EUCALYPTUS LONGIROSTRATA: A POTENTIAL SPECIES FOR AUSTRALIA'S TOUGHER SITES?*

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ABSTRACT

In 2004 and 2005, Forests NSW established six progeny trials of *Eucalyptus longirostrata* (Blakely) L.A.S.Johnson & K.D.Hill (grey gum), in the Hunter Valley and northern New South Wales, Australia, with a total of 79 families in the two trial series. A third series of trials, with 74 families, was planted on four sites during 2007. The three trial series eventually contained a total of 121 families from eight provenances.

The 2004 series of trials located near Casino and Grafton (northern NSW) and Singleton (Hunter Valley) were assessed at age 31 months for growth and stem straightness. Survival was high on all three sites, ranging from 89% (Grafton) to 95% (Singleton). Height growth was greatest at Grafton (trial mean 8.6 m) with the poorest growth recorded at Singleton (trial mean 2.4 m) reflecting the severe drought conditions at this site. Height was under moderate to high genetic control with individual-tree, narrow-sense heritabilities ($\hat{h}^2$) for height at 31 months estimated to be 0.34, 0.49, and 0.33 at the Casino, Grafton, and Singleton trials, respectively, assuming a coefficient of relationship within open-pollinated families of 0.25. The across-site correlations for all traits measured were high, suggesting that at age 31 months there was little genetic × environment interaction across the range of site types represented by the three trial series.

Keywords: *Eucalyptus longirostrata*; low rainfall; marginal sites; genotype by environment interaction.

INTRODUCTION

Eucalyptus longirostrata has a natural distribution in south-eastern Queensland from Toowoomba northwards to Maryborough and extending north-west and west to Monto, the Expedition Range, and the Blackdown Tableland (Brooker & Kleinig 2004). The species grows on a range of sites on low hills and ridges on shallow

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soils derived from sandstone (Boland *et al*. 2006), within the 700–1200 mm rainfall zone, with a summer maximum rainfall. The species is tolerant of poor, shallow soils and has shown potential for growth on a range of sites in Queensland (Lee *et al*. 2003).

The taxonomy of the grey gums has been revised (Chippendale 1988). Previously a subspecies of *Eucalyptus punctata* DC., *E. longirostrata* was elevated to species in its own right, although it is still grouped with *E. punctata* and *E. propinqua* Deane & Maiden as a grey gum in the series Lepidotae-Fimbriatae (Brooker 2000). As a species closely allied to *E. punctata* (Boland *et al*. 2006), the wood is expected to be of similar quality. The wood from native forests is of high density (basic density 850 kg/m^3), with highly durable heartwood (Class 1), and is used for heavy engineering construction, poles, and sleepers (Timber Development Association (NSW) Ltd 2003; Bootle 2005). Plantation-grown wood was found in one study to have a basic density of 574–637 kg/m^3 (Gardner *et al*. 2007).

Gardner (2001) reported that *E. longirostrata* performed well over a range of sites in coastal Zululand, South Africa, comparing favourably with commercial clones of *E. grandis* Hill ex Maiden × *E. urophylla* S.T.Blake and *E. grandis* × *E. camaldulensis* Dehnh. for tree growth and wood volume, disease incidence, screened pulp yield, and "pulp ability" factor. In the same series of trials, trees of this species were also found to have wood density suitable for wood-chip export (Gardner *et al*. 2007). The species was promising over a range of sites from high rainfall coastal regions in central and southern Queensland to the lower rainfall regions in the dry tropics in north Queensland and to the Darling Downs in the south, based on 3- to 5-year-old growth data from species trials conducted throughout the state (Lee *et al*. 2003).

The Forests NSW hardwood estate has traditionally been established in higher rainfall areas, particularly on the north coast of NSW. With current alternative uses and high costs for land, sites for plantation establishment in this region are becoming rarer and less economic to plant. There is pressure to move into more marginal sites which generally have lower rainfall and poorer soils, with the aim of planting species that are suitably productive within these environments to produce a plantation which is economic to harvest. In addition, it has been recognised that there can be both economic and environmental benefits in planting trees in low rainfall and marginal agricultural sites. Planting of trees on these sites can reduce erosion, mitigate salinity, enhance biodiversity, and may assist in mitigating the impacts of climate change by long-term sequestration of carbon (Rural Industries Research and Development Corporation 2000).

