

Performance of spotted gum provenances for timber production on former bauxite mines in Western Australia

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Revised manuscript received 4 September 2002

Summary

Sixteen provenances of spotted gum — eight provenances of *Corymbia variegata*, seven provenances of *C. maculata* and one provenance of *C. henryi* — were assessed for growth and form in two trials, 13.5 y old, established on former bauxite mines in the northern jarrah forest of Western Australia. At Jarrahdale, *C. henryi* yielded the greatest volume followed by *C. maculata* and *C. variegata*. At Huntly, *C. maculata* yielded the greatest volume followed by *C. henryi* and *C. variegata*. Form was similar at both sites, with *C. variegata* having the largest proportion of single-stemmed trees followed by *C. maculata* and *C. henryi*. For straightness of single-stemmed trees, *C. variegata* and *C. maculata* were similar on both sites whilst *C. henryi* was the most crooked. *C. variegata* had the smallest branches followed by *C. henryi* and *C. maculata*. Across-site interactions, between Jarrahdale and Huntly, were not significant at the species level nor at the provenance within species level. Best provenances of *C. maculata* and *C. variegata* tended to be the same at both sites. *C. maculata* is the preferred species for growth on the mined environment because of greater volume production and better survival. A comparison of these results with those obtained at age 4.5 y indicates that selection of the best seed sources should be delayed for as long as possible.

Keywords: species trials; provenance trials; mined land; bauxite; rehabilitation; growth; spotted gum; *Corymbia henryi*; *Corymbia variegata*; *Corymbia maculata*; Western Australia

Introduction

Spotted gum timber is commercially important in eastern Australia where it is used in the building industry for flooring and structural timber and is well suited for use as tool handles (Boland *et al.* 1984). In Western Australia spotted gum is recognised as being well suited to establishment in lower-rainfall areas and is rapidly gaining popularity as a sawlog species for farmland planting.

The spotted gums (*Corymbia* section *Politaria*) consist of four species: *Corymbia citriodora* (Hook.) K.D.Hill and L.A.S.Johnson which occurs in Queensland from about 15°S to 25°S; *C. variegata* (F.Muell.) K.D.Hill and L.A.S.Johnson (formerly *Eucalyptus maculata* Hook.) occurring in northern New

South Wales and southern Queensland within the latitudinal range of about 25°S to 30°S; *C. henryi* (S.T.Blake) K.D.Hill and L.A.S.Johnson, comb. nov. which occurs in northern New South Wales and southern Queensland between latitudes of about 27°S and 30°S; and *C. maculata* (Hook.) K.D.Hill and L.A.S.Johnson (also formerly *E. maculata*), occurring in New South Wales within the latitudinal range of about 30°S to 37°S (Hill and Johnson 1995). This study investigated the performance of *C. variegata*, *C. maculata* and *C. henryi*, but not the fourth species, *C. citriodora*, in trials in Western Australia.

Results from a number of spotted gum provenance trials have been reported in the literature and reviewed by Mazanec (1999). The most significant trials overseas were those reported by Andrew (1970) in Zambia, Darrow (1985) in South Africa and Pasztor and Coehlo (1978) in Brazil. Eight trials containing the same seedlots as those investigated by Larsen (1965) were established on widely different sites. In the Brazilian trial at age 5 y, Pasztor and Coehlo (1978) found significant differences in survival between provenances. These differences were considered to be a result of problems with seedling handling and planting, rather than intrinsic differences between provenances. No significant difference was observed between provenances for height, diameter, basal area or plot volume.

In a 3-y-old *E. maculata* trial established in Zambia, Andrew (1970) found that a provenance from Grafton grew tallest and had the greatest volume, whereas the southernmost provenance from Mt Tara had the least height and volume. Darrow (1985) reported the results of six trials in South Africa ranging in age from about 4.5 y to 11.5 y. He observed that seedlots from northerly latitudes tended to grow taller than those from southerly latitudes. Within Australia, a 16-y-old Australian trial of the same seedlots was measured for diameter (Doran and Brown 1982). Trees of the Casino provenance, followed by the Grafton provenance, had marginally greater diameters than other provenances in the trial.

