

**GENETIC VARIATION IN COMMERCIAL PROPERTIES OF SIX- AND 15-YEAR-OLD
*EUCALYPTUS GLOBULUS***

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ABSTRACT

Solid wood properties were measured on samples cut from two progeny trials of *Eucalyptus globulus*: a six-year-old trial of later-generation controlled-pollinated progeny; and a 15-year-old provenance-progeny trial of first generation open-pollinated natural stand collections. Both stands had been grown under fibre-production management without early thinning and pruning. Tree size, stem sweep, and branch score was assessed, a subset of trees felled (34 age-6 and 253 age-15 trees) and 1.5-metre-long mini-sawlogs were harvested from a height of two metres. Back-sawn and quarter-sawn boards were cut from the mini-sawlogs with portable sawmills. Whilst the sample sizes were relatively small and thus estimates of variances and heritabilities somewhat dubious, we observed apparent exploitable genetic variation in most traits. Growth, branch score and spring in green quarter-sawn boards showed significant between-subrace and probably within-subrace genetic variation. Bark thickness showed only between-subrace variance, and stem sweep showed only within-subrace genetic variation. Wood colour may have a low heritability but only very low additive variance, and cup in back-sawn boards appeared to have a high degree of additive variance but very low heritability. No genetic variation in taper was observed.

INTRODUCTION

There is currently around 350,000 hectares of *Eucalyptus globulus* plantation in Australia. Much is currently managed for pulpwood: typical management involves establishment of 1,200 stems per hectare which are grown without thinning or pruning to a clearfall harvest at age 10 to 20 years. The *E. globulus* estate is relatively new and is only now beginning to reach harvest age. The perceived end use of much of the grown material is wood chips for export to be manufactured into fine paper elsewhere.

The current breeding objective employed by the Southern Tree Breeding Association aims to minimise the total cost of producing kraft pulp from grown trees, after the method of Borralho *et al.* (1993), adapted by Greaves *et al.* (1997) and Dutkowski *et al.* (2000) to include the costs of kraft pulp production. The STBA needs to be responsive to potential changes in the utilisation of grown wood. Breeding trees is a long-term business - improvements made via selection of superior breeding parents today will not significantly impact profitability for at least 20 years. An attempt to predict forest product demand in 2030 (Greaves 2003) concluded that with decline in availability of natural-stand roundwood, increased human population, and some change in product preference away from sawn solid wood towards reconstituted structural panels (plywood and OSB) there would be shortfalls (exclusive of increased resource base) in sawn solid wood, reconstituted structural panels, paper, export wood chips and fuelwood.

The aim of the work reported here was to find characteristics or traits of selection-age and mature-age *E. globulus* that show exploitable genetic variation, and that will have relevance in the value of the grown wood for utilisation for wood products other than kraft pulp.

An important consideration when assessing trees for solid wood traits is that stand management is critical in the successful utilisation of plantation-grown *E. globulus* for sawn timber or laminated products. Stands grown at relatively high stocking for much of their rotation and not subjected to pruning, produce low volumes of sawn timber (Yang and Waugh 1996, Washusen 2004a). On the other hand, stand management involving pruning and early, heavy thinning can produce large diameter trees with relatively defect-free butt-logs. A recent study involving pruned and thinned 22-year-old *E. globulus* grown in Western Australia (Washusen 2004b) demonstrated high sawlog recovery (60% of stand volume) and high recoveries of select-grade sawn-timber. Unfortunately, the only available *E. globulus* progeny trials have been grown under fibre-production management, without thinning or pruning, and to attempt to assess these trees with conventional

sawing and recovery standards would yield meaningless results as little of the sawn timber would be suitable for conventional solid-wood products.