Forests NSW is focusing on *E. longirostrata* as a species for planting on sites that are currently considered marginal for the establishment of economically viable plantations, with low mean annual rainfall (550–800 mm) and often poor quality soils. The species is being evaluated on these sites for deployment as a pure species or in hybrid combinations with other species such *E. dunnii* Maiden or *E. pellita* F.Muell.

Since 2004, Forests NSW has established three series of progeny trials of *E. longirostrata* across site types ranging from harsh dry sites in the Hunter Valley, with planting on mine overburden, to a relatively fertile soil with mean annual rainfall of 1000 mm north of Grafton.

In 2006 Forests NSW received funding to develop elite germplasm of *Eucalyptus* species suitable for planting on marginal sites, as potential mitigation and adaptation mechanisms to climate change. This work will focus on improving the productivity and wood density of a range of emerging commercial species including *E. longirostrata*. The current paper reports results from the first trial series for the species, planted in 2004.

METHODS

Genetic Resources

During 2004, 2005, and 2007 Forests NSW established 10 progeny trials of *E. longirostrata* (Fig. 1).

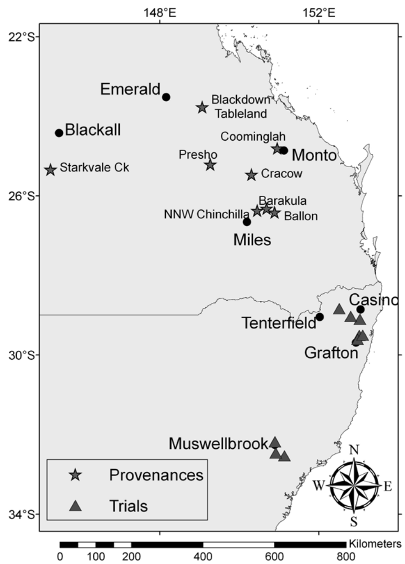

FIG. 1–Provenances of Eucalyptus longirostrata represented in the three trial series (stars) and locations of progeny trials established by Forests NSW (triangles).

The three trial series comprised a total of 121 families from eight provenances (Table 1, Fig. 1), representing the natural range of the species. The CSIRO Australian Tree Seed Centre Seedlot No. 20464 has been accessioned with a provenance name of “Moura”; however, the provenance name could be more appropriately Coominglah (D. Kleinig, Brisbane, pers. comm.), and that is the name that has been used in this paper.

TABLE 1–Provenances and number of families per provenance represented in each trial series.

Origin	Latitude	Longitude	Altitude (m)	Trial series 2004	2005	2007
NNW Chinchilla, Qld	26°22´S	150°27´E	330	5	5	
Coominglah, Qld	24°48´S	150°57´E	480	12	12	12
Starkvale Creek, Qld	25°20´S	145°15´E	450	10	10	
Blackdown Tableland, Qld	23°46´S	149°04´E	900	10	10	
Barakula, Qld	26°19´S	150°41´E	300	10	24	14
Ballon, Qld	26°25´S	150°53´E	362		18	18
Cracow, Qld	25°28´S	150°18´E	358			20
Presho, Qld	25°12´S	149°16´E	394			10

Sites

Three progeny trials of *E. longirostrata* were established in early 2004 at sites near Grafton, Casino, and Singleton (Table 2), with 20 replicates of each treatment (family) in single-tree plots, in row-column designs. The mean annual rainfall in Table 2 is the long-term average rainfall at the nearest Bureau of Meteorology Climate Station, although because of the drought conditions, the actual rainfall was less during the 3-year period (2004–2006) between establishment and assessment of the trials. The actual rainfall for 2006 at the Singleton site was only 457 mm, but the rainfall at the Grafton and Casino sites, although lower than normal, was closer to the average (Australian Government Bureau of Meteorology 2007). The Singleton trial was established on mine overburden along a ridge with minimal top soil. A soil survey in 2005 reported a very high A Horizon soil pH for the site, with some areas having a pH of over 10.