Within Australia, Measki *et al.* (1998) observed that spotted gum from Orbost in Victoria grew tallest in two trials in southern Victoria whilst a provenance from Dalby in Queensland produced the shortest trees in the same trials.

In Western Australia *E. maculata*, along with *E. resinifera* Smith and *E. wandoo* Blakely, was considered to be a species with significant potential in the rehabilitation of bauxite mines, owing to its tolerance of the soil-borne dieback-causing fungus *Phytophthora cinnamomi* Rands, its good timber and its satisfactory performance in past minepit plantings. The dominant native overstorey species, jarrah (*E. marginata* Donn ex Smith subsp. *marginata* and *E. marginata* Donn ex Smith subsp. *thalissica* Brooker and Hopper), which is susceptible to *P. cinnamomi*, was considered of limited use as a rehabilitation species in the highly disturbed post-mining environment (Department of Conservation and Environment 1984).

As part of a program to find the best seed source for use in rehabilitation, Alcoa World Alumina Australia, in collaboration with the Forests Department of Western Australia, sponsored the CSIRO Division of Forestry in Canberra to collect seed from across the natural range of *E. maculata*. In 1983 this seed was used to establish two trials on the Huntly and Jarrahdale former minesites in the northern jarrah forest at latitude about 32°S, and a third trial on farmland in the Wellington catchment of south-western Australia.

Mazanec (1994) found that, at age 4.5 y, provenances (Table 1) from north of 32°S were likely to produce taller trees in the Jarrahdale and Huntly trials. Mazanec (1999) reported results from the trial in the Wellington catchment, where *C. henryi* had the greatest volume growth, followed by *C. maculata* and *C. variegata*. The present paper presents results at 13.5 y from the two trials established on the Jarrahdale and Huntly former minesites, and first reported by Mazanec (1994).

Methods

Trial design

Family seed lots were bulked within provenance groupings and sown in the nursery. Sixteen provenances (see Table 1) were established in a 4 × 4 balanced lattice with five replications. Provenances were randomly allocated to plots consisting of five rows of ten trees, spaced at 2.5 m between trees within rows and 3.5 m between rows.

Establishment

Trial I was established in June 1983 north of Jarrahdale in Western Australia, at latitude 32°15'47"S and longitude 116°04'17"E. The site is 300 m above sea level and has an annual rainfall of 1183 mm. Trial II was established at Huntly, north-west of Dwellingup, at latitude 32°38'05"S and longitude 116°04'32"E, at an altitude of 275 m. Annual rainfall is 1266 mm.

Both sites had been mined for bauxite. In this process the topsoil is stripped and stockpiled, and the cap rock and underlying friable bauxite horizon are removed down to or close to a relatively impermeable pallid clay horizon. Four to five metres of the soil profile may be taken in this operation. Upon completion of mining, the topsoil is redistributed over the mine floor and the truncated soil profile is ripped to a depth of 2 m (Department of Conservation and Environment 1984). At establishment of the trial, no weed control was necessary and the trial seedlings were planted once the trial sites had received adequate rain. All trees were fertilised with 100 g of mono-ammonium phosphate.

