PROVENANCE TRIALS OF FOUR EXOTIC EUCALYPTS IN BAUXITE MINES IN WESTERN AUSTRALIA

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ABSTRACT

One provenance trial of *E. maculata* and three family/provenance trials of *E. resinifera, E. saligna, E. pilularis* were grown on bauxite minesites in the northern jarrah forest of Western Australia. Early results suggest that the use of environmental parameters such as altitude, rainfall, soil type or latitude of seed sources in eastern Australia should be used with caution in selecting provenances for introduction to Western Australia. Heritability of height and diameter indicated that significant gains from breeding could be made for *E. saligna* and *E. pilularis* in these traits.

INTRODUCTION

Identification of tree species suitable for rehabilitation of bauxite mines in W.A. was a high priority for research in the late 1970's and early 1980's. Much of the mining lease is located in forest designated as water production Management Priority Areas (Dept. Conservation and Environment 1984). For these areas the primary objective of rehabilitation is to maintain the quality and quantity of water produced. Concern existed that the dominant native species jarrah (*Eucalyptus marginata* Donn ex Smith subsp. *marginata* and *Eucalytpus marginata* Donn ex Smith subsp. *thalassica* Brooker and Hopper) may be of limited use in rehabilitation because it is susceptible to the soil borne, dieback causing fungus *Phytophthora cinnamomi* rands. Resulting uncertainty as to the future role of jarrah in rehabilitation led to a search for suitable tree species to replace it on mined areas (Dept. Conservation and Environment 1984). It was considered essential that appropriate species be found before mining began in the salt prone areas well to the east of current mining activity.

Species selection for rehabilitation planting on bauxite mines was based on criteria indicative of species survival and timber production potential in the post mining environment. These criteria included high water use capacity, dieback resistance, fire tolerance, merchantable timber, demonstrated survival and growth in past minepit plantings and elsewhere in the northern jarrah forest region. To enhance the species selection procedure, research into the performance of some 70 species was conducted in 5 large aboreta established over the period 1976-1979 on sites within the high (>1100 mm) rainfall and the low (<900 mm) rainfall zones. In additon to species selection, the importance of finding the best seed source within a species for successful establishment of forest tree plantations is well documented (Zobel 1984) and was considered a necessary part of the selection process.

Initially *Eucalyptus resinifera* Smith, *Eucalyptus maculata* Hook and *Eucalyptus wandoo* Blakely were the species used most extensively in rehabilitation and were the first species to be studied for provenance variation. A large family/provenance trial of *E. wandoo* was established in 1982 at Jarrahdale minesite. Alcoa sponsored CSIRO Division of forestry in Canberra to collect seed for *E. resinifera* and *E. maculata* in 1981. Trials of *E. maculata* and *E. resinifera* were established in 1983 and 1984 respectively at Jarrahdale and Huntly minesites. Subsequent assessment of species performance on the basis of growth and water relations in the above arboreta (Davey and Bartle unpublished report, 1984, Hookey *et al.* 1987) indicated a range of other species which were likely to be suitable for use in rehabilitation.

A priority listing of species to be tested for provenance variation in high and low rainfall zones was drawn up. In 1985, Alcoa, in collaboration with the department of Conservation and Land Management (CALM), sponsored a seed collection of key species with the CSIRO Division of Forestry. Trials were established as seed became available. In the late 1980's however, it became apparent that jarrah was growing quite well in better drained areas on the minesites. Furthermore, the form of jarrah saplings grown from broad cast seed was better than that achieved from nursery stock. A policy of rehabilitating the bauxite pits with seed of native species taken from the local area has been adopted. To futher support this policy, CALM has begun breeding jarrah for resistance to *P. cinnamomi* (Stukely and Crane 1994). As a result of these policy changes provenance testing of exotic eucalypts in the mine-site environment has become a low priority, however the trials have been retained and will be a valuable resource should these species be required in the future.

This paper reports early results from provenance trials of Eucalyptus *maculata*, *Eucalyptus resinifera*, *Eucalyptus pilularis*, and *Eucalyptus saligna* Smith established in the minesite environment.

MATERIALS AND METHODS

Seed Collection

Seed was collected from provenances within the natural range of each species in eastern Australia, matching where possible the climatic and edaphic conditions of the mined areas. Within a provenance, seed from well-formed parent trees separated by at least 100m was collected. Parent trees were widely spaced to avoid collection of seed from related parents. Where practicable seed from a minimum of 10 trees per provenance was collected.

Trial design.

Incomplete block designs were used where possible for provenance trials owing to their potential for greater efficiency over randomised complete block designs of equivalent size.