We adopted a sampling strategy involving the sawing of only one back-sawn and two quarter-sawn boards from 1.5m long mini-sawlogs cut from a height of greater than two metres. This methodology allowed the individual-tree sampling of a relatively large number of trees. In developing the sampling strategy we sampled 34 six-year-old *E. globulus* using relatively crude but efficient measurement techniques which indicated exploitable genetic variation did exist in traits not previous included in the breeding program. Next we refined the sampling techniques and sampled 253 15-year-old *E. globulus*. This paper reports our results from the sampling of the 34 six-year-old *E. globulus* and our results thus far for the 253 15-year-old *E. globulus*.

SIX-YEAR-OLD *E. GLOBULUS* IN WESTERN AUSTRALIA

The first study involved 6-year-old later-generation controlled-pollinated *E. globulus* growing in south Western Australia (location 430901E 6246629N, altitude 240 m a.s.l., rainfall 700 mm/yr, planting density 1250 s.p.h., silviculture: fibre) - the trial contained 37 families, 10 trees per family, and had been previously sampled for core basic density. All surviving trees (271) were assessed for branch score and stem form score (both three-point scores) and sweep was measured as stem deviation in the middle of a 2 m stem section from 1.5 to 3.5 m from the ground. 34 trees were felled, small sawlogs, 1 m long, were cut from a height of 1.5m, and a sample disk taken from a height of 1.3 m. The mini-sawlogs averaged 139 mm mid-diameter (range 105 - 186 mm). The selected trees represented seven families and were chosen with the aim of sampling suitable-sized trees from the best, worst, and average families as defined by the current breeding objective. Varying numbers of trees per family were sampled (5,1,7,3,2,12,4). The mini-sawlog was sawn using a portable Lucas Mill to recover two 15mm-thick quarter-sawn boards and one back-sawn board (Figure 1).

Spring in the green quarter-sawn boards (QS spring) was measured as the average end-gap between two boards cut through the centre of the log (Figures 1 and 2). Cup in back-sawn samples (BS cup - Figure 3) was measured after air-drying, and the angle of the crack opened in breast-height disks upon oven-drying (OD T-shrinkage - Figure 4) was measured. Wood colour was assessed by photographing all disks together under a relatively uniform light and sampling reflected light from the photograph with image-processor software (PhotoImpact 1999). Variances were estimated by fitting uni-variate linear models for all traits ($y_i = \bar{x} + REP_r + family_f + e_i + covariates$ - covariates were fitted to adjust for the position of back-sawn boards within the stem cross-section) using ASREML software (Gilmour *et al.* 1999). Heritabilities were calculated after $h^2 = 2\sigma_{fam}^2 / (\sigma_{fam}^2 + \sigma_{res}^2)$.

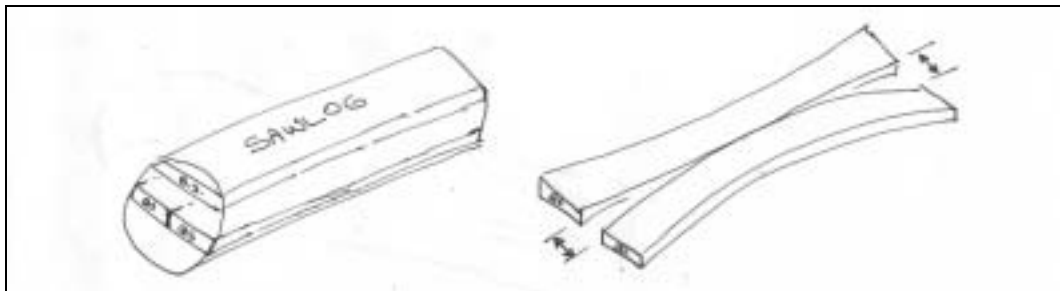


Figure 1: Sawlog sawing pattern (one back-sawn and two quarter-sawn boards), and the measurement of quarter-sawn green spring.

Figure 2 shows spring in quarter-sawn boards. Figure 3 depicts the observed variation in cup-on-drying of back-sawn boards and Figure 4 depicts the observed variation in the degree to which disks cracked and shrunk tangentially on drying. Table 1 presents genetic parameters estimated from uni-variate analysis.

