Resources

Re-measurement of lower-rainfall farm forestry species in Victoria to improve genetic quality and establishment:

A report on Establishment Techniques, Sawlog Species Comparison and Eucalyptus cladocalyx Progeny Trials in south-west Victoria after eighteen years

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Prepared for

Forest & Wood Products Australia

by

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Executive Summary

This report documents the results from three trials in the Lismore area of Western Victoria that were established in 2002-2003 to improve knowledge of growth rates and species suitability for farm forestry plantings on lower rainfall sites in Victoria.

They include a trial of establishment techniques, a sawlog species comparison and a progeny trial for *Eucalyptus cladocalyx* (Sugar Gum).

The *E. cladocalyx* progeny trial is particularly significant and can provide a principal source of improved seed for this species which demonstrably has a lot to contribute to the development of lower rainfall sawlog and biomass production.

This report was commissioned to capture the results of the studies and provide guidance for new initiatives to re-integrate woody vegetation into farming landscapes and contribute to new directions in production of wood and wood energy in these landscapes.

The Establishment Techniques Trial using *E. cladocalyx* did not show any significant differences in growth at 18 years from the various combinations of ripping, mounding, fertilisation and second year weed control on the two sites. This suggests that a variety of establishment techniques can be used, provided that effective weed control from grasses is maintained for at least the first year on ex-pasture sites.

The Sawlog Species Comparison Trial tested the growth of the following species: Sugar Gums *E. cladocalyx* (3 provenances), Spotted Gums *Corymbia variegata* (2 provenances) and *C. maculata* (2 provenances), Blue Gums *E. globulus* and *E. bicostata* (one provenance each), Ironbarks (*E. tricarpa* and *E. sideroxylon* one provenance each) *Acacia mearnsii* (1 provenance), and *Grevillea robusta (1 provenance).*

Results showed that survival and mean annual increments (MAI) for *E. cladocalyx* were superior to all other species.

Survival was remarkably high for the Sugar Gums (96%) and the Ironbarks (92%), and Blue Gums (85%) all satisfactory. The Spotted Gums were variable, averaging 72%, and wattle

lower at 69%. All Grevilleas died. There was a significant (P<0.001) range in MAI, with Sugar Gums and Blue Gums having the highest mean MAI (average 13.3 m^3 ha^{-1} yr^{-1}). The Ironbarks ranked next (10.2 m^3 ha^{-1} yr^{-1}) followed by the Spotted Gums (7.6 m^3 ha^{-1} yr^{-1}), Acacia MAI was 2.1 m^3 ha^{-1} yr^{-1}. Multiple leaders, particularly in the Spotted Gums suggest that sawlog production would require attention to form pruning after establishment.

The volumes recorded here for 16-year-old un-thinned *E. cladocalyx*, and 16.8 m^3 ha^{-1} yr^{-1} over a period of 16 years is an unexpectedly high value (Table 9). This result should be considered by forest growers planning the future of medium rainfall sawlog farm forestry.

The *Eucalyptus cladocalyx* Progeny Trial at Naringal was one of three locations that were established to develop an improved Sugar Gum seed resource for future farm plantings. 120 seedlots were collected form the natural populations in the southern Flinders Ranges: Wirrabara, Wilmington North and South, Mt Remarkable; as well as Kangaroo Island, (American river, Cygnet river, Flinders Chase). The balance of collections were taken from farm plantations of good form and seed production areas or seed orchards.

The mean diameter of the seed parent population was 14.8 cm; the pollen parent population 12.2 cm and the overall population 11.0 cm.). The weighted mean diameter of the seed and pollen parents is 12.7 cm; an increase of 1.7 cm over the current population mean.

A selection strategy has been outlined to thin the trial and ensure improved seed is available for future farm forest plantings.

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Background

The period from 1990 – 2005 saw substantial activity at both federal and state levels to support farm forestry ventures. This was driven by an increased awareness of the need for landscape restoration to mitigate dryland salinity, reduce soil erosion, improve supply of habitat for woodland species, expansion of export markets for wood fibre and proposals for radical expansion of Australia's plantation industries. With the development and expansion of Landcare, there was a perceived path for increased cross-tenure management, and this was strengthened by the re-positioning of land management based on catchments, which demonstrated the linkage between healthy waterways and management of upper catchment landscapes.

A specific focus on plantations was created with the release of the policy Plantations for Australia: The 2020 Vision (2020 Vision), released in 1997, which was a three way partnership involving the Australian Government, state and territory governments, and industry. The 2020 Vision aimed to secure long-term plantings for sawlogs and provided the target of three million hectares of plantations by 2020 starting from a base area of just over one million hectares in 1996.

At the time and for 120 years previously there have been interesting plantations of *Eucalyptus cladocalyx* (Sugar Gum) on the western plains of Victoria, poorly managed yet healthy and clearly adapted to the region. They were known to produce very good quality sawn timber, and the hypothesis implied was that with good forestry practices both growth rate and the proportion of millable timber from wood from these stands could be improved through application of improved forestry practices.

Programs to expand farm forestry initiatives at the time included the West Victoria Sawlog Farming Project, and the Plantations for Greenhouse initiative (DNRE 2002). Growers were also establishing plantations through the 'Smartimber' cooperative, and as part of routine farming programs.

The momentum for this effort dissipated with the creeping 'Millenium drought' (from around 2000-2009), the global financial crisis (2008) and the collapse of forestry managed investment schemes (2009). At the same time there was a steady decrease in publicly funded investment into the sector, which had previously created an enabling environment through funding of research, major landscape restoration (particularly along waterways) and administrative infrastructure to support the Landcare movement which co-ordinated and linked communities and governments to work together on landscape restoration.

The failure of Forestry Managed Investment Schemes were the subject of a federal parliamentary enquiry in 2014. It noted that the peak years of MIS driven plantation establishment across Australia were between 2000 and 2009, with a high of 111 000 hectares established in 2000 (81 per cent of total plantation establishment in that year) and all other years varying between 24 000 to 75 000 hectares of MIS plantation establishment (ABARES, 2019). With two major MIS companies going into receivership in 2009, subsequently plantation ownership became the province of large institutional investors known as timberland investment management organisations.

Within the public domain, much of the intellectual framing of new concepts of catchment and land management was dissolved with the closure of the Land and Water Australia (LWA) research and development corporation, and the conclusion of major federal funding programs which had underpinned the re-imagining of the rural landscape. In addition, the millenium drought (in conjunction with decades of engineering and replanting programs designed to manage salinity levels) effectively resolved many of the issues of increasingly saline surface water tables as water scarcity increased across the country. Moreover, farmers were entirely focussed on their core businesses of grazing and cropping and had scant surplus cash flows or time for more speculative and long-term ventures such as commercial or semi-commercial tree growing.

Fundamentally there is a good claim for improvement of species that can grow in 800-600 mm rainfall zones, as there are substantial amounts of land in this rainfall zone and several species are capable of producing quality sawn timber at near-economic rates in these landscapes (depending upon interest rates, the mix of forestry within the farm business, availability of export markets and the advent of specialty and local timber markets.

Despite the hiatus in momentum for farm forestry in Western Victoria, the trials reported on here have remained in place and can provide useful data on establishment, survival and growth rates for future initiatives. Some of these possibilities include the creation of local or regional energy hubs using wood for heat energy (such as boiler systems at Meredith and Beaufort), the contribution of biofuels for supplementing solar energy systems such as Concentrating Solar Thermal (CST), household space heating, and specialty hardwood sawlog and veneer production.

Overview of the trials in this paper

Establishment Techniques Trial

As described in the establishment report for the Establishment Techniques Trial (Stackpole & Wang, 2004), since the 1990s, the conventional establishment approach for trees on farms has been to plant containerised seedlings into newly-cultivated ex-pasture or ex-cropping land. Government assisted programs specified that cultivation comprise simultaneous ripping and mounding as used in the establishment of *E. globulus* in higher rainfall areas, along with broad-acre or row-based chemical weed control. Lower intensity methods have been used by independent landholders with varying success. These techniques resulted in acceptable survival and early growth, but data on the relative effectiveness of more intensive approaches compared to less intensive silviculture is required.

The optimum combination of silvicultural treatments may vary with climatic and edaphic factors. Complete control of weeds in the first growing season has been proven a primary requirement for plantation establishment on former pastures (Nielsen 1990, Bandara *et al.* 2001). The omission of weed control treatments in the first season usually negates the potential benefit of any further input. The importance of second season weed control is less clear. Where growth rate of a species is insufficient to occupy a site by the commencement of the second spring, a response to second spring weed control is a possibility which was included in this trial design. Other inputs typically used (individually or in combination) include cultivation treatments (ripping and/or mounding), and fertiliser applied shortly after planting.

The need to evaluate possible combinations of establishment methods was recognised by Central Victoria Farm Plantations Inc. (CVFP), which sought technical assistance from the Forest Science Centre to design, implement and evaluate establishment techniques trials for *E. cladocalyx*. In 2002, the two organisations collaboratively established two trials, one at Lismore and Wallinduc in the Corangamite region. The trials tested cultivation treatments (ripping and mounding), establishment with fertiliser, and second-season weed control treatments (first-season weed control having been undertaken in all treatments) at these lower rainfall (< 650 mm) sites.

Sawlog Species Comparison Trial

The State government Western Victoria Regional Forest Agreement (WVRFA) support program included establishment of sawlog species trial plantations. These were planted on typical agricultural land to demonstrate regimes that might supplement or replace sawlog supply from public forests. Trials were established on 1400-500 mm rainfall sites in central and western Victoria; including Korweinguboora, Mt Sabine, Crosbie and Lismore (see Table 1). The trials were established close to the time of the breakup of the research division of the Victorian government and while measurements were established by 2006, since then growth has not been monitored. The Crosbie trial is managed by the city of Bendigo and was thinned in 2010. The Lismore trial has been managed by several owners of the property since.

Table 1 WVRFA species sawlog demonstration trials.

