EARLY GROWTH OF *EUCALYPTUS DELEGATENSIS* PROVENANCES IN FOUR FIELD TRIALS IN SOUTH-EASTERN AUSTRALIA

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ABSTRACT

Growth and survival of 64 provenances of *Eucalyptus delegatensis* R.T. Baker from the whole natural range of the species in south-eastern Australia were assessed in four field trials in Tasmania and New South Wales. At 3 years from planting there was significant variation among provenances in height, diameter, and volume. The better provenances across all sites came from the mainland, and in particular from Victoria. The Tasmanian provenances had poorer survival and grew more slowly on the mainland, indicating that if these were the only selection criteria then material from this part of the range should not be included in mainland breeding programmes.

Keywords: provenance trials; growth rates; tree selection; *Eucalyptus delegatensis*.

INTRODUCTION

Eucalyptus delegatensis is one of the major commercial eucalypt species in south-eastern Australia. The species is widely used for structural purposes and for pulp-making. Overall, for Tasmania and Victoria it constitutes about 20% of the eucalypt cut for pulpwood and about 25% for sawlog production (Tasmanian Forestry Commission and Victoria Department of Conservation Forests and Lands, pers. comm.). *Eucalyptus delegatensis* and two other ash group species, *E. obliqua* L'Her. and *E. regnans* F. Muell., together constitute the main group of commercial eucalypts in south-eastern Australia. Harvesting has been almost exclusively from natural stands with regeneration normally by natural seedfall, but increasingly in Tasmania and Victoria aerial seeding is being employed.

Eucalypt planting in Australia has generally been on a small scale. Nevertheless, *E. delegatensis* has been one of the main plantation species in Tasmania. Like other species in the informal subgenus *Monocalyptus* (Pryor & Johnson 1971), it has been planted on only a limited scale outside Australia, principally in New Zealand and France.

The species usually occurs in pure stands in wet sclerophyll forests between latitudes 35°S and 44°S (Fig. 1). Its altitudinal range is about 900–1500 m on the mainland and 160–1200 m in Tasmania. On the mainland it typically occupies steep mountain slopes, especially those with a south-eastern aspect. In Tasmania it occurs extensively on the edge of the central plateau. Over its range the species has a mosaic distribution with each population extending from about one to many hundreds of hectares (Boland & Dunn 1985).

Provenance variation has been studied in only a very small number of eucalypts in field trials within Australia. Generally these studies have not shown that the provenances with

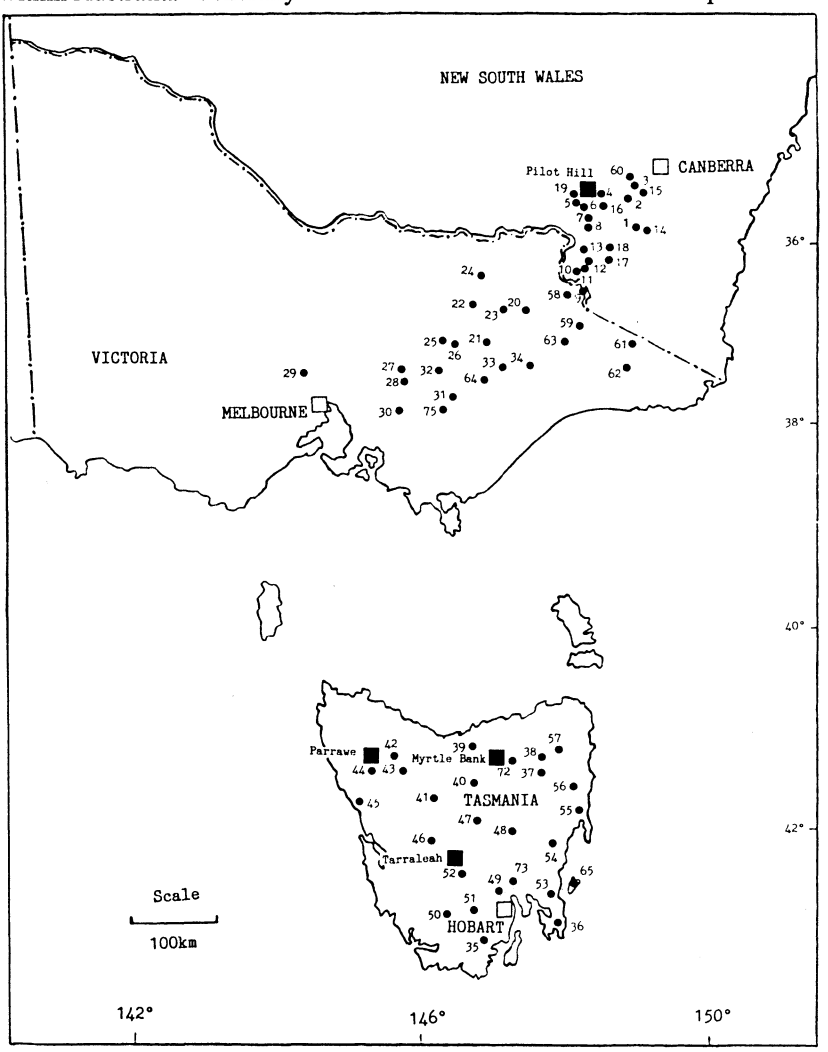

FIG. 1–Distribution of *Eucalyptus delegatensis* showing provenance (●) and trial site (■) locations.

superior growth rates are clustered in discrete geographic regions nor that they are associated with specific environmental factors. Thus, in eucalypts such as *E. pilularis* Sm. (Burgess 1974), *E. grandis* Maiden (Burgess 1988), and *E. regnans* F. Mueller (Griffin *et al.* 1982) there is no general geographic grouping of provenances superior in growth. On the other hand, *E. obliqua* provenances from parts of the geographic range such as south-eastern South Australia consistently show inferior growth over several sites (Brown *et al.* 1976; Matheson *et al.* 1986).

