

BREEDING OBJECTIVES FOR EUCALYPTUS GLOBULUS FOR PRODUCTS OTHER THAN KRAFT PULP

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ABSTRACT

The Southern Tree Breeding Association (STBA) is breeding *Eucalyptus globulus* in Australia to maximise the profitability of growing plantation trees for kraft pulp production (NPV/ha). Growth rate and wood basic density are assessed and used to select parents for use in breeding and deployment. Increases in demand, changing availability of natural-forest wood, and environmental concerns may lead to increased use of plantations for other products in the next 20 years. The STBA needs flexibility in its breeding programs to respond to possible future shifts in plantation use. To this end a multi-product wood utilisation model was constructed to determine the value of trait improvement on the profitability of growing and utilising *E. globulus* for alternative wood products. These products included: wood chips for export, fine printing and writing paper from kraft pulp, sawn timber, oriented strand board, medium density fibre board, and fuelwood. The influence of objective-traits on wood production and utilisation for alternative products was examined. Some traits influence the cost of growing plantation wood, some influence the efficiency of conversion, whilst others influence the value of products. The value of improvement in each trait to the entire wood utilisation structure was estimated for various future scenarios. A general breeding objective was also derived to maximise the opportunities for future use of plantation-grown *E. globulus*. The derived breeding objective was combined with estimated genetic parameters of production traits and selection traits to compare measurement strategies for breeding for multi-product objectives.

INTRODUCTION

There are currently around 400,000 hectares of *Eucalyptus globulus* plantations in Australia. Almost all 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 with some plantations 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 includes three objective traits: volume per hectare, average basic density and average kraft pulp yield at rotation end (Dutkowski *et al.* 2000). Selection traits have been tree diameter (and some heights), pilodyn penetration and core basic density. Near-infrared-analysis-predicted (NIRA) kraft pulp yield is currently assessed and will be included in the next round of genetic evaluation and selection (Pilbeam and Dutkowski 2004). Objective trait breeding values are estimated from available selection trait data using assumed genetic correlations and variances, and the overall value (V) for each genotype is determined as a linear index $V = blup_{VOL}w_{VOL} + blup_{DENS}w_{DENS} + blup_{KPY}w_{KPY}$ where: $blup_{VOL}$ is the breeding value for volume-per-hectare-at-rotation for a genotype, estimated as a BLUP with units of m^3/ha at rotation; w_{VOL} is the estimated economic weight for volume at rotation and has the units of $(\$/_{NPV/ha})/(m^3/ha)$, and similarly for density and kraft pulp yield. Thus $blup_{VOL}w_{VOL}$ and total index value have the units of $\$/_{NPV/ha}$. NPV is the total Net Present Value for one rotation estimated as total discounted income less total discounted costs. The economic weights currently used by the STBA were derived after the method of Borralho *et al.* (1993) and 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 supply. Breeding trees is a long-term business - improvements made via selection of superior breeding parents today will not significantly impact on profitability for at least 20 years. In 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 product preference move away from sawn solid wood towards reconstituted structural panels (plywood and OSB) there would be shortfalls (exclusive of increased plantation resource base) in sawn solid wood, reconstituted structural panels, paper and export wood chips and fuelwood.

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). In contrast, 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 outturn (60% of stand volume) and high recoveries of select-grade sawn-timber. Pruned plantation-grown logs are believed to be suitable for peeling for structural plywood manufacture, and fibre logs potentially suitable for oriented strand board, chips, pulp, paper or fuelwood (and possibly medium density fibre-board) (Volker 2002).

The work reported here is aimed at addressing the questions: (1) what are the most likely alternative breeding objectives for *E. globulus*? (2) what should STBA be measuring at selection age for the alternative breeding objectives?, and specifically, (3) what is the relationship between selection for an export wood-chip objective (the current objective) and selection for the most likely future utilisation alternatives? The reported results represent calculations made using many assumptions, most of which are largely unvalidated. However, the work presents a framework for undertaking the necessary analysis, which will be refined as better information becomes available.

METHOD

The method (adapted from the steps in defining a breeding objective of Ponzoni and Newman (1989)) was: (1) Define the production and utilisation system identifying areas of income and expense; (2) Determine the biological traits influencing income and expense; and (3) Derive the economic value of each trait defined as the economic effect of a change in the level of a trait.