Site	LOCALITY	SOIL	RAINFALL (mm)	SPECIES on Site	status
Korweinguboora	Wombat		1400	EC, VC, RI, AM1, GR EG, EN, EO, ER, EV, AM2	Extant but heavily blanked
Mt Sabine	Otway		1800	EG, EN, EO, ER, EV, AM1	Harvested and replanted to nitens
Wallinduc	Lismore		700	EC, VC, RI, AM1, GR	Active, unmanaged
Crosbie	Heathcote		500	AM2 CM, CV, ET, ES, EC	Active (thinned in 2010)

EC= E. cladocalyx, VC = Corymbia, RI = Red Ironbark, AM1 = A. melanoxylon , GR = Grevillea robusta, EG = E. globulus, EN = E. nitens , EO = E. obliqua, ER = E. regnans, EV= E. viminalis, AM2 = A. mearnsii

Crosbie has a demonstration of E. polybractea (blue mallee)

Eucalyptus cladocalyx Progeny Trial

The progeny trials were established as part of a joint venture agroforestry program which was supported by the Rural Industries Research Corporation, Land and Water Australia, the Forest and Wood Products Research and Development Corporation and the Murray Darling Basin Commission. Within this program a specific group, the Australian Low Rainfall Tree Improvement Group (ALRTIG) sought to improve the process of tree improvement by coordinating efforts across Australia, thereby contributing to the integration of sustainable and productive agroforestry into Australian farming systems.

One of the authors was involved in these programs closely, and was familiar with several preceding programs over the previous 110 years which had been aimed at developing trees for use on the lower rainfall plains. Data on real growth rates presented here is vital to calibrate future economic models that will guide investment decisions, and guide the selection of species and most suitable establishment techniques. Critically, the progeny trial data is of particular significance in ensuring that the next wave of forest establishment using *E. cladocalyx* will have access to proven select seed.

The planting details and growth rates of the trials are summarised in Table 2.

Table 2. Planting details and relative performance of *E. cladocalyx* in the four trials across two sites.

Trial	subset	n trees	Area (ha)	Planted DDMMYY	years	Sph (Stems.ha^{-1})	Survival (%)	mean DBH (cm)	BA ($m^2.ha^{-1}$)	Mean ht (m)	Plot htp (m)	Vol ($m^3.ha^{-1}$)	MAI ($m^3.ha^{-1}.yr^{-1}$)
Progeny	Seed parents	2400	1.5	230801	15.7	1587	100	14.9	9.9	14.1		189	12.0
	Pollen Parents						100	12.2		12.7		139	8.9
	Cull						100	10.1		11.6		105	6.7
Establish-ment	Naringal	2304	1.6	120802	17.5	1428	81	16.1	20	15.0	13.7	158	9.0
	Titanga	2560	1.8	160802	17.5		92	14.4	20	13.5	12.8	144	8.3
Sawlog	Kersbrook SSO	2830	2.2	110903	16.4	1298	90	21.4		17.1	17	242	14.7
	Rowe						98	19.5		17.0	16.9	238	14.5
	Wirra						97	18.9		16.5	14.9	222	13.5

Establishment Techniques Trial

Effect of intensive establishment techniques on Eucalyptus cladocalyx at Naringal and Titanga.

Introduction

Around the year 2000 there was considerable activity in farm forestry in Victoria, where pulp crops were being grown on rural (usually ex-grazing) land in western Victoria. *Eucalyptus globulus* was being planted on a large scale using intensive establishment techniques such as cultivation, chemical weed control and fertilisation. *E. cladocalyx* was also being proposed on a large scale in the same district for sawlog or firewood crops. Intensive establishment methods were presumed to also have a positive benefit on the growth of *E. cladocalyx*, and as none had been reported an experimental trial was established. The trial was established with the assistance of the Ballarat Victorian Regional Plantation committee, and Lismore landholders.

The experiment comprised two trial sites on representative landforms and was established in 2002. The trials were measured in November 2004 (Stackpole and Wang, 2004), and that analysis revealed no interactions among the treatments and the only significant single effect being second year weeding; which gave a positive influence on height growth. The trials were re-measured in February 2020 to gain a general overview of survival and productivity over a longer period and re-analysed to test if any of the treatment effects had resulted in significant differences in volume production at age 18 years.

Method

Treatments were establishment ripping (R1), mounding (M1), establishment fertiliser (F1) and second year weed control. These were applied with ripping and mounding in factorial combination with weed control overlaid as a split plot treatment. Trials were established at two sites in the Lismore area (see Table 3). While ripping and mounding were intended as full factorials, the R1M1 treatment was done with a commercial John Deere tracked machine used for *E. globulus* establishment, the ripping done with D5 bulldozer, and the mounding done using twin opposable discs pulled by a 60 KW tractor. These cultivation treatments are thus considered as 4 separate treatments rather than a 2 x 2 combination of ripping and mounding. Once the ground was prepared *E. cladocalyx* seedlings were planted. These had been raised in 110 cc Hiko cells, using seed collected from good quality Lismore windbreak parents, and spacing of 1420 stems per hectare. Pivot 900 fertiliser was applied at 150 grams per tree to nominated plots. Full weed control was maintained for the first spring. In the subsequent spring full weed control was maintained only in the F1 plots. After that time, all silvicultural treatments ceased, and the plantations were permitted to grow.

Table 3 Summary of site variables for the two Establishment Techniques Sites.

		Lismore	Wallinduc
Location	Landowner	Lang	Wills
	Property name	*Titanga*	*Naringal*
	VicRoads reference	Map 75 F8	Map 76 A7
	Latitude (°S)	37° 55'	37° 51'
	Longitude (°E)	143° 18'	143° 30'
	Altitude (m asl)	200	220
Climate *[1]*	Annual rainfall (mm)	610	577
	Annual pan evaporation (mm)	1182	1172
	Average monthly min./max. temp. (°C)		
	January	10.7 / 25.4	10.9 / 25.9
	July	3.5 / 11.7	3.4 / 11.7
	Average daily solar radiation ($MJ/m^2.day$)[2]	15.52	15.62
Soils	Soil parent material	basalt	granite
	Surface soil texture	clay-loam	loam
Slope	Aspect and slope (°)	level	south 2-3°

[1] estimated from ESOCLIM (Hutchison, 1999)

[2] Solar radiation modified for slope and aspect

The two trials were measured in February 2020. The inner two lines of each four-row plot were measured, thus 18 (Naringal) or 20 (Titanga) trees per plot were measured. For each planted position, the status was recorded, and where a tree was present the diameter over bark at 1.3 m above ground level (DBHOB) was measured and recorded. For each plot, the two largest-diameter trees of good form were selected and their height (H_s as metres) measured and recorded. Data was processed by modelling H_s by DBHOB across the trial and predicting height (H_p) for all trees. Where two or more stems were present on the same stump the quadratic mean (square root(sum of squares) was calculated. Stem volume were calculated as $(DBHOB(m)/2)^2*Pi*H_p\ (m)*k$, where k is a form factor commonly applied for younger plantation eucalypts (note that form factor for a cone is 0.333, and this was used for volume estimates here). Tree volumes were accumulated by plot and expressed on a per hectare basis.

Analysis

Stem volume was analysed in GenStat using a general ANOVA with cultivation, weed and fertiliser at equal rank in a full factorial, with replicate as the blocking factor. Each trial was done separately. After that analysis rip and mound were analysed as a 2 x 2 factorial. Where effects were significant the means were separated using standard errors.

Stem volume and plot volume were standardised against the treatmeant mean (n1/nx) and regressed against survival.

Results

Survival was above 80% at both sites (Naringal 81% and Titanga 93%, Table 4). Total stem volume of measured trees including missing was 127 and 104 m^3 ha^{-1}; corresponding to an overall MAI of 7.2 and 6.0 m^3 ha^{-1} yr^{-1} for Naringal and Titanga, respectively.

Table 4 Survival and productivity of the two sites averaged over all treatments.

Site	Surv	DBH(cm)	Hp (m)	BA (m2)	vol all trees	n planted	sph	Vol m^3 ha^{-1}	Age	MAI ($m^3.ha^{-1}.yr^{-1}$)
Naringal	0.81	16.0	13.7	0.021	102.8	1152	1420	126.8	17.5	7.24
Titanga	0.93	14.4	12.8	0.017	94.0	1280	1420	104.3	17.5	5.96

Details of the results are shown in Table 5.

Table 5 Establishment Techniques Trial Treatment means for survival, diameter, height and volume at Naringal and Titanga at age 18 years.

Effect	Site	Levels	Survival	Diameter	Hp	Volume
			proportion	cm	m	$m^3\ ha^{-1}$
Cultivation	Naringal	nil	0.90	16.0	13.63	139
		rip	0.92	15.4	13.27	125
		mound	0.69	17.2	14.32	124
		rip + mound	0.75	16.2	13.76	121
	Titanga	nil	0.89	14.3	12.78	99
		rip	0.94	14.4	12.84	106
		mound	0.92	14.4	12.84	105
		rip + mound	0.97	14.3	12.80	108
Rip	Naringal	0	0.91	15.7	13.45	132
		1	0.72	16.7	14.04	122
	Titanga	0	0.92	14.4	12.81	102
		1	0.94	14.4	12.82	106
Mound	Naringal	0	0.79	16.6	13.97	131
		1	0.83	15.8	13.51	123
	Titanga	0	0.91	14.4	12.81	102
		1	0.95	14.4	12.82	107
Weed	Naringal	0	0.80	16.0	13.64	123
		1	0.82	16.4	13.84	131
	Titanga	0	0.92	14.3	12.76	102
		1	0.94	14.5	12.86	106
Fert	Naringal	0	0.82	15.9	13.58	125
		1	0.80	16.5	13.90	129
	Titanga	0	0.93	14.5	12.86	106
		1	0.93	14.3	12.76	103
Overall		Mean	0.87	15.3	13.28	116

At Naringal there was one significant effect among the three crossed treatments and all their interactions (Table 6). This was Cultivation (P<0.001), with the treatment means reversed against the expected benefits of the treatments (R0M0 139 m^3 ha^{-1}; R1M0 125 m^3 ha^{-1}; R0M1 124 m^3 ha^{-1}; and R1M1 121 m^3 ha^{-1}) (See Table 5).

Table 6 ANOVA of the two establishment trial sites.