Table 1. Provenance data and number of parent trees

Provenance	Species	No. of parent trees	Latitude (S)	Altitude (m asl)	Rainfall (mm y ⁻¹)
Monto Qld	<i>C. variegata</i>	10	24°50'	390	720
Barakula Qld	<i>C. variegata</i>	11	26°10'	410	690
Gympie Qld	<i>C. variegata</i>	10	26°17'	150	1148
Pomona Qld	<i>C. variegata</i>	5	26°22'	150	1148
Wondai Qld	<i>C. variegata</i>	10	26°25'	370	816
Dalby Qld	<i>C. variegata</i>	11	27°09'	340	666
Samford Qld	<i>C. variegata</i>	10	27°21'	100	861
Casino NSW	<i>C. variegata</i>	10	28°53'	440	1387
Grafton NSW	<i>C. henryi</i>	10	29°45'	85	983
Dunedoo NSW	<i>C. maculata</i>	10	32°04'	410	657
Buladelah NSW	<i>C. maculata</i>	10	32°27'	160	1142
Wyang NSW	<i>C. maculata</i>	10	33°08'	120	1162
Nowra NSW ^a	<i>C. maculata</i>	10	34°57'	30	1153
Batemans Bay NSW	<i>C. maculata</i>	10	35°34'	55	1021
Bermagui NSW ^b	<i>C. maculata</i>	2	36°29'	90	915
Orbost Vic	<i>C. maculata</i>	6	37°37'	300	841

^a conforms to Larsen (1965) seedlot 6173

^b conforms to Larsen(1965) seedlot 6175

Measurement

The trials were measured at age 13.5 y for height and diameter. All trees were classified into crown classes, scoring 5 for dominant trees, 4 for codominant trees, 3 for sub-dominant trees, 2 for runts or very suppressed trees, 1 for dead trees and 0 for missing trees. All stems above category 2 were assessed for form and measured for height and diameter. Forking was assessed by counting forks in the stem down to an approximate diameter of 1.5 cm. Straightness of single-stemmed trees was assessed using a 6-point scale (Cotterill and Dean 1990), in which a score of 6 was very straight for the site and a score of 1 was very poor for the site. Forked trees were not assessed for straightness. Similarly, for branch size, a score of 6 indicated very small branches and a score of 1 indicated large branches for the site.

An approximation of mean annual volume increment per hectare was calculated for each provenance plot: conic volumes for individual trees above crown class two were summed to give total volume per plot of 0.04375 ha; this volume was then converted to cubic metres per hectare and divided by the trial age to give mean annual volume increment.

Data analysis

Percentages of trees with no forks were transformed to arcsin square roots. Survival data were similarly transformed and analysed on the basis of presence or absence of living trees, irrespective of size or form. Prior to further analysis all runts were removed from the data set. Plot means were examined for normality (Williams *et al.* 2002) and mean annual volume increment per hectare was log transformed. Individual trials were analysed using the SAS Mixed procedure using the following mixed model:

$$Y_{ijkl} = \mu + R_i + B_j(R_i) + S_k + P_l(S_k) + e_{ijkl},$$

where Y_{ijkl} is the plot mean, μ is the grand mean, R_i is the fixed replicate effect, $B_j(R_i)$ is the random incomplete block nested within replicate effect, S_k is the fixed species effect, $P_l(S_k)$ is the fixed provenance nested within species effect, and e_{ijkl} is the random error.

Replicates were considered fixed (Williams *et al.* 2002). Correlation analysis, using provenance means for the two sites, was used to determine whether there was any significant relationship between environmental parameters at seed source and mean performance on the trial site.

Across-site analysis was conducted using the model

$$Y_{ijklm} = \mu + T_i + R_j(T_i) + B_k(T_i R_j) + T_i S_l + P_m(S_l) + T_i P_m(S_l) + e_{ijklm},$$

where Y_{ijklm} is the plot mean, μ is the grand mean, T_i is the trial effect, $R_j(T_i)$ is the fixed replicate within trial effect, $B_k(T_i R_j)$ is the random incomplete block within replicate effect, $T_i S_l$ is the trial \times species effect, $P_m(S_l)$ is the provenance within species effect, $T_i P_m(S_l)$ is the trial \times provenance within species effect, and e_{ijklm} is the random error.

Results

Across-site analysis

Site differences between Jarrahdale and Huntly were significant ($P < 0.01$) for all traits except branch size and number of single-stemmed trees. Species were significantly different ($P < 0.001$) for all traits across sites as were provenance within species differences ($P < 0.001$). No site \times species interactions were significant.