Two forest management systems were modelled, based upon the growth and yield model of the Farm Forestry Toolbox (FFT.V.4.0 - Private Forests Tasmania 2004): the first using silvicultural practices typical of pulpwood managed stands; the second using sawlog management as was applied to the stand sawn by Washusen (2004) involving two early non-commercial thinning operations to a final crop stocking of 225 stems per hectare at age 5 years and pruning in three lifts to 10 metres (Moore *et al.* 1996). Average volume growth by log type for the two forest management systems are shown in Table 1. As future desired utilisation of grown roundwood is not known, and various options exist (Volker 2002), a computer model was constructed encompassing growing, harvesting, transport, export chip-mill, in-forest chipper, plywood mill, sawmills for pruned and unpruned sawlogs, OSB and MDF mills, a chip/kraft-pulp/fine-paper mill, and a fuelwood plant. Log volumes by grade were defined by the growth model. Log flows to various processes were defined as inputs. Product quantities, costs and values were estimated by the model. In all, six production-utilisation scenarios were defined as combinations of the two forest management systems and various utilisation options (Table 1).

A list of selection traits that might be considered as candidate traits for selection of elite genotypes in a breeding program was compiled (Table 2). The assumed genetic coefficient of variation (being the genetic standard deviation divided by the mean), heritability, and cost of assessment are tabulated. These represent the best estimates available, as all are needed to undertake an analysis of which traits should be measured. These represent a starting point that will be refined as better information becomes available. Gain due to univariate trait selection of 10 genotypes from 1,000 (Table 2) was estimated as $G = 2.67\sqrt{h^2}CV_a$ where gain is expressed as a fraction of the trait mean. Although for low heritability traits, gain would be improved with combined-index or BLUP-based selection, the tabulated gain estimate shows the relative gains that could be achieved in a generation of breeding.

Derivation of the economic value of each selection trait was undertaken in two steps. First, the *Target Traits* were defined, mostly as product conversion efficiencies and costs, and product values at rotation end (Table 3). For each target trait, a *Value Weight* was estimated as the change in total production-utilisation system Net Present Value per hectare associated with a 10% trait increase. Value weights were estimated for each

target trait for each production-utilisation scenerio (Table 3). Next, genetic correlations relating selection traits to target traits were estimated/assumed, based upon the expectation of effect as summarised by Raymond (2000), and our understanding of each of the conversion processes. Similarly, the genetic variation of each target trait, and the genetic correlations between selection traits, were similarly estimated. Whilst these parameters are critical to the analysis, they are also constrained by defined boundaries and common sense. The correlation matrices are not reproduced here for lack of space.

Selection index coefficients were estimated for selection after $\mathbf{b} = \mathbf{G}_{ss}^{-1} \mathbf{G}_{st} \mathbf{w}$ where \mathbf{b} is a vector of index coefficients for selection traits, \mathbf{G}_{ss} is the (co)variance matrix relating the selection traits, \mathbf{G}_{st} is the (co)variance matrix relating the selection traits to the target traits, \mathbf{w} is a vector of economic weights for target traits calculated from derived value weights after $w = 10V / \bar{t}$ where V is the value weight and \bar{t} is the target trait mean. Covariance elements were calculated after $\text{cov}_{1,2} = r_{1,2} CV_1 \bar{x}_1 CV_2 \bar{x}_2$ where $r_{1,2}$ is the assumed genetic correlation between the traits (1 and 2) and CV is the assumed genetic coefficient of variation (being the genetic standard deviation divided by the mean). To compare the value of alternative selection traits for each production-utilisation scenario, the value of 1:100 single trait selection was estimated. This number encompasses the correlations between the selection trait and all target traits and indicative of the value of the selection trait to the breeder. It is but an indicator of selection trait value, as the cost of assessment and the measurement of multiple traits influence to value of an individual trait in a selection program.

To compare objectives - in particular the current objective versus a solid-wood utilisation system - genetic correlations between selection index sets were estimated using $r_{12} = \mathbf{b}_1 \mathbf{G}_{ss} \mathbf{b}_2 / \sqrt{(\mathbf{b}_1 \mathbf{G}_{ss} \mathbf{b}_1)(\mathbf{b}_2 \mathbf{G}_{ss} \mathbf{b}_2)}$ (James 1982).

RESULTS AND DISCUSSION

The results are presented in the following five tables. Table 1 presents a summary of the six modelled production-utilisation scenerios, including: silviculture, roundwood utilisation and products produced. Each are model outputs estimated from the specified model input parameters. Table 2 presents a compiled list of possible selection traits including best estimates/guesses of genetic coefficient of variation, heritability, assessment cost and estimated gain from uni-trait selection of 1:100.