This paper reports on provenance trials of *E. delegatensis* at four sites in south-eastern Australia. Height growth was analysed for each of the first 3 years after outplanting and diameter, volume, and survival at age 3 years are presented. A measure of stem bending due to snow damage was assessed at one site.

MATERIALS AND METHODS

Sampling and Seed Collections

Seed of 68 provenances over the whole of the natural distribution of *E. delegatensis* was sampled (*see* Fig. 1). Two seedlots from different generations of the so-called Crookston land race from Southland, New Zealand, were also included. Provenances were selected to cover a range of environmental variables such as rainfall, climate, geology, and altitude. In particular, disjunct outliers were sampled somewhat more intensively than populations within the main range. Within provenances sampling was essentially random, with the provision that trees had adequate seed crops and were where possible at least 50 m apart. At least five trees were sampled per site. At 13 sites 10 trees were sampled and at three sites 30 trees per provenance were sampled (*see* Boland *et al.* 1980 for details of sites and collections).

Nursery

For each of the 68 provenances, seeds from all trees were mixed so that each parent tree supplied an approximately equal proportion of seedlings for the provenance sample. A subset of 64 provenances was planted at each site (*see* Table 1). Those provenances chosen for the Pilot Hill site were the only ones for which seed had been collected by the time of sowing. Generally, for each of the Tasmanian sites the 64 provenances were selected with the aim of maximising the number of Tasmanian provenances represented. Seedlings for the Pilot Hill trial were raised in the controlled-environment rooms at CSIRO in Canberra. Seed was stratified for 6 weeks at 3°C and germinated in punnets before being pricked out into paper pots in March 1978. The planting at Pilot Hill took place in September 1978, 24 weeks after germination.

All seedlings for the Tasmanian trial sites were raised at Ridgley in a manner similar to that described above. They were pricked out into paper pots in March 1979. Germination of some seedlots was poor and, as a second sample of these was stratified and pricked out in July 1979, a few were smaller at time of planting. All seedlings in the Tasmanian trials were planted in October 1979.

For all trials the experimental design was an 8×8 balanced square lattice (Cochran & Cox 1957) with 64 provenances represented in each of nine replicates. The exception was at the

Myrtlebank site where two provenances, 26 and 47, were represented twice in each replicate. Each replicate was divided into eight incomplete blocks of eight treatments and each treatment was a six-tree row plot. Spacing at each site was 2 m between trees within a row and 3 m between rows.

Locations of the four trial sites are shown in Fig. 1. At Pilot Hill the site was at 1100 m on NSW Forestry Commission land. For the other sites the collaborators were AFH Pty Ltd—Myrtlebank (altitude 580 m), ANM Ltd—Tarraleah (altitude 600 m), and APPM Ltd— Parrawe (altitude 620 m). A fifth site, at Diddleum Plains (Forestry Commission of Tasmania) in north-east Tasmania, failed completely apparently because the site was poorly drained. This trial was abandoned in 1980 and is not reported here. All sites were well cleared and ploughed, with Myrtlebank and Parrawe being mound ploughed. Weed control was carried out with "Roundup" before planting. All seedlings at the Tasmanian sites were treated with 20 g MAGAMP fertiliser after planting. At the Pilot Hill site 30 g "Starter 15" slow-release fertiliser was placed in the planting hole about 10 cm from the tree during planting. Each trial was buffered with at least one external row and, wherever possible, two rows of *E. delegatensis* routine stock or left-over trial plants (Bell 1979).

Measurement of Characters and Analysis

Height and survival were assessed at all sites at 1, 2, and 3 years after planting but only the third-year data are presented in this paper. Also, at all sites, except Parrawe where the plants were too small, stem diameter at 1.2 m overbark was measured at 3 years of age. Tree volume was calculated as V = height × basal area/3. Frost damage, assessed at Pilot Hill by scoring foliar damage at 1 and 2 years of age, has been reported by Boland & Dunn (1985). Snow damage (stem bending and breakage) was also assessed at 3 years of age at Pilot Hill. Trees were scored for stem bending (scale 0 = no damage, 5 = severe damage) and presence or absence of stem breakage. All variables were analysed using the statistical package GENSTAT (Alvey *et al.* 1977). In order to stabilise the variance, stem volume was log transformed in the analysis of variance. Survival data for each site were analysed using a generalised linear model with binomial errors and logit link function.

From the results of the analyses of variance for height, diameter, and volume, it was evident that there were differences between the behaviour of different provenances at different sites. In order to study more closely this "provenance × environment" interaction, we followed the method outlined by Williams & Luangviriyasaeng (1989). The adjusted provenance means from the site ANOVAs can be written as a two-way site × provenance array for each variate. For height we have the simple model

$$E[y_{ij}] = \mu + \theta_i + w_j$$

where y_{ij} is the height for provenance i at site j
E is the symbol for the expected value of y_{ij}
μ is the parameter for the grand mean
θ_i and w_j are the effects for provenances and sites respectively.

This analysis is non-orthogonal since not all provenances are present at all sites. We partitioned the provenance effects into effects due to provenance regions and effects due to provenances within regions. The regions were New South Wales (including the A.C.T.), Victoria, Tasmania, and New Zealand (two races).

RESULTS

Survival

Differences in survival between provenances at each field site were highly significant (Table 1). Survival was greatest at Myrtlebank (84.1%) and lowest at Pilot Hill (76.6%). Although the over-all means for sites were not significantly different, the differences appear to be a reflection of the range of environmental conditions across field sites. At Pilot Hill frosts and snow result in very severe winter conditions whereas at Myrtlebank conditions are comparatively mild. As well, the range of means for provenances within sites was greater at the harsher sites, Pilot Hill and Parrawe, than at Myrtlebank.