Test			Titanga			Naringal	
cult × fert x weed	Change	d.f.	v.r.	F pr.		v.r.	F pr.
	+ rep	3	5.43	0.003		3.66	0.019
	+ cult	3	1.94	0.138		**18.53**	**<.001**
	+ fert	1	0.62	0.437		0.07	0.790
	+ weed	1	0.78	0.381		0.00	0.976
	+ cult.fert	3	2.29	0.091		0.14	0.937
	+ cult.weed	3	1.72	0.176		0.72	0.545
	+ fert.weed	1	0.23	0.637		0.00	0.976
	+ cult.fert.weed	3	1.89	0.145		1.69	0.182
	Residual	44					
	Total	62					
mound × rip	Source	d.f.	v.r.	F pr.		v.r.	F pr.
	rep	3	4.81	0.005		3.97	0.012
	mound ignoring rip	1	2.03	0.16		**15.03**	**< 0.001**
	mound eliminating rip	1	2.1	0.153		14.16	< 0.001
	rip ignoring mound	1	3.03	0.087		**45.97**	**< 0.001**
	rip eliminating mound	1	3.11	0.083		45.10	< 0.001
	mound.rip	1	0	0.997		0.06	0.802
	Residual	56					
	Total	62					

A subsequent 2-way ANOVA for ripping and mounding at Naringal showed no interaction between ripping and mounding, and that adding either treatment reduced volume growth (Table 6). This is driven especially by the R1M0 treatment which suffered higher mortality within the first few months, the result being detectable 17 years later as reduced volume. Further, at Naringal, nil mounding gave higher volume (P<0.001) than mounding, (M0 = 131m^3 ha^{-1} v M1 123 m^3 ha^{-1}), again in contradiction of the expected response.

Table 7. Effects of cultivation treatments on volume m3 ha-1 at 18 years

Effect	Level	Titanga			Naringal	
		m^3 ha^{-1}	se Δ means		m^3 ha^{-1}	se Δ means
mound	0	101.7	3.1		107.9a	7.1

	1	106.1			134.9b	
rip	0	101.0	3.1		146.0a	7.2
	1	106.5			97.6b	
		103.8			121.5	

At Titanga no silvicultural treatment had any significant effect; and while means of treatments did increase with level of input, the response was not significant (R0M0 99 m^3 ha^{-1}; R1M0 106 m^3 ha^{-1}; R0M1 105 m^3 ha^{-1}; and R1M1 108 m^3 ha^{-1}). From the present data it appears that (i) planting into stubble, with (ii) no further cultivation, (ii) no added fertiliser, and (iv) first year weed control is sufficient to establish a crop capable of at least an MAI of 6 m^3 ha^{-1} yr^{-1}at age 18 years at Titanga (Table 4).

The full summary of treatment means is given in Table 8.

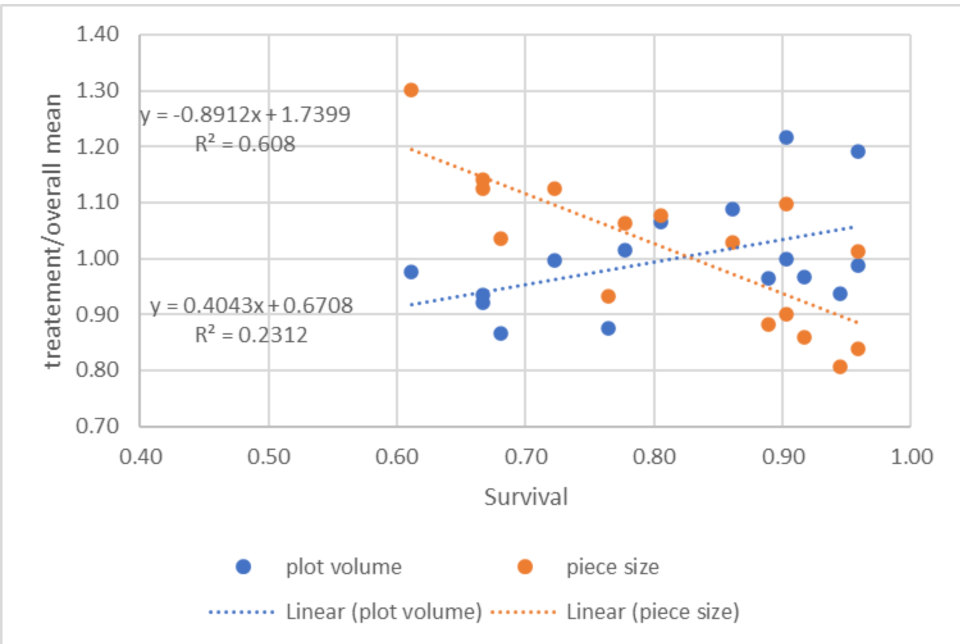
Table 8. Treatment mean values for Establishment trial at age 18.

Site	Treat	Cult	Rip	Mound	Weed	Fert	Surv	DBH	HT_p	Volume m^3 ha^{-1}	
							%	cm	m	tree	Plot
Naringal	1	1	0	0	0	0	0.89	15.0	13.09	0.09	5.87
	2					1	0.88	15.9	13.57	0.11	6.62
	3				1	0	0.92	16.7	13.99	0.12	7.87
	4					1	0.92	16.4	13.85	0.12	7.61
	5	2	0	1	0	0	0.93	15.2	13.20	0.09	6.29
	6					1	0.89	15.8	13.50	0.10	6.52
	7				1	0	0.93	15.2	13.19	0.09	6.11
	8					1	0.93	15.2	13.20	0.09	6.21
	9	3	1	0	0	0	0.76	16.7	14.03	0.12	6.68
	10					1	0.67	17.2	14.30	0.13	6.11
	11				1	0	0.68	16.4	13.84	0.12	5.68
	12					1	0.63	18.6	15.09	0.17	6.46
	13	4	1	1	0	0	0.69	16.0	13.63	0.12	5.79
	14					1	0.71	16.3	13.82	0.11	5.69
	15				1	0	0.79	16.1	13.68	0.11	6.33
	16					1	0.79	16.5	13.89	0.12	6.63
Titanga	1	1	0	0	0	0	0.89	14.3	12.78	0.08	5.37
	2					1	0.86	14.1	12.69	0.08	5.25
	3				1	0	0.91	14.7	12.95	0.09	6.16
	4					1	0.91	14.1	12.68	0.07	5.39
	5	2	0	1	0	0	0.95	13.8	12.57	0.07	5.26
	6					1	0.94	14.6	12.92	0.08	6.21

	7				1	0	0.90	15.1	13.11	0.09	6.33
	8					1	0.98	14.2	12.75	0.08	5.88
	9	3	1	0	0	0	0.90	14.3	12.77	0.08	5.64
	10					1	0.89	14.4	12.81	0.08	5.70
	11				1	0	0.93	14.7	12.97	0.08	6.06
	12					1	0.96	14.3	12.80	0.08	6.02
	13	4	1	1	0	0	1.00	14.5	12.87	0.08	6.72
	14					1	0.96	14.1	12.70	0.07	5.74
	15				1	0	0.94	14.5	12.88	0.08	6.05
	16					1	0.96	14.2	12.73	0.08	5.79

It is possible that silvicultural interventions at some stage in the intervening years (3-17 years) may have provided some change in growth, and we leave this to future investigation as required.

Figure 1. Correlations of survival with plot volume and piece size



Survival was positively correlated with plot volume (R^2 = 0.23, slope 0.40), and negatively correlated with piece size (R^2 0.61, slope -0.89, Figure 1). The higher negative slope indicates that larger piece size in the low survival plots is not compensating the difference in total plot volume. The progression from this is that establishment stockings could be evaluated using a Scotch plaid or Nelder experimental design to efficiently guide selection of the appropriate planting stocking.

Discussion

This experiment was intended to demonstrate the response of volume of *E. cladocalyx* to treatment combinations. A positive response of value that is correlated positively with silvicultural investment would warrant cost benefit analysis. However the lack of strong responses signals that the treatments applied did not influence growth, and future management should consider simple hand- or machine-planting methodsof quality seedling stock and maintenance of weeds during the first growing season.

We did not evaluate the cost of planting and thus while cultivation gave no positive effect on volume growth it may have increased the speed of planting and thus reduced the cost per seedling planted. Indicative rates of planting into cultivated (e.g. mounded) sites are 3000 plants per man day when planted by potti putki®, at $0.20/tree to the contract owner = $600 for those 3000 plants. Alternatively, manual pit planting into uncultivated soils may only achieve 1000 seedlings per man day, assuming AWU wages and overheads =$400 for those 100 plants, twice the cost per 10000 seedlings of the planting scheme above.

Other silvicultural options that may be considered are (i) use of control release fertiliser mixed directly into the planting hole at planting, and (ii) application of controlled release or NPK blends at later ages.

Recommendations

Operational recommendations can be summarised as follows:

- Obtain maximum survival at planting, by using best plantation management
- It is probably appropriate to use cultivation to loosen soil but harrow back in to fill voids and reduce ridging effects, as this will reduce planting cost. However care should be taken to avoid gross modification of the soil environment.

Management recommendations for further experimentation and analysis:

- Cost benefit analysis could be undertaken using existing data or monitor loosely on new plantings
- Nelder trials could be installed to evaluate optimum establishment spacing
- Use of control release fertiliser to minimise bulk and target the nutrients to the seedling
- Later age fertiliser trials.
- Intercropping at planting with legumes to reduce weed competition and increase nitrogen availability on the sites.

Sawlog Species Comparison Trial

Introduction

In 2003 the Victorian Government required the Forest Research Branch to establish a series of species comparison trials. The trials were an outcome of the Regional Forest Agreement process. The species and seedlots therein were to be assessed on sawlog growth rate under plantation silviculture. One of these sites was established in the Lismore area, and tested the suite of species known to be suited to the low and moderate (500-800 mm) annual rainfall zones.

Eighteen years after planting we have remeasured the stands to obtain a measure of volume growth and general assessment of species suitability for sawlogs. The inclusion of several seedlots of some of these species also enabled informed inference to be drawn on their genetic origin.

This paper reports the 18-year growth, sawlog quality and intra species variations observed at the Lismore site.

Method

Seedlots

Species selected (and number of seedlots from each) were Sugar Gums *E. cladocalyx* (3), the Spotted Gums *Corymbia variegata* (2) and *C. maculata* (2), the Blue Gums *E. globulus* and *E. bicostata* (one each), the Ironbarks *E. tricarpa* and *E. sideroxylon* one each) *Acacia mearnsii* (1), and *Grevillea robusta* (1). Details of seed origins are given in Table 8. All of these can produce sawlogs. In the general region previous experience had shown that relative growth rates are higher for the Blue and Sugar Gums, moderate for Spotted Gums and slow for the Ironbarks.