TABLE 2–Trial site details for 2004 series of progeny trials.

Location	Provenances	Families	Total trees	Planted	Average soil pH	MAR*
Grafton	6	47	940	Jan 04	5.5	1000 mm
Casino	6	47	940	Mar 04	6.0	1240 mm
Singleton	6	42	840	Apr 04	>10	730 mm

* MAR = mean annual rainfall

Silviculture

All sites had mechanical strip cultivation consisting of a single pass that ripped and mounded. Spacing in all trials was 4 m between rows and 2 m between trees within the row, giving a stocking of 1250 stems/ha. The trials were treated at planting with a custom blend fertiliser of N:P:K (8:18:5) with micronutrients, at a rate of 100 g/tree. The planting stock was grown from seed in Hiko V-93 containers in the Forests NSW Grafton Nursery.

Treatments

The Grafton and Casino trials contained 47 *E. longirostrata* families from six provenances (seven CSIRO ATSC seedlots) and the third trial located near Singleton in the Hunter Valley contained 42 families. Both the Grafton and Casino trials included a commercial seedlot of *E. propinqua* as a control.

Assessments

In September and October 2006 the three trials were assessed for total tree height (HT), diameter at breast height over bark (dbh), and stem straightness.

Diameter was not assessed at the Singleton site owing to the small size of the trees, which had a mean height of only 2.4 m at 30 months. Individual tree volume was calculated from the measured height and diameter at breast height using the equation below and a form factor of 35%.

$$\text{Volume}_{\text{(individual tree)}} = \text{ff} \times \pi \times \text{HT} \times (\text{dbh}/200)^2$$

where ff is the form factor of 0.35;
π = pi (3.14),
HT is the height of the tree in metres, and
dbh is the diameter over bark in centimetres.

All trees were assessed for stem straightness. This assessment is a subjective score of 1 to 6, with 1 being least straight and 6 being most straight. Stem straightness scores are independent of site and time variations, with a specific evaluation of the best and worst trees for each site being made at each assessment. The scoring system is site-specific and is biased to attempt to produce an approximately normal distribution at each site, i.e., 5% of all trees with a score of 1, 15% of trees with 2, 30% of trees with 3, 30% of trees with 4, 15% of trees with 5, and 5% of trees with 6.

Analyses

An Individual Tree Model in ASREML (Version 2.00a Build P) (Gilmour *et al.* 2006) was used to analyse growth traits and stem straightness. The following mixed model was used:

$$y = X\beta + Za + e$$

where y is a vector of phenotypic observations,
β is the vector of fixed effects (Replicate and Seedlot),
a is a vector of genetic effects, and
e is a vector of residuals.

X and Z are design matrices linking phenotypic observations with fixed and random effects. Narrow sense heritability ($\hat{h}^2$) was estimated using a coefficient of relatedness of 0.25 assuming fully out-crossed progeny. Owing to our lack of specific information regarding the levels of inbreeding in this species, we have assumed *E. longirostrata* is fully outcrossed, and therefore these heritabilities are probably over-estimated. It is also important to note that the number of families per provenance is low and therefore the genetic parameter estimates should be used only as a guide.

The genetic correlations between sites and traits were estimated in ASREML using an Individual Tree Model, with Replicate and Seedlot as fixed effects.

RESULTS

Survival at 30–31 months was good at all three sites (Table 3) ranging between 89% (Grafton) and 95% (Singleton).

TABLE 3–Mean values for traits assessed at age 30–31 months for the 2004 series of progeny trials.