Survival

Overall survival at Jarrahdale was 93.3% and at Huntly 91.2%. Species survival was significantly different at both Jarrahdale ($P < 0.001$) and Huntly ($P < 0.01$), as was survival of provenances within species ($P < 0.05$ and $P < 0.01$, respectively). Best survival on both sites was observed in *C. maculata*, followed closely by *C. henryi* and then *C. variegata* (Table 2). Within species, provenance rankings were variable, but within *C. maculata* the provenances Bermagui, Wyong and Batemans Bay were nearly the best on both sites, and for *C. variegata* the provenances Casino, Samford and Pomona were among the best on both sites. The *C. henryi* provenance from Grafton ranked sixth overall on both sites (Tables 3, 4).

Within *C. variegata*, survival was highly correlated with latitude ($r = 0.73$, $P < 0.05$). No significant correlation was found for *C. maculata*.

Height

Trees were taller on average at Jarrahdale than at Huntly. Species differences and differences between provenances within species were significant at both sites ($P < 0.001$). *C. variegata* grew tallest on both sites (Table 2). At Jarrahdale, *C. henryi* was on average taller than *C. maculata*, whilst at Huntly the reverse was true. Within *C. maculata*, trees from Bermagui, Wyong and Nowra ranked in the top four provenances on both sites (Tables 3, 4). Within *C. variegata*, provenances from Monto, Dalby, Wondai and Barakula were the tallest on both sites. The *C. henryi* provenance ranked eleventh overall at Huntly and seventh at Jarrahdale. Height and rainfall at seed source were negatively correlated ($r = -0.80$, $P < 0.05$) within *C. variegata*. No significant correlations were found for *C. maculata*.

Diameter

Diameter was greater on average at Jarrahdale than at Huntly (Table 2), with *C. maculata* yielding the largest mean diameter on both sites followed by *C. henryi* and *C. variegata*. On both sites, differences between species were significant ($P < 0.001$), but differences between provenances within species were significant only at Huntly ($P < 0.01$). Within *C. maculata*, Bermagui, Wyong and Nowra were the best provenances whilst Casino, Barakula, Dalby and Wondai ranked in the top half for *C. variegata* on both sites (Tables 3, 4). The *C. henryi* provenance ranked eighth at Huntly and seventh at Jarrahdale.

Table 2. Adjusted data on survival, growth and form for species in 13.5 y spotted gum trials

Species	Survival ^a (%)		Height (m)		Stem dbhob (cm)		Mean ^a annual volume increment (m ³ ha ⁻¹)		Incidence ^a of single stemmed trees		Straightness (score 1–6)		Branch size (score 1–6)	
	Jarrahdale	Huntly	Jarrahdale	Huntly	Jarrahdale	Huntly	Jarrahdale	Huntly	Jarrahdale	Huntly	Jarrahdale	Huntly	Jarrahdale	Huntly
<i>C. henryi</i>	95.7	93.2	11.4	10.1	13.0	11.8	4.8	3.2	62.7	59.2	3.4	3.2	3.4	3.5
<i>C. maculata</i>	96.5	93.6	10.8	10.2	13.4	12.2	4.6	3.3	74.6	71.3	3.6	3.6	3.2	3.2
<i>C. variegata</i>	91.9	90.2	11.9	11.0	12.0	10.8	3.9	2.8	78.6	75.0	3.7	3.6	3.7	3.9
Std error	0.1	4.5	0.2	0.2	0.3	0.3	0.3	1.1	8.5	7.6	0.1	0.1	0.1	0.2

^abacktransformed**Table 3.** Adjusted provenance means for survival, growth and form. Jarrahdale spotted gum trial, 13.5 y old.

