MULGA RESEARCH CENTRE

annual report 1980

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Contents

STOCKING AND GROWTH OF *ACACIA ANEURA* FOLLOWING OVERWOOD THINNING

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Introduction

An investigation was commenced in 1956 aimed at determining the effect of removal and partial removal of the tree cover upon the grass and herbage production of a mulga association (Wilcox 1968). The present report deals with the effects of this intervention on the population of *Acacia aneura* trees.

The study site is at Albion Downs (27°17'S, 120° 23'E) about 78 km south of Wiluna and 21 km north-east of Yeelirrie. It has been mapped by Churchward (1977) as Bigida Landform. The soil of the area is a red earth with hardpan generally <0.5 m from the surface. Mulga is the most conspicuous plant at the site, though *Acacia tetragonophylla* of lower stature, tends to be locally common. Several species of *Eremophila* are present, *Canthium lineare* is common, particularly in close proximity to mulga of bushy form. Low shrubs of *Ptilotus exaltatus, Maireana triptera, Rhagodia drummondii, Spartothamnella teucriiflora* and *Bassia* sp. are also present. Wilcox (1968) recorded the following grass species: *Aristida arenaria, Danthonia bipartita* and *Eragrostis setifolia*.

The study site was visited in July 1978, July 1979 and again in September 1980.

Experimental Design

An area of 9 acres (3.6 ha) was vermin-proof fenced in 1956. On one third of the area all the trees were cut down and removed from the enclosure. On another section one third of the trees were removed, and on the remaining portion the trees were left undisturbed. Fig. 1 illustrates the design of the original experiment. In July 1978 a set of 12 standard plots of 25 x 20 m was established in the area such that three plots sampled each of the three treatment categories, and a further three sampled the adjacent area (Fig. 1). The north-east corner of plots 1 - 9 were selected in the field, subjectively, such that the following criteria were met:

1. plots definitely within each of the three distinctive treatments
2. plots not immediately adjacent to the fence
3. spatial coverage of each treatment achieved
4. relocation readily achievable.

Figure 1. Albion Downs enclosure. Layout of overwood thinning experiment and sample plot positions. The solid line represents the fence.

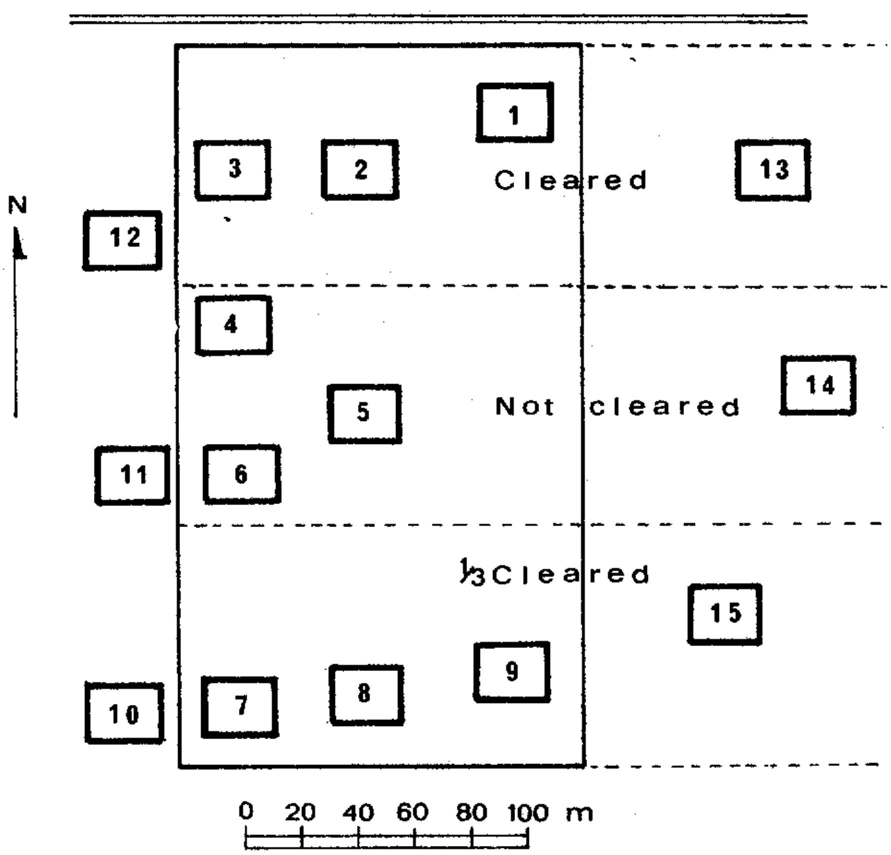

TABLE 1. Albion Downs Overwood Thinning Stand Tables by Plots 1978*, *Acacia aneura* only