Trial	Age	Trait	Unit	Mean	SD	CV
Grafton	31 months	Survival		89%		
		Dbh	cm	8.69	2.63	30%
		Height	m	8.60	1.82	21%
		Volume	m^3	0.0211	0.0124	59%
		Straightness	1–6) (6=straight	3.92	1.05	27%
Casino	30 months	Survival		93%		
		Dbh	cm	6.06	1.82	30%
		Height	m	5.75	1.38	24%
		Volume	m^3	0.0070	0.0045	64%
		Straightness	1–6 (6=straight)	4.04	1.07	26%
Singleton	30 months	Survival		95%		
		Height	m	2.37	0.79	33%
		Straightness	1–6 (6=straight)	3.22	1.04	32%

The Grafton trial was the best performing in terms of growth with a trial mean height of 8.6 m at 31 months, mean trial diameter at breast height of 8.7 cm, and a mean annual increment for volume of 9 m^3/ha. The Casino site had intermediate growth (mean height 5.75 m and 6.1 cm dbh at 30 months). The Singleton site was the least productive with a mean height of only 2.4 m at 30 months. Although the mean annual rainfall for Singleton was 724 mm (1969–90), in 2006 it was recorded that the town received only 457 mm of rain and less than average rainfall also occurred in 2004 and 2005. The drought was not as pronounced in the two northern sites, with the sites receiving between 80% and 90% of their average rainfall (Australian Government Bureau of Meteorology 2007). The assessment data for the three trials are summarised in Table 4.

TABLE 4–Provenance performance at the three trial sites.

Provenance	Families	Height (m)			Straightness (1–6)			Volume (m^3)	
		Grafton	Casino	Singleton	Grafton	Casino	Singleton	Grafton	Casino
Significance		0.007	<0.001	0.002	0.057	0.994	0.053	0.025	<.001
Coominglah (Moura)	7	9.47	6.34	2.83	3.85	4.23	3.38	0.0241	0.0082
Coominglah SF	5	9.04	6.22	2.91	3.59	4.09	3.34	0.0215	0.0082
Starkvale Ck	10	9.14	5.92	2.78	3.85	4.19	3.27	0.0234	0.0068
NNW Chinchilla	5	9.04	5.82	2.55	3.79	4.13	3.21	0.0225	0.0060
Barakula	10	9.24	5.63	2.66	4.04	4.15	3.36	0.0221	0.0053
Blackdown Tableland	10	8.22	5.44	2.34	3.45	4.09	2.79	0.0192	0.0058
E. propinqua	Bulk	8.04	4.42		3.71	4.14		0.0123	0.0020

Provenance Performance

Significant differences ($p<0.05$) between seedlots (provenances) were found for height at all three sites (Table 4). The high altitude (900 m) provenance, Blackdown Tableland, had the poorest height performance in each of the three trials. All provenances of *E. longirostrata* in the Grafton and Casino trials showed superior growth performance over the bulk *E. propinqua* control. The *E. propinqua* control was not planted in the Singleton trial.

Significant differences ($p<0.001$) between provenances existed for individual tree volume in the Casino trial but the differences were only marginally significant ($p=0.051$) in the Grafton trial. Blackdown Tableland was the worst performing *E. longirostrata* provenance for volume at the Grafton site, although Barakula provenance had the lowest mean individual tree volume in the Casino trial. In both trials where volume was assessed (Grafton and Casino), the *E. propinqua* performance was inferior to the performance of all *E. longirostrata* provenances.

There were no significant differences ($p<0.05$) between provenances for stem straightness in the three trials and the *E. propinqua* performance was not significantly different from that of *E. longirostrata* for this trait.

There appears to be a general trend for northern provenances to have better growth performance than the more southern provenances, within the group of provenances with mid-range altitudes (300 to 500 m). This was supported by results from two trials in Zululand, South Africa (Gardner *et al.* 2007), in which *E. longirostrata* from Monto (24°49´S) had higher productivity than the more southerly Gympie (26°18´S) provenance.

Genetic Parameters

Height was under moderate genetic control at the three sites, with estimates of narrow sense heritability ($\hat{h}^2$) ranging from 0.33 in the Casino and Singleton trials to 0.49 in the Grafton trial (Table 5). Stem straightness was under moderate genetic control in all three trials with narrow sense heritability ($\hat{h}^2$) ranging from 0.38 at Grafton to 0.45 at Singleton.