Generally, across all sites, the survival of the northern provenances from New South Wales and the A.C.T. was very good. In marked contrast, the greater variation in survival of the provenances at Pilot Hill and to a lesser extent at Parrawe appears to be largely due to poorer survival of Tasmanian provenances. Thus, at Pilot Hill the mainland provenances with a mean of 82.2% show significantly greater survival than the Tasmanian provenances with 67.2% ($p<0.001$). However, the same comparison is not significant at the Tasmanian sites (Myrtlebank 87.4% mainland, 85.5% Tasmania). Even at Parrawe where the same trend is apparent the difference between means is not significant.

Height

There were significant differences ($p< 0.001$) between provenances in third-year height at all sites. Over-all growth was greatest at the Pilot Hill site and least at the Parrawe site (Table 2). The Royston River provenance ranked well for height at all sites. Other provenances that consistently ranked well across all sites were the southern Victorian provenances Ada River, Mt Useful, and Mt St Gwinear. However, an analysis across sites showed significant differences in height between trial sites, among regions and region × site interactions (Table 3).

At Pilot Hill, there was very marked separation in the rankings of provenances into geographic regions (Table 2). The mainland provenances were taller than those from Tasmania (Table 4). Victorian provenances along with four New South Wales provenances were in the top group of the rankings. Generally, the western provenances from the northern part of the geographic range (i.e., New South Wales and the A.C.T.) were taller, although not significantly so, than those from south-east of the A.C.T. and adjacent areas of New South Wales. It was also noticeable that the top-ranking Tasmanian provenances such as Luina and Surrey Hills tended to be from the north-west of the State.

At the trial sites in Tasmania the same trends in rankings of means were evident as at Pilot Hill but the geographic split was not as marked (Tables 2 and 4). Generally, provenances at the top of the rankings were Victorian and they were primarily from the central and southern part of the mainland range. In contrast to the result at Pilot Hill, the New South Wales provenances were not present in the top group of rankings at any Tasmanian site. Geehi was the tallest of the New South Wales provenances at Myrtlebank and Parrawe. At Tarraleah and Parrawe the only Tasmanian provenance in the top group was Surrey Hills. This provenance and others from the north-west of Tasmania, Luina and Yellow Marsh Rd, were also in the top group at Myrtlebank.

TABLE 1–Survival (%) of provenances of *E. delegatensis* after 3 years at the four field sites

No.	Provenance name	Elev. (m)	Pilot Hill	Myrtlebank	Tarraleah	Parrawe
1	Yaouk Bill Range, NSW	1433	83			63
2	Leura Gap, ACT	1425	83		80	61
3	Smokers Flat, ACT	1310	82	93	83	89
4	Mt Bogong, NSW	1525	80	67		
5	Clear Creek, NSW	1240	94	89	85	93
6	The Granites, NSW	1385	76		85	65
7	Mt Nurenmerenmang, NSW	1230	87	89	85	87
8	Mt Black Jack, NSW	1430	76	76	72	89
9	Cascade, NSW	1400	80	89	83	89
10	Youngal, NSW	1130	87	95	93	89
11	Geehi, NSW	1140	80	93	83	80
12	The Pinnacle, NSW	1500	85	97	85	78
13	Dargals Range, NSW	1240	78	85	74	83
14	Mt Flinders, NSW	1360	80	91	78	83
15	Peppercorn Hill, NSW	1400	87	89	87	93
16	Yarrangobilly, NSW	1260	89			
17	Gungarlin River, NSW	1255	89	76	72	78
18	Bald Hill, NSW	1410	83		74	59
19	Pilot Hill, NSW	1100	89	80	80	87
20	Mt Wills, Vic	1240	80	85	83	89
21	Beecher Hill, Vic	1200	78			
22	Mt Buffalo, Vic	1350	82	100	80	80
23	Big Hill, Vic	1005	82	96	69	82
24	Big Ben, Vic	1100	83	82	87	78
25	Razorback Spur, Vic	1280	65	82	82	95
26	Upper Howqua, Vic	1068	87	88	54	72
27	Royston River Rd, Vic	960	76	95	80	78
28	Lake Mountain, Vic	1310	87	87	80	74
29	Mt Macedon, Vic	945	76	80	87	87
30	Ada River, Vic	925	74	95	76	87
31	Mt Useful, NSW	1220	91	89	87	87
32	Mt Skene, Vic	1150	87	80	85	61
33	Mt Ewen, Vic	1230	78	65	76	85
34	Mt Baldhead, Vic	1220	74	95	82	83
35	Hartz Mt, Tas	560	65	95	80	80
36	Plateau Road, Tas	550	43			
37	Ben Lomond, Tas	1220	74	89	93	87
38	Ben Nevis, Tas	820	74	87	80	87
39	Dazzler Range, Tas	480	54	74	72	50
40	Cluan Tier, Tas	550	76	78	72	48
41	Maggs Mountain, Tas	820	65	91	82	87
42	Surrey Hills, Tas	580	82	93	87	89
43	Yellow Marsh Rd, Tas	660	70	91	76	95
44	Luina, Tas	450	70	80	89	85
45	Heemskirk River, Tas	160	65	82	74	63
46	King William Saddle, Tas	800	82	87	82	87
47	Miena, Tas	960	82	89	89	85
48	Tunbridge Tier, Tas	820	69	85	74	85
49	Mt Dromedary, Tas	800	74	82	76	83
50	Lake Pedder, Tas	380	72	91	80	83
51	Russell River, Tas	500	65	91	83	72
52	Maydena, Tas	650		85	98	82
53	Middle Peak, Tas	500	52	82	78	58
54	Lake Tooms, Tas	600	70	80	76	67
55	Bicheno, Tas	460	32	69	80	45
56	Fingal Tier, Tas	760	67	85	76	69
57	Bendover Hill, Tas	550	80	89	89	76
58	Mt Gibbo, Vic	1310		91	69	85
59	Forlorn Hope Track, Vic	1400		96	83	89
60	Bulls Head, ACT	1125	87	85		
61	Mt Delegate, NSW	915	91	95	87	70
62	Mt Ellery, Vic	1150	72	93	83	
63	Nunniong Plateau, Vic	1320			59	59
64	Cromwell Knob, Vic	1280		89	78	93
65	Maria Island, Tas	450		80	89	70
70	Base Population, NZ		78	91	83	83
71	2nd & 3rd Generation, NZ		89	95	76	91
72	Eagle Hawk Tier, Tas	460	59	95	82	74
73	Misery Plateau, Tas	920	70	85	74	83
75	Mt St Gwinear, Vic	1260	85	82	78	87
	Mean		76.6	84.1	80.2	78.9

TABLE 2–Adjusted mean height (m) at 3 years of age for provenances of *E. delegatensis* at the four field sites tabulated according to rank (R) at Pilot Hill.

