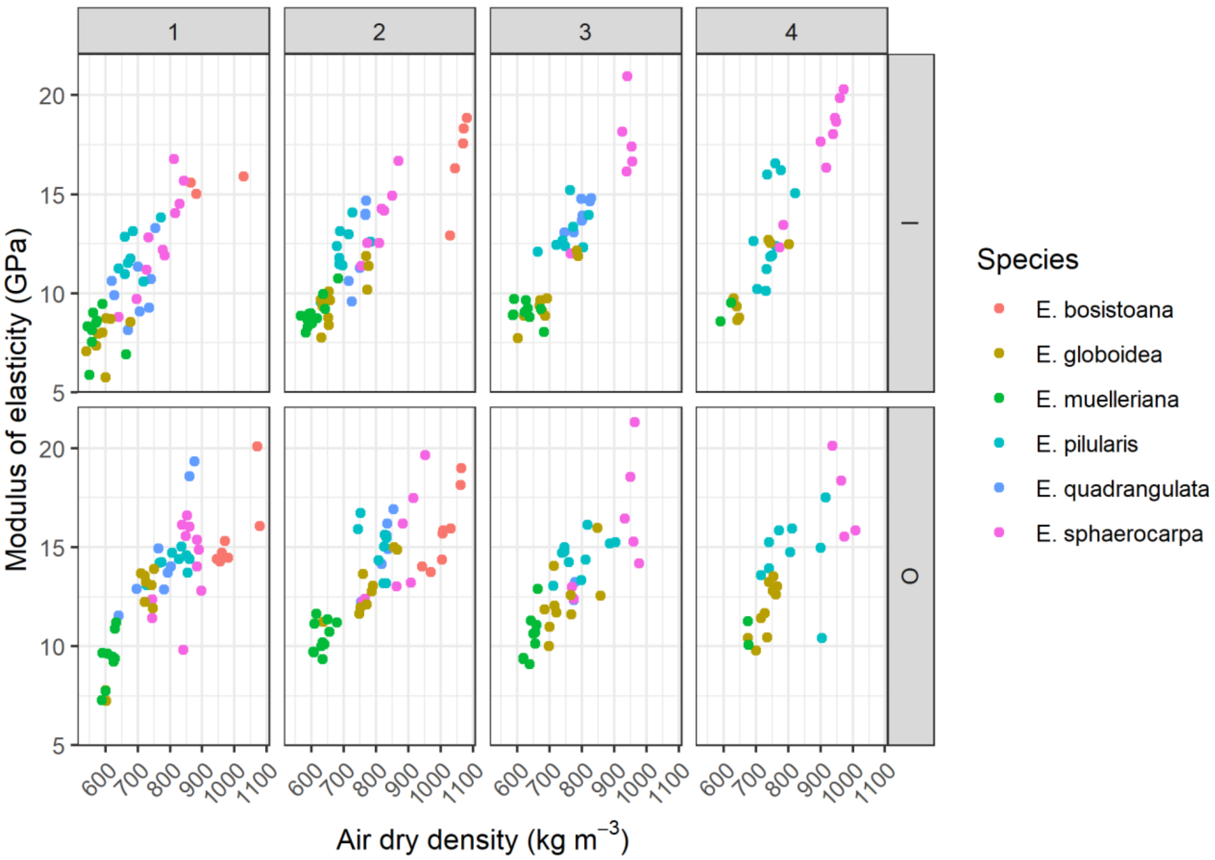

Figure 19: *MoE vs density according to position in tree Logs 1-4, I (inner heartwood) and O (outer heartwood)*

There was a strong relationship between air dry density and MOE. The slope and intercept of this relationship differed by species and radial position, but not by log height class. A similar relationship was found between density and MOR. In this case there was also a significant positive effect of log height class.

Density-MOE

	numDF	denDF	F-value	p-value
(Intercept)	1	232	3746.748	<.0001
dens.emc	1	232	719.213	<.0001
Species	5	18	5.990	0.0020
Inner.Outer	1	232	8.365	0.0042
dens.emc:Species	5	232	7.676	<.0001
dens.emc:Inner.Outer	1	232	28.306	<.0001
Species:Inner.Outer	5	232	3.832	0.0024
dens.emc:Species:Inner.Outer	5	232	2.740	0.0199

Density - MOR

	numDF	denDF	F-value	p-value
(Intercept)	1	232	11654.573	<.0001
dens.emc	1	232	626.117	<.0001
Species	5	18	12.035	<.0001
Inner.Outer	1	232	5.315	0.0220
LogHeight	1	53	6.337	0.0149
dens.emc:Species	5	232	8.328	<.0001
dens.emc:Inner.Outer	1	232	16.338	0.0001
Species:Inner.Outer	5	232	2.088	0.0677
dens.emc:Species:Inner.Outer	5	232	3.175	0.0086