Table 9. Species and seedlots used in the Naringal Sawlog species trial

Field Code	Species	Improved	Locality	Town	[1] FSC number
8	*E. bicostata*	Wild	Mt Cole	Avoca	
9	*E. globulus*	Wild	Otway NP	Apollo Bay	
11	*A. mearnsii*	Wild	Snowy river	Orbost	CSIRO 16381
12	*Grevillea robusta*	Wild	Bacchus Marsh	Bacchus Marsh	
13	*C. variegata*	Wild			
14	*C. variegata*	Wild			
15	*C. maculata*	SSO	Deniliquin SSO	Deniliquin	CSIRO SSO seedlot 1942
16	*C. maculata*	Wild	20542-		CSIRO 20542
17	*E. cladocalyx*	Wild	Wirrabara	Wirrabara	
18	*E. cladocalyx*	SSO	Kersbrook	Adelaide	
19	*E. cladocalyx*	Farm	Naringal	Lismore	
20	*E. tricarpa*	Wild	Mt Nowa Nowa	Orbost	
22	*E. sideroxylon*	Wild	Killawarra	Wangaratta	

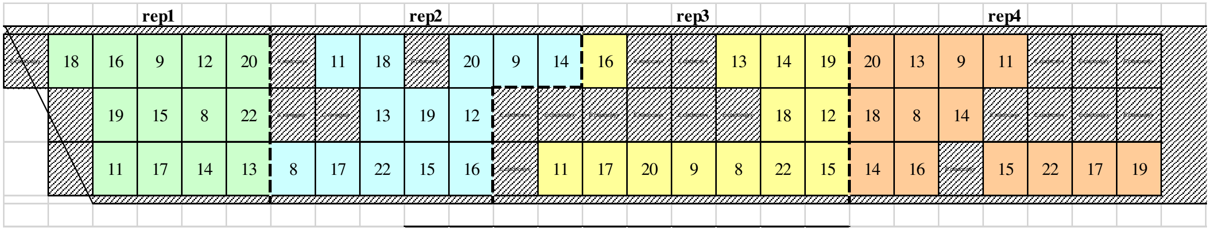
[1] Forest Science Centre, Victorian government forest research department ca 2002, based at 123 Brown Street Heidelberg. Broken up and disbanded 2009.

Establishment

The trial was planted in 2003. Site preparation was regular cultivation with light bulldozer, and pre-plant spraying of weeds. Fertiliser was not applied. The weeds were controlled for the first and second years, and some poor plots were re-planted in the second spring with *E. cladocalyx*; which have been omitted from plot volumes. The layout of the experiment is shown in Figure 2.

Figure 2 Field layout of the trial.

For species match numeral in cell with field code column in Table 8.



Measurement

The plots were measured in February 2020. Edge effects were minimised by measuring the inner 5 rows by 6 trees (of 7 rows x 8 trees planted per plot). The status of all planted spots per plot was recorded, and where the tree was alive, the diameter at breast height. Where two or more diameters occurred at breast height all diameters were recorded and summarised to a single diameter value as the square root of the sum of squared diameters. For each plot, the height of the largest three trees of good form were measured and recorded. These heights were used to develop a simple regression to predict the heights of all trees in the plot. Most regressions had positive slopes although R^2 in three seedlots were low (see Appendix 2: Height function regression, Table 16). Sum diameter at breast height and predicted height were used to estimate tree volume using a conic function whereby the DDBY value is used to represent the base of the cone. A form function of 0.333 is implicit in the conic function, and larger form factors (e.g. 0.36) may be applicable from other studies in *E. cladocalyx*. Where two or more stems were present on the same stump the quadratic mean (square root(sum of squares) was calculated.

Analysis

Tree data was summarized to plot means for survival, stem diameter, number of forks and volume per hectare. These data were analysed using one-way ANOVA using seedlot and group as the factor. Where differences were significant, they were separated using Bonferroni adjusted means comparisons.

Results

Survival was remarkably high for the Sugar Gums (96%) and the Ironbarks (92%), and Blue Gums (85%) all satisfactory. The Spotted Gums were variable, averaging 72%, and wattle lower at 69%. All Grevilleas died. Fork score was negatively correlated with survival (negative slope, r^2 = 0.31), and while this is not a causal relationship it at least demonstrates an interesting relationship among the species under test. The actual fork scores were high for the wattle and Spotted Gum (1.6) and Ironbarks (1.45). The mean fork for Blue Gums and Sugar Gums was 0.9, and all these seedlots had a reasonable number of sawlog quality stems.

There was a significant ($P<0.001$) range in MAI, with Sugar Gums and Blue Gums having the highest mean MAI (average 13.3 m^3 ha^{-1} yr^{-1}). The Ironbarks ranked next (10.2) followed by the Spotted Gums (7.6), Acacia MAI was 2.1.

Table 10 Survival and growth at age 16.5 years of 13 seedlots used in the WVRFA Wallinduc Sawlog Trial.

Group	Seedlot	Survival	Fk	QDBH	HTt	vtree	volha	MAI
Sugar Gums	Naringal	0.98	1.0	19.5	16.1	0.21	272	16.5
	Kersbrook	0.90	0.9	21.4	16.7	0.24	277	16.8
	Wirrabara	0.98	0.9	18.7	16.5	0.15	195	11.8
Blue Gums	Otway NP	0.83	0.9	19.7	17.4	0.20	216	13.1
	Mt Cole	0.87	0.7	17.6	13.2	0.12	139	8.4
Ironbarks	Killawarra	0.93	1.4	18.1	13.0	0.14	163	9.9
	Mt Nowa Nowa	0.92	1.5	18.6	11.4	0.15	174	10.5
Spotted Gums	DenilSSO 1942	0.65	1.9	19.4	12.5	0.15	171	10.4
	20542-family	0.89	1.6	16.7	12.6	0.11	128	7.8
	variegata	0.61	1.4	16.1	12.3	0.10	77	4.6
Wattle	16381-Orbost	0.69	1.6	11.3	9.7	0.04	35	2.1
		0.85	1.2	18. 6	14.2	0.16	180	11.0

To compare within species and among seedlots see Figure 1. Among the *E. cladocalyx* seedlots, those of seed orchard origin (Kersbrook, MAI = 16.8, Naringal MAI= 16.5) had higher MAI than the wild seedlot (Wirrabara, 11.8). Among the Blue Gums, the *E. globulus* seedlot had higher MAI than the *E. bicostata* (MAI = 11.8 vs 8.4). The Ironbarks were similar in growth rate with MAI of 9.9 (Killawarra) vs 10.5 (Mt. Nowa Nowa).

The full summary of the Sawlog Species trial results is shown in Table 16.

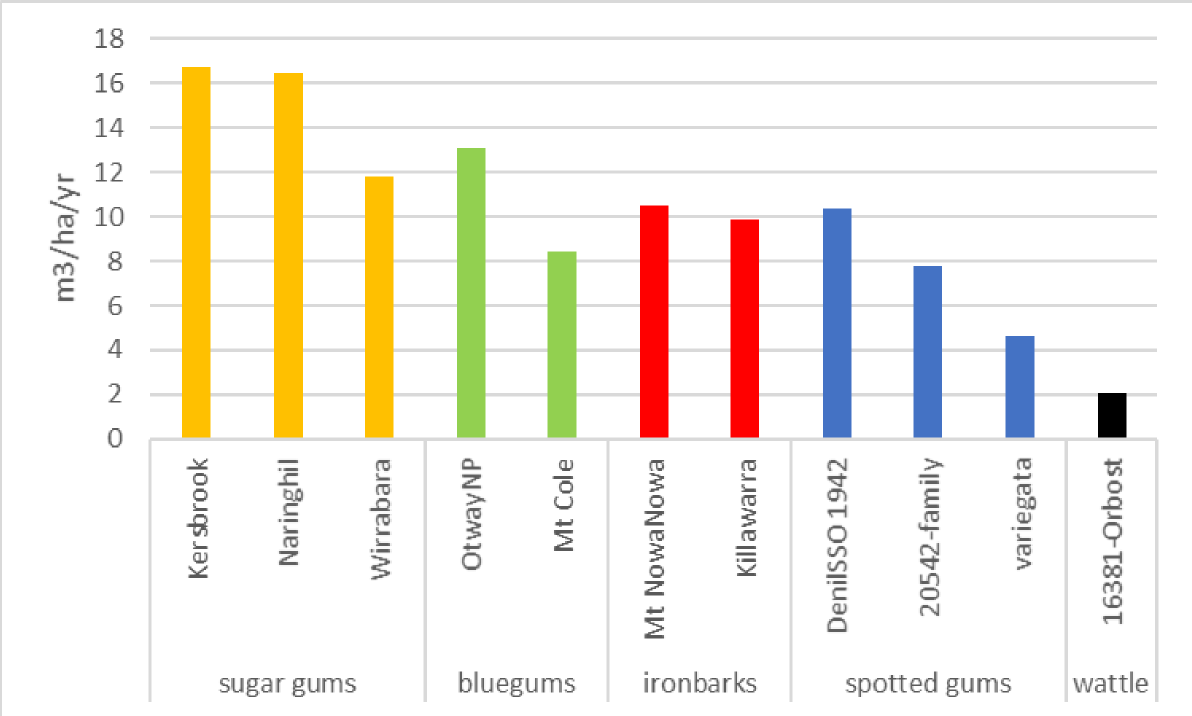
Table 11. Species means and significance of differences among seedlots for Survival\, quadratic diameter, stem fork, predicted height tree volume and volume per hectare.