No.	Provenance	State*	Pilot Hill	Myrtlebank (m)	(R)	Tarraleah (m)	(R)	Parrawe (m)	(R)
27	Royston River	V	5.64	4.11	2	3.45	6	2.35	2
11	Geehi	N	5.54	3.46	14	2.65	30	2.13	13
33	Mt Ewen	V	5.28	3.56	13	3.57	2	2.14	11
13	Dargals Range	N	5.27	3.11	35	2.17	56	2.05	14
32	Mt Skene	V	5.25	3.32	18	3.05	13	1.75	34
20	Mt Wills	V	5.19	3.27	23	2.95	16	2.05	15
22	Mt Buffalo	V	5.18	3.40	16	2.65	31	1.48	48
23	Big Hill	V	5.13	3.58	12	3.18	10	1.76	32
24	Big Ben	V	5.12	3.29	21	2.59	33	2.23	6
26	Upper Howqua	V	5.08	3.24	27	2.39	45	2.13	12
7	Mt NurenmerenmangN		5.07	3.09	36	2.02	61	1.87	24
21	Beecher Hill	V	5.05						
34	Mt Baldhead	V	5.05	3.61	10	3.46	4	2.21	7
5	Clear Creek	N	4.98	2.82	5	2.75	24	1.85	26
62	Mt Ellery	V	4.96	3.59	11	3.51	3		
6	The Granites	N	4.74			2.53	36	0.69	60
71	2nd & 3rd Gener. NZ		4.67	2.92	44	2.31	47	1.81	29
25	Razorback Spur	V	4.64	3.13	34	2.49	38	1.93	20
16	Yarrangobilly	N	4.63						
29	Mt Macedon	V	4.62	3.63	9	3.05	12	2.56	1
10	Youngal	N	4.60	3.29	22	2.71	26	1.86	25
61	Mt Delegate	N	4.57	3.26	25	2.78	22	0.87	58
31	Mt Useful	V	4.55	3.95	4	3.29	7	2.30	4
19	Pilot Hill	N	4.53	2.88	50	2.27	51	1.72	36
60	Bulls Head	A	4.52	2.57	61				
28	Lake Mountain	V	4.52	2.88	49	3.28	8	1.98	17
30	Ada River	V	4.51	4.17	1	3.72	1	2.21	8
75	Mt St Gwinear	V	4.48	4.10	3	3.46	5	2.27	5
8	Mt Black Jack	N	4.48	2.41	8	2.27	49	1.74	35
3	Smokers Flat	A	4.39	2.71	57	2.16	57	1.93	19
12	The Pinnacle	N	4.37	2.95	41	2.41	43	1.89	22
2	Leura Gap	A	4.36			2.82	20	0.67	61
17	Gungarlin River	N	4.34	3.02	39	2.54	35	1.66	39
1	Yaouk Bill Range	N	4.29					0.58	63
4	Mt Bogong	N	4.28	2.85	52				
9	Cascade	N	4.18	2.97	40	2.72	25	1.59	44
44	Luina	T	4.16	3.69	6	2.88	18	1.89	23
42	Surrey Hills	T	4.16	3.81	5	3.06	11	2.34	3
15	Peppercorn Hill	N	4.14	2.66	59	2.11	58	1.65	40
18	Bald Hill	N	4.12			2.26	53	0.62	62
70	Base Pop. NZ		3.99	2.89	48	2.52	37	2.04	16
14	Mt Flinders	N	3.72	2.86	51	2.20	54	0.87	59
41	Maggs Mountain	T	3.66	2.84	53	3.00	15	1.95	18
39	Dazzler Range	T	3.53	3.35	17	2.88	19	1.68	38
40	Cluan Tier	T	3.53	3.26	24	2.47	39	1.64	41
72	Eagle Hawk Tier	T	3.52	3.24	26	2.76	23	1.43	52
57	Bendover Hill	T	3.38	3.64	8	2.63	32	1.84	27
49	Mt Dromedary	T	3.32	3.17	30	2.92	17	1.69	37
48	Tunbridge Tier	T	3.24	3.13	32	2.58	34	1.83	28
35	Hartz Mt	T	3.23	3.07	37	2.70	27	1.51	46
51	Russell River	T	3.15	3.29	20	2.67	28	1.80	30
43	Yellow Marsh Rd	T	3.07	3.65	7	2.38	46	1.92	21
38	Ben Nevis	T	3.07	2.68	58	1.90	63	1.29	56
47	Miena	T	3.05	2.93	43	2.41	44	1.50	47
54	Lake Tooms	T	3.03	2.91	46	2.28	48	1.34	54
53	Middle Peak	T	2.89	3.43	15	3.03	14	1.46	50
73	Misery Plateau	T	2.87	2.91	47	2.02	60	1.59	43
46	King William	T	2.86	2.47	62	2.19	55	1.61	42
36	Plateau Rd	T	2.73						
50	Lake Pedder	T	2.73	2.94	42	2.41	42	1.45	51
56	Fingal Tier	T	2.69	2.64	60	1.55	64	1.41	53
45	Heemskirk River	T	2.55	3.04	38	2.10	59	1.76	33
37	Ben Lomond	T	2.38	2.36	64	1.99	62	1.20	57
55	Bicheno	T	2.34	2.76	56	2.42	41	1.32	55
52	Maydena	T		3.13	33	2.27	50	1.48	49
58	Mt Gibbo	V		3.17	31	2.80	21	1.77	31
59	Forlorn Hope Track	V		3.23	28	2.66	29	2.19	10
63	Nunniong Plateau	V				2.43	40	0.58	64
64	Cromwell Knob	V		3.32	19	3.19	9	2.21	9
65	Maria Island	T		2.78	55	2.26	52	1.56	45
	Average S.E. (diff.)		0.36	0.26		0.27		0.18	

* State of origin of provenances: A = Australian Capital Territory, N = New South Wales, T = Tasmania, V = Victoria.