Table 3 presents value weights estimated for each target trait and each production-utilisation scenerio. For example, for plantations managed for sawlogs (pruned and thinned) with fibre going to export wood chips, a 10% increase in green-off-saw recovery of the unpruned sawlog mill will increase overall Net Present Value per hectare by \$59 compared to \$565 per hectare from increasing green-off-saw recovery of the pruned sawlog mill (largely reflecting the difference in unpruned and pruned sawlog volumes produced - Table 1).

Table 4 presents the estimated change in Net Present Value due to the expected gain due to 1:100 uni-trait selection of each possible selection trait individually, for each production-utilisation scenario. For example, 1:100 selection for core basic density will increase core basic density by 7%, which will have a net effect of increasing Net Present Value per hectare by \$370 for a fibre crop grown for export wood-chips, but reducing NPV by \$102 for a pruned sawlog crop with residue exported as wood-chips (the negative weight reflecting the assumed negative correlation with growth-rate of -0.15 - dual-trait selection for dbh and density results in positive coefficients for both). The reported numbers are a preliminary indication of the relative value of each trait for selection for each production-utilisation system. Further analysis is required to determine optimum trait combinations and assessment strate for multi-trait multi-stage selection.

Table 5 presents estimated genetic correlations between various single-stage multiple-trait selection strategies for three production-utilisation scenarios. When selecting for only *dbh* and core basic density, the best selections for a fibre crop for export chips or for paper from kraft pulp are well aligned with the best selections for a multiple-product pruned-thinned stand ($r = 0.84$ and 0.91 , respectively). However, when more solid-wood-specific traits are included in selection for the multiple-product pruned-thinned stand (core collapse and silviscan traits), the genetic correlation with the fibre-crop objectives drops markedly ($r = 0.09$ to 0.29).

Table 1: Summary of production-utilisation scenerios modelled: silviculture, roundwood utilisation and products

production-utilisation scenario:		fibre crop for export wood-chips	fibre crop for export wood-chips, fine paper, OSB	fibre crop for fine paper	pruned sawlog crop - fibre for export wood-chips	pruned peeler-log crop - fibre for export wood-chips	pruned sawlog/peeler crop - fibre for export wood-chips, paper, OSB
management							
rotation length	years	15	15	15	25	25	25
forest management strategy		fibre	fibre	fibre	sawlog: prune, non-commercial thin	sawlog: prune, non-commercial thin	sawlog: prune, non-commercial thin
fibre use strategy		chipmill for export	mixed - fibre crop	kraft pulp to fine paper	chipmill for export	chipmill for export	mixed - sawlog
roundwood utilisation							
sawlogs - pruned	m3/ha/yr				6.9		3.5
sawlogs - unpruned	m3/ha/yr				1.2	1.2	1.2
peeler logs	m3/ha/yr					6.9	3.5
fibre logs	m3/ha/yr	22.7	22.7	22.7	11.1	11.1	11.1
sawmill chips	m3/ha/yr				2.8	0.4	1.6
fibre use	in-forest chipping for export	m3/ha/yr					
	chip-mill for export	m3/ha/yr	22.7	15.9		13.9	11.5
	kraft pulp to fine paper	m3/ha/yr		4.5	22.7		4.9
	OSB	m3/ha/yr		2.3			2.2
	MDF	m3/ha/yr					
forest products							
total sawn timber - pruned	m3/ha/yr				2.4		1.2
total sawn timber - unpruned	m3/ha/yr				0.4	0.4	0.4
plywood - pruned logs	m3/ha/yr					2.4	1.2
in-forest chips for export	m3/ha/yr						
export chipmill chips	m3/ha/yr	21.6	15.1		13.3	10.9	5.3
fine paper from kraft pulp	t/ha/yr		1.0	5.1			1.2
OSB	m3 OSB/ha/yr		1.8				1.8
MDF	m3 MDF/ha/yr						

Table 2: Possible selection traits in *E. globulus* - best estimates/guesses of genetic coefficient of variation, heritability, assessment cost and estimated gain from uni-trait selection of 1:100. No indicator of estimate reliability is provided, and whilst some are based upon field measurements, others are based upon little more than considered opinion.