Figure 2: Spring in green quarter-sawn boards (QS spring) - samples are matched bark to pith : pith to bark as they were in the log (see Figure 1) (age 6 *E. globulus*).

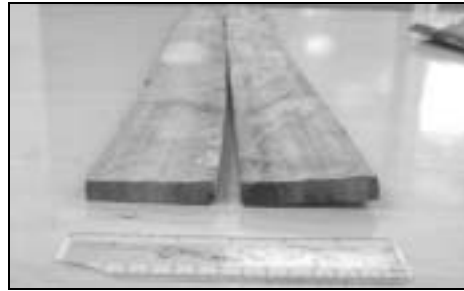


Figure 3: Variation in cup in air-dried back-sawn boards (BS cup) (dried without restraint) (age 6 *E. globulus*).



Figure 4: Variation in the size of the gap that appeared when the disks were oven-dried (at 104°C) (OD T-shrinkage) - observed variation could be the result of variation in both tangential shrinkage and in the strength of the fibre structure to resist formation of a crack when dried (age 6 *E. globulus*).



Table 1: Uni-variate analysis results: mean, sample size, variances, heritability and additive coefficient of variation. Bold numbers indicate estimate is > 2 standard errors, *italic* numbers indicate estimate is greater than 1.2 standard errors.

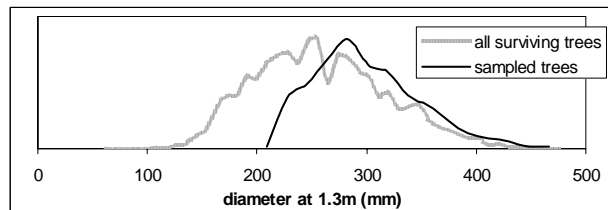
trait	mean	unit	sample size	V(family)		V(resid.)		h ² _{add}		CV _a
				est.	est/se	est.	est.	est.	s.e.	
QS spring	15	mm	34	1.15	1.1	2.13	<i>0.70</i>	0.44	10%	
core basic density	0.466	t/m ³	216	0.00041	3.4	0.00049	0.91	0.16	6%	
OD T-shrinkage	38	degrees	34	103	0.8	396	0.41	0.44	38%	
BS cup	0.026	mm	34	0.00002	0.2	0.00102	0.04	0.25	25%	
dbh	122	mm	360	463	1.9	5069	<i>0.17</i>	0.09	25%	
branch score	1.66	1-3 score	271	0.0606	2.2	0.380	0.28	0.12	21%	
sweep	2.5	cm	264	0.106	1.2	1.97	<i>0.10</i>	0.08	18%	
stem score	2	1-3 score	271	0		0.379	0.00		0%	
light reflectance	116	0-256 scale	34	7.22	0.4	121	0.11	0.30	3%	

FIFTEEN-YEAR-OLD *E. GLOBULUS* IN TASMANIA

The second study involved 15-year-old first-generation open-pollinated *E. globulus* growing in north-west Tasmania, Australia (latitude -41.1, longitude 145.8, altitude 180 m a.s.l., rainfall 1273 mm/yr, silviculture: fibre). The trial of 4,600 trees was established with open-pollinated seed collected from 455 natural-stand trees representing 22 subraces. Subraces are geographical areas of genetic similarity within which individuals can be considered to have equivalent parentage, as defined by Dutkowski and Potts (1999). The trial had been assessed for tree size at various ages, about half the trees had been assessed for Pilodyn penetration at age five years, and cores had been extracted from 190 trees for chemical and density analysis at age 11 years. We remeasured the trial at 15 years for diameter at 1.3 m, branch score (six-point score), and stem sweep (measured as stem deviation in the middle of a 2 m stem section 1.5-3.5 m from the ground).