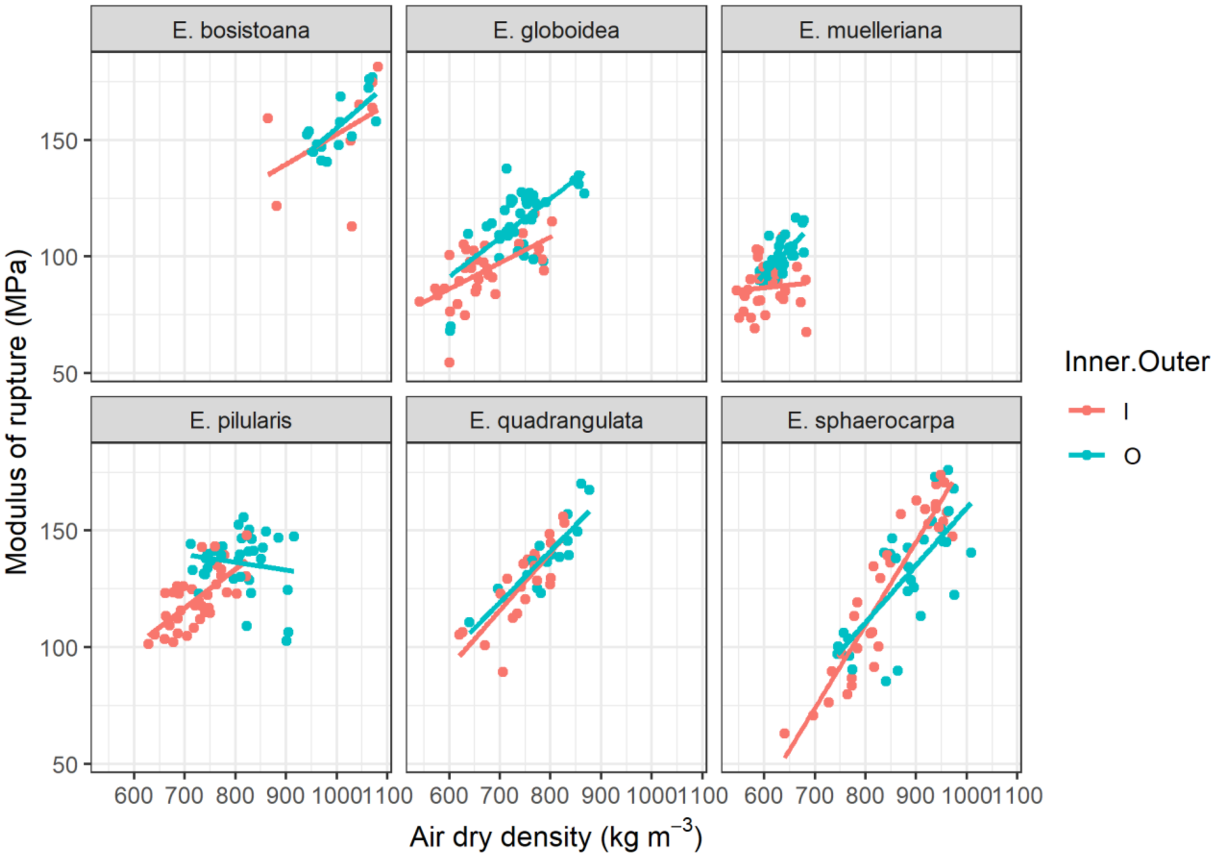

Figure 20: *MoR vs density*

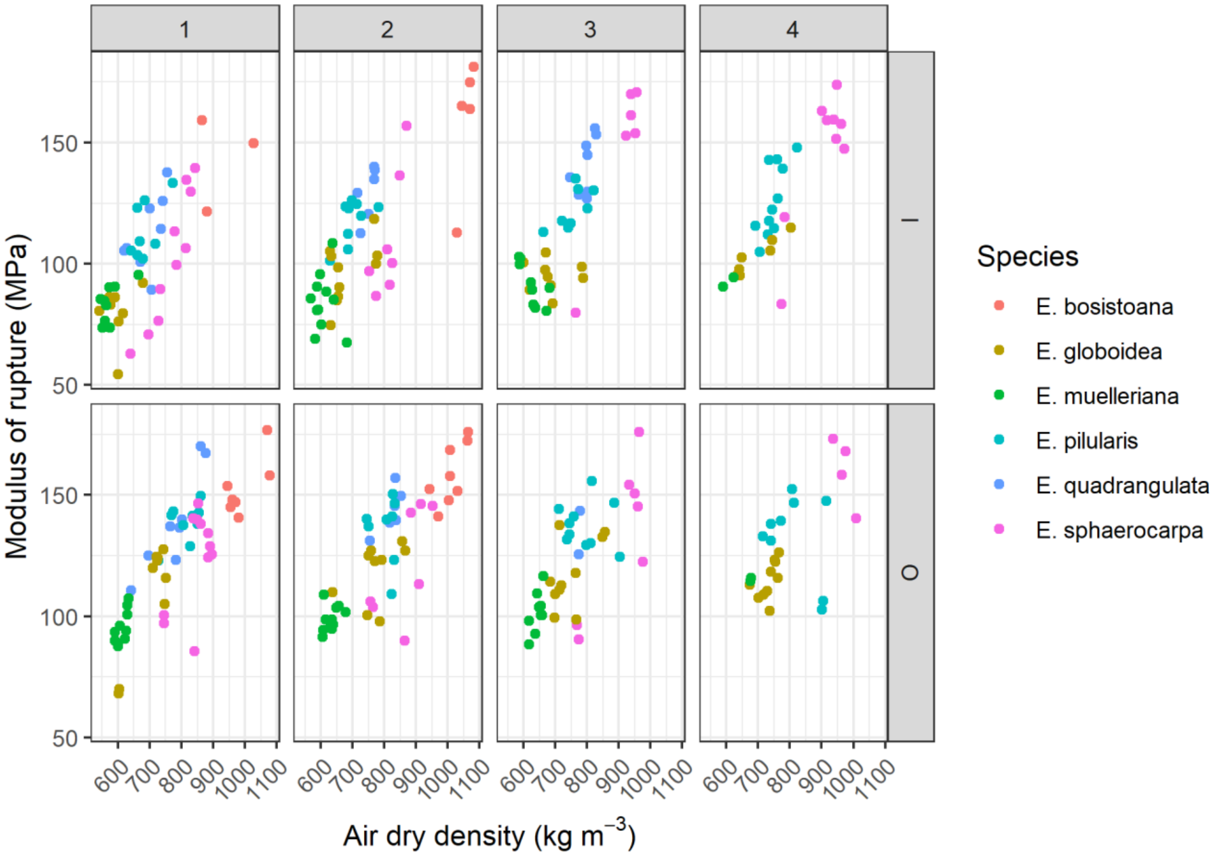

Figure 21: *MoR vs density according to position in tree Logs 1-4, I (inner heartwood) and O (outer heartwood)*

CONCLUSION

Durable eucalypt species offer the opportunity for young wood to be utilised for structural applications requiring good levels of stiffness, with good stiffness and strength properties observed for some species in particular at this young age, especially *E. bosistoana, E. quadrangulata, E. pilularis* and *E. sphaerocarpa*.

Because stiffness and strength increase radially and vertically as the tree matures, for most species age will likely offer improved mechanical properties. For two species, *E. bosistoana* and *E. sphaerocarpa*, mechanical properties appear to be very good even in central material and consistent from inner to