selection trait	unit	discription	tree average	between-tree CVa	h2	assessment costs		gain: uni-trait selection 10:1000
						per tree	1000 trees	
dbh	cm		25	15%	0.15	\$0.5	\$500	16%
branch score	1-6 score	6 is best	3.5	10%	0.2	\$0.5	\$500	12%
branch size	cm	average age 6	10	10%	0.2	\$1.0	\$1,000	12%
form	1-6 score	6 is best	3.5	10%	0.2	\$0.5	\$500	12%
taper	mm/m		10	5%	0.1	\$1.0	\$1,000	4%
pilodyn	mm/m		12	8%	0.4	\$3.0	\$3,000	14%
SWV		non-destructive	1	4%	0.4	\$30	\$30,000	7%
core basic density	t/m3	core	0.54	4%	0.4	\$22	\$22,000	7%
core collapse		core	1	4%	0.3	\$22	\$22,000	6%
S:G ratio		one core?	2.5	1.5%	0.5	\$342	\$342,000	3%
nira cellulose content			0.5	1.5%	0.3	\$52	\$52,000	2%
silviscan traits			1	4%	0.3	\$312	\$312,000	6%
kraft pulp yield			0.5	1.5%	0.5	\$1,030	\$1,030,000	3%
decay trait			1	5%	0.2	\$40	\$40,000	6%
warp: back-sawn cup			1	5%	0.1	\$110	\$110,000	4%
warp: quarter-sawn spring			15	5%	0.5	\$105	\$105,000	9%
MOE and MOR		desctructive tree sample	1	5%	0.4	\$150	\$150,000	8%
hardness/impact resistance			1	5%	0.3	\$110	\$110,000	7%
tangential shrinkage			1	5%	0.3	\$140	\$140,000	7%
colour			1	5%	0.3	\$110	\$110,000	7%
checking			1	5%	0.3	\$110	\$110,000	7%
drying rate			1	5%	0.3	\$120	\$120,000	7%
tension wood	score ?	propensity	1	5%	0.3	\$62	\$62,000	7%

Table 3: Estimated value weights for target traits, by production-utilisation system configuration. A value weight is the change in production system Net Present Value per hectare associated with a 10% trait increase (Δ NPVha/+10%).

target trait	unit	fibre crop for export wood-chips	fibre crop for export wood-chips, fine paper, OSB	fibre crop for fine paper	pruned sawlog crop - fibre for export wood-chips	pruned peeler-log crop - fibre for export wood-chips	pruned sawlog/peeler crop - fibre for export wood-chips, paper, OSB
MAI(10)	m3/ha/yr	\$330	\$594	\$1,459	\$813	\$840	\$1,459
density	t/m3	\$916	\$931	\$1,737	\$382	\$385	\$496
pulp yield	ODt/ODt	\$0	\$347	\$1,737	\$0	\$0	\$355
pulping cost	/ODt BEK	\$0	-\$171	-\$854	\$0	\$0	-\$168
paper-making cost	/t paper	\$0	-\$558	-\$2,790	\$0	\$0	-\$549
paper value	/t paper	\$0	\$1,116	\$5,581	\$0	\$0	\$1,099
unpruned sawlog fraction age 25	fraction	\$0	\$0	\$0	\$23	\$23	\$39
pruned log fraction age 25	fraction	\$0	\$0	\$0	\$354	\$502	\$420
peeler log fraction	of pruned logs	\$0	\$0	\$0	\$0	\$148	-\$27
sawmill green recovery unpruned	of log volume	\$0	\$0	\$0	\$59	\$59	\$20
sawmill green recovery pruned	of log volume	\$0	\$0	\$0	\$565	\$0	\$168
sawing conversion cost unpruned	/m3 sawn	\$0	\$0	\$0	-\$110	-\$110	-\$110
sawing conversion cost pruned	/m3 sawn	\$0	\$0	\$0	-\$651	\$0	-\$325
sawmill drier recovery	of dried volume	\$0	\$0	\$0	\$597	\$55	\$326
sawn-timber value - unpruned	/m3	\$0	\$0	\$0	\$165	\$165	\$165
sawn-timber value - pruned	/m3	\$0	\$0	\$0	\$1,193	\$0	\$597
plywood recovery	m3/m3 log	\$0	\$0	\$0	\$0	\$670	\$335
plywood conversion cost	/m3 ply	\$0	\$0	\$0	\$0	-\$447	-\$223
plywood value	/m3 ply	\$0	\$0	\$0	\$0	\$1,117	\$558
drying rate	score	\$0	\$0	\$0	\$0	\$89	\$45
MDF recovery	m3/m3 log	\$0	\$0	\$0	\$0	\$0	\$0
MDF conversion cost	/m3 MDF	\$0	\$0	\$0	\$0	\$0	\$0
MDF value	/m3 MDF	\$0	\$0	\$0	\$0	\$0	\$0
OSB recovery	m3/m3 log	\$0	\$99	\$0	\$0	\$0	\$81
OSB conversion cost	/m3 OSB	\$0	-\$494	\$0	\$0	\$0	-\$407
OSB value	/m3 OSB	\$0	\$592	\$0	\$0	\$0	\$489

