Pinus - subgenus *Strobus*. Silvae Genetica **32**: 119—126 (1983). —— WHITE, M. J. D.: Animal Cytology and Evolution. William Clowes and Sons Ltd., London. pp. 334—406 (1973). —— YUNIS, J. J.: High-resolution human chromosomes. Science **191**: 1268—1270 (1976). —— YUNIS, J. J. and PRAKASH, O.: The origin of man: a chromosomal pictorial legacy. Science **215**: 1525—1530 (1982).

Provenance Trials of Eucalyptus grandis and E. saligna in Australia

By I. P. BURGESS

Division of Forestry and Forest Products, CSIRO, Canberra, A. C. T., Australia

(Received 12th August 1987)

Summary

The growth of provenances of *E. grandis* was examined in four trials, and *E. saligna* in two of these, in eastern Australia and compared with results from a number of countries also growing these species. In two Australian trials the performance of the commonly-used Coffs Harbour provenance was not outstanding and there was much variation between provenances collected from the broad Coffs Harbour area. Overall the better provenances of *E. grandis* came from a wide range of collection sites from the furthest north to the furthest south. There is an apparent lack of a geographic pattern associated with the growth of *E. grandis* provenances. Implications for future provenance introduction strategies are discussed. *E. saligna* provenances performed well at one trial but not at the other.

Key words: E. grandis, E. saligna, provenance trials, breeding strategy.

Zusammenfassung

Der Zuwachs von *Eucalyptus grandis*- und *E. saligna*-Provenienzen wurde in vier bzw. in zwei Feldversuchen in Ostaustralien gemessen, und die Ergebnisse wurden mit Messungen aus anderen Ländern verglichen. In zwei australischen Versuchen zeigte das gewöhnliche, von Coffs Harbour stammende Provenienz kein außergewöhnliches Wachstum. Außerdem zeigten diese Provenienzen aus dem Großraum Coffs Harbour eine höhere Zwischenvariabilität. Die *E. grandis* Provenienzen, die insgesamt eine höhere Zuwachsleistung zeigten, stammen aus einer weitrangigen Sammlung von den nördlichsten bis zu den südlichsten Vorkommen.

Weitere Folgerungen für die zukünftigen Strategien zur Auswahl von Provenienzen wurden diskutiert. Gute Ergebnisse über den *E. saligna* wurden nur in einem Versuch erzielt, nicht jedoch in dem anderen.

Introduction

Flooded gum (*E. grandis* HILL ex MAIDEN) is among the most widely planted eucalypts in the world. It appears that about two million hectares have been established as industrial plantations but it is difficult to be exact because of the uncertainty of some records. South Africa had just under 300,000 ha planted by 1984 (Anon., 1985) while Brazil has probably more than 1 million ha (GALVAO and COUTO, 1984). *E. grandis* occurs between latitudes 17° S and 32° S within about 100 km of the coast of eastern Australia (*Fig. 1*). *E. saligna* SM. has not been so widely planted but is considered to be of importance in Hawaii (KING, 1983). The natural distribution of *E. saligna* overlaps that of *E. grandis* and ranges from about 25° S to 36° S (*Fig. 1*). A number of countries have provenance studies in progress, e.g. Australia (ADES and BURGESS, 1983), Brazil (PIRES *et al.*, 1983), India (DEO *et al.*, 1986), Madagascar (RAKOTOMANAMPISON, 1983), South Africa (DARROW and ROEDER, 1983; DARROW, 1983), USA (KING, 1983; LEDIG, 1983; BAILEY and LEDIG, in preparation) and Zimbabwe (BARRET *et al.*, 1975; MATHESON and MULLIN, in press). Also PEDERICK (1983) organised an extensive series of trials involving 15 countries under the auspices of the International Union of Forestry Research Organisation's working party on eucalypt provenances.

In general the results of these trials have indicated that the most productive provenances came from the northern part of New South Wales (NSW) centered around Coffs Harbour e.g. BAILEY and LEDIG (in preparation), DARROW (1983), LEDIG (1983), MATHESON and MULLIN (in press), PIRES *et al.* (1983) RAKOTOMANAMPISON (1983) and DEO *et al.* (1986). Within Australia, CLARKE (1975), demonstrated that Coffs Harbour provenances grew better at Coffs Harbour than the range extremes from Atherton and Minmi. ADES and BURGESS (1983) also reported that the Coffs Harbour district provenances together with a provenance from southern Queensland were the most productive, when planted in the Coffs Harbour area, but this trial did not include the more northern Queensland populations.

The apparent superiority of this provenance is questioned only when disease problems arise, particularly *Cryphonectria cubensis* (BRUNER) HODGES. CAMPHINOS and IKEMORI (1978)

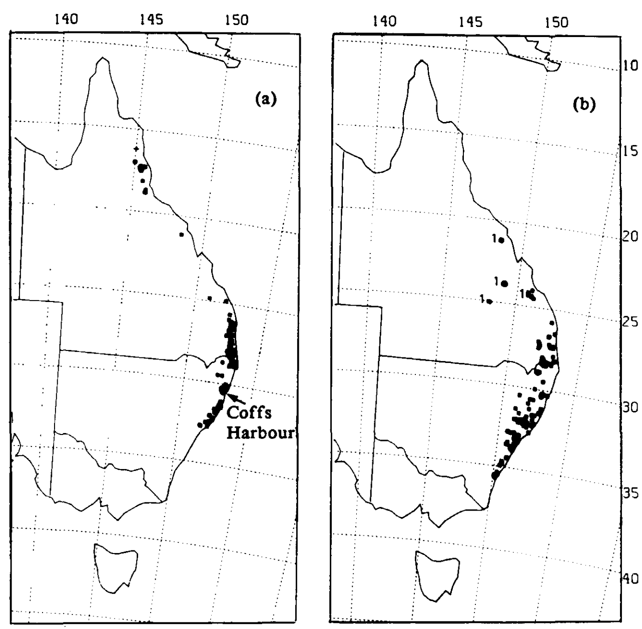

Figure 1. — Distribution map *E. grandis* (a), *E. saligna* (b) and *E. grandis/E. saligna* complex 1.

found that the Atherton region provenances developed fewer cankers than the more southern lots including two Coffs Harbour provenances. However there was considerable variation in the fraction of trees with canker within each broad provenance region. On the other hand, DEO *et al.* (1986) noted that all four provenances from northern NSW were resistant to pink disease (*Corticium salmonicolor* BERK et BR.) in Kerala, India.