251 trees were selected, felled, and 1.5 m-long mini-sawlogs cut from a height of between 1.5 and 5.5 m from the ground (mostly 2 to 3.5 metres from the ground) - sampling height varied to avoid sweep and obvious stem defects. Sample disks were cut from six heights (0.2 m, 1.3 m, base-sawlog, top-sawlog, and 40% and 60% of total height). The mini-sawlogs averaged 231 mm mid-diameter (range 165 - 345 mm). The felled trees represented 118 families and 13 subraces and were selected for number of surviving siblings, sufficient suitable trees per family, and balanced sampling across sampled subraces and trial replicates. The diameter distributions of sampled trees and all surviving trees are depicted in Figure 5.

Figure 5: Diameter distributions of the 251 sampled trees and the 2,123 surviving trees in the trial that could have been sampled.



The mini-sawlog was sawn using a portable chainsaw-mill to recover four 25 mm-thick boards: one back-sawn board, two matched pith-to-bark quarter-sawn boards (Figure 1) and a pith-to-pith quarter-sawn slab.

Spring in the green quarter-sawn boards was measured as described above (Figure 1). The green sawn samples are in transit to a kiln for controlled drying. Shrinkage blocks 25 mm (T) x 25 mm (R) x 300 mm (L) (Kingston and Risdon 1961) will be cut from green clearwood in a quarter-sawn board. The remaining whole quarter-sawn and back-sawn boards will be kiln-dried, reconditioned, finished and assessed for warp and apparent quality. A 300 mm long sample of the seasoned quarter-sawn board will be measured for MOE and MOR (stiffness and strength), and another for Janka hardness.

The sample disks were cut in half: one half was frozen for future analysis if required (Silviscan, NIRA or chemical analysis); the other half was soaked and green volume estimated using a water displacement method. The half disks will be kiln-dried and measured for shrinkage and collapse (Figure 6), steam reconditioned and re-measured, and finally oven-dried at 104°C and weighed to complete basic density estimation. Shrinkage and collapse behavior will be compared to shrinkage and collapse of 12 mm cores also cut from sampled disks.

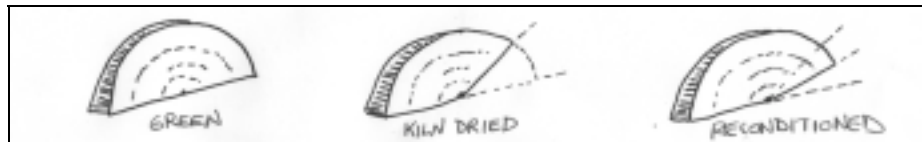


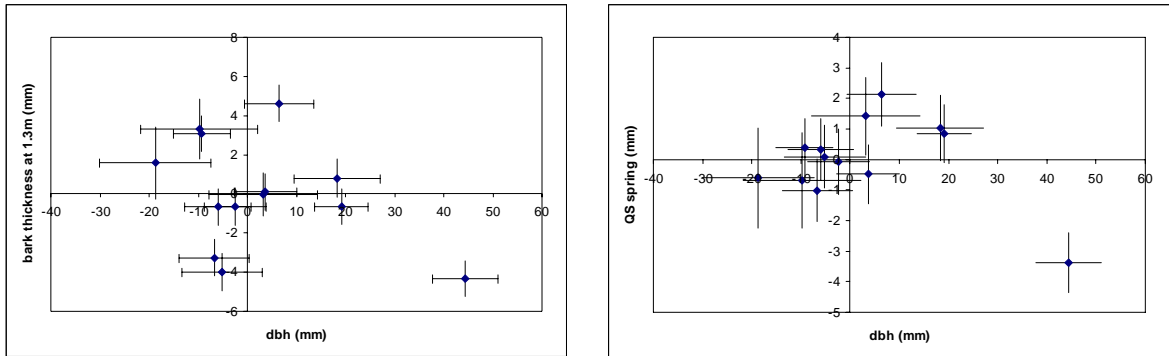
Figure 6: Measuring tangential shrinkage and collapse on half disks.

The variation in available data was estimated by fitting uni-variate linear models for all traits ($y_i = \bar{x} + REP_r + SUBRACE_s + family_f + e_i$ after Lopez *et al.* 2002) using ASREML software (Gilmour *et al.* 1999). Heritabilities were calculated after $h^2 = 2.5\sigma_{fam}^2 / (\sigma_{fam}^2 + \sigma_{res}^2)$. Table 2 presents means, variance estimates, and calculated heritabilities after uni-variate analysis.