Species 1: *E. maculata.*
Fifteen provenances of *E. maculata* and one of *Eucalyptus henryi* S.T. Baker were included in a 4 x 4 balanced lattice design with 5 replicates. The trial was duplicated on both Huntly minesite latitude 32°37' longitude 116°04' and Jarrahdale minesites latitude 32°17' longitude 116°04' in the northern jarrah forest of WA. This trial was also replicated in the Wellington catchment but is not dealt with here. Family seedlots were bulked and sown in the nursery. The trials were planted in June 1983. Provenance plots consisted of five rows of 10 trees. Spacing within rows was 2.5 meters between trees and 3.5 meters between rows. A double row of buffer trees was planted around each trial to minimise edge effects. The trials were measured for height, diameter and suvival in December 1987 and January 1988 at age 4.5 years.

Species 2: *E. resinifera.*
One hundred and forty four families from eighteen provenances were included in two 12 x 12 quadruple lattices, each with 4 replicates at Huntly and Jarrahdale minesites. Families were randomly allocated to incomplete blocks within whole replicates. Family identity was maintained in the nursery and in the field. The trial was planted in June 1984 on Huntly and Jarrahdale minesites. Families were planted in 10 tree row plots. Spacing within rows was 2 meters between trees and 4 meters between rows. Provenance plots can be considered as non-contiguous throughout a replicate. A double row of buffer trees was planted around the border of the trial to minimise edge effects. The trials were measured for height, diameter and survival in January 1988 age 3.5 years.

Species 3: *E. pilularis.*
Eighty nine families from nine provenances were established in a 3 x 3 balanced lattice with four replicates at Huntly in July 1986. Provenances were randomly allocated to main plots. Families were randomly allocated to ten-tree row plots nested within provenance mainplots. A double row of buffer trees was planted around the border of the trial to minimise edge effects. Spacing within rows was 2 meters between trees and 4 meters between rows. The trials were measured in December 1988 age 2.5 years for heights and diameters.

Species 4: *E. saligna.*
One hundred and fifty five families from eleven provenances of pure *E. saligna*, three provenances regarded as transitional between *E. saligna* and *Eucalyptus botryoides* Smith and three provenances exhibiting characteristics intermediate between *E. saligna* and *Eucalyptus grandis* Hill ex maiden, were established in a randomised complete block design with 5 replicates, at Willowdale minsite, latitude 32°55', longitude 116°00' in July 1987. Provenances were randomly allocated to main plots and families were randomly allocated to 5-tree row plots, nested within provence main plots. A double row of buffer trees was planted around the border of the trial to minimize edge effects. Spacing within rows was 2

meters between trees and 4 meters between rows. The trial was measured for height and diameter in December 1991and January 1992 at age 4.5 years.

ANALYSIS METHODS

All trials were analysed as mixed models using the Mixed procedure in SAS (SAS 1992). Site and provenance were assumed to be fixed effects because provenance performance at individual sites and across different sites were the features of interest. Survival data was analysed using arcsine square root transformed data. Preliminary analysis was carried out to determine the efficiency of the incomplete block design (Cochran and Cox 1957). If incomplete blocking was not effective the trial was analysed as a randomised complete block design. Contrasts were used to determine if significant differences in growth existed between groups of provenances with distinctive differences in altitude rainfall, latitude and where data was available, soil type. The frame of reference for contrasts was taken from the mine site environment and included an approximate altitude of 300m, rainfall of 1100mm and a latitude of 32 south.

Contrasts were made for i) an altitude of 300m or greater versus trees of lower altitude, ii) less than 1100 mm rainfall versus higher rainfall, iii) provenances from latitudes further north than latitude 32 versus provenances at 32 or further south and iv) sandy soils versus heavier clay and loam soils. Additional contrasts pertinent to the individual seed collections were also made.

Heritability

To estimate heritability, family-within-provenance and block-within-replication were considered random, provenances and replicates fixed. The assumption in this analysis is that subsequent selection in the trials for future parent trees would be carried out using data adjusted for the fixed effects (replicates) in which they occur (White and Hodge 1989, Cotterill 1987). Heritability was estimated from restricted maximum likelihood (Reml) variance components for individual sites for *E. pilularis* and *E. saligna* according to the formula $h^2=2.5*f(p)/f(p) + r*f(p)$ (Griffin and Cotterill 1988). For *E. resinifera* incomplete blocks were considered random effects and the appropriate components included in the denominator.