Most of the early "Coffs Harbour" collections probably came from the Orara East or adjacent forests as these areas were part of the Coffs Harbour sub-district of the Coffs Harbour forestry district and from the administrative point of view requests for seed would have been sent there. The two adjacent forests, to the south which have been managed for a long period, Pine Creek and Newry were administratively in the Kempsey forestry district and unless specifically requested may not have been included in Coffs Harbour provenance in the broad sense.

Early importations of seed into South Africa were of unknown origin (POYNTON, 1979) but probably came from northern NSW or southern Queensland (BURGESS *et al.*, 1985). Material from South Africa spread freely into adjoining southern African countries before 1960 and large quantities of seed were exported from Zimbabwe to Brazil in the 1970s.

Thus most reported trials suggest that the Coffs Harbour provenances perform very well in other countries and it would seem that the original importations came from around that area and nearby in Queensland, i.e. from about 30° S to 26° S. However the products of breeding programs presumed to be based on this material, particularly in South Africa, have not compared well with open-pollinated provenance collections from Coffs Harbour more recently introduced into South Africa (ROEDER, 1980) nor with bulked open-pollinated collections from plus trees when grown at Coffs Harbour (ADES and BURGESS, 1982).

The comparison between sets of *E. grandis* and *E. saligna* SM. provenances has been made in only a few trials. ROEDER (1980) reported that *E. saligna* from Bulahdelah in NSW was the top-ranked lot at kwaMbonambi in South Africa at age 38 months but had fallen to mid-rank by 50 months. At Frankfort, a Ulong (NSW) collection of *E. saligna* was the most productive at age 42 months, but by age 7.75 years *E. grandis* had exceeded the volume production of *E. saligna* (DARROW, 1983).

This paper reports on two sets of trials in eastern Australia in which a range of provenances of *E. grandis* (12), *E. saligna* (7), intermediate populations or species complex (5) and a Zambian seed orchard lot (see BURGESS and BELL, 1983) were grown. Further, the data presented by ADES and BURGESS (1983) augmented by a 1987 re-measurement, are re-examined in terms of the alto-latoclinal collection strategy.

Materials and Methods

E. grandis/E. saligna trials

Details of the seed collections

Provenance collection details were reported by BURGESS and BELL (1983) but for ease of access, and to include CSIRO seedlot numbers and the distance from the sea, they are given in *Table 1*.

The trials were planted on three sites; (1) Peachester, Qld, lat 26° 49', long 152° 53', alt 100 m, co-operator APM Forests Pty Ltd; (2) Coffs Harbour NSW, lat 30° 10', long 153° 07', alt 50 m, co-operator NSW Forestry Commission; (3) Mtao, Zimbabwe, lat 19° 22', long 30° 39', alt 1477 m, co-operator Zimbabwe Forestry Commission.

Table 1. — *E. grandis/E. saligna.* Details of seed collections.

CSIRO number	Approximate location +		Lat °S	Long °E	Alt (m)	Distance from sea(km)	No.of trees
12409	Mt Pandanus	Qld	17 42	145 28	940	67	10
12423	Danbulla	Qld	17 11	145 36	800	39	10
12970	Herberton	Qld	17 21	145 27	1000	72	bulk
13023	Woondum	Qld	26 17	152 48	100	27	10
13022	Bellthorpe	Qld	26 49	152 45	140	40	10
13021	Whian Whian	NSW	28 31	153 22	475	18	8
13019	Orara East	NSW	30 31	153 02	135	11	10
13018	Nulla Five Day	NSW	30 48	152 49	150	20	10
13017	Lorne	NSW	31 37	152 43	40	12	10
13016	Wallingat	NSW	32 22	152 28	80	30	9
12223 *	Crediton	Qld	21 09	148 30	700	73	10
13028 *	N Eungella	Qld	21 04	148 30	900	71	10
13026 *	Kroombit	Qld	24 23	151 00	860	101	10
13025	Paluma	Qld	19 01	146 08	920	29	10
13027 *	Blackdown	Qld	23 50	149 05	900	223	10
13263 *	Carnarvon	Qld	24 57	148 03	1090	450	10
12798	Pomona	Qld	26 22	152 52	140	21	2
12974 #	Flat Rock	NSW	35 20	150 16	45	20	9
7786 #	Wollemi Ck	NSW	32 55	150 33	300	115	10
13168 #	Gibraltar Range	NSW	30 00	151 44	970	110	bulk
11045 #	Stewarts Brook	NSW	32 00	151 19	1040	115	bulk
13033 #	Kenilworth	Qld	26 40	152 33	600	56	3
12226 #	Gladfield	Qld	28 13	152 02	500	124	bulk
NSW FC#	Cascade	NSW	30 04	152 50	580	35	bulk
10630	Zambia		12 50	27 50	1250		bulk

+) location names vary from BURGESS and BELL (1983) and reflect more precise locations. #) = *E. saligna*, *) = *E. grandis/E. saligna* complex, remainder are *E. grandis*. The first four letters of the location are used to identify provenances in subsequent tables.