Provenance	Species	Survival ^a		Height		Stem dbhob		Mean annual volume increment		Incidence ^a of single stemmed trees		Straightness		Branch size	
		Rank	%	Rank	m	Rank	cm	Rank	m ³ ha ⁻¹	Rank	%	Rank	Score (1–6)	Rank	Score (1–6)
Bermagui, NSW	<i>C. maculata</i>	2	98.1	11	10.9	4	13.5	1	5.0	10	71.1	3	3.8	15	3.0
Wyang, NSW	<i>C. maculata</i>	3	97.9	10	11.0	1	13.8	2	4.9	11	70.5	6	3.7	15	3.0
Grafton, NSW	<i>C. henryi</i>	6	95.7	7	11.4	7	13.0	3	4.8	15	62.7	14	3.4	7	3.4
Orbost, NSW	<i>C. maculata</i>	11	92.7	5	11.8	2	13.6	3	4.8	1	90.5	1	3.9	7	3.4
Casino, NSW	<i>C. variegata</i>	7	94.4	9	11.1	9	12.8	5	4.7	12	70.4	1	3.9	7	3.4
Nowra, NSW	<i>C. maculata</i>	14	89.7	12	10.8	2	13.6	5	4.7	13	69.6	16	3.3	12	3.1
Dalby, Qld	<i>C. variegata</i>	16	88.7	1	13.0	9	12.8	7	4.6	2	88.1	9	3.6	1	4.0
Buladelah, NSW	<i>C. maculata</i>	1	99.1	14	10.5	6	13.2	8	4.5	16	58.6	14	3.4	12	3.1
Dunedoo, NSW	<i>C. maculata</i>	5	97.2	13	10.7	5	13.3	9	4.4	6	83.8	12	3.5	10	3.3
Wondai, Qld	<i>C. variegata</i>	13	90.8	3	12.5	12	12.2	10	4.3	5	85.0	3	3.8	5	3.8
Barakula, Qld	<i>C. variegata</i>	10	92.9	4	12.4	11	12.6	11	4.2	4	85.3	9	3.6	3	3.9
Batemans Bay, NSW	<i>C. maculata</i>	4	97.4	16	10.1	8	12.9	11	4.2	8	73.4	9	3.6	12	3.1
Samford, Qld	<i>C. variegata</i>	8	93.4	6	11.6	13	11.9	13	3.9	14	63.6	12	3.5	3	3.9
Monto, Qld	<i>C. variegata</i>	15	88.9	1	13.0	14	11.5	14	3.8	3	85.7	3	3.8	1	4.0
Pomona, Qld	<i>C. variegata</i>	9	93.0	8	11.3	15	11.4	15	3.6	9	72.5	6	3.7	6	3.6
Gympie, Qld	<i>C. variegata</i>	12	92.2	15	10.4	16	10.7	16	2.8	7	73.7	6	3.7	10	3.3
Std error			0.2		0.4		0.5		1.1		25.5		0.1		0.1

^a backtransformed

Diameter was strongly correlated with altitude ($r = 0.81$, $P < 0.05$) for *C. variegata*.

Mean annual volume increment

Differences between species in mean annual volume increment were significant at both sites ($P < 0.05$ and $P < 0.01$), but differences between provenances within species were significant only at Huntly ($P < 0.01$). On average, a greater volume of wood was produced at Jarrahdale (Table 2). On both sites *C. variegata* produced the least volume of wood. At Jarrahdale *C. henryi* produced slightly more wood than *C. maculata*, whilst at Huntly *C. maculata* was marginally superior to *C. henryi*. Within *C. maculata*, provenances from Bermagui, Wyong and Nowra were the best producers on both sites (Tables 3, 4). Within *C. variegata*, provenances from Casino, Dalby, Wondai and Barakula were the best. The *C. henryi* provenance ranked third at Jarrahdale and eighth at Huntly. Volume and altitude at seed source were strongly correlated ($r = 0.84$, $P < 0.01$) for *C. variegata*.

Incidence of single-stemmed trees

On both sites, significant differences in the incidence of single-stemmed trees were found between species and between provenances within species ($P < 0.01$ and $P < 0.001$, respectively). *C. variegata* had the highest proportion of single-stemmed trees followed by *C. maculata* and then *C. henryi* (Table 2).