Species	Seedlot	Improve [2]	Survival %		Diameter cm		Fork		Dominant height m		Volume m^3 $tree^{-1}$		Volume m^3 ha^{-1}			MAI m^3 ha^{-1} yr^{-1}
E. cladocalyx	Kersbrook SSO	2	0.90	ab	21.4	a	0.9	a	16.7	a	0.24	a	277	a		16.7
E. cladocalyx	Naringal Farm	1	0.98	a	19.5	ab	1.0	a	16.1	abc	0.21	ab	272	a		16.4
E. globulus	Otway NP forest	0	0.83	ab	19.7	ab	0.9	a	17.4	a	0.20	abc	216	ab		13.0
E. cladocalyx	Wirrabara forest	0	0.98	a	18.7	abc	0.9	a	16.5	ab	0.15	bcd	195	abc		11.8
E. tricarpa	Mt Nowa Nowa forest	0	0.92	ab	18.6	abc	1.5	ab	11.4	de	0.15	bcd	174	bc		10.5
E. maculata	Deniliquin1942	2	0.65	ab	19.4	ab	1.9	b	12.5	de	0.15	bcd	171	bc		10.3
E. sideroxylon	Killawarra forest	0	0.93	ab	18.1	abc	1.4	ab	13.0	cde	0.14	cd	163	bc		9.8
E. bicostata	Mt Cole forest	0	0.87	ab	17.6	bc	0.7	a	13.2	bcd	0.12	d	139	bcd		8.4
E. maculata	20542-family SSO	2	0.89	ab	16.7	bc	1.6	b	12.6	de	0.11	d	128	cd		7.7
E. variegata	NA	NA	0.61	b	16.1	c	1.4	ab	12.3	de	0.10	d	77	de		4.6
A. mearnsii	16381-Orbost forest	0	0.69	a	11.3	d	1.6	b	9.7	e	0.04	e	35	e		2.1

Species	Seedlot	Improve [2]	Survival %		Diameter cm		Fork		Dominant height m		Volume m^3 $tree^{-1}$		Volume m^3 ha^{-1}			MAI m^3 ha^{-1} yr^{-1}
				b												
	f pr		0.004		<.001		<.001		<.001		<.001		<.001			
	Df_{num}		10		10		10		10		10		10			
	Df_{dnom}		34		34		34		34		34		34			
	Vr		3.35		15.12		9.27		14.9		19.08		21.55			
	Mean		0.84		17.9		1.3		13.8		0.15		168			10.2
	Min		0.98		21.4		1.9		17.4		0.24		277			16.8
	Max		0.61		11.3		0.7		9.7		0.04		35			2.1

[2] Improvement level 0 = wild; 1 = farm plantation e.g. land race subject to selection in situ; 2= Seedling seed orchard. Comprises a range of provenanced and families, which have been thinned according to a plan to maximize General Combining Ability of the target trait.

Figure 3 Mean Annual increment ($m^3 .ha^{-1} .yr^{-1}$) of species in Naringal Sawlog species trial.



Mean Stem diameter was correlated with MAI (R^2 = 0.82), so that larger productivity had DBHOB over 20 cm.

Figure 4 Fork score of seedlots within species in Naringal Sawlog species trial

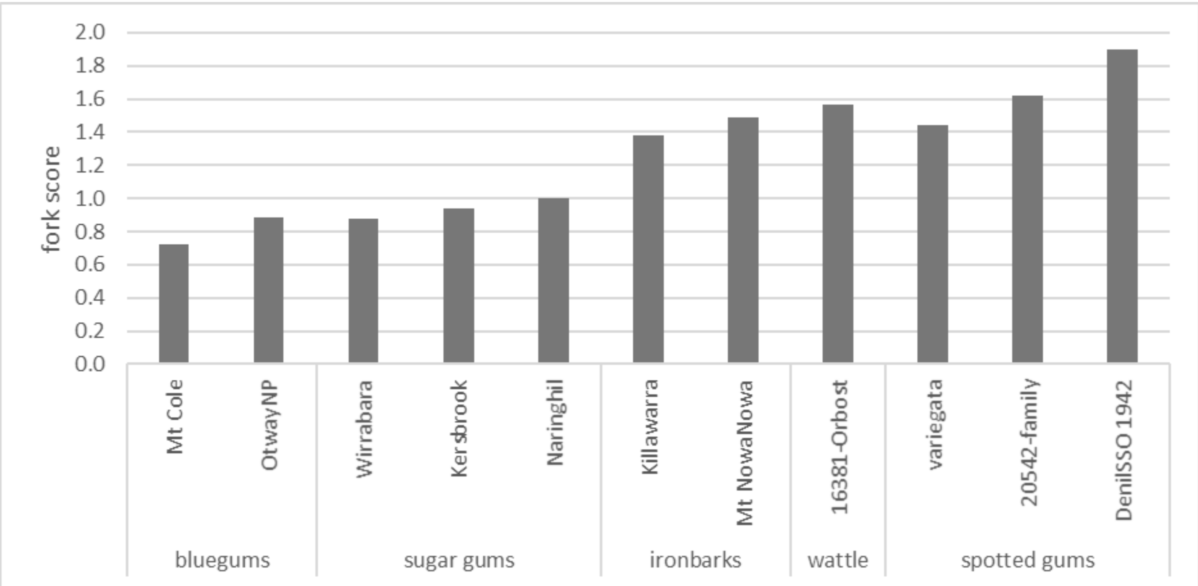
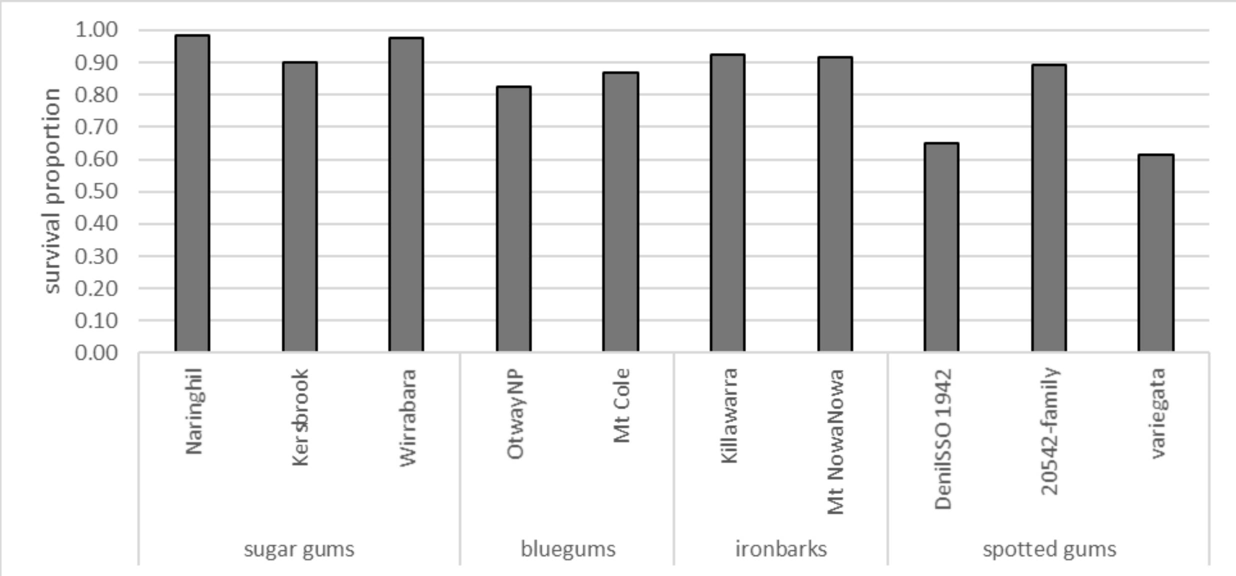


Figure 5 Survival of seedlots within species in Naringal sawlog species trial.



Discussion

The volumes recorded here may be the first reported for 16-year-old unthinned *E. cladocalyx*, and 16.8 m^3 ha^{-1} yr^{-1} over a period of 16 years is an unexpectedly high value. This result should be considered by forest growers planning the future of medium rainfall sawlog farm forestry. The ranking of responses by nominal degree of genetic improvement at least reflects the theory and may be worth following up with further assessment of current genetic gains trials, or in establishment of new genetic gain trials. The Blue Gums grew as expected, with the Otway *E. globulus* growing close to the speed of the E. cladocalyx, whereas the *E. bicostata* was well behind, which is typical of previous species comparison trials at Shepparton, Buffalo River and in this program’s sister trial at Mt Sabine in the Otway Ranges.

The performance of the Ironbarks was of interest, as they are not often measured unthinned at this age. The MAI achieved by the Ironbarks will have been overstated due to the use of a taper model common to thin-barked eucalypts. An adjustment for bark content is required, and this would be developed based on harvesting and sampling of a subset of the trees in the plots.

The Spotted Gums and Acacia were extremely forked. The Acacia forking appears to be a natural tendency to enable it to rapidly occupy incoming radiation. The Spotted Gums displayed excessive forking probably in response to frost nipping of tips. As there was no follow up silviculture (e.g. form pruning) the forks remained unmanaged, leaving little of commercial value at the time of measurement. This is not to write off the species, which can be successful if tending is performed in a timely manner, or if frost resistant varieties become available.

Eucalyptus cladocalyx Progeny Trial

Selection strategy for turnover and improved seed production.

Introduction

Genetic studies of *E. cladocalyx* in the Lismore area commenced in 2001 with the assistance of the Forest Science Centre (Victoria) and the Commonwealth Joint Agroforestry Program. The project aims were to develop knowledge of the genetics, and to provide improved germplasm for local reforestation purposes, as outlined in the Australian Low rainfall tree Improvement Group Strategy document (Harwood et al., 2001). The project supported the establishment of progeny trials of seedlots collected from individual trees in the wild as well as some from within previous seed orchards. The purpose of these trials was to study the genetic characteristics of E. cladocalyx, and to provide the base populations upon which to further improve the species. The improvements required are mainly in growth rate and stem form.

The document is specific regarding the purpose of progeny trials, as per the following from Harwood et al. (2001):

> *ALRTIG will facilitate the…"Establishment of a series of progeny trials, which will be progressively thinned to seedling seed orchards, for production of high quality seed. Some may be retained longer for collection of progeny data, while others may be thinned more rapidly, to meet demand for improved seed."*

This objective was known to local stakeholders. They have pressed for support in completing the selections and conducting the thinning to enable generation of improved seed. This is being addressed by the current program in conjunction with the local stakeholders.

The purpose of the stand is twofold: (i) to provide seed from the best individual in each family, this to comprise the base population for the next generation, and (ii) to provide seed of greater genetic values (e.g. increased growth) from the current seedling stand. Both of these depend of identifying the best trees, removing the culls, allowing the remaining trees to cross pollinate and set seed, and then collect that seed and use for one of the above two purposes.

Method

In 2001 a progeny trial of *E. cladocalyx* was established using the same 120 seedlots in 3 trials, one each in WA, SA and Victoria. 120 seedlots were collected form the natural populations in the southern Flinders Ranges: Wirrabara, Wilmington North and South, Mt Remarkable; as well as Kangaroo Island, (American river, Cygnet river, Flinders Chase). The balance of collections were taken from farm plantations of good form and seed production areas or seed orchards. All collection localities and the number of families is listed in table 1. A full description of the seedlots and establishment process is provided in Stackpole (2001).