outer wood, with *E. sphaerocarpa* showing a dramatic increase in stiffness with tree height, potentially offering opportunities to segregate logs for different applications.

ACKNOWLEDGEMENTS

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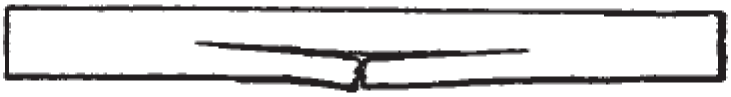
REFERENCES

ASTM D 143 – 94 (Reapproved 2000) Standard Test Methods for Small Clear Specimens of Timber.

Forest Research Bulletin 41 Strength Properties of Small Clear Specimens of New Zealand-Grown Timbers, H. Bier revised by R. A. J. Britton, 1999

APPENDICES

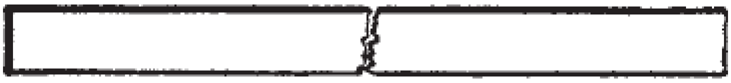
ASTM D143-94 Small Clear failure modes



(*a*) Simple Tension.
(Side View)

(*b*) Cross-Grain Tension.*
(Side View)

(*c*) Splintering Tension.
(View of Tension Surface)



(*d*) Brash Tension.
(View of Tension Surface)

(*e*) Compression.
(Side View)

(*f*) Horizontal Shear.
(Side View)