Within *C. variegata*, provenances from Monto, Barakula, Wondai and Dalby had the least number of forked stems, and within *C. maculata* provenances from Orbost, Bermagui and Dunedoo ranked in the top half for that species on both sites (Tables 3, 4). The *C. henryi* provenance ranked fifteenth at Jarrahdale and Huntly. Within *C. maculata*, the percentage of single-stemmed trees was strongly correlated with rainfall at seed origin ($r = -0.8$, $P < 0.05$).

Straightness of single-stemmed trees

Analysis of variance at each site showed highly significant differences between species, and between provenances within species, for straightness of single-stemmed trees ($P < 0.01$ and $P < 0.001$, respectively). On both sites *C. henryi* produced the most crooked trees on average. *C. maculata* and *C. variegata* were very similar on both sites, with *C. variegata* having a slight edge at Jarrahdale (Table 2). Within *C. maculata*, provenances producing the straightest single-stemmed trees were Bermagui, Wyong, Batemans Bay and Orbost (Tables 3, 4). Within *C. variegata*, provenances from Casino, Pomona and Wondai ranked in the top half for this species on both sites. Bermagui was the straightest provenance overall. The *C. henryi* provenance ranked fourteenth at Jarrahdale and sixteenth at Huntly.

Branch size

On both sites, significant differences in branch size were found between species, and between provenances within species ($P < 0.001$). *C. maculata* had on average the largest branch size

on both sites, followed by *C. henryi* and *C. variegata* (Table 2). The Dunedoo, Nowra and Buladelah provenances ranked in the top four for *C. maculata* on both sites, whilst for *C. variegata* Barakula, Samford and Monto ranked amongst the top four provenances on both sites for this species (Tables 3 and 4). The *C. henryi* provenance ranked seventh at Jarrahdale and eighth at Huntly.

Branch size was negatively correlated with rainfall ($r = -0.95$, $P < 0.001$) within *C. variegata*. Within *C. maculata*, branch size was correlated with altitude ($r = 0.8$, $P < 0.05$).

Discussion

Interaction across sites

No significant interactions at either the species level or provenance-within-species level were observed between the sites at Jarrahdale and Huntly for survival, growth, percentage of single-stemmed trees, straightness or branch size.

Species

C. variegata was the tallest species at age 13.5 y at both Huntly and Jarrahdale. This is consistent with the pattern observed when the trees were only 4.5 y old (data not shown). Similar trends are evident in other trials planted overseas which range from about 4.5 y to about 11.5 y of age, as reported by Andrew (1970), Pasztor and Coelho (1978) and Darrow (1985). As these reports were published prior to the revision of the species complex, the provenances were grouped into their respective species and averaged for each site. On all sites except Frankfort and Kwambonombi in South Africa, *C. variegata* grew taller than *C. maculata*.

In the Wellington catchment of Western Australia, *C. maculata* and *C. variegata* were the same height (Mazanec 1999). By contrast, data reported by Measki *et al.* (1998) from two trials in south-western Victoria suggest that *C. maculata* grew taller on average than *C. variegata*. It should be noted that of the spotted gums formerly recognised as *E. maculata*, only three *C. variegata* provenances were included in the Victorian trials together with six *C. maculata* provenances and one *C. henryi* provenance.

Although *C. variegata* generally grew taller than *C. maculata*, analyses of the data reported here indicate that *C. maculata* will produce larger volumes of wood than *C. variegata* in the rehabilitated mine environment. These results are similar to those obtained in the Wellington catchment, where *C. henryi* and *C. maculata* produced similar volumes and were both more productive than *C. variegata*.

Form was variable, with *C. variegata* yielding, on average, more single-stemmed trees than *C. maculata*. There was little practical difference between species for straightness of single-stemmed trees. Similar results were obtained in the Wellington catchment trial (Mazanec 1999). Branch size was largest in *C. maculata* and smallest in *C. variegata*.

Table 4. Adjusted provenance means for survival, growth and form. Huntly spotted gum trial, 13.5 y old.