TABLE 3–Analyses of variance across sites for height, diameter, and volume

	Height			Diameter			Volume		
	DF	MS	VR	DF	MS	VR	DF	MS	VR
Site	3	65.09		2	34.15		2	1.362	
Region	3	8.80		3	6.23		3	0.220	
Provenance within region	66	0.34		66	0.24		66	0.007	
Site•region	9	2.50	7.92	6	1.96	4.53	6	0.081	5.81
Site•provenance within region	172	0.09	0.29	112	0.11	0.25	112	0.003	0.19
Between plot residual		0.31			0.43			0.014	

TABLE 4–Site × region means for height, diameter, and volume from combined analyses of variance.

Site	Region			
	Tasmania	NSW	Victoria	New Zealand
		Height (m)		
Pilot Hill	3.13	4.55	4.74	4.93
Myrtlebank	2.80	2.86	3.99	2.81
Tarraleah	2.07	2.55	3.51	2.36
Parrawe	1.80	0.79	2.47	2.02
		Diameter (cm)		
Pilot Hill	2.77	3.94	3.97	4.24
Myrtlebank	2.29	2.45	3.58	2.38
Tarraleah	1.70	1.92	2.83	1.85
		Volume (dm^3)		
Pilot Hill	0.88	2.26	2.95	2.78
Myrtlebank	0.59	0.63	1.95	0.68
Tarraleah	0.22	0.30	1.08	0.32

Diameter

Significant differences between provenances were found at Pilot Hill, Myrtlebank, and Tarraleah (Table 5). Plants at Parrawe were too small for diameter at 1.2 m to be measured at 3 years of age. At Pilot Hill most of the Victorian provenances and some local New South Wales provenances were among the leaders. In fact, five out of the top 15 ranking provenances were from New South Wales. As in the height results, Royston River and Geehi performed well at this site. All the Tasmanian provenances performed poorly, with the majority being significantly smaller in diameter than the top 15 provenances in the trial.

At both Myrtlebank and Tarraleah the majority of the better performing provenances for diameter were from Victoria—in particular, Royston River, Ada River, Mt St Gwinear, and Mt Useful (Tables 4 and 5). The New South Wales provenances were substantially less successful at both trial sites whereas a small group of northern Tasmanian provenances were consistently in the top 15. However, a number of New South Wales and Tasmanian provenances ranked very poorly at both sites.

Rank Correlation Between Height and Diameter Over Years

Height and diameter data are presented only for 3-year-old trees but measurements were also made at 1 and 2 years of age. Within each site, first-year height measurements were

TABLE 5–Mean diameter (cm) at 3 years of age for provenances of *E. delegatensis* at three sites tabulated according to rank (R) at Pilot Hill.