The seedlots were raised as seedlings and 20 strong plants from each seedlot selected for the Lismore trial. The plants were set out in 5-tree row-plots, randomised within 4 replicates.

Each replicate comprised 15 rows wide at 3.5 metres, and 6 plots long, at 1.5 metres between trees. Layout is as in figure 1.

Figure 6. Region, locality and number of families of E. cladocalyx in the Naringal trial

Region	Locality	N families
Kangaroo Island	American river	6
	Cygnet river	5
	Flinders Chase	25
Flinders Ranges	Mt Remarkable	16
	Sth Wilmington PO	7
	Wilmington	7
	Wirrabara	22
Seedling seed orchard	Kersbrook SSO	15
	Mt Burr	5
Plantation	Lismore	3
	Majorca	5
	Wail	3

The trial was established in 2001 on a site at Naringal near Lismore. The site has ironstone loam soils, annual rainfall 600 mm, and slopes slightly to the south. The trial appears to have been thinned in around 2010, with 950 cut stems presently in the stand.

In 2017, the trial was measured to capture all remaining diameters and a form score. The diameter data was analysed in ASReml in a mixed (fixed and random effects) model with replicate as a fixed effect, and family and plot set as random terms. Setting terms to random provides the variance components, which are estimates of the variation due to additive genetic effects (V_A) and the overall Phenotypic Variance (V_P).

Heritability for the trait DBH_{OB} was estimated using the family model:

$$h^2 = (V_A \times 0.4)/V_P \qquad \text{(Equation 1)}$$

where (i) h^2 is the estimated genetic control of traits as correlated on parental and offspring breeding values, V_A is the additive genetic variance, 0.4 is the inbreeding coefficient typically adopted for partially-selfing eucalypts (Griffin & Cotterill, 1988), and V_P is the phenotypic variation.

The response R to selection is calculated with the following equation

$$R = ih^2\sigma_P \qquad \text{(Equation 2)}$$

Where i = selection intensity (see Falconer 1989, Fig 11.3), h^2 = heritability as calculated in Equation 1), and σ_P = population standard deviation for that trait. The function applies where selection is by truncation.

Truncation selection means that no individual that has been selected to remain in the breeding population is less good for that trait than any individual rejected. This does not hold in the present trial as our selection strategy is to retain the best individual from as many families as is reasonable, and in some of those families the selected individual is less good than culled individuals from stronger families. This compromise is required as part of the objective is to generate a turnover population representing as many of the original families as possible, in order to retain genetic variability.

A selection strategy was made whereby up to 20 of the poorest 20 families would be eliminated, and the best individual from each remaining family being retained as a seed parent. The seed parent is the sole maternal representative of its family to be taken forward in the breeding population. The selection strategy also retains 2-3 pollen parents, these are competitive individuals in each family that are retained to contribute pollen to the crossing process, and to increase the amount of improved seed harvestable.

Results

The mean diameter of the seed parent population was 14.8 cm; the pollen parent population 12.2 cm and the overall population 11.0 cm (Table 11). The weighted mean diameter of the seed and pollen parents is 12.7 cm; an increase of 1.7 cm over the current population mean.

Selections

Of the 120 families tested, seven were too poor to warrant retention as Seed Parents, leaving 113 seed parent selections. A total of 387 pollen parents was selected, and 903 individuals from the current standing trees should be culled. This leaves the figure (113+387)/(113+387+903) = 0.36 of the standing trees to be retained, which equates to a selection intensity (e.g. number of standard deviations of the full retained cohort from the population mean) = 0.95 (The full listing of retained seed and pollen parents is given in Appendix 2).

Table 12. Phenotypic values for DBH at age 16 years of the Seed, Pollen Cull and Overall cohorts of the Naringal E. cladocalyx progeny test

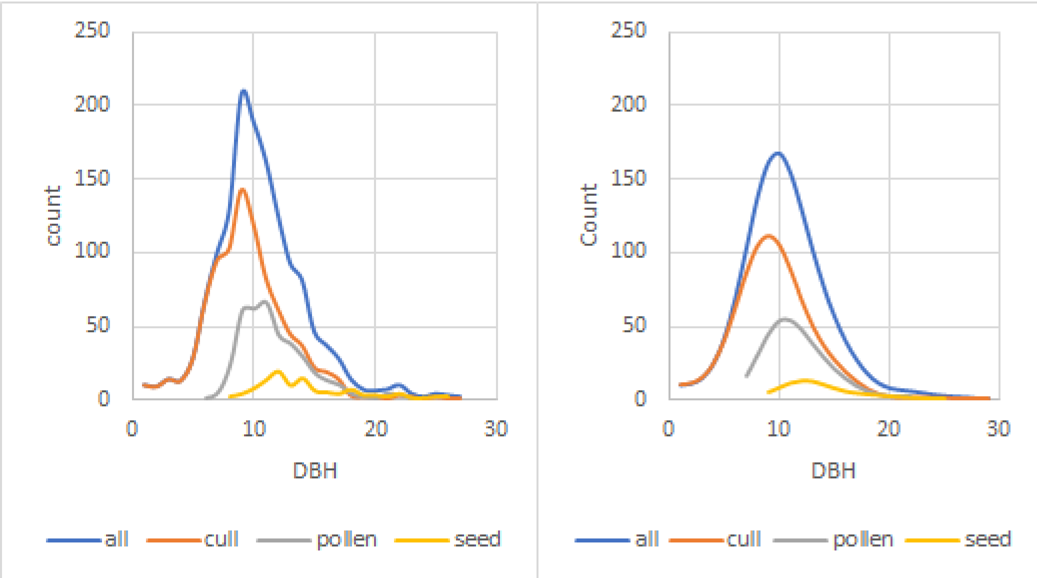
Cohort			DBH Phenotypic			Std Dev
	Number	Mean	Min	Max	Mode	
Seed Parent	113	14.8	8.4	26.7	13	4.0
Pollen Parent	387	12.2	6.9	27.6	11	3.0
Overall 2017	1403	11.0	0.5	29.0	10	3.8
Cull 2017	903	10.1	0.5	29.0	9	3.6
Cut before 2017	997	-	-	-		-
Overall	2400	11.0	0.5	29		3.8

[1] removed in 2010

The selection cohorts are plotted (Figure 2), to indicate the relative numbers of individuals in each selection cohort, proportional to the areas under the curves. Figure 2b has been smoothed to indicate the mode for each population. Note that gain is the difference between the seed and pollen curves relative to the 'all' curve.

Figure 7. Histograms of diameter distribution among the three selection cohorts.

(i) seed parents, (ii) pollen parents and (iii) culls, as well as (iiii) all. [a: (left) = raw group data, b: right = Smoothed].



Diameters are of all live trees at April 2017. Nine hundred and ninety seven stems had previously been thinned from below.

Response to selection

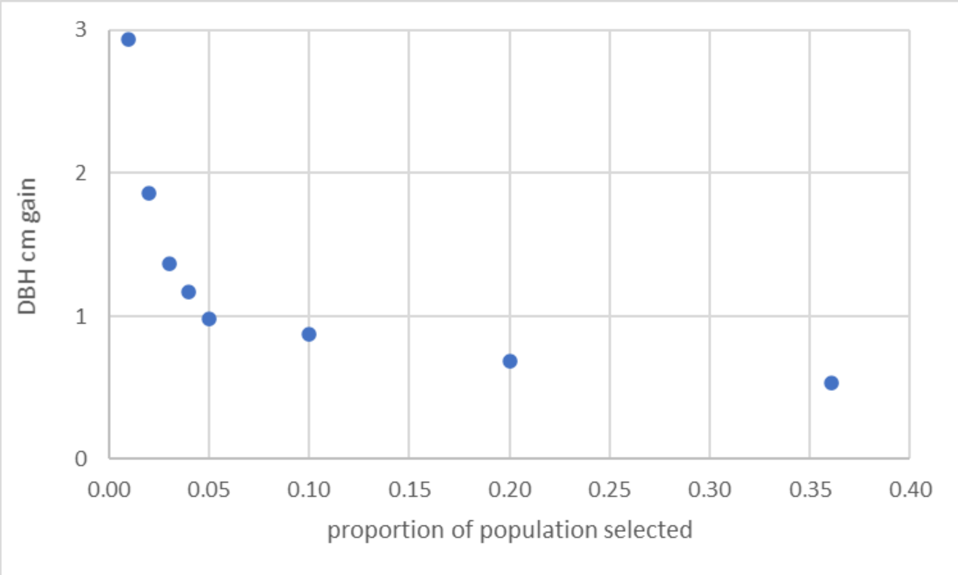
We present nominal response to selections assuming truncated selection. With the parameters from this study (i = 0.95, h^2 = 0.13 and σ_P = 3.8) response of diameter to the present section is 0.46 cm (Table 13). If we reduce the selected proportion to 20 and 10 % the predicted gain in diameter is 0.68cm and 0.88cm respectively. Assuming 1000 sph at 16 years and that height is related to stem diameter at 100:1, these cohorts may provide 13%, 20% and 26% increase in volume. These gains are eroded somewhat in the real selection by the exclusion of trees for reasons other than size, typically branching and stem form.

Table 13. Calculation of volume gain using Phenotypic functions R=ih2σP (Falconer)

h^1	σ_P	Stems Retained	i	DBH		basal area	Volume [1]		volume increase	
		%		response	group mean	tree	tree	Ha	over all	prop
				Cm	cm	m^2	m^3	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}
0.13	3.76	100	-	-	11.02	0.0095	0.038	45.4	-	-
		36	0.95	0.46	11.48	0.0104	0.043	51.4	6.0	0.13
		20	1.40	0.68	11.70	0.0108	0.045	54.4	9.0	0.20
		10	1.80	0.88	11.90	0.0111	0.048	57.1	11.8	0.26

[1] Volume assumes conic function and 1:100 proportion between diameter and height.

Figure 8. response of DBH to selection intensity assuming truncated selection



Production seed can be a bulk of whatever is available now on the pollen and seed parents. These may be kept as separate grades with the seed parents being best. As selection intensity increases it is theoretically possible to obtain larger gains (Figure 3), hence seed can also be grouped on the basis of stem diameter. Seed with the best growth potential may come from narrow cohorts of the largest diameter parents. These gains are rarely explicitly documented from other breeding programs, however the theory is the basis on which seed from breeding programs is sold.