The Peachester site is on private property and originally carried a stand of *E. grandis*, but was cleared about the turn of the century and grassland established. The site was ripped and the grass poisoned prior to tree planting. The Coffs Harbour site is in Wedding Bells State Forest; the natural *E. grandis* stand was logged and the debris windrowed and burnt. Mtao was a deciduous *Brachystegia* woodland on relatively infertile deep Kalahari sand, with successful *E. grandis* plantations adjacent.

Peachester and Coffs Harbour were planted in late summer 1982, while Mtao was planted in summer 1984.

The design used was a 5 × 5 balanced lattice square with two sets (Mtao one set) of three blocks. Each plot was 36 (6 × 6) trees at a 3 m × 3 m spacing.

The most recent measurements were 1) Peachester in May 1986, internal 16 trees, all diameters and height of the three largest diameter trees per plot; 2) Coffs Harbour

Table 2. — *E. grandis* alto-latocline series. Details of seed collections.

Provenance location	Lat °S	Long °E	Alt (m)	Distance from sea(km)
Minmi	32 52	151 39	30	19
Wallingat	32 20	152 27	30	4
Wang Wauk	32 13	152 13	150	32
Lorne	31 39	152 32	250	27
Queens Lake	30 35	152 48	30	6
Tanban	30 52	152 53	30	11
Nulla Five Day	30 43	152 32	200	42
Newry*	30 31	152 58	10	16
Bellinger River*	30 27	152 37	70	66
Pine Creek*	30 24	153 03	10	3
Tucker's Knob*	30 22	153 00	110	17
Orara West*	30 15	152 57	180	18
Cascade*	30 14	152 51	580	32
Orara East*	30 13	153 06	120	7
Newfoundland*	29 55	153 07	80	15
Cherry Tree	28 53	152 47	180	77
Yabbra	28 34	152 36	400	95
Mebbin	28 26	153 12	120	35
Lower Stanly River	26 52	152 48	50	43
Brooloo	26 37	152 25	520	68

*) = alto-cline series, remainder lato-cline series. A three letter code is used to identify provenances in subsequent tables.

in May 1985, internal 16 trees, all diameters and heights; 3) Mtao in August 1986, internal 16 trees, all heights.

E. grandis alto-latocline trials

Details of the seed collection are listed in Table 2. All collections were from five trees at each location.

Two trials were established in 1972 in the Coffs Harbour area, one at Wedding Bells State Forest, the other near Timmsvale in Wild Cattle Creek State Forest. Each planting was of a randomised block design with three replications of 25 tree plots and twenty provenances. The January 1980 (age 7 years 8 months) measurement was reported by Ades and Burgess (1983). Diameters of all trees and the heights of the three biggest trees per plot were measured in April 1987 (age 15 years).

Characterisation of climate of seed collection localities

For all sites from which seed was collected the latitude, longitude, altitude and straight-line distance to the sea were determined. Twelve climatic variables (annual mean temperature, minimum temperature of the coldest month, maximum temperature of the hottest month, annual temperature range, mean temperaure of the wettest quarter, mean temperature of the driest quarter, annual mean precipitation, precipitation of the wettest month, precipitation of the driest month, annual precipitation range, precipitation of the wettest quarter and precipitation of the driest quarter) were estimated for each collection site by T. H. Booth using the BIOCLIM model (Booth, 1985).

Analysis

All growth data were analysed using the Genstat package (Alvey *et al.*, 1983) with associated macros using individual tree values for diameter and plot means for height and volume. National volume was calculated as ht((diam/2) **2*3.14159/3)*f where f was a constant to convert volume to m^3 per ha. For the regression analysis to determine the relationship of volume and the location/climatic variables, the best set of these variables was chosen by the "stepwise regression" approach (Draper and Smith, 1966).

Table 3. — *E. grandis/E. saligna* provenance trial diameter-all trees (cm).

Peachester age 4 years		Coffs Harbour age 3 years	
Casc#	13.15	Bell	6.38
Woon	12.89	Whia	6.35
Gibr#	12.81	Woon	6.30
Krom*	12.79	Wall	6.17
Keni#	12.68	Pand	6.13
Bell	12.45	Danb	5.97
Woll#	12.43	Herb	5.94
Glad#	12.23	Palu	5.91
Danb	12.16	Casc#	5.72
Null	12.11	Pomo	5.64
Pomo	12.08	Cred*	5.58
Palu	11.93	Krom*	5.49
Flat#	11.79	Lorn	5.43
Whia	11.67	Keni#	5.39
Cred*	11.57	Orar	5.23
Eung*	11.43	Eung*	5.17
Pand	11.42	Gibr#	4.92
Herb	11.34	Stew#	4.91
Blac*	11.33	Flat#	4.58
Orar	11.32	Null	4.46
Lorn	11.21	Gibr#	4.23
Wall	11.02	Woll#	3.94
Carn*	10.38	Zamb	3.73
Zamb	9.81	Blac*	3.61
Stew#	9.42	Carn*	3.61

Means included in the same bracket do not differ significantly at the 5% probability level — Duncan's multiple range test. #) = *E. saligna*, *) = *E. grandis/E. saligna* complex, remainder are *E. grandis*.

Results

E. grandis/E. saligna trials

Significant differences between provenances and species were found for diameter (*Table 3*), height, except at Mtao (*Table 4*) and volume (*Tables 5* and *6*). The rankings of provenances, however, varied markedly between sites. Combined analysis over the two sites of Coffs Harbour and Peachester is not presented as there were differences in site preparation and age when measured, which precluded pooling the results.