No.	Provenance	State*	Pilot Hill (cm)	Myrtlebank (cm)	Myrtlebank (R)	Tarraleah (cm)	Tarraleah (R)
22	Mt Buffalo	V	4.72	3.21	10	2.07	30
11	Geehi	N	4.68	3.09	13	2.15	26
27	Royston River	V	4.68	3.89	1	2.87	3
32	Mt Skene	V	4.59	2.81	22	2.57	12
7	Mt Nurenmerenmang	N	4.58	2.78	25	1.45	63
13	Dargals Range	N	4.50	2.50	45	1.56	60
33	Mt Ewen	V	4.44	2.99	18	3.03	1
5	Clear Creek	N	4.39	2.62	35	2.26	23
20	Mt Wills	V	4.36	2.63	33	2.38	15
23	Big Hill	V	4.35	3.36	5	2.70	9
26	Upper Howqua	V	4.34	2.80	23	1.89	42
21	Beecher Hill	V	4.32				
24	Big Ben	V	4.26	2.78	26	2.17	25
34	Mt Baldhead	V	4.10	3.16	12	2.98	2
2	Leura Gap	A	4.08				
10	Youngal	N	4.07	3.02	17	2.05	33
19	Pilot Hill	N	4.06	2.61	36	1.80	45
60	Bulls Head	A	4.06	1.95	61		
6	The Granites	N	4.02			1.92	40
71	2nd & 3rd Generation NZ		3.99	2.59	37	1.89	41
25	Razorback Spur	V	3.98	2.65	30	2.14	27
62	Mt Ellery	V	3.96	3.04	14	2.74	8
15	Peppercorn Hill	N	3.93	2.01	59	1.51	62
8	Mt Black Jack	N	3.91	1.65	64	1.84	43
61	Mt Delegate	N	3.91	2.88	20	2.18	24
29	Mt Macedon	V	3.90	3.23	9	2.35	16
16	Yarrongobilly	N	3.90				
28	Lake Mountain	V	3.85	2.26	36	2.77	7
12	The Pinnacle	N	3.82	2.55	40	1.79	46
9	Cascade	N	3.72	2.34	52	1.99	38
75	Mt St Gwinear	V	3.72	3.79	2	2.86	4
1	Yaouk Bill Range	N	3.69				
3	Smokers Flat	A	3.64	2.20	58	1.62	56
39	Dazzler Range	T	3.64	2.76	28	2.27	21
17	Gungarlin River	N	3.62	2.43	46		
4	Mt Bogong	N	3.61	2.42	47		
31	Mt Useful	V	3.57	3.67	3	2.84	6
40	Cluan Tier	T	3.55	3.03	15	2.06	32
44	Luina	T	3.40	3.26	7	2.42	13
18	Bald Hill	V	3.38			1.65	55
14	Mt Flinders	N	3.31	2.40	48	1.61	57
70	Base Population NZ		3.28	2.62	34	2.00	37
30	Ada River	V	3.15	3.61	4	2.85	5
49	Mt Dromedary	T	3.10	2.80	24	2.33	18
35	Hartz Mt	T	3.04	2.51	42	2.02	35
72	Eagle Hawk Tier	T	3.00	2.89	19	2.34	17
48	Tunbridge Tier	T	2.99	2.72	29	2.04	34
41	Maggs Mt	T	2.97	1.98	60	2.63	11
38	Ben Nevis	T	2.97	2.31	54	1.58	59
42	Surrey Hills	T	2.95	3.24	8	2.30	19
57	Bendover Hill	T	2.94	3.35	6	2.11	28
51	Russell River	T	2.75	2.64	31	2.29	20
54	Lake Tooms	T	2.68	2.53	41	1.75	49
43	Yellow Marsh Rd	T	2.59	3.18	11	1.71	52
46	King William	T	2.58	1.76	63	1.60	58
53	Middle Peak	T	2.56	3.02	16	2.42	14
56	Fingal Tier	T	2.53	2.35	51	1.10	64
47	Miena	T	2.53	2.50	44	1.81	44
73	Misery Plateau	T	2.52	2.50	43	1.74	50
50	Lake Pedder	T	2.50	2.32	53	1.69	53
37	Ben Lomond	T	2.41	1.82	62	1.52	61
36	Plateau Rd	T	2.39				
55	Bicheno	T	2.33	2.25	57	1.76	48
45	Heemskirk River	T	1.86	2.36	50	1.66	54
52	Maydena	T		2.63	32	1.94	39
58	Mt Gibbo	V		2.59	38	2.06	31
59	Forlorn Hope Track	V		2.77	27	2.01	36
63	Nunniong Plateau	V				1.78	47
64	Cromwell Knob	V		2.84	21	2.65	10
65	Maria Island	T		2.37	49	1.74	51
	Average S.E. (diff.)		0.42	0.38		0.29	

* State of origin of provenances: A = Australian Capital Territory, N = New South Wales, T = Tasmania, V = Victoria.

significantly correlated with all later measurements but all the correlations were comparatively weak. In contrast, the correlations of second-year height with third-year height and third-year height with third-year diameter were very high at all sites. These results suggest that first-year height data may not be a good indicator of final performance.

Volume

The volume data demonstrated the same general trends as the height and diameter data, with the Victorian and local New South Wales provenances having the largest volumes at Pilot Hill (Table 6). Volumes were greatest at Pilot Hill and least at Tarraleah (Tables 4 and 6). On this early volume data, the Victorian provenances were generally superior at the three sites. In particular, provenances from central-southern Victoria were performing well at both Tasmanian sites. Nevertheless there were significant site × region interactions in volume (Table 3). Several New South Wales provenances were ranked in the top 20 at the Pilot Hill site and generally these same provenances also had the largest volumes of the New South Wales provenances at the other two sites, but all were much further down the rankings. When only Tasmanian provenances were considered, most of the top-ranking provenances were of low-altitude northern origin. However, as for height and diameter, all Tasmanian provenances were at the bottom of the volume rankings in the Pilot Hill trial but several were in the top 15 at Myrtlebank and these differences contributed substantially to the significant site × region interaction (Table 3). The base and advanced-generation breeding populations from New Zealand were well down in the rankings, especially at the Tasmanian sites. The Royston River population ranked highly at all sites and the Ada River, Mt Useful, and Mt St Gwinear provenances were close to the top at the two Tasmanian sites.

Snow Damage

At Pilot Hill heavy snow damage occurred during the third winter. Since the measures of stem bending and breakage proved to be highly correlated, only the stem bending data are presented (Table 7). The Tasmanian provenances showed very high damage with many of the most affected being the low-altitude provenances. The local, high-altitude, New South Wales provenances exhibited the least stem bending. The Tasmanian provenances were slow-growing so the damage to them was not due to larger crowns trapping more snow but could possibly have been due to smaller diameter stems. On the other hand, it might be due to some differences in wood properties between the mainland and Tasmanian provenances.

DISCUSSION

The growth performance of provenances of *E. delegatensis* varied significantly at the four sites. Generally the southern Victorian provenances had best growth across all sites. The Royston River provenance was the best performer over-all with Ada River, Mt Useful, and Mt St Gwinear consistently ranking very highly at most sites. Rankings for growth parameters very similar to those reported for Pilot Hill were obtained at two Victorian trial sites (L.A. Pederick, pers. comm.). Thus, results from all mainland trials showed Victorian provenances performing well, along with several New South Wales provenances and particularly the Geehi one.

TABLE 6–Mean volumes (dm^3) for provenances of *E. delegatensis*. Provenances are ranked for each of the three experimental sites at which diameter was measured.