The practical applications are more important in this program. After 17 years' of progress the next steps are listed in Table 12.

Table 14 Tasks for managing the progeny trial.

Task	Status
1. Established a diverse population	DONE
2. Selected outstanding individual in each family.	DONE
3. Thin stand and allow these and a few sub-elites to cross	TO DO NOW
4. Collect seed from seed parents, establishment next generation	2 YEARS
5. Current seed on pollen and seed parents can be deployed as seedlings.	NOW

Recommendations and follow up actions

The main objective is to achieve the goal of thinning the *E. cladocalyx* progeny trial at Naringal in support of its original aim; that being to produce seeds of greater genetic value for afforestation in the SW Victorian 600 mm rainfall zone.

1. Thinning should occur at the first opportunity
2. The trees have been marked in the plantation with 2 painted hoops (seed Parents) and single hoops (Pollen Parent)

3. Unmarked trees can be removed by falling and can be kept as coppice if the landowner wished to maintain visual appearance and shelter for livestock
4. The thinned stand is permitted to flower and set seed
5. Seed set subsequent to the thinning will immediately benefit from crossing only with selections of higher breeding value
6. The gains indicated will result in a positive change to the NPV/IRR or plantation enterprises.
7. The next seed crop to be harvested will be taken in several arrangements
8. Single tree selections from each of the Seed Parents. This selection to be raised as seedling stock and planted into the next series of progeny tests. The seed should be offered to other former members of ALRTIG.
9. Bulk seed collected from the Seed and Pollen parents can be graded according to breeding value and deployment seedlots made up in several grades Table 13.

Table 15. Seed combination groups following post-thinning seed sed.

Group	Group	description	COMMENT
Turnover population	TP	113 seedlots	to progeny test, Full genetic information, maximum genetic variability. Turnover, cloning and crossing experiments.
Deployment	A1	Best 1%	Fastest growth
	A2	Best 5%	Fast growth
	A3	Mix all seed parents	Maximum genetic variability, graft selection
	B1	Mix best 50% of pollen parents	Mod Growth
	B2	Mix second 50% pollen parents	Fair growth

Synthesis

The establishment techniques trials show no difference among the cultivation treatments compared to nil cultivation. In a few cases ripping alone appeared to decrease establishment success. So following basic site clearing with proper first and second year weed control seems to be the most appropriate method for establishing *E. cladocalyx* on these ex-pasture sites. Growth rate was in the order of an MAI of 9 $m^3.ha^{-1}.y^{-1}$ for both sites; which is a good indicator of the performance of a well- established plantation even if tending and fertilising ceased at the end of age two years.

The species trial indicated that gains were demonstrated by improved seedlots, whether mildly or intensively selected, with the improvement heading in the direction of the intensity of improvement from wild Wirrabara seed, to Lismore plantation seed and then Kersbrook seed orchard seed.

There is no effect of any site preparation in the establishment trial. The site MAIs are consistent with the species and progeny trials if a bit lower. Nicely established plantation should easily give 10 MAI of 10 $m^3.ha^{-1}.y^{-1}$ to 10+ years of age and could probably be improved with fertilisation, particularly in wet spring seasons.

E. cladocalyx had better growth, survival and form than all other species. The growth of the three seedlots indicate improved growth commensurate with their level of genetic improvement or adaptation to local conditions. For instance, the Wirrabara seedlot originates in the Flinders ranges and occurs in this trial as a first introduction without selection. The Lismore seedlot is collected from trees growing in the Lismore area for 100 years; and these may have been survivors of a larger gene pool, with their survival and vigour presumbly associated to adaptation to local conditions. The Kersbrook seed orchard is based on x selections of y provenances, and was selected at z intensity; propsed Improvements in growth over base populations was … and this is reflected here.

The effectiveness of the open-pollinated plant breeding approach is demonstrated by the improved MAI, from wild seed collection of 10.4 $m^3.ha^{-1}.y^{-1}$, to low improvement 11.9 $m^3.ha^{-1}.y^{-1}$, and high improvement of 13.3 $m^3.ha^{-1}.y^{-1}$. This trend is as expected, although not statistically significant . With the two *C. maculata* provenances there is no difference.

The *C. maculata*, *C. variegata* and *E. sideroxylon* all showed good survival but significantly slower growth than the *E. cladocalyx*. A general comment is that all would have benefited from tending to remove multiple leaders and improve the form, so while the results may be useful to compare in terms of total volume growth, no conclusions can be made about sawlog suitability. From the point of view of integration with grazing activities, the *Corymbia* species are attractive and retain heavy canopies and so could be assumed to provide additional cover and protection to stock, although they are more frost-prone than the *E. cladocalyx*. Interestingly, for a part of the period of this trial, the species establishment was chosen by a previous owner of Naringal as the location for a free-range piggery, due to the excellent shelter provided by the trees. (Note that there were no signs observed of pigs having caused damage to the trees, or affecting the trial results.)

The *Grevillea robusta* species trial was a complete failure. It is unclear whether this was due to a planting stock being too small or tender at time of planting, or effect of browsing or unsuitability to the site. In other trials near Bendigo the species survived and grew well until about age 3 years, at which time it failed due to dry conditions. *Acacia mearnsii* was also unsuccessful with poor form, poor survival and the lowest growth rate. Again the reasons for the low growth are unclear, but could be inherent or due to poor nodulation and mycorrhizal innoculation.

The remeasurement of the Progeny Trial of *E. cladocalyx* gave a mean diameter of the seed parent population of 14.8 cm; the pollen parent population 12.2 cm and the overall population 11.0 cm. The weighted mean diameter of the seed and pollen parents is 12.7 cm; an increase of 1.7 cm over the current population mean. The site has been marked for thinning and seed collection can occur at that time. This would be an important investment to make available improved seed for future plantings of Sugar Gum.

Recommendations

Plantation economists should be aware of these results, demonstrating that the MAI values obtained for *E. cladocalyx* match and exceed *E. globulus*. *E. cladocalyx* has also demonstrated the hardiness required to survive over the periods required to grow sawlogs in many westerm plains locations over the past 140 years.

Up to 216 m^3/ha was grown over 16 years with improved *E. cladocalyx* using good establishment silviculture, and little management input after that. It may be possible to improve on that volume with additional post-planting management such as fertilising and thinning.

The precision of the present data can be improved by (i) remeasurement of all heights, (ii) recording bark thickness and (iii) developing taper functions tailored to each species. Systematic measurement of bark thickness and stem sections would enable modelling of appropriate taper functions. This would require a subset of trees with species of interest from this trial, namely the Sugar Gums, Blue Gums and Ironbarks.

E. cladocalyx provides the best prospect for growing sawlogs, and improved seed appears to provide faster growth. We suggest that local seed production areas are used to provide base germplasm for further plantations in the district. Further consideration needs to be made to optimise (i) planting espacement, (ii) cultivation and weed control, (iii) nutrition at planting and later, and (iv) the timing and intensity of thinning; and these can be implemented alongside new plantations.

References

ABARES (2019) Australian Plantation Statistics 2019 update. Australian Bureau of Agriculture and Economics Resource Sciences.

https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/abares/publications/AustPlantationStats_2019_v.1.0.0.pdf

Bandara, G. and Baker, T. G. (2001). Longer Term Growth Responses of *Eucalyptus globulus* to Soil Cultivation, Weed Control and Fertiliser Application at Establishment on a Former Agricultural Site at Buffalo River, Victoria. CFTT Report No. 2001/044(unpublished).

Falconer, D. S. (1989) Introduction to Quantitative Genetics. Longman Scientific and technical Harlow UK.

Griffin, A. & Cotterill, P.P. (1988). Genetic variation in growth of outcrossed, selfed and open-pollinated progenies of Eucalyptus regnans and some implications for breeding strategy. Silvae Genetica. 37. 124-131.

Harwood, C., Bulman, P., Bush, D., Mazanec, R., Stackpole, D. (2001) Australian Low Rainfall Tree Improvement Group: Compendium of Hardwood Breeding Strategies A report for the RIRDC/LWA/FWPRDC Joint Venture Agroforestry Program. August 2001 RIRDC Publication No 01/100. RIRDC Project No CSF-58A. https://www.agrifutures.com.au/wp-content/uploads/publications/01-100.pdf

Nielsen, W. (1990). Plantation Handbook. Forestry Commission Tasmania, Hobart.

Sheriff, DW (1998) Productivity and Economic Assessment of Hardwood Species for Scrimber Production. A report for the Rural Industries Research and Development Corporation. January 1998 RIRDC Publication No 98/4 RIRDC Project No. CSF-38A

Stackpole D & Wang Y (2004) Lismore and Wallinduc Eucalyptus cladocalyx Establishment Techniques Trials: Progress Report 2004/05. Forest Science Centre, Department of Sustainability and Environment, Victoria (unpublished).

Stackpole D, (2001) Eucalyptus cladocalyx Provenance by Family trial: Establishment of Experiment and Lismore Victoria. Centre for Forest Tree Technology, 123 Brown Street Heidelberg; Report number 2001-051

Appendix 1

Rationale for the Species Comparison trial seed lot selections

Eucalyptus cladocalyx has long been known and planted as a suitable species for the Western Plains of Victoria and used for firewood farm timbers and sawn timber; in which in all applications it excels. Interest in improved seed sources for this species developed from the mid 1990s, resulting in various publicly and privately funded genetic resources from which studies of the parent populations ascertained which genetic material may be suitable for improved germplasm lines. Alongside this activity was an interest in demonstrating the relative performance of seedlots arising from previous improvement efforts, e.g. the ALRTIG genetic gains trials established 2001. The material under comparison was from wild, low and high intensity improvement schemes. In the present trial these levels of improvement are represented by Kersbrook Seed orchard SA, Lismore Rowe plantation (low) and Wirrabara provenance (wild). The last was demonstrated to be a good wild seed lot in previous provenance trials

Corymbia maculata and *C. variegata* had been of interest in the mid to lower rainfall parts of SE Australia for sawlog production. A wild and seed-orchard population of *C. maculata* is under consideration here. This includes *Corymbia maculata* bulk seed collection from CSIRO's Deniliquin seedling seed orchard (SL 1942) and a wild collection (CSIRO 20542). Two *C. variegata* of doubtful origin are included here.