Table 2: Uni-variate analysis results: mean, sample size, variances (and standard errors), heritability and additive coefficient of variation. Bold numbers indicate estimate is > 2 standard errors, *italic* numbers indicate estimate is greater than 1.6 standard errors. * indicates subrace effect significant at $p < 0.001$.**

trait	mean	unit	n	F(subrace)	V(family)		V(resid.)		h ²		CV _a
					est.	est/se	est.	est.	s.e.		
dbh 2004 age 15	254	mm	2123	7.0 ***	237	3.8	3221	0.17	0.04	9%	
QS spring	17	mm	253	4.3 ***	<i>4.06</i>	1.9	19.4	<i>0.43</i>	0.22	17%	
stem sweep	1.94	cm	957	0.8	<i>0.173</i>	1.7	2.83	<i>0.14</i>	0.09	30%	
taper lower log	1.6	mm/m	252	0.6	0		1.25	0.00		0%	
taper 50% ht	1.0	mm/m	250	0.7	0.00469	0.4	0.140	0.07	0.21	9%	
bark thick. 1.3m	14	mm	253	20.5 ***	0.180	0.3	7.16	0.06	0.21	4%	
bark thick. 40%ht	7.1	mm	252	9.0 ***	0		2.37	0.00		0%	
branch score	3.6	1 - 3	2214	0.8	0.108	4.1	1.26	0.20	0.05	13%	

Figures 7 and 8 compare estimates of subrace effects bark thickness and dbh, and spring in quarter-sawn boards and dbh showing little relationship between these traits at a subrace level. These traits all show significant differences between subraces for these traits.



Figures 7 and 8: Comparing subrace mean values (estimated as random effects) of bark thickness and dbh, and spring in green quarter-sawn boards and dbh - error bars represent plus and minus one standard error.

DISCUSSION AND CONCLUSIONS

The results indicate that there is significant exploitable variation between-subrace and probably within-subrace for growth, branch score and spring in green quarter-sawn boards. Bark thickness showed only between-subrace variance, and stem sweep showed only within-subrace genetic variation. Wood colour may have a low heritability but only very low additive variance, and cup in back-sawn boards appeared to have a high degree of additive variance but very low heritability. No genetic variation in taper was observed.

The commercial value of the measured traits is the subject of another paper (Greaves *et al.* 2004). Spring in green quarter-sawn boards may have commercial importance in production of quarter-sawn solid wood through its influence on recovery. However, the recovery of back-sawn boards using a radial sawing system would be unaffected by growth-stress-induced spring. The expressed spring may be an indicator of the propensity of sawlogs to end-split - a significant cause of recovery-loss of sawn-timber and veneer production, although end-split may be related to both the degree of growth-stress and the ability of the wood fibre structure to resist formation of cracks. The degree of growth-stress-induced spring in boards cut from fibre-managed plantations may be less relevant when grown trees are managed for sawlogs, as Washusen (2004b) reported minimal growth-stress-induced distortion when sawing sawlog-managed 22-year-old *E. globulus* in Western Australia.

The variation in shrinkage and collapse behaviour is expected to have commercial value in the recovery of veneer, in the stability of back-sawn boards, and in the value of appearance grade sawn-products through a relationship with internal and surface checking.

The applicability of the reported results are limited in that only one site was sampled for each population, and variation due to GxE is unknown. Further, sampling was not random either between- or within-family and the resulting genetic parameters must be considered in this light. Since sawlog-management involves selective retention of established trees, selection within family for suitable trees may not be an unrepresentative strategy for progeny sampling for solid-wood traits.

One subrace stands out as having high growth and low quarter-sawn green-spring (Figure 8), although no conclusions can yet be drawn regarding subrace ranking as the quality recovery of sawn boards after drying will be a critical performance characteristic.

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