Rank	Pilot Hill		Myrtlebank		Tarraleah	
	Provenance	Vol.	Provenance	Vol.	Provenance	Vol.
1	Royston River Rd	4.28	Mt St Gwinear	2.31	Ada River	1.31
2	Mt Skene	4.11	Royston River Rd	2.14	Mt St Gwinear	1.25
3	Geehi	4.06	Mt Useful	2.07	Mt Useful	1.21
4	Dargals Range	4.01	Bendover Hill	1.72	Mt Ellery	1.20
5	Mt Buffalo	3.79	Mt Baldhead	1.66	Mt Ewen	1.19
6	Big Hill	3.71	Ada River	1.66	Royston River Rd	1.16
7	Mt Ewen	3.62	Luina	1.52	Mt Baldhead	1.13
8	Mt Wills	3.38	Big Hill	1.50	Lake Mountain	1.09
9	Mt Nurenmerenmang	3.38	Mt Ewen	1.47	Mt Skene	0.94
10	Upper Howqua	3.37	Yellow Marsh Rd	1.46	Cromwell Knob	0.91
11	Mt Baldhead	3.36	Mt Ellery	1.40	Luina	0.90
12	Big Ben	3.34	Surrey Hills	1.39	Maggs Mountain	0.83
13	Clear Creek	3.23	Middle Peak	1.35	Big Hill	0.82
14	Beecher Hill	3.19	Cluan Tier	1.32	Russell River	0.76
15	Mt Macedon	3.05	Mt Macedon	1.27	Mt Macedon	0.75
16	Youngal	2.96	Dazzler Range	1.25	Middle Peak	0.71
17	Leura Gap	2.92	Geehi	1.23	Surrey Hills	0.70
18	Razorback Spur	2.86	Russell River	1.21	Mt Wills	0.68
19	Mt St Gwinear	2.85	Mt Buffalo	1.20	Dazzler Range	0.65
20	Mt Ellery	2.80	Razorback Spur	1.20	Leura Gap	0.62
21	The Granites	2.79	Cromwell Knob	1.19	Eagle Hawk Tier	0.61
22	2nd & 3rd Gen. NZ	2.75	Mt Skene	1.18	Bendover Hill	0.59
23	Cascade	2.74	Youngal	1.16	Mt Dromedary	0.57
24	Lake Mountain	2.69	Upper Howqua	1.12	Razorback Spur	0.54
25	Mt Delegate	2.67	Big Ben	1.07	Clear Creek	0.53
26	Peppercorn Hill	2.66	Mt Dromedary	1.07	Mt Delegate	0.52
27	Yarrangobilly	2.62	Mt Delegate	1.06	Geehi	0.52
28	Pilot Hill	2.60	Tunbridge Tier	1.04	Tunbridge Tier	0.49
29	Mt Black Jack	2.53	Upper Howqua	1.03	Mt Buffalo	0.48
30	Bulls Head	2.51	Eagle Hawk Tier	1.03	Gungarlin River	0.47
31	The Pinnacle	2.36	Forlorn Hope Track	1.00	Cluan Tier	0.47
32	Gungarlin River	2.21	Mt Wills	0.98	Big Ben	0.46
33	Mt Useful	2.16	Lake Mountain	0.96	Youngal	0.45
34	Smokers Flat	2.13	Dargals Range	0.91	Mt Gibbo	0.45
35	Mt Bogong	2.09	Heemskirk River	0.89	Hartz Mountain	0.42
36	Luina	2.06	Mt Gibbo	0.88	Forlorn Hope Track	0.42
37	Dazzler Range	2.03	Base Pop. NZ	0.87	Base Pop. NZ	0.41
38	Cluan Tier	1.98	Mt Nurenmerenmang	0.85	Upper Howqua	0.41
39	Ada River	1.94	Clear Creek	0.84	Miena	0.40
40	Yaouk Bill Range	1.89	Pilot Hill	0.83	Cascade	0.39
41	Base Pop. NZ	1.67	Maydena	0.82	The Granites	0.38
42	Mt Flinders	1.64	2nd & 3rd Gen. NZ	0.82	2nd & 3rd Gen. NZ	0.37
43	Hartz Mt	1.61	Maria Island	0.81	Maydena	0.37
44	Maggs Mountain	1.57	Hartz Mountain	0.80	The Pinnacle	0.37
45	Bald Hill	1.57	Miena	0.80	Mt Black Jack	0.35
46	Eagle Hawk Tier	1.43	Cascade	0.79	Bicheno	0.33
47	Bendover Hill	1.36	Mt Flinders	0.78	Nunniong Plateau	0.32
48	Surrey Hills	1.30	Bicheno	0.76	Lake Tooms	0.31
49	Tunbridge Tier	1.24	Mt Bogong	0.76	Pilot Hill	0.30
50	Mt Dromedary	1.19	Misery Plateau	0.76	Yellow Marsh Rd	0.30
51	Ben Lomond	1.16	Gungarlin River	0.75	Maria Island	0.28
52	Ben Nevis	1.12	Lake Tooms	0.75	Misery Plateau	0.27
53	Lake Tooms	1.12	Lake Pedder	0.74	Bald Hill	0.27
54	Russell River	1.11	Fingal Tier	0.71	Ben Nevis	0.27
55	Middle Peak	1.07	Miena	0.71	Dargals Range	0.27
56	Fingal Tier	0.95	Smokers Flat	0.69	Lake Pedder	0.26
57	King William Saddle	0.95	The Pinnacle	0.69	Smokers Flat	0.25
58	Yellow Marsh Rd	0.92	Ben Nevis	0.63	Heemskirk River	0.23
59	Misery Plateau	0.89	Maggs Mountain	0.61	Mt Flinders	0.22
60	Miena	0.83	Peppercorn Hill	0.57	King William Saddle	0.21
61	Bicheno	0.76	Bulls Head	0.55	Peppercorn Hill	0.21
62	Plateau Road	0.74	Ben Lomond	0.54	Ben Lomond	0.19
63	Lake Pedder	0.69	Mt Black Jack	0.49	Mt Nurenmerenmang	0.15
64	Heemskirk River	0.54	King William Saddle	0.48	Fingal Tier	0.02
Av. S.E.(diff.)		0.07		0.05		0.05

TABLE 7–Snow damage at Pilot Hill. High scores indicate greatest snow damage.