Trial 1: *E. maculata.*
This trial was analysed using an incomplete block analysis at individual sites and across sites.
The model used for the across site analysis was:

$$y_{ijklm} = + s_i + r(s)_{j(i)} + b(r\ s)_{k(ji)} + p_l + (s^*p)_{il} + e_{ijklm}$$

Where
y_{ijklm} = individual tree observations
s_i = site effects,
$r(s)_{j(i)}$= replicate nested within site effect,
$b(r\ s)_{k(ji)}$= incomplete block effect
p_l = provenance effect
$(s^*p)_{il}$ = site*provenance interaction
e_{ijklm} = error

Differences between *E. henryi* and *E. maculata* were examined by contrasting *E. henryi* against the remaining *E. maculata* provenances.

Trial 2: *E. resinifera.*
This trial was analysed using incomplete block analysis at individual sites and across sites. Fourteen families in replicate 4 of the Huntly trial were eliminated from the analysis owing to a lack of fertilizer applied at time of planting. The across site analysis was done using the following model:

$$y_{ijklmn} = + s_i + r(s)_{j(i)} + b(r\ s)_{k(ji)} + p_l + (s^*p)_{il} + f(p)_{m(l)} + s^*f(p)_{j^*m(l)} + e_{ijklmn}$$

Where
y_{ijklmn} = individual tree observations
s_i = site effects,
$r(s)_{j(i)}$= replicate nested within site effect,
$b(r\ s)_{k(ji)}$= incomplete block effect
p_l = provenance effect
$(s^*p)_{il}$ = site*provenance interaction
$f(p)_{m(l)}$ = family(provenance) effect
$s^*f(p)_{j^*m(l)}$ = site*fam(provenance) effect
e_{ijklmn} = error

In addition to the contrasts outlined above, the two provenances Stradbroke Island and Fraser Island were contrasted against the remaining mainland provenances. Heritability was estimated as outlined above.

Trial 3: *E. pilularis.*
Preliminary analysis indicated that incomplete blocking was ineffective and

therefore the trial was analysed using the randomised complete block model:

$$y_{ijkl} = + r_i + p_j + f(p)_{k(p)} + (r^*p)_{ij} + r^*f(p)_{i^*k(p)} + e_{ijkl}$$

Where

y_{ijkl} = individual tree observations
r_i= replicate effect,
p_j = provenance effect
$f(p)_{m(l)}$ = family(provenance) effect
$(r^*p)_{ij}$ = replicate*provenance interaction
$r^*f(p)_{j^*m(l)}$ = replicate*fam(provenance) effect
e_{ijkl} = error

In addition to the contrasts outlined above, Fraser Island was contrasted against the remaining mainland provenances. Heritability was estimated as outlined above.

Trial 4: *E. saligna*
This trial was analysed using the same model as for *E. pilularis*. Additional contrasts were made between groups of "hybrid" provenances and between "hybrid" provenances and the pure *E. saligna* provenances. A second analysis was conducted excluding "hybrid" provenances to determine if there were significant differences between pure *E. saligna* provenances. Soil data was not available for this trial. Heritability was estimated as outlined above.

RESULTS

Trial 1: E. maculata

Survival
Within individual sites there was no difference ($p>0.05$) between provenances for survival and no differences for altitude ($p>0.05$), rainfall ($p>0.05$), latitude ($p>0.05$) or soil type ($p>0.05$) were found. Overall survival across sites was 91.6%. Survival at Jarrahdale (94.1%) was better than at Huntly (89.1%, $p<0.01$). Site x environment interaction was not significant. Across sites, provenances did differ in survival ($p<0.01$). No differences for altitude ($p>0.05$), rainfall ($p>0.05$), latitude ($p>0.05$) or soil type ($p>0.05$) were found. *E. henryi* was not significantly different to *E. maculata* for survival.

Height and diameter
E. maculata grew faster at Jarrahdale for height ($p<0.001$)and diameter ($p<0.001$). Provenances differed for height ($p<0.001$) but not for diameter ($p>0.05$). Site x provenance interactions were highly significant for both height ($p<0.0001$) and diameter ($p<0.0001$). Contrasts for height indicated that provenances from higher altitudes ($p<0.0001$), latitudes above 32° ($p<0.0001$) and to a lesser extent rainfall below 1100mm ($p<0.01$) were more likely to grow faster than provenances from lower altitude and higher rainfall (Table 1). An exception is the Dunedoo provenance which comes from a similar altitude and rainfall to that of the Barakula provenance (Table 1) but came from a lower latitude, has sandy soil and ranks lower than Barakula for both height and diameter. Provenances from higher altitudes were also more likely to produce larger diameters ($p<0.05$) although the Nowra and Grafton provenances from low altitudes ranked third and fourth for diameter. Rainfall and latitude were not significant for diameter growth. Three provenances, Dunedoo, Orbost and Pomona had sandy soil (Table 1). Contrasts between these and provenances with heavy soils showed no difference for height or diameter. *E. henryi* was not significantly different from *E. maculata* for height or diameter ($p>0.05$).