At Peachester most *E. saligna* provenances ranked highly for diameter, with Casade, Gibraltar Range, Kenilworth, Wollemi and Gladfield among the leaders. The south coast lot from Flat Rock was in the middle while the Stewarts Brook collection was ranked last. Among the *E. grandis* provenances the two from southern Queensland, Woondum and Bellthorp ranked well. However the Orara East provenance, a major collection area in the Coffs Harbour district, was less successful, being significantly smaller than the top seven provenances. Kroombit, a collection from the *E. grandis/E. saligna* species complex was ranked fourth from the top and significanty larger than the other members of that species complex. The Zambian seed orchard collection was ranked second last.

Table 4. — *E. grandis/E. saligna* provenance trial height (m).

Peachester-3 largest age 4 years		Coffs Harbour-3 largest age 3 years		Coffs Harbour-all trees age 3 years	
Whia	14.9	Whia	10.7	Whia	8.0
Woon	14.3	Bell	9.4	Bell	7.6
Woll#	14.2	Pand	9.2	Pand	7.2
Casc#	14.2	Woon	9.2	Danb	7.2
Null	14.1	Wall	8.9	Woon	7.2
Keni#	13.7	Danb	8.9	Wall	7.0
Lorn	13.4	Pomo	8.8	Herb	6.9
Orar	13.4	Orar	8.7	Palu	6.9
Bell	13.3	Lorn	8.7	Lorn	6.7
Pomo	13.2	Null	8.4	Pomo	6.7
Gibr#	12.9	Herb	8.4	Casc#	6.7
Danb	12.9	Palu	8.4	Orar	6.4
Glad#	12.9	Casc#	8.2	Null	6.2
Wall	12.7	Cred*	7.8	Cred*	6.1
Eung*	12.7	Stew#	7.6	Eung*	5.9
Flat#	12.5	Eung*	7.4	Kroo*	5.8
Pand	12.2	Kroo*	7.3	Gibr#	5.8
Herb	12.0	Zamb	7.3	Keni#	5.7
Zamb	11.9	Gibr#	7.3	Stew#	5.7
Palu	11.6	Keni#	7.1	Flat#	5.1
Kroo*	11.4	Glad#	7.0	Zamb	5.1
Stew#	11.4	Woll#	6.9	Woll#	5.1
Cred*	11.0	Flat#	6.5	Glad#	5.0
Carn*	10.2	Carn*	6.0	Carn*	4.6
Blac*	10.0	Blac*	6.0	Blac*	4.4

Mtao – age 18 months

Lorn	4.7
Pomo	4.6
Zamb	4.5
Pand	4.3
Null	4.3
Woon	4.3
Bell	4.2
Glad#	4.1
Keni#	4.0
Whia	4.0
Blac*	4.0
Woll#	4.0
Herb	4.0
Casc#	3.9
Danb	3.8
Orar	3.8
Flat#	3.8
Kroo*	3.7
Gibr#	3.7
Cred*	3.7
Wall	3.5
Carn*	3.4
Stew#	3.4
Eung*	3.1
Palu	2.9

Means included in the same bracket do not differ significantly at the 5% probability level — Duncan's multiple range test. #) = *E. saligna*, *) = *E. grandis/E. saligna* complex, remainder are *E. grandis*.

At Coffs Harbour, Cascade *E. saligna* was not significantly smaller in diameter than eight *E. grandis* provenances but was ranked ninth. The other *E. saligna* lots did not perform particularly well at Coffs Harbour. Bellthorp and Woondum provenances of *E. grandis* were again among the top-ranked lots together with a range of collections from the most southern in NSW (Wallingat) to the Atherton Tableland (Danbulla) in north Queensland. Orara East provenance was ranked fifteenth. The species complex lots ranked from the worst to about the middle. Again the Zambian lot performed poorly.

Provenance heights showed a reasonably similar picture but at the Peachester trial the *E. saligna* provenances were somewhat more scattered in height ranking than in diameter. Cascade, Wollemi and Kenilworth were in the top group and Stewarts Brook again near the bottom. Whian Whian, Woondum and Nulla Five Day were the tallest *E. grandis* provenances while Orara East was significantly shorter than the leaders. The Zambian lot performed poorly as did the collections from the species complex.

At Coffs Harbour all trees were measured for height and these data, as well as the mean heights of the three trees of largest diameter are presented. The best and worst provenances were ranked similarly by each measure, but there was some change of rank in the middle order. The simple correlation coefficient between the two sets of means was 0.96 and highly significant. There were some differences in the results of the range test: the data set for all trees shows greater discrimination between provenances than that for the three largest trees. As with diameter, the *E. saligna* provenances were well down in rank, with Cascade the tallest. The tallest *E. grandis* lots were again from a wide latitudinal range with those from Whian Whian and Bellthorpe being the tallest in the trial. The Orara East lot was ranked somewhat higher for height than diameter but was still significantly shorter than the best provenances, particularly if all tree heights were considered. The species complex and Zambian collections are in the bottom half of the rankings.

There were no significant differences between heights at Mtao but this was a very early measurement, 18 months. In general the *E. grandis* provenances were the tallest, but the Orara East provenance was only sixteenth out of twenty-five. The Zambian seed orchard lot has grown well but the species complex lots have not performed well. The best *E. saligna* was from Gladfield but the Cascade lot was only 0.8 m shorter than the tallest *E. grandis*.

The analysis of variance for volume at the two sites is given in *Table 5*.

The volume data (*Table 6*) show that five of the seven *E. saligna* provenances ranked highly at Peachester and were not significantly different from each other. Cascade had the largest volume followed by Wollemi, Kenilworth, Gibraltar Range and Gladfield. The Stewarts Brook collection was the least productive. Woondum, Whian Whian, Nulla Five Day, Bellthorpe and Pomona provenances of *E. grandis* were the better performers. The Orara East provenance was ranked in the middle and was significantly less productive than either Cascade *E. saligna* and Woondum *E. grandis*. The Zambian lot was ranked third last. Of the species complex group, Kroombit was significantly lower in volume than Cascade while the other lots were ranked in the lower half of twenty-five provenances.