The genetic correlations between height, diameter at breast height, and volume were very high (>0.93) in the Grafton and Casino trials and those between growth traits and stem straightness were high (>0.66) at all three trial sites. The within-site heritability, genetic correlations, and phenotypic correlations at the three trial sites are shown in Table 5.

TABLE 5–Summary of genetic parameters for the three trials; within each trial, narrow sense heritability (h^2) is on the diagonal, genetic correlations are above the diagonal, and phenotypic correlations below the diagonal. Standard errors are shown in parentheses.

	Height	Dbh	Volume	Straightness
Grafton Trial				
Height	**0.49 (0.14)**	0.96 (0.02)	0.98 (0.03)	0.77 (0.11)
Dbh	0.88	**0.44 (0.13)**	1.00 (0.01)	0.81 (0.10)
Volume	0.82	0.95	**0.37 (0.12)**	0.78 (0.12)
Straightness	0.59	0.57	0.49	**0.38 (0.12)**
Casino Trial				
Height	**0.34 (0.11)**	0.93 (0.04)	0.94 (0.04)	0.67 (0.14)
Dbh	0.91	**0.34 (0.11)**	0.98 (0.02)	0.71 (0.13)
Volume	0.85	0.93	**0.26 (0.10)**	0.66 (0.16)
Straightness	0.58	0.55	0.44	**0.39 (0.12)**
Singleton Trial				
Height	**0.33 (0.12)**			0.81 (0.13)
Straightness	0.64			**0.45 (0.14)**

Across-site Correlations

Across-site genetic correlations for height were high (Fig. 2), ranging from 0.76 (0.22) between the Casino and Singleton sites to 0.95 (0.13) between the Casino and Grafton sites. The across-site correlations for diameter at breast height and volume between the Casino and Grafton trials were 0.88 (0.14) and 0.79 (0.19) respectively. For stem straightness, the across-site genetic correlations were very high (Fig. 2) with the lowest correlation of 0.91 (0.16) between the Casino and Singleton sites.

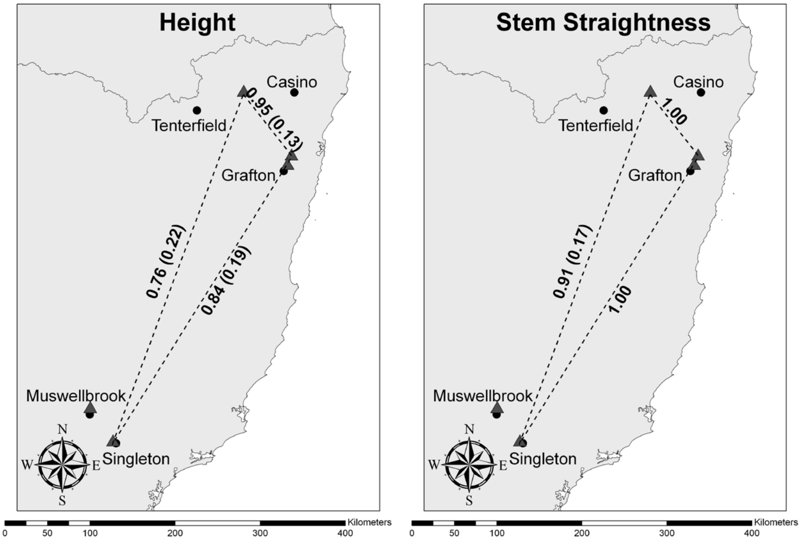

FIG. 2–Across site correlations for height and stem straightness in the 2004 trial series.

DISCUSSION

The early survival, growth, and stem straightness results demonstrate that *E. longirostrata* has potential as a commercial plantation species in NSW. The species has shown particular promise on marginal sites with poor site quality and low rainfall, where other species have not performed well. The severe drought and poor soil conditions in the Singleton region over the 3 years since planting (2006 rainfall was 457 mm) would account for the poor productivity on this site compared to the other two sites.