Provenance	Score	Provenance	Score	Provenance	Score
Geehi	0.23	Lake Mt	1.00	Mt Dromedary	2.33
Clear Creek	0.28	Smokers Flat	1.01	Lake Pedder	2.36
Pilot Hill	0.31	Razorback Spur	1.08	Mt Macedon	2.36
2nd & 3rd Gen. NZ	0.31	King William	1.09	Ben Lomond	2.39
Upper Howqua	0.32	Mt Ewan	1.09	Maggs Mt	2.39
Mt Nurenmerenmang	0.43	Peppercorn Hill	1.11	Cluan Tier	2.41
Youngal	0.49	Leura Gap	1.15	Lake Tooms	2.44
Mt Bogong	0.52	Mt Delegate	1.19	Yellow Marsh Rd	2.46
Mt Black Jack	0.52	Mt Ellery	1.19	Hartz Mt	2.48
The Granites	0.52	Bulls Head	1.19	Fingal Tier	2.55
Big Hill	0.53	Ada River	1.21	Ben Nevis	2.59
Yarrangobilly	0.60	Cascade	1.24	Bicheno	2.66
Mt Buffalo	0.60	Yaouk Bill Range	1.24	Eagle Hawk Tier	2.72
Mt Wills	0.63	Mt Baldhead	1.25	Heemskirk River	2.76
Royston River Rd	0.68	Bald Hill	1.33	Surrey Hills	3.07
Dargals Range	0.73	Gungarlin River	1.42	Middle Peak	3.39
Base Population NZ	0.77	Mt Useful	1.51	Luina	3.39
Mt Flinders	0.81	Mt St Gwinear	1.75	Bendover Hill	3.41
Beecher Hill	0.82	Russell River	2.17	Plateau Road	3.45
The Pinnacle	0.89	Tunbridge Tier	2.20	Dazzler Range	3.82
Mt Skene	0.90	Miena	2.22		
Big Ben	0.98	Misery Plateau	2.30	Av. S.E.(diff.)	0.32

Tasmanian provenances exhibited slower growth and lower survival on the mainland than provenances from the northern part of the geographic range. Even in Tasmania, the Tasmanian provenances generally did not perform very well, although several north-western Tasmanian provenances ranked in the top 20. At Tarraleah a number of New South Wales provenances ranked near the bottom for growth. However, the growth rates at the three Tasmanian sites were lower than those at Pilot Hill, and it will be important to see whether the provenance and region × site interactions persist in later measurements. Clearly, provenances of *E. delegatensis* from defined geographic regions may be grouped together on growth performance, in contrast to the patterns of variation found in some other eucalypts such as *E. grandis* (Burgess 1988). The early data from this study and the Victorian trials suggest that these groupings should be useful for choosing stock for planting at sites on the mainland. More data from the trials at later ages will be required to establish whether these groups are also a useful basis for selection strategies for Tasmanian plantings.

A noticeable feature is that early growth was better at the Pilot Hill site than at the Tasmanian sites. Together with the 4-year growth performance of the same provenances at two Victorian sites (L.A. Pederick, pers. comm.) and 2-year data from a trial in the North Island of New Zealand (M.D. Wilcox, pers. comm.), all the results indicate that growth is faster at the more northern sites. This was not necessarily so for other ash eucalypts such as *E. obliqua* (Brown *et al.* 1976; Matheson *et al.* 1986) and *E. regnans* (Griffin *et al.* 1982).

The tendency for provenances within growth classes to be geographically related may be a feature of some other temperate eucalypts. In the lower-altitude species *E. regnans*, differences in early growth were small and showed no clear-cut regional differences or site interactions (Griffin *et al.* 1982). Current evidence suggests a similar variation pattern in

E. globulus Labill (Volker & Orme 1988). In contrast, *E. obliqua* shows large differences in diameter, with most Tasmanian provenances performing well but with only a few provenances from other parts of the geographic range doing as well. Distinct regional groups have been demonstrated in *E. nitens* (Deane et Maiden) Maiden, with material from the central highlands of Victoria showing superior growth at most sites in Australia and New Zealand (Pederick 1979). The limited data available suggest that broad geographic groupings of provenances on the basis of growth may be more common within the higher-altitude eucalypts, at least in south-eastern Australia.

The differences in growth, stem bending, and, to a lesser extent, survival between the mainland and Tasmanian provenances support other evidence of two evolutionary lineages within *E. delegatensis*. Between mainland and Tasmanian provenances there is evidence of differential defoliation by insects (Ohmart *et al.* 1984), of differences in several seedling characters (Boland & Dunn 1985), and of marked allelic frequency changes at a number of isozyme loci (Moran in prep.). On the basis of seedling characters, *E. delegatensis* was divided into two subspecies, with subsp. *tasmaniensis* comprising all populations in Tasmania (Boland 1985). Data on the quantitative characters reported here and from isozyme studies (Moran in prep.) support this separation.

In a morphological study of *E. delegatensis* (Boland & Dunn 1985), cluster analysis split the mainland provenances into two geographic groups and the Tasmanian provenances into three areas, the latter including a north-western group. The growth data do not support the division of the mainland range but the faster-growing Tasmanian provenances do tend to be from the north-western Tasmanian group.

These early results already suggest that some preliminary selection strategies for material for plantations and breeding programmes can be formulated. General susceptibility to frost (Boland & Dunn 1985), lower survival, and significantly lower growth rates seem a sound basis for excluding Tasmanian provenances from mainland breeding programmes. Further, current evidence suggests that inclusion of material from a number of mainland provenances would most likely be an optimal strategy. Which provenances would be best as a source for Tasmanian plantation material is more uncertain and decisions should probably be based on later results from these trials. However, it is likely that the source of superior provenance material for Tasmania will be from southern Victoria. It is also apparent that the introductions forming the basis of the New Zealand breeding programme in the late 1970s came from the mainland, but, more importantly, that it would be beneficial to introduce new material to New Zealand from superior provenances as has been done (M.D. Wilcox, pers. comm.).

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