At the Coffs Harbour site the top nine rankings for volume were all *E. grandis* and ranged from the relatively southern source from Wallingat to the Atherton Tableland populations from Mt Pandanus, Danbulla and Herberton. Orara East was in the middle but not significantly different from the best provenances. Cascade, Kenilworth and Stewarts Brook provenances of *E. saligna* were the best performers and were not significantly smaller in volume than the best *E. grandis* lots. Crediton and Kroombit populations of the species complex were also not significantly smaller than the best provenances. None-the-less there were absolute differences in volume between the species complex lots and the best *E. grandis* collections. This is also true for the *E. saligna* collections. The Zambian seed orchard lot was ranked third last.

Table 5. — Analysis of variance table, *E. grandis/E. saligna* trial.

(a) – Coffs Harbour, volume/ha (m^3)

Source of variation	DF	SS	SS%	MS	VR
Sites.rep stratum	5	249.92	5.41	49.98	
Sites.rep.treat stratum					
treat	24	1475.40	31.94	61.47	2.549
residual	120	2894.10	62.65	24.12	

(b) – Peachester, volume/ha (m^3)

Source of variation	DF	SS	SS%	MS	VR
Sites.rep stratum	5	1736.0	16.19	1487.2	
Sites.rep.treat stratum					
treat	24	19161.9	41.71	798.4	4.954
residual	120	19338.5	42.10	161.2	

Table 6. — *E. grandis/E. saligna* provenance trial, volume (m^3/ha) based on the three largest trees per plot.

Peachester age 4 years		Coffs Harbour age 3 years	
Casc#	73.2	Woon	13.6
Woon	70.9	Whia	13.5
Woll#	65.4	Bell	11.9
Keni#	65.3	Pand	11.3
Gibr#	63.3	Wall	10.3
Whia	61.2	Danb	9.8
Null	60.6	Palu	9.6
Bell	60.5	Herb	9.2
Glad#	56.7	Pomo	8.8
Danb	56.3	Casc#	8.3
Pomo	56.3	Cred*	8.0
Kroo*	54.8	Lorn	8.0
Lorn	50.6	Orar	7.9
Flat#	50.4	Kroo*	7.7
Orar	50.0	Keni#	6.9
Eung*	48.6	Stew#	6.8
Palu	48.4	Eung*	6.0
Pand	46.4	Null	5.2
Herb	45.9	Gibr#	5.2
Wall	45.2	Flat#	4.3
Cred*	43.4	Glad#	3.9
Blac*	38.1	Woll#	3.7
Zamb	33.9	Zamb	3.4
Carn*	32.0	Carn*	2.8
Stew#	30.3	Blac*	2.5

Means included in the same bracket do not differ significantly at the 5% probability level — Duncan's multiple range test. #) = *E. saligna*, *) = *E. grandis/E. saligna* complex, remainder are *E. grandis*.

Table 7. — *E. grandis* latocline, volume (m^3/ha) age 15 years.

Timmsvale		Wedding Bells		Both sites	
Que	424.4	Lsr	401.9	Lsr	411.1
Lsr	420.3	Tan	386.0	Tan	381.8
Tan	377.7	Wal	378.4	Que	365.4
Nul	366.8	Meb	375.0	Meb	361.0
Lor	350.4	Wan	354.0	Wal	355.2
Meb	346.9	Bro	341.2	Lor	345.6
Wal	332.1	Lor	340.8	Bro	326.4
Yab	319.5	Que	306.3	Nul	322.0
Bro	311.6	Yab	305.7	Wan	320.5
Wan	287.0	Nul	277.1	Yab	312.6
Che	286.8	Che	274.6	Che	280.7
Min	228.5	Min	203.9	Min	216.2

Means included in the same bracket do not differ significantly at the 5% probability level — Duncan's multiple range test.

Table 8. — *E. grandis* altocline, volume (m³/ha) age 15 years.

Timmsvale		Wedding Bells		Both sites	
Tuc	459.1	Ore	423.4	Ore	423.5
Ore	423.7	Pin	392.4	Orw	385.4
Orw	422.0	Nfd	367.9	Tuc	375.7
Cas	386.4	New	359.5	Pin	373.4
Nfd	356.1	Orw	348.9	Nfd	362.0
Pin	354.3	Cas	319.6	New	356.5
New	353.5	Tuc	292.3	Cas	353.0
Bel	345.3	Bel	256.2	Bel	300.8

Means included in the same bracket do not differ significantly at the 5% probability level — Duncan's multiple range test.

E. grandis alto-latocline trials

There were significant differences in the volume of provenances in the latocline series (Table 7).

The south Queensland provenance from the lower Stanly River performed well on both sites as did the more southerly collections from Queens Lake and Tanban. The most southerly source from Minmi was ranked last. However the regression of volume on latitude was negative and non-significant at both sites (r^2 0.12 at both Timmsvale and Wedding Bells) and when both sites were combined (r^2 0.16).

The altocline series (*Table 8*) at Wedding Bells is confounded to some extent by the poor growth of some plots due to site compaction when the windrows were stacked by a tractor (Ades and Burgess, 1983). This effect was evident, particularly in a plot of the Tuckers Knob treatment, at age 8 years, and still apparent at age 15 years. The coastal provenances from Orara East, Orara West and Pine Creek have grown well, while the more inland Cascade collection grew well on the escarpment site at Timmsvale but rather poorly at the coastal site at Wedding Bells. The consistently poor growth shown by the Bellinger River provenance is difficult to explain.

The differences between provenances in this series are of interest as they sample a relatively small area in the Coffs Harbour district (*Fig. 2*).