Provenance performance and family performance within provenance for early growth and form were stable across the range of sites sampled by the trials. The high across-site correlations suggest that there is little genetics by environment (G×E) interaction for family performance within provenance, for either early growth traits or stem straightness across a range of different site types. Therefore superior trees selected at one site should perform well at other sites. Genetics by environment interaction may become more significant as the trials age, and the across-site performance of the material should continue to be monitored.

Results from two species trials in South Africa (Gardner *et al*. 2007) demonstrated that at age 7 years *E. longirostrata* had excellent potential when tested on high productivity (wet = mean annual rainfall 1197 mm) sites in Zululand, on the basis of merchantable wood production and fibre production. Gardner *et al*. (2007) also reported that *Corymbia henyri* (S.T.Blake) K.D.Hill & L.A.S.Johnson and *C. citriodora* (Hook.) K.D.Hill & L.A.S.Johnson subsp. *citriodora* showed greater potential than *E. longirostrata* on a low rainfall site (mean annual rainfall 764 mm) in the same region. Forests NSW results from early trial assessments on the lowest rainfall site, Singleton, differ from the latter findings. Progeny trials of *Corymbia* spp. (spotted gums) have been established on all sites on which the *E. longirostrata* trials are planted, selecting a suitable species for each site type. On the Singleton site the adjacent trial of *C. maculata* (Hook.) K.D.Hill & L.A.S.Johnson, when assessed at age 34 months, had lower survival than the *E. longirostrata* trial (80% compared with 95%) and a lower mean trial height (2.0 m compared with 2.4 m).

Although *E. longirostrata* has shown excellent early potential across a range of sites, the long-term performance and health of the species need to be monitored. The species has been shown to be moderately frost tolerant in Queensland (Queensland Department of Primary Industries and Fisheries 2007) but may have limited potential for deployment on sites that experience heavy frosts.

In Australia stem borers may present a considerable constraint to the suitability of the species for high-value end uses. Bootle (2005) stated that the grey gums, *E. punctata* (including *E. longirostrata*), and *E. propinqua* are often marked by characteristic “grub holes”. In Queensland *E. longirostrata* has been classified as having high susceptibility to the giant wood moth (*Endoxyla cinerea* (Tepper)) although the level of attack was less than that in *E. dunnii* and *E. grandis* (Lawson 2003a). The species has also been classified as having moderate susceptibility to longicorn beetles (*Phoracantha* spp.) based on results from species trials in Queensland (Lawson 2003b). In the Grafton *E. longirostrata* progeny trial 6% of the surviving trees at 31 months were reported as having borer damage, although the species of borer was not identified in this assessment. It is planned to conduct a more detailed quantitative assessment of borer damage in the trials in autumn 2007.

Carnegie (in press) reported the incidence of a range of foliar fungal pathogens on *E. longirostrata* in NSW, including *Aulographina eucalypti* (Cooke & Massee) Arx & E.Müller, *Kirramyces eucalypti* (Cooke & Massee) J.Walker *et al.*, and *Mycosphaerella* spp. In addition, *E. longirostrata* has recently been observed to be infected by *Quambalaria eucalypti* (M.J.Wingf.) (Carnegie in press), the causal fungus of a shoot blight disease of eucalypts.

Forests NSW has successfully crossed *E. longirostrata* with a range of species including *E. dunnii*, *E. grandis* × *E. urophylla*, and *E. pellita* and it is planned to evaluate these hybrids in a range of environments in NSW and Queensland in 2007 and 2008. Hybrids between *E. longirostrata* and *E. grandis* are showing promise in South Africa (S. Verryn, CSIR South Africa, pers. comm.).

Preliminary results from limited vegetative propagation studies have demonstrated that E. longirostrata can be vegetatively propagated as rooted cuttings (Forests NSW, unpubl. data). This ability to clone selected genotypes will allow genetic gains to be delivered to operational plantations in short timeframes, in comparison to some species including *Corymbia* spp., for which vegetative propagation is erratic and not economically viable. Forests NSW plans to select and develop clones of *E. longirostrata* for testing and for establishing clonal seed orchards.

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