Provenance	Species	Survival ^a		Height		Stem dbhob		Mean annual volume ^a increment		Incidence ^a of single stemmed trees		Straightness		Branch size	
		Rank	%	Rank	m	Rank	cm	Rank	m ³ ha ⁻¹	Rank	(%)	Rank	Score (1–6)	Rank	Score (1–6)
Bermagui, NSW	<i>C. maculata</i>	3	95.5	5	10.9	1	12.9	1	4.3	7	73.3	1	4.1	14	3.0
Casino, NSW	<i>C. variegata</i>	2	95.9	6	10.6	3	12.3	2	3.7	10	67.8	2	3.9	9	3.4
Barakula, Qld	<i>C. variegata</i>	14	87.2	1	12.4	10	11.5	3	3.5	4	80.4	6	3.6	1	4.4
Dunedoo, NSW	<i>C. maculata</i>	1	97.8	8	10.4	7	12.0	4	3.4	3	82.7	6	3.6	7	3.6
Wyong, NSW	<i>C. maculata</i>	5	94.0	8	10.4	3	12.3	4	3.4	9	70.0	3	3.8	12	3.2
Nowra, NSW	<i>C. maculata</i>	12	89.5	10	10.2	6	12.4	6	3.3	12	63.4	13	3.4	12	3.2
Wondai, Qld	<i>C. variegata</i>	4	94.4	4	11.5	2	10.8	6	3.3	4	80.4	4	3.7	3	4.2
Grafton, NSW	<i>C. henryi</i>	6	93.2	11	10.1	8	11.8	8	3.2	15	59.2	16	3.2	8	3.5
Batemans Bay, NSW	<i>C. maculata</i>	7	92.6	13	9.9	5	12.2	9	3.1	14	61.9	6	3.6	14	3.0
Dalby, Qld	<i>C. variegata</i>	13	87.7	2	11.9	11	10.9	10	3.0	6	76.8	6	3.6	1	4.4
Orbost, Vic	<i>C. maculata</i>	9	91.5	11	10.1	6	12.1	10	3.0	2	85.1	6	3.6	14	3.0
Buladelah, NSW	<i>C. maculata</i>	8	92.3	15	9.8	9	11.6	12	2.9	15	59.2	14	3.3	9	3.4
Monto, Qld	<i>C. variegata</i>	15	86.4	3	11.7	13	10.5	13	2.6	1	88.1	12	3.5	3	4.2
Gympie, Qld	<i>C. variegata</i>	16	85.5	13	9.9	13	10.5	14	2.4	11	67.6	4	3.7	9	3.4
Pomona, Qld	<i>C. variegata</i>	11	90.8	7	10.5	15	10.3	15	2.3	8	72.0	6	3.6	6	3.7
Samford, Qld	<i>C. variegata</i>	10	90.9	15	9.8	16	9.7	16	2.2	13	63.3	14	3.3	5	3.9
Std error			13.1		0.3		0.4		1.1		17.4		0.1		0.1

^abacktransformed

Stem form and branch size are important traits in selecting plantation trees for sawlogs (Neilsen and Pinkard 2000). Early selection of potential crop trees, followed by pruning and thinning to between 150 and 300 stems ha⁻¹, is a common feature of silvicultural regimes for sawlog production (e.g. Neilsen and Pinkard 2000; Moore *et al.* 2001). Deployment of genetically-improved trees with low rates of forking and straight stems could increase the number of potential crop trees, from which selections might be made, by up to 30%, and would minimise the need for corrective pruning. Maximising the number of single-stemmed trees available to select from may be particularly important in areas where damage by parrots (Ritson 1995; Mazanec 1999; Moore *et al.* 2001) adversely affects form. Slightly larger branch size in *C. maculata* may be overcome by selection and breeding as well as silviculture. Spacing is known to influence branch size (James 2001; Moore *et al.* 2001) and pruning of green branches when they are still small (James 2001; Moore *et al.* 2001) is necessary to maximise production of clearwood.