At Huntly provenances differed for height ($p<0.001$) but not for diameter ($p>0.05$). Contrasts for rainfall and soil type were not significant. The tallest provenances were more likely to come from altitudes above 300 m ($p<0.0001$) and latitudes north of 32° ($p<0.0001$). Altitude and latitude did not influence diameter growth significantly. At Jarrahdale provenances differed for height ($p<0.001$) but not for diameter ($p>0.05$). The tallest provenances tended to come from altitudes greater than 300 m ($p<0.0001$), rainfall lower than 1100 mm ($p<0.01$) and latitudes north of 32° ($p<0.0001$). Soil type was not significant for height or diameter. Altitude, rainfall and latitude did not significantly influence diameter growth. There were no differences ($p>0.05$) between *E. henryi* and *E, maculata* at either site.

TABLE 1: Survival, mean height and diameter rankings across sites Huntly and Jarrahdale. *E. maculata* 4.5 years

Provenance	Altitude (m)	Rainfall (mm)	Latitude	Survival (%)	Rank	Height (m)	Rank	Diameter (cm)	Rank
Monto Qld	390	720	24°50'	87.4	16	6.66	1	6.37	9
Dalby Qld	340	666	27°09'	88.6	13	6.43	2	6.54	5
Wandai Qld	370	816	26°25'	94.0	5	6.31	3	6.48	7
Barakula Qld	410	690	26°10'	90.4	11	6.21	4	6.59	2
Casino NSW	440	1387	28°53'	94.2	2	6.05	5	6.85	1
Pomona Qld*	150	1148	26°22'	93.8	6	5.82	6	6.02	14
Samford Qld	100	861	27°21'	92.2	8	5.76	7	6.04	13
Grafton NSW#	85	983	29°45'	95.0	1	5.72	8	6.57	4
Dunedoo NSW*	410	657	32°04'	93.8	7	5.65	9	6.51	6
Nowra NSW**	30	1153	34°57'	87.6	15	5.63	10	6.57	3
Bermagui NSW**	90	875	36°29'	94.2	3	5.52	11	6.04	12
Gympie Qld	150	1148	26°17'	89.2	12	5.48	12	5.77	15
Wyong NSW	130	1162	33°08'	90.8	10	5.45	13	6.12	10
Orbost NSW*	300	841	37°37'	88.4	14	5.44	14	5.70	16
Buladelah NSW	160	1142	32°27'	92.0	9	5.39	15	6.40	8
Batemans Bay NSW	55	1021	35°34'	94.2	4	5.24	16	6.05	11

* Denotes sandy soil, ** No soil data available, #Denotes *E. henryi*

Trial 2: E. resinifera

Survival

At Jarrahdale overall survival was 94.4%. Provenance differences were not significant. At Huntly, overall survival was 93.5%. Provenances were significanctly different (p=0.01) and contrasts indicated that the best survival (p<0.01) occured in provenances from altitudes below 300 m. Rainfall, latitude and soil type were not significant. Overall survival across sites was 93.8%. No differences were found between sites (p>0.05) or amongst provenances across sites (p>0.05). Provenance x site interaction was significant (p<0.01). Contrasts showed that provenances from altitudes less than 300 m had better survival (p<0.01) than provenances from altitudes 300 m and greater. Rainfall, latitude and soil type were not significant.

Height and diameter

Across site analysis indicated that site differences were not significant. Provenances were significantly different for both height (p<0.001) and diameter (p<0.01). Site x provenance interaction was not significant for height or diameter.

Contrasts indicated that differences exist in height (p<0.01) and diameter (p<0.05) between provenances at or above 300 meters and those below 300 m. The ten tallest provenances came from altitudes below 300m (Table 2). Similarly, the ten provenances with the largest diameters came from altitudes below 300 m. Only one provenance Urbenville, had rainfall lower than 1100 mm and across sites was not significantly different to other provenances for height or diameter. Latitude was not significant for height or diameter. Three provenances Beerburrum, Stradbroke Island and Fraser Island have sandy soil. The Beerburrum provenance has soil consisting of sand over mottled yellow clays and the soils of the two island provenances consist of leached sand. Contrasts between these three provenances and the remaining provenances with heavier clay or loam soils were not significant (p>0.05). Beerburrum ranked first for height and diameter. Contrasts indicated that the two island provenances were slower growing for both height (p<0.001) and diameter (p<0.01), than most of the other provenances. Only NW Pomona ranked between Stradbroke Island and Fraser Island for height (Table 2).