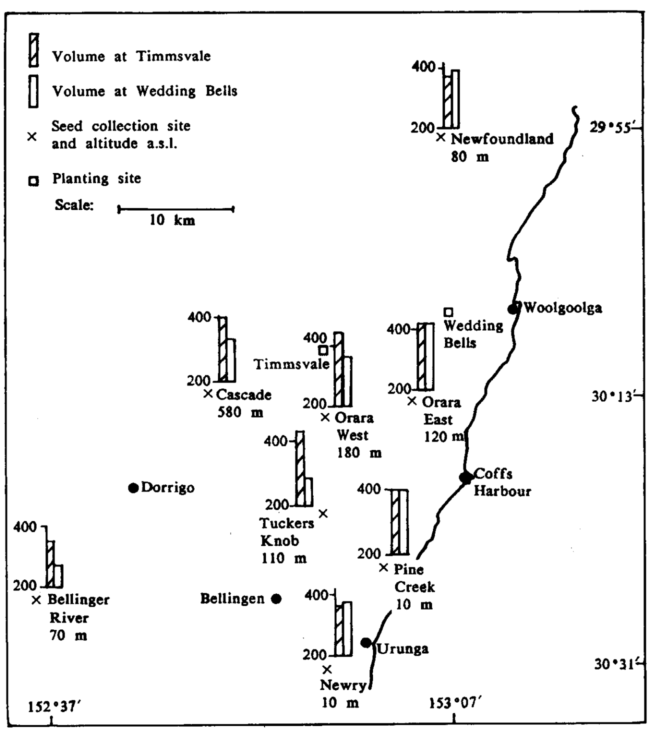

Figure 2. — *E. grandis* altocline series Volume (m³/ha) age 15 years of seed from each collection site.

Table 9. — *E. grandis* alto-latocline, sites combined, volume (m³/ha) age 15 years.

Both sites	
Ore	423.5
Lsr	411.1
Orw	385.4
Tan	381.8
Tuc	375.7
Pin	373.4
Que	365.4
Nfd	362.0
Meb	361.0
New	356.5
Wal	355.2
Cas	353.0
Lor	345.6
Bro	326.4
Nul	322.0
Wan	320.5
Yab	312.6
Bel	300.8
Che	280.7
Min	216.2

Means included in the same bracket do not differ significantly at the 5% probability level — Duncan's multiple range test.

Table 10. — Analysis of variance table, alto-latocline trials-both sites combined, volume/ha (m³).

Source of variation	DF	SS	SS%	MS	VR
Sites stratum					
sites	1	15002	2.51	15002	
total	1	15002	2.51	15002	
Sites.rep stratum	4	39443	6.60	9861	
Sites.rep.treat stratum					
treat	19	250185	41.85	13168	5.272
treat.sites	19	103423	17.30	5443	2.179
residual	76	189822	31.75	2498	

The regression of volume on altitude was negative and effectively non-existent with r^2 values of 0.002 at Timmsvale, 0.001 at Wedding Bells and 0.01 when both sites were combined.

The volume data, pooled across sites for all provenances are given in *Table 9*. The analysis of variance table is in *Table 10*.

The better performing provenances came from the southern Queensland (lower Stanly River) and the Coffs Harbour area. However Brooloo (68 km from the sea) from southern Queensland was significantly smaller in volume than lower Stanly River (43 km from the sea). The more inland provenances from NSW, Yabbra, Cherry Tree and Bellinger River ranked near the bottom, just above Minmi.

Regression analysis

Four location indices and twelve climatic variables were available for inclusion in the multiple regression analyses. The decision to include or exclude the variable was arbitrarily made if the correlation coefficient exceeded 0.4.

While it was possible to calculate significant regressions for both sets of trials, they did not include the same set of independant variables and were thus not predictive in the broad sense. Only the distance from the sea was retained in both.

Discussion

The inferior performance of the one Coffs Harbour provenance (13019 Orara East) of *E. grandis* when grown at either Coffs Harbour or Peachester in the *E. grandis*/*E. saligna* trials was unexpected. This has possible implications for many breeding programs as this area is the location for provenance collections reported in a number of publications. For example Darrow (1983), King (1983), Pederick (1983), Rakotomanampison (1983) and Matheson and Mullin (in press) all comment on the excellent performance of seedlot 7823, collected in 1966 from Orara East, or have included it in trials, the results of which are yet to be published. Seedlots 7823 and 13019 (collected in 1980) were both obtained from similar localities only 6 km apart, on sites in gully bottoms with similar altitudes and vegetation. An examination of the data sheet for the 13019 collection does not reveal any reason for the poor growth. The ten trees ranged in height from 27 to 32 m and were of average to very good form. The data sheet for 7823 indicates that the collection was from twelve trees with a height range from 28 to 38 m, all of good to excellent form.

Variation in the growth of provenances of *E. grandis* collected within a small geographical area near Atherton in north Queensland has been observed by MATHESON and MULLIN (in press); these authors conclude that broad geographic zones may not be of practical value for defining populations of *E. grandis* in terms of growth performance. The same phenomenon is well illustrated by the results from the trials discussed here and particularly the altocline series of *E. grandis*. The eight collections came from an area of about 49 × 36 km with a maximum distance between collections of 56 km. The two inland collections (Bellinger River 80 m and Cascade 580 m) have performed poorly, particularly at the more coastal site (Wedding Bells) and when both sites are considered together, while the more coastal collections are generally very good (see *Fig. 2*).

The poor predictability of the geographic location of collections is also evident in the *E. grandis/E. saligna* trials where the best collections come from northern Queensland (Danbulla), southern Queensland (Woondum), northern NSW (Whian Whian) to as far south as Wallingat for the Coffs Harbour trial and Lorne for the Peachester trial.