Table 4: Estimated gain from 1:100 uni-trait selection (trait gain after Table 2) by selection trait for each modelled production system configuration. Each gain estimate is the change in total production system Net Present Value per hectare associated with a 1:100 uni-trait selection gain.

selection trait	gain: uni-trait selection 10:1000	production-utilisation system					
		fibre crop for export wood-chips	fibre crop for export wood-chips, fine paper, OSB	fibre crop for fine paper	pruned sawlog crop - fibre for export wood-chips	pruned peeler-log crop - fibre for export wood-chips	pruned sawlog/peeler crop - fibre for export wood-chips, paper, OSB
dbh	16%	\$353	\$679	\$1,703	\$985	\$1,018	\$1,780
branch score	12%	\$0	\$0	\$0	\$136	\$137	\$116
branch size	12%	\$0	\$0	\$0	-\$85	-\$120	-\$100
form	12%	\$0	\$0	\$0	\$113	\$183	\$132
taper	4%	\$0	\$0	\$0	\$51	-\$28	\$31
pilodyn	14%	-\$350	-\$290	-\$452	\$89	\$21	\$162
SWV	7%	\$0	\$0	\$0	\$28	\$28	\$28
core basic density	7%	\$370	\$391	\$326	-\$102	\$40	-\$119
core collapse	6%	\$0	\$0	\$0	-\$485	-\$64	-\$274
S:G ratio	3%	\$0	\$42	\$212	\$0	\$0	\$43
nira kraft pulp yield	2%	\$0	\$28	\$142	\$0	\$0	\$30
silviscan traits	6%	\$0	\$65	\$326	\$516	\$191	\$401
kraft pulp yield	3%	\$0	\$121	\$604	\$0	\$0	\$122
decay trait	6%	\$0	\$12	\$62	-\$16	-\$20	\$9
warp: back-sawn cup	4%	\$0	\$0	\$0	-\$172	-\$21	-\$96
warp: quarter-sawn spring	9%	\$0	\$0	\$0	-\$392	-\$48	-\$177
MOE and MOR	8%	\$0	\$0	\$0	-\$59	\$5	-\$27
hardness/impact resistance	7%	\$0	\$0	\$0	\$87	\$8	\$48
tangential shrinkage	7%	\$0	\$0	\$0	\$32	\$16	\$24
colour	7%	\$0	\$5	\$25	\$87	\$0	\$49
checking	7%	\$0	\$0	\$0	-\$460	-\$24	-\$242
drying rate	7%	\$0	\$0	\$0	\$56	\$8	\$32
tension wood	7%	\$0	-\$24	-\$49	-\$314	-\$28	-\$150

Table 5: Estimated genetic correlations between selection objectives - numbers on the left correspond to numbers and production/selection scenarios along the top

	1	2	3	4	5	6	7
production-utilisation scenario	pruned sawlog/peeler crop - fibre for export wood-chips, paper, OSB				fibre crop for export wood chips	fibre crop for fine paper from kraft pulp	
selection traits	dbh core-basic-density core-collapse silviscan-traits	dbh core-basic-density silviscan-traits	dbh core-basic-density core-collapse	dbh core-basic-density	dbh core-basic-density	dbh core-basic-density	dbh core-basic-density nira-KPY
1	1						
2	0.75	1					
3	0.65	0.08	1				
4	0.10	0.24	0.34	1			
5	0.09	0.20	0.29	0.84	1		
6	0.10	0.24	0.34	0.99	0.91	1	
7	0.10	0.24	0.34	0.99	0.91	1.00	1

CONCLUSION

The results presented here are the first estimates from a complex computer model constructed to address the difficult question of what should we be measuring now in breeding *E. globulus* for a future market which is unknown. Many assumptions underpin the presented results, and as yet, no formal sensitivity analysis has been undertaken. As such the results must be considered with caution until we do more work on the model!

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