At Jarrahdale provenances were significantly different for both height (p<0.001) and diameter (p<0.01). For heights and diameters the best growth was achieved by provenances from lower altitudes. The provenance Urbenville, with rainfall below 1100 mm was a poor performer for height (p<0.05) and diameter (p<0.05). Trees from Stradbroke Island and Fraser Island were significantly slower for height growth (p<0.01) than mainland provenances but not for diameter growth. Both provenances ranked toward the bottom for height and diameter. Contrasts for soil type were not significant. At Huntly, provenances were different for both height ($p<0.001$) and diameter ($p<0.01$). Contrasts were not significant for altitude, rainfall or latitude. The Stradbroke Island and Fraser Island provenances were significantly different from mainland provenances for both height ($p<0.001$) and diameter ($p<0.001$) and ranked at the bottom for both traits. The contrast for the three sandy soil provenances versus heavier soil provenances was significant for height ($p<0.01$) and diameter ($p<0.01$). Heritability for height was low to intermediate (Cotterill and Dean 1990) (h^2 = 0.09 at Huntly and h^2 = 0.12 at Jarrahdale). Heritability was low for diameter at both sites (h^2 = 0.03 at Huntly and h^2 = 0.1 at Jarrahdale)

Trial 3: E. pilularis

Survival

Overall survival was 89.5%. Highly significant differences existed between provenances ($p<0.001$). Contrasts indicated that altitudes at or above 300 m versus lower altitudes differed ($p<0.001$), with one provenance from above 300 m having the best survival (Table 3). Survival of trees from sandy soil provenances was lower ($p<0.0001$) than survival in provenances with heavier soils. Fraser Island, a provenance with soil consisting of leached sand yielded lower survival than mainland provenances and ranked last. Termeil, with sand over clay soils ranked next lowest. Fraser Island had significantly lower survival ($p<0.0001$) than all the mainland provenances. Rainfall and latitude were not significant.

Height and diameter

Provenance differences were significant for height ($p<0.001$) and diameter ($p<0.05$). Contrasts indicated that provenance altitude was a significant factor in provenance performance for height ($p<0.05$) and diameter ($p<0.05$). Ranking of means indicated that the provenances Gallangowan and NW Moleton, both from altitudes above 300 m, were tallest. Gallangowan ranked first for height and diameter. NW Moleton which ranked second for height, ranked only fourth for diameter (Table 3). Rainfall and latitude were not significant. Contrasts indicated that provenance soil type was significant in height performance ($p<0.001$) and diameter performance ($p<0.01$). Fraser Island with its

TABLE 2: Across site provenance rankings for survival, mean height and diameter at Huntly and Jarrahdale minesites. *E. resinifera* 3.5 years.

Provenance	Altitude (m)	Rainfall (mm)	Latitude	Survival (%)	Rank	Height (m)	Rank	Diameter (cm)	Rank
Beerburrum Qld*	40	1611	26°56'	94.8	5	5.49	1	6.13	1
NE Kendall NSW	90	1309	31°34'	94.6	7	5.38	2	6.13	2
Nowra NSW	40	1153	35°02'	93.8	11	5.24	3	5.90	5
N Coffs Harbour	45	1656	29°52'	93.5	12	5.20	4	6.02	4
Casino NSW	30	1107	29°12'	95.0	4	5.17	5	5.86	6
Gympie Qld	115	1148	26°13'	99.6	1	5.17	6	6.04	3
W Woolgoolga NSW	30	1656	30°04'	93.2	13	5.12	7	5.81	8
N Woolgoolga NSW	30	1656	29°53'	92.2	16	5.12	8	5.78	9
NNE Kendall NSW	40	1309	31°34'	94.7	6	5.11	9	5.83	7
SW Coffs Harbour NSW	200	1656	30°12'	94.4	9	5.09	10	5.70	12
NW Dorrigo NSW	760	2028	30°02'	91.6	17	5.00	11	5.76	10
Ravenshoe Qld	940	1212	17°42'	92.7	15	4.93	12	5.42	15
Urbenville NSW	560	1082	28°31	90.6	18	4.89	13	5.38	16
Buladelah NSW	300	1193	32°19'	92.8	14	4.89	14	5.74	11
Pomona Qld	140	1148	26°22'	97.0	2	4.83	15	5.46	14
Fraser Is. Qld*	55	1758	25°37'	95.4	3	4.71	16	5.29	17
NW Pomona Qld	445	1148	26°15'	93.9	10	4.61	17	5.47	13
Stradbroke Is. Qld*	40	1135	27°25'	94.6	8	4.59	18	5.24	18

* Denotes sandy soil

TABLE 3: Provenance rankings in *E. pilularis* for survival, mean height and diameter, age 2.5 years, Huntly minesite.