Plot No.	Size Classes (M) <0.1	0.1 - 0.49	0.5 - 0.99	1 - 1.99	2 - 2.99	3 - 3.99	4 - 4.99	5+	Totals
Cleared									
1	-	1	2	3	1	-	-	-	7
2	-	-	3	7	1	-	-	-	11
3	-	3	2	30	5	-	-	-	40
12		9	10	14	6	1	-	2	42
13		2	-	11	4	1	-	-	18
1/3 Cleared									
7	-	2	1	6	3	1	-	3	16
8	-	3	-	3	3	1	-	3	13
9	-	1	-	1	-	2	1	3	8
10	4	9	3	6	-	1	4	1	28
15	-	10	4	-	3	3	2	4	26
Not Cleared									
4	-	16	7	8	-	-	2	7	40
5	-	6	2	-	-	-	-	8	16
6	1	3	-	4	4	1	1	11	25
11	-	4	8	10	3	1	4	3	33
14	-	2	1	-	2	3	6	6	20

* Values for plots 13, 14, 15 obtained 12 months later than the rest.

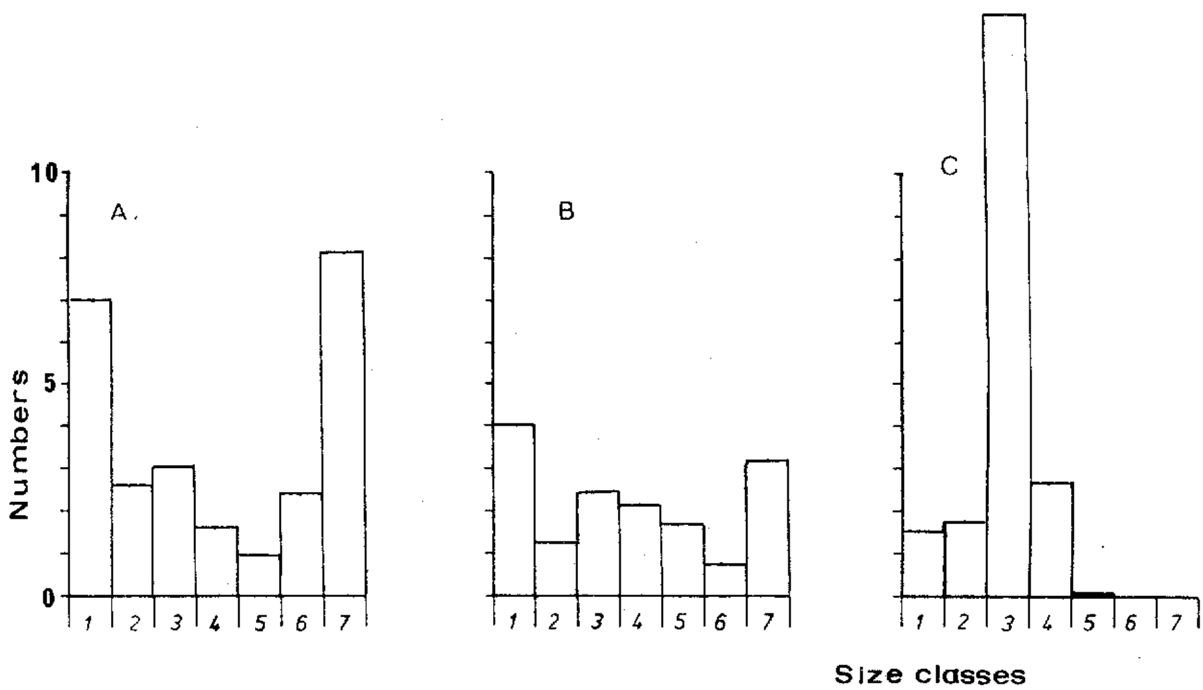

Figure 2. Mean Size Class Distributions. Average numbers of *Acacia aneura* per 0.05 ha plot by treatment. A - not cleared (plots 4, 5, 6, 14); B 1/3 cleared (plots 7, 8, 9, 15); C - cleared (plots 1, 2, 3, 13). Size classes as in table 1 viz 1 = <0.5 m, 2 = 0.5 - 0.99 m .... 7 = 5 m+.