Good survival in each species on both sites suggests that there would be ample opportunity to select sawlog crop trees at the established stocking rate of 1142 stems ha⁻¹.

Provenances

Ranking of provenances was generally similar between Huntly and Jarrahdale, although minor rank changes occurred in all traits between the sites. For example Bermagui, Wyong and Nowra provenances ranked amongst the top four *C. maculata* provenances for volume production at both Huntly and Jarrahdale. For height, the top four provenances, although ranked differently, remained in the same quartile on both sites.

Changes in ranking for both height and diameter also occurred between age 4.5 y (Mazanec 1994) and 13.5 y. At Jarrahdale, height rankings at the two ages were quite similar, with only minor changes. At Huntly, height rankings at the different ages were similar within *C. variegata* but changed markedly within *C. maculata*. Wide variation in provenance ranking occurred on both sites for diameter between the ages of 4.5 and 13.5 y, suggesting that selection of the best provenances for a particular site is best delayed as long as possible.

Relatively high survival for all provenances on both sites suggests that, irrespective of provenance, poor survival is unlikely to be an impediment to growing sawlogs in the mined environment.

With the exception of percentage of single-stemmed trees, at least one or more of the better provenances

at Jarrahdale and Huntly for a given trait were also amongst the best in the Wellington trial (Mazanec 1999) (data not shown). Using volume production as an example, *C. maculata* provenances Nowra and Wyong both occurred in the top half of provenance rankings at Jarrahdale, Huntly and Wellington. Similarly, Casino and Wondai ranked amongst the top four provenances of *C. variegata* at Wellington as well as at Jarrahdale and Huntly.

Correlation with environmental variables at seed source

Correlations with environmental variables were often not significant for *C. maculata*, suggesting that a wider range of provenances may be well adapted to the trial environment. Within *C. maculata*, correlation analysis suggests that trees from higher rainfall areas were more likely to have a higher incidence of forking, whilst those from higher altitudes were more likely to have smaller branches. Wider sampling of provenances may be required to better understand any underlying adaptive trends.

C. variegata was more reactive and more likely to show a significant correlation for different traits. For example, the lower survival of *C. variegata* relative to the other species (Table 2), combined with the positive correlation of survival with latitude, suggest the existence of a geographic cline in adaptation to site at both the species level and within *C. variegata* itself.

Within *C. variegata*, diameter and volume were strongly correlated with altitude, and height was negatively correlated with rainfall. The relative importance of altitude and rainfall at site of origin is apparent when comparing mean volume production across trial sites (data not shown) with rainfall and altitude. The Casino collection site had the highest altitude and rainfall, and yielded the greatest volume ($4.2 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$). The Barakula collection site had the second-highest altitude and yielded the second-greatest volume ($3.9 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$), yet had the second-lowest rainfall of all the *C. variegata* provenances, suggesting that altitude may be the more important factor.

The strong negative correlation between branch size and rainfall may in part be attributable to the correlation of height with branch size ($r = 0.9$, $P < 0.01$). The analysis suggests that, on average, *C. variegata* trees from high-rainfall areas will be shorter and have bigger branches than those from lower-rainfall areas. It may be that *C. variegata* trees which originated in high-rainfall areas do not prosper under the dry summer conditions prevailing in southern Western Australia.

Conclusion

Interactions of species and environment, and of provenance within species \times environment, were not important between Jarrahdale and Huntly minesites.

C. maculata is the preferred species for growth in the mined environment because of its greater volume production and better survival. Although *C. variegata* produces slightly more single-stemmed trees, wide variation within and between provenances of *C. maculata* provides a good opportunity to select against forking.

Selection of the best seed sources should be delayed for as long as possible to allow for changes in ranking as the stand matures and competition effects come into play.

Acknowledgements

The authors thank M. Byrne and M. Williams for comments on the manuscript, T. Butcher for designing and establishing the trials and for useful comments on the manuscript, and Alcoa World Alumina Australia for providing the seedlings.

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