Provenance	Altitude (m)	Rainfall (mm)	Latitude	Survival (%)	Rank	Height (m)	Rank	Diameter (cm)	Rank
Gallangowan Qld	580	1148	26°28'	95.4	1	4.63	1	5.32	1
NW Moleton NSW	550	1758	30°08'	92.7	3	4.59	2	5.24	3
Newfoundland NSW	60	1656	29°55'	90.7	4	4.53	3	5.23	4
W Beerburram Qld	40	1611	26°57'	90.0	6	4.51	4	5.29	2
NE Kendall NSW	90	1309	31°34'	88.0	7	4.29	5	4.92	5
Pine Creek NSW	20	1656	30°25'	93.2	2	4.28	6	4.86	7
Termeil NSW	40	1021	35°28'	86.3	8	4.26	7	4.87	6
E Grafton NSW	60	983	29°35'	90.0	5	3.98	8	4.79	8
Fraser Is. Qld*	80	1758	25°32'	79.0	9	3.51	9	4.00	9

* Denotes sandy soil

leached sandy soil yielded the lowest heights and diameters in the trial. Termeil ranked seventh for height and sixth for diameter out of nine provenances. Fraser Island was significantly different from mainland provenances for height ($p<0.001$) and diameter ($p<0.001$). Heritability for height ($h^2=0.31$) and diameter ($h^2=0.20$) were high.

Trial 4 : E. saligna

Survival

Overall survival was 93.6%. Differences between provenances were significant ($p<0.05$). Contrasts were not significant for altitude, rainfall or latitude.

Height and diameter

Provenance differences were significant for height and diameter. Contrasts revealed significant differences between the *E.botryoides/grandis* provenance and *E. saligna* for diameter only, with the "hybrid" provenances ranking towards the top (Table 4). *E.botryiodes/saligna* provenances were better than *E. saligna/grandis* provenances for height ($p<0.0001$) and diameter ($p<0.0001$). Examination of rankings indicates that the *E.botryoides/saligna* provenance from the Wandandian area was the strongest performer for both height and diameter.

TABLE 4: Provenance rankings in *E. saligna* for survival, mean height and diameter age 4.5 years. Willowdale minesite.

Provenance	Altitude (m)	Rainfall (mm)	Latitude	Survival (%)	Rank	Height (m)	Rank	Diameter (cm)	Rank
W Wandandian NSW*	210	1153	35°05'	93.3	13	8.83	1	10.13	1
W CoffsHar NSW	600	1758	30°12'	93.6	10	8.29	2	8.77	4
Armidale NSW	910	795	30°46'	95.4	6	8.07	3	8.99	2
NE Batemans Bay NSW*	10	1021	35°38'	90.8	15	8.06	4	8.77	5
Kenilworth Qld	470	1380	26°41'	93.5	12	7.91	5	8.75	6
E Glen Innes NSW	1000	836	29°48'	93.6	11	7.80	6	8.37	11
E Guyra NSW	1100	882	30°06'	96.0	3	7.77	7	8.52	9
W Bulahdelah NSW	53	1193	32°24'	96.0	4	7.73	8	8.47	10
Termeil NSW*	45	1021	35°26'	99.6	1	7.68	9	8.83	3
NE Warwick Qld	850	703	27°58'	90.0	16	7.65	10	8.60	7
N Windsor NSW	300	961	32°55'	95.1	7	7.54	11	8.52	8
Barrington Tops NSW	540	1045	31°40'	81.8	17	7.40	12	8.14	13
Kroombit Tops Qld**	800	825	24°25'	94.7	9	6.99	13	8.22	12
NW Kyogle NSW	350	1207	28°32'	95.6	5	6.97	14	7.81	14
W Herons Creek NSW	70	1309	31°34'	91.5	14	6.92	15	7.65	15
Blackdown Tablelands Qld**	780	718	23°50'	96.8	2	6.22	16	7.58	16
Consuelo Tablelands Qld**	1090	680	24°57'	94.8	8	5.01	17	5.47	17

* Denotes *E. saligna /botryoides* provenance, **Denotes *E. saligna/ E.grandis* provenance

There were no significant differences between pure *E. saligna* provenances for height or diameter. Heritability was intermediate for height (h^2=0.18) and for diameter (h^2=0.11).