Some of the variation found, particularly in the alto-latocline series, may be associated with the relatively small number of trees from which seed was collected at each site. This number may be insufficient to reliably represent the population or environment sampled and this should be kept in mind when interpreting the results. The distance between individual trees in each collection was not recorded but each collection site was several hectares in area.

A comparison of the ranking between the plantings of the alto-latocline series in Australia, South Africa (DARROW and ROEDER, 1983) and USA (BAILEY and LEDIG, in preparation) shows that some provenances perform consistently well while others vary between sites. In the latocline group Tanban and lower Stanly River are always ranked near the top while Lorne ranks reasonably well in Australia but near the bottom at Port Dunford in South Africa (DARROW and ROEDER, 1983). Minmi is generally at or near the bottom at most sites but ranks fifth out of twelve at the J. D. M. Keet Forest Research Station, near Sabie in South Africa (DARROW and ROEDER, 1983). Tuckers Knob provenance in the altocline series is ranked at or near the top at all sites but the positions of Orara East and Orara West vary considerably. Bellinger River is a poor performer at all sites.

Overall the better provenances of *E. grandis* came from a wide range of collection sites from the furthest north to the furthest south. Growth potential is not obviously related to provenance location and quite large variations may be expected between collections from the same general area. An exception may be the Minmi provenance which came from a limited number of presumably relic trees in an open paddock and may well produce highly inbred seed.

The outcrossing rate, and thus the level of inbreeding may well differ between provenance collections, both from different sites and between collections at different years from much the same site. This could lead to dramatic reversals in performance and help to explain some of the variation found in these trials.

By world standards the growth rates of *E. grandis* in these Australian trials are low. However the degree of site preparation and follow-up tending practiced in Australia is often less for eucalypts than for pines and mostly does not approach that afforded eucalypt plantations in many other countries.

The good performance of some *E. saligna* provenances, particularly at Peachester, is contrary to the eccepted, but generally untested, view that this species does not perform as well as *E. grandis*. However the experience in South Africa of ROEDER (1980) and DARROW (1983) where *E. saligna* grew very well early in their trials but could not maintain its position indicates that the future growth of this species will have to be carefully watched. HOWLAND and FREEMAN (1970) also found that a single provenance of *E. grandis* from Queensland produced more wood over two rotations than *E. saligna* collections from NSW and a local Kenyan lot when grown at Muguga in Kenya. Unfortunately no details on the actual collection sites or the number of trees in each collection were given.

The scattered populations of the species complex do not compare well with the best of either of the core species. Kroombit was the best of this group and could be of some use in breeding programs if coppicing is important as a fraction of the population, unlike *E. grandis*, develops lignotubers (BURGESS and BELL, 1983).

The attempt to relate provenance growth to location and climatic variables was not particularly instructive. The straight-line distance from the sea was overall, the most useful single variable to predict performance, the populations nearer the coast providing the fastest growing seed sources.

If differences in provenance performance in *E. grandis* eventually do prove to be as irregular and difficult to predict, on the basis of location, as indicated by these results and those of MATHESON and MULLIN (in press), the introduction and breeding strategy to be adopted by countries with active tree improvement programs with *E. grandis* needs some re-thinking. The most rewarding policy may be to plant a wide range of provenances and to select the best individual trees regardless of provenance, as was done successfully in Florida (MESKIMEN, 1983), rather than to pursue the search for the single "best" provenance of the species.

Acknowledgements

Data for the alto-latocline series were supplied by the Forestry Commission of NSW; the Commission's permission to use these and remeasure the plots is gratefully acknowledged. Establishment of the trials was made possible by the co-operation of that organisation, APM Forests Pty Ltd, D. M. CAMERON and the Zimbabwian Forestry Commission. A. C. MATHESON analysed the Mtao data and T. H. BOOTH estimated the climatic characteristics of the seed collection localities. K. G. ELDRIDGE and A. G. BROWN made many helpful comments on the manuscript.

References

ADES, P. K. and BURGESS, I. P.: Improvement in early growth rate achieved by phenotypic selection of *Eucalyptus grandis*. Aust. For. Res. **12**: 169—173 (1982). —— ADES, P. K. and BURGESS, I. P.:

Provenance trials of *Eucalyptus grandis* in northern New South Wales. IUFRO Symp. 'Fast Growing Trees' Brazil, 1980. Silvicultura SBS 31: 396—397 (1983). —— ALVEY, N. G. and 17 authors: Genstat A general statistical program. Lawes Agricultural Trust (Rothamsted Experimental Station). Numerical Algorithms Group (1983). —— Anon.: Commercial timber resources and roundwood processing in South Africa 1983/1984. Forestry Branch, Dept of Environment Affairs, Pretoria. (1985). —— BAILEY, D. B. and LEDIG, F. T.: Provenance variation in flooded gum (*Eucaluptus grandis* HILL ex MAID.). In preparation. —— BARRETT, R. L., CARTER, D. T. and SEWARD, B. R. T.: *Eucalyptus grandis* in Rhodesia. Rhodesia Bull. of For. Res. No. 6 (1975). —— BOOTH, T. H.: A new method for assisting species selection. Commonw. For. Rev. 64: 241—250 (1985). —— BURGESS, I. P. and BELL, J. C.: Comparative morphology and allozyme frequencies of *Eucalyptus grandis* HILL ex MAIDFN and *E. saligna* SM. Aust. For. Res. 13: 133—149 (1983). —— BURGESS, I. P., BELL, J. C. and VAN WYK, G.: The identity of trees currently known as *Eucalyptus grandis* in the Republic of South Africa based on isozyme frequencies. South African For. J. 135: 24—30 (1985). —— CAMPINHOS, E. and IKEMORI, Y. K.: Tree improvement program of *Eucalyptus* spp. preliminary results. Proc. FAO Third World Consultation on Forest Tree Breeding. Vol. 2: 717—738. CSIRO: Canberra (1977). —— CLARKE, B.: Establishment of eucalypt plantations. Science and Technology, Melbourne 12: 10—13 (1975). —— DARROW, W. M.: Provenance-type trials of *Eucalyptus grandis* and *E. saligna* in South Africa: Eight year results. South African For. J., 30—38 (1983). —— DARROW, W. M. and ROEDER, K. R.: Provenance studies of *Eucalyptus grandis* (HILL) MAIDEN in South Africa. IUFRO Symp. 'Fast Growing Trees' Brazil, 1980. Silvicultura SBS 31: 402—406 (1983). —— DEO, A. D., NAIR, T. J. C., KUMAR, D. and RAMASWAMY, V.: Provenance trials of *Eucalyptus grandis* in Kerala. *In:* Eucalypts in India: Past, Present and Future. Eds. J. K. SHARMA, C. T. S. NAIR, S. KEDHARNATH and S. KONDAS. Kerala For. Res. Ins. pp 285—289 (1986). —— DRAPER, N. R. and SMITH, H.: Applied regression analysis. Wiley, New York (1966). —— GALVAO, A. P. M. and COUTO, H. T. Z.: Man-made industrial forests in Brazil: prospects and constraints. *In:* Strategies and designs for afforestation, reforestation and tree planting. Ed. K. F. WIERSUM. Pudoc, Wageningen. pp 129—136 (1984). —— HOWLAND, P. and FREEMAN, G. H.: Interim results of a fuel yield trial on eucalypts. East African Ag. and For. J. 35: 257—264 (1970). —— KING, J. P.: Provenance studies of *Eucalyptus saligna* and *E. grandis* in Hawaii. IUFRO Symp. 'Fast Growing Trees' Brazil, 1980. Silvicultura SBS 31: 412—413 (1983). —— LEDIG, F. T.: Eucalypt improvement for California: progress and plans. Proc. workshop on *Eucalyptus* in California. Pacific Southwest Forest and Range Experiment Station. Gen. tec. rpt PSW-69: 115—120 (1983). —— MATHESON, A. C. and MULLIN, L. J.: Variation among neighbouring and distant provenances of *Eucalyptus grandis* and *Eucalyptus tereticornis* in Zimbabwean field trials. Aust. For. Res. (in press). —— MESKIMEN, G.: Realised gain from breeding *Eucalyptus grandis* in Florida. Proc. workshop on *Eucalyptus* in California. Pacific Southwest Forest and Range Experiment Station. Gen. tec. rpt PSW-69: 121—128 (1983). —— PEDERICK, L. A.: IUFRO international provenance trials with *Eucalyptus grandis* and *E. tereticornis*. IUFRO Symp. 'Fast Growing Trees' Brazil, 1980. Silvicultura SBS 31: 415—418 (1983). —— POYNTON, R. J.: Tree planting in southern Africa. Vol 2. The eucalypts. Dept. of For., Pretoria (1979). —— RAKOTOMANAMPISON, A.: Teste de procedencia de *Eucalyptus grandis* em Madagascar. IUFRO Symp. 'Fast Growing Trees' Brazil, 1980. Silvicultura SBS 31: 420—422 (1983). —— ROEDER, K. R.: "Provenance" variation in growth features of *Eucalyptus grandis* and *Eucalyptus saligna* in South Africa. South African For. J.: 36—41 (1980).

Estimation of Gamete Pool Compositions in Clonal Seed Orchards

By G. R. ASKEW

Belle W. Baruch Forest Science Institute
of Clemson University,
P.O. Box 596,
Georgetown, SC 29442, USA

(Received 21st September 1987)

Summary

Nineteen loblolly pine clones were monitored for flowering activity during three successive years. Phenology data and flower production data were used to develop a mathematical model to predict the genetic composition of the resulting seed crops. Variation in pollen production, flower production, foreign pollen intrusion and clone size were found to impact the final gamete distribution. The mathematical model proved useful for evaluating the effects of seed orchard roguing and implementation of cultural treatments.

Key words: phenology, pollen management, seed orchard management.

Zusammenfassung

Das Blühverhalten von 19 *Pinus taeda* Klonen wurde während 3 aufeinanderfolgenden Jahren beobachtet. Phänologische und Daten über den Blütenansatz wurden für die Entwicklung eines mathematischen Modells verwendet, um Voraussagen über die genetische Zusammensetzung des resultierenden Saatgutes machen zu können. Variation in der Pollenmenge, des Blütenansatzes, Fremdpollenflug und Klongröße hatten Einfluß auf die Gametenverteilung. Das mathematische Modell erwies sich als nützlich für die Überprüfung des Effektes einer Negativselektion und Pflegemaßnahmen in Klonsamenplantagen.

Introduction

Seed orchards are designed and managed to produce forest tree seed that are superior in value to that obtained from seed production areas or random unimproved collections. Superiority of the seed can be judged for quantity and quality which is a function of the percentage of filled seed and the genetic composition of the seed crop. Clonal seed orchards are established by careful selection and testing of many "elite" trees and ideally will provide a gamete pool whose mean genetic value is greatly superior to "unimproved" seeds.

Determining the exact composition of the genetic pool in a wind-pollinated orchard is an improbable task. Roguing, specific combining abilities, and foreign pollen intrusion can affect the accuracy of predicting the genetic composition (ASKEW, 1986), and obtaining accurate estimates of both gamete sources may be difficult. Seed parent contributions can be measured by partitioning the cone harvest into family lots, which is a common practice for forest products companies that plant trees in family blocks. However, pollen-parent contributions are not as easily measured. Electrophoretic analysis of seed samples can be used to provide some insight into the distribution of pollen from clones that have recognizable "markers" and to