The sacrifice of randomness is not likely to influence the results as the sampling percentages are high - three plots of 0.05 ha sample areas of c. 1.2 ha, i.e., 12.5 percent sampling proportion.

The adjacent area plots 10-12 were placed close to the fence so that loss of comparability would be minimal. While these are used in the following analysis, it must be emphasised that they are not strict 'controls' in respect of felling and fencing. An area to the east of the fenced block was treated in the same way, plots 13-15 were established here in July 1979. These three plots thus sample the same three treatments but have been open to grazing since disturbance.

Stocking and Size Class Distribution

A summary of stand tables for each plot at first assessment is presented in Table 1. These data both confirm the effect of the 1956 treatment and indicate definite changes following intervention. By comparison with the 'not cleared' set the 'cleared set' shows absence of taller trees (except for plot 12, which may not have been cleared to the same degree) and scarcity of small plants, with a bulge in the range 1 m to 3 m. Similarly the one third cleared set has fewer large trees, and while it has more in the size <0.5 m than the cleared set, it has fewer in this class than does the not cleared set.

TABLE 2. Albion Downs Overwood Thinning Stocking Summary

Plot No.	*Acacia aneura* Live Trees <2m (a)	1<3m (b)	>4m (c)	Cut stumps (d)	Sum of (c) & (d)
1	6	4	0	5	5
2	10	8	0	19	19
3	35	35	0	15	15
13	13	15	0	18	18
Mean	16	15.5	0	14.3	14.3
7	9	9	3	2	5
8	6	6	3	8	11
9	2	1	4	1	5
15	14	3	6	3	9
Mean	7.7	4.7	4	3.5	7.5
4	31	8	9	3	12
5	8	0	8	0	8
6	8	8	12	4	16
14	3	2	12	0	12
Mean	12.5	4.5	10.3	1.7	12
10	22	6	5	0	5
11	22	13	7	1	8
12	33	20	2	0	2
Mean	25.6	13	4.7	0.3	5

These trends are illustrated in histogram form in Fig. 2 where the mean per plot numbers for sets of four plots per treatment are given. The values for plots 10, 11, 12 have not been included in these averages as on the whole their stocking relationships are more closely allied with the uncleared plots, particularly in respect of high numbers of smaller mulga.

Overwood thinning by removing large trees has altered the competitive conditions within the stands in various ways. The original objective was to determine whether thinning could cause beneficial alterations in herbage. Effects on the perennial shrubs and trees operate over a longer time scale. Nevertheless these measurements 22 years after intervention show clearly that removal of competition has allowed vigorous, if patchy, natural regeneration to occur. The time period has allowed this regrowth to exceed a metre in height, and in many cases to grow much larger. Table 2 compares the regrowth with taller trees and cut stumps taken from the area. The relationship between cut stumps and regrowth is not clear on the ground and has not been analysed here. Whereas small mulgas tend to be found around larger individuals, the trees of 1<3 m in plots 1, 2, 3, 13 tend to occur across the plot generally. This suggests that perhaps pre-existing seedlings contributed little to the regrowth.

On the other hand there seems to be a general relationship between the occurrence of vigorous regrowth and the absence of shade. (Tables 3-5, Fig. 3). Plots (and also quartered plots) with more shade from residual trees tend to have fewer mulga in the 1<2.5 m height class. In Fig. 3 all plots are illustrated and two logarithmic regressions are given!

Plots

Stocking ha^{-1} = -40.9 ln shade % + 222
n = 15, r = 0.543; sig. p. 0.05

Plot quarters

Stocking ha^{-1} = - 78.4 ln shade % + 313
n = 60, r = 0.453; sig. p. 0.001

In the following section general descriptions are given of each plot by treatment set. Tables 3-5 present summarised growth data for *Acacia aneura* in two broad size classes, < 1.00m and 1 < 2.5m in height. The legend appended to Table 3 also applies to Tables 4 and 5.