DISCUSSION

Performance evaluation of introduced species should ideally be carried out on mature stands since tree growth and response to stress change with time (Bartle and Shea 1978). However, early trends are important in breeding programs and valuable data can be collected at an early age.

Different trends in early growth data exist between the four species. Higher altitude provenances of *E. pilularis* and *E. maculata* tend to be tallest. For these species frost tolerance associated with high altitude may be an important factor in early establishment. A reverse trend occurs in *E. resinifera* and an indeterminate pattern exists for *E. saligna*. Patterns for diameter are similar but less distinctive, possibly as a result of variable spacing caused by mortality or within plot competition between vigorous dominants, co dominants and subdominants. Low rainfall provenances grow quickest for *E. maculata*. For the other species no particular trends concerning rainfall are obvious. Latitude was significant for *E. maculata* and *E. resinifera* with the best *E. maculata* provenances tending to come from north of 32° and the reverse occurring for *E. resinifera*. No latitudinal trends were apparent for *E. pilularis* or *E. saligna*. Consistent patterns for provenances from different soil types were only observed for Fraser Island and Stradbroke Island, both of which have soil consisting of leached sand. Both the *E. resinifera* and *E. pilularis* trials had island provenances. In each case these provenances were amongst the worst or were the worst performers for height and diameter. By contrast Beerburrum, a provenance of *E. resinifera* with sand over clay soils performed well in the combined analysis, ranking first for height and diameter. Florence (1964) has suggested that there is a genetic difference between *E. pilularis* on Fraser Island and the mainland. It is possible that some genetic differences also occur between *E. resinifera* on these islands and the mainland. Whether any genetic differences in height and diameter growth by these provenances are due to adaptation to growth in sand or other factors is a topic for further study. The *E. maculata* trial had three mainland provenances with sandy soils which displayed no clear differences from provenances with heavier soils.

Survival patterns were best developed in *E. resinifera* with low altitude provenances having the best survival. In *E. pilularis*, provenances with sandy soils yielded poorest survival. *E. saligna* and *E. maculata* survivals did not adhere to any particular trend and could result from poor planting technique, adverse micro-site conditions e.g. nutrient status or frost susceptibility of families or individuals within families. It is evident from these data that simple climatic parameters such as rainfall or geographic parameters such as altitude, latitude and soil types alone are not strong predictors of early provenance performance within species or across species. Limiting factors in the new environment such as soil nutrient status may exert important early selection pressure against trees. For example, Dell and Bywaters (1988) reported growth deformities caused by copper deficiency, in 2-3 year old *E. maculata* plantations at Jarrahdale minesite. Early growth performance in these *E. maculata* trials is likely to have been affected and may have contributed to provenance x site interaction.

Significant provenance x site interactions for *E. maculata* suggest that provenances may need to be selected to suit particular sites for this species. Rankings of provenances of *E. resinifera* changed from site to site although provenance x site interactions were not significant. This may be an artefact of the analysis in which some missing cells were present in 1 replicate at Huntly. If this is the case, provenances of *E. resinifera* may also need to be selected specifically for each site.

Heritability

Heritability estimates for height were high and intermediate for diameter in *E. pilularis*, indicating that useful genetic gains can be made. Intermediate heritability for height and diameter in *E. saligna* suggest moderate genetic gains are possible. For *E. resinifera*, heritabilities were relatively low therefore gains from breeding may not be high. In line with current rehabilitation policy, a breeding program for exotic eucalypts on the bauxite mines will not be initiated in the forseeable future.

Seed orchards

A reliable supply of seed for an ongoing plantation program is essential. This need can be met in different ways. Two methods may include collection from wild populations or seed orchards depending on the objectives of the organisation. A seed orchard can be defined as an area where seed are mass produced to obtain the greatest genetic gain as quickly and as inexpensively as possible (Zobel and Talbert 1984). A seed orchard does not have to be used for genetic improvement but may simply be used as an economical seed source containing provenances well adapted to a new environment. Seed orchards have not been established for the four species mentioned in this paper, however the trials could be thinned down for use as open pollinated seedling seed orchards if required at a later date. Of local species a 20 ha gene pool for *E. wandoo* was established at Jarrahdale minesite in 1988 and will provide a valuable seed source in the future. Small seed orchards of *Eucalyptus diversicolor* F.Muell. have also been established at Jarrahdale and Huntly minesites and a clonal seed orchard of *P. cinnamomi* resistant families of jarrah is being established. Potential problems which need to be addressed in seed orchard management are those of projected demand for the seed, quantity of seed produced by the individuals of a given species, the area of orchard required to supply adequate seed, different flowering time between provenances and siting of the seed orchard.