Acacia mearnsii showed suitable growth and form in CSIRO trials at Mount Gambier (Sheriff 1989), and we sought the same seedlot (CSIRO 14926 37° 10' 147° 45' 300 m). *E. tricarpa* and *E. sideroxylon* were included as well-known species suited to lower rainfall areas. *E. globulus* was included as it has long been planted on the 600 mm rainfall zone of western Victoria, while an *E. bicostata* seedlot was included as it is reputed to have tolerance to lower rainfall conditions. *Grevillea robusta* was included on the recommendation of the then director of the School of Forestry Creswick, Dr Mark Adams, as it has been successfully used as a plantation species in other parts of the world.

Appendix 2

Appendix 1. Phenotypic diameter over bark at breast height (DBH) for Seed, Pollen and Cull cohorts from each family in the Naringal E. cladocalyx progeny test.

Locality		mother	total	cut		culled			pollen			seed	
		ID	n	n		N	DBH		n	DBH		n	DBH
American river	FI	1	20	8		7	12.1		4	10.3		1	15.1
		2	20	8		10	12.1		1	8.9		1	21.1
		3	20	8		7	11.9		4	14.0		1	18.0
		4	20	8		7	13.1		4	11.5		1	12.9
		5	20	8		8	9.3		3	10.7		1	13.2
		6	20	8		7	12.8		4	11.9		1	22.9
		Mean					11.8			11.6			17.2
Cygnet river	FI	7	20	8		9	11.3		2	11.3		1	14.0
		8	20	9		7	12.1		3	18.7		1	26.7
		9	20	9		7	12.6		3	12.5		1	14.3
		11	20	7		8	11.9		4	14.0		1	23.0
		13	20	8		8	12.1		3	13.2		1	13.8
		Mean					12.0			14.1			18.4
Filler (Oz Trees)		999	20	10		6	7.5		3	9.7		1	18.7

Locality		mother	total	cut		culled			pollen			seed	
		ID	n	n		N	DBH		n	DBH		n	DBH
Flinders chase	FI	15	20	8		10	11.0		1	14.7		1	13.3
		17	20	9		6	13.4		4	13.4		1	19.6
		18	20	8		8	15.7		3	18.0		1	25.1
		22	20	8		7	12.5		4	15.3		1	20.7
		24	20	8		8	13.8		3	16.0		1	14.4
		25	20	8		7	11.0		4	14.8		1	17.7
		27	20	8		9	11.8		3	14.5			
		28	20	8		8	12.6		3	15.6		1	18.4
		29	20	8		10	13.1		1	14.5		1	15.1
		30	20	8		7	13.9		4	14.7		1	18.3
		33	20	8		9	15.0		2	11.6		1	11.7
		34	20	10		10	7.4						
		35	20	8		6	9.4		5	16.0		1	22.7
		36	20	8		7	11.3		4	19.7		1	
		37	20	7		8	11.4		4	14.9		1	14.2
		38	20	8		12	11.1						
		39	20	8		7	11.2		4	12.5		1	16.6
		40	20	8		11	10.1					1	12.9
		41	20	9		9	11.7		1	17.3		1	12.5
		42	20	8		7	11.6		4	13.0		1	14.4
		43	20	8		7	11.5		4	14.5		1	20.1
		44	20	8		8	14.8		3	12.7		1	22.9
		45	20	9		11	11.8						
		46	20	8		7	11.2		4	13.1		1	16.3
		47	20	8		6	12.0		5	19.2		1	25.4
		Mean					12.0			15.1			16.8
Kersbrook SSO	SSO	48	20	8		7	11.0		4	13.7		1	13.8
		49	20	8		7	9.3		4	10.6		1	12.8
		50	20	8		7	7.6		4	9.1		1	11.4
		51	20	8		7	8.9		4	10.5		1	12.7
		52	20	9		6	13.6		4	14.1		1	16.4
		53	20	9		6	9.5		4	18.1		1	19.6
		54	20	8		6	9.2		5	15.6		1	16.6
		55	20	8		7	9.4		4	11.4		1	17.1
		56	20	9		6	9.9		4	14.8		1	24.3
		57	20	10		5	8.2		4	11.2		1	11.6
		58	20	8		9	9.8		2	9.0		1	18.9
		59	20	8		8	5.3		3	11.7		1	12.2
		60	20	8		7	8.8		4	12.3		1	15.6
		61	20	9		6	9.7		4	12.6		1	12.7
		62	20	8		7	10.1		4	11.1		1	11.6
		Mean					9.3			12.6			15.2

Locality		mother	total	cut		culled			pollen			seed	
		ID	n	n		N	DBH		n	DBH		n	DBH
Lismore	PLANT	63	20	8		7	10.5		4	9.5		1	12.2
		65	20	8		10	11.4		1	10.3		1	14.0
		66	20	9		6	9.6		4	9.6		1	14.1
		Mean					10.6			9.6			13.4
Majorca	PLANT	67	20	8		7	8.7		4	10.3		1	10.7
		68	20	8		7	11.6		4	11.8		1	15.0
		69	20	8		7	9.4		4	10.2		1	14.4
		70	20	8		7	9.3		4	10.8		1	21.4
		71	20	8		7	7.9		4	9.8		1	12.6
		Mean					9.4			10.6			14.8
Mt Burr	SSO	72	20	9		6	10.7		4	11.4		1	11.4
		73	20	9		6	10.2		4	11.6		1	11.6
		74	20	8		6	10.4		5	13.3		1	17.0
		75	20	8		7	8.9		4	12.4		1	13.8
		76	20	8		7	10.4		4	13.0		1	14.3
		Mean					10.1			12.4			13.6
Mt Remarkable	FR	77	20	8		7	8.0		4	9.9		1	11.8
		78	20	8		9	10.2		2	9.4		1	9.4
		79	20	8		7	8.7		4	10.7		1	10.9
		80	20	8		7	8.5		4	10.4		1	10.3
		81	20	8		7	9.1		4	11.1		1	12.4
		82	20	9		8	8.8		2	9.1		1	9.8
		83	20	8		9	7.2		2	8.6		1	12.6
		84	20	8		7	9.8		4	10.1		1	14.4
		85	20	10		8	4.6		1	9.2		1	8.9
		86	20	8		8	6.0		3	9.6		1	13.6
		87	20	8		12	11.9						
		88	20	9		7	6.4		3	11.8		1	18.2
		89	20	10		5	8.7		3	12.0		2	12.4
		90	20	8		7	10.2		4	12.1		1	11.8
		91	20	8		7	10.6		4	10.4		1	10.6
		92	20	8		7	8.5		4	13.7		1	14.3
		Mean					8.7			10.8			12.1
Sth Wilmington PO	FR	93	20	9		8	6.5		2	10.2		1	12.6
		94	20	8		8	9.0		3	9.6		1	10.6
		95	20	8		7	10.7		4	8.8		1	10.0

Locality		mother	total	cut		culled			pollen			seed	
		ID	n	n		N	DBH		n	DBH		n	DBH
		96	20	8		7	6.2		4	11.6		1	17.1
		97	20	8		7	11.1		4	10.5		1	13.9
		98	20	8		11	9.8		1	9.4			
		102	20	8		9	12.6		2	9.1		1	9.6
		Mean					9.5			10.0			12.3
Wail	PLANT	103	20	9		6	7.6		4	11.4		1	14.1
		109	20	8		8	12.7		3	10.7		1	11.5
		110	20	8		7	10.3		4	11.9		1	15.3
		Mean					10.4			11.4			13.6
Wilmington	FR	112	20	8		7	10.1		4	11.1		1	12.1
		113	20	8		7	9.1		4	13.1		1	18.2
		114	20	10		8	6.9		1	10.1		1	11.0
		116	20	8		7	9.4		4	11.1		1	12.4
		117	20	8		8	4.4		3	10.8		1	16.4
		118	20	8		8	10.4		3	15.1		1	22.4
		121	20	8		11	7.8					1	8.4
		Mean					8.2			12.0			14.4
Wirrabara	FR	122	20	8		8	12.4		3	9.3		1	9.8
		123	20	8		7	9.1		4	13.9		1	20.0
		124	20	11		5	4.7		3	8.3		1	13.8
		125	20	8		8	12.1		3	14.3		1	19.9
		126	20	10		10	8.4						
		128	20	9		6	7.2		4	10.5		1	12.7
		129	20	8		10	8.1		1	13.2		1	11.3
		130	20	8		8	9.0		3	10.1		1	15.3
		131	20	8		7	7.9		4	9.5		1	12.7
		132	20	8		7	9.4		4	11.1		1	14.9
		133	20	8		7	10.4		4	13.0		1	13.8
		134	20	12		3	8.7		4	10.1		1	12.6
		135	20	8		7	8.0		4	13.9		1	11.3
		136	20	8		7	9.1		4	11.7		1	12.9
		137	20	8		10	9.4		1	9.0		1	11.7
		138	20	8		7	9.5		4	10.1		1	10.9
		139	20	9		7	10.0		3	10.4		1	11.2
		140	20	8		7	10.2		4	11.5		1	13.4
		141	20	8		7	9.7		5	11.8			
		142	20	8		7	10.0		4	10.6		1	12.4
		143	20	8		8	7.3		3	9.9		1	12.1
		144	20	8		7	9.2		4	11.1		1	14.7
		Mean					9.2			11.2			13.4

Appendix 3

Height function regression

Table 15 provides the regression equation coefficients for converting heights measured on trees of good form across a range of diameters for each species, to enable development of predicted height (Hp) using diameter breast height overbark (DBHOB).

Table 16 Slope and intercept coefficients used for predicting height

Trial	TREAT	SLOPE	INT	R^2
Sawlog	OVERALL	0.0368	6.8425	0.3225
	11	0.0016	9.6678	0.0137
	8	0.0184	9.6244	0.563
	18	0.0224	12.268	0.3508
	19	0.0209	12.89	0.2964
	17	0.0461	6.1734	0.7218
	9	0.0083	15.71	0.0281
	16	0.0347	6.1917	0.2454
	15	0.0241	7.4281	0.7462
	22	0.0206	9.4973	0.2243
	20	0.0487	3.6195	0.8635
	13	0.011	10.183	0.1918
	14	0.011	10.183	0.1918
Establishment Naringal	E. cladocalyx			
Establishment Titanga	E. cladocalyx			