CONCLUSIONS

Results from these trials indicate that significant provenance variation in early height and diameter growth does exist in all 4 species. Selection of the best provenances for use over a full rotation can only be tentative based on early growth. Future assessments would be recommended if any of these species were to be used again in revegetation. Climatic and geographic parameters such as annual rainfall, altitude, latitude and soil type should be used with caution as indicators of provenance suitability for the minesite environment and should not be substituted for testing on the ground. Inclusion of a wide range of provenances in provenance tests will maximise opportunities to explore and exploit genetic variation within a species to the full. Good potential for genetic gains exist for breeding *E. pilularis* and *E. saligna*.

ACKNOWLEDGEMENTS

Seed collection, raising seedlings in nursery and trial planting was sponsored by ALCOA of Australia. Measurement of the *E. resinifera, E. maculata* and *E. pilularis* trials was also funded by ALCOA.

The *E. maculata* and *E. resinifera* trial was established under the supervision of Mr. T. Butcher of the Department of Conservation and Land Management. The author thanks Messrs T. Butcher, J. Bartle and J. Mcgrath for comments on the manuscript and Mr M. Williams for advice on the analysis.

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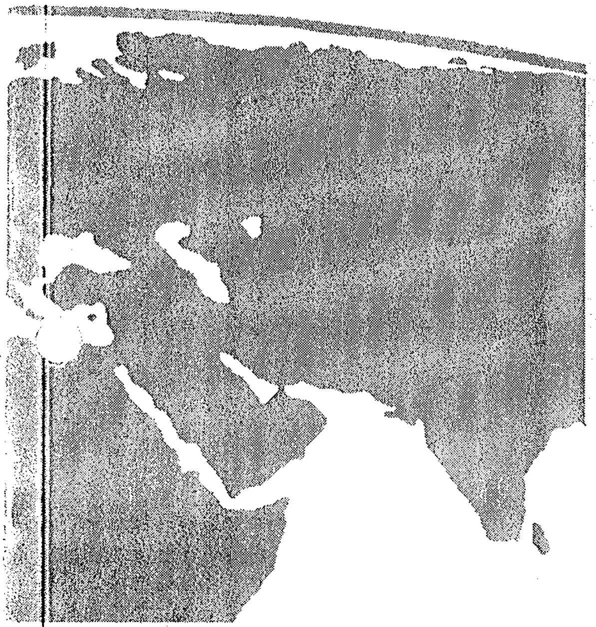

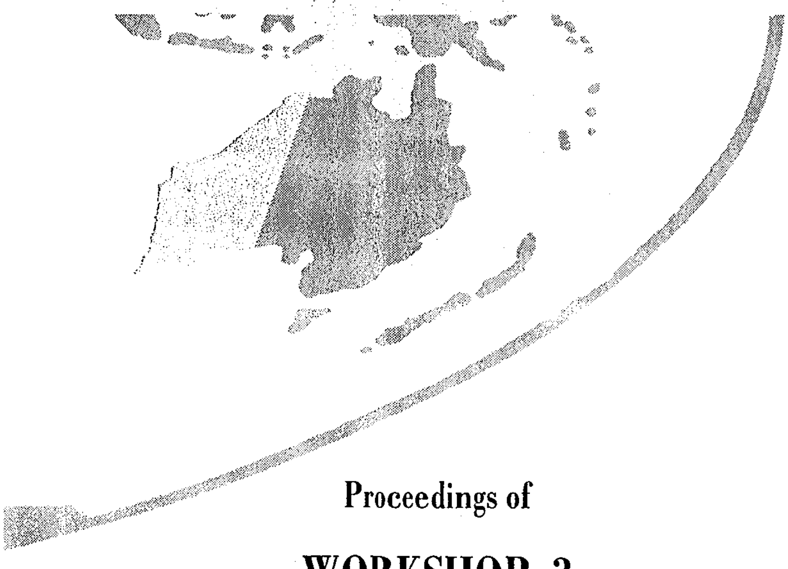

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3rd International Conference on Environmental Issues and Waste Management in Energy and Mineral Production

29th August - 1st September

Burswood Resort Convention Centre

Edited by K. A. O'Connell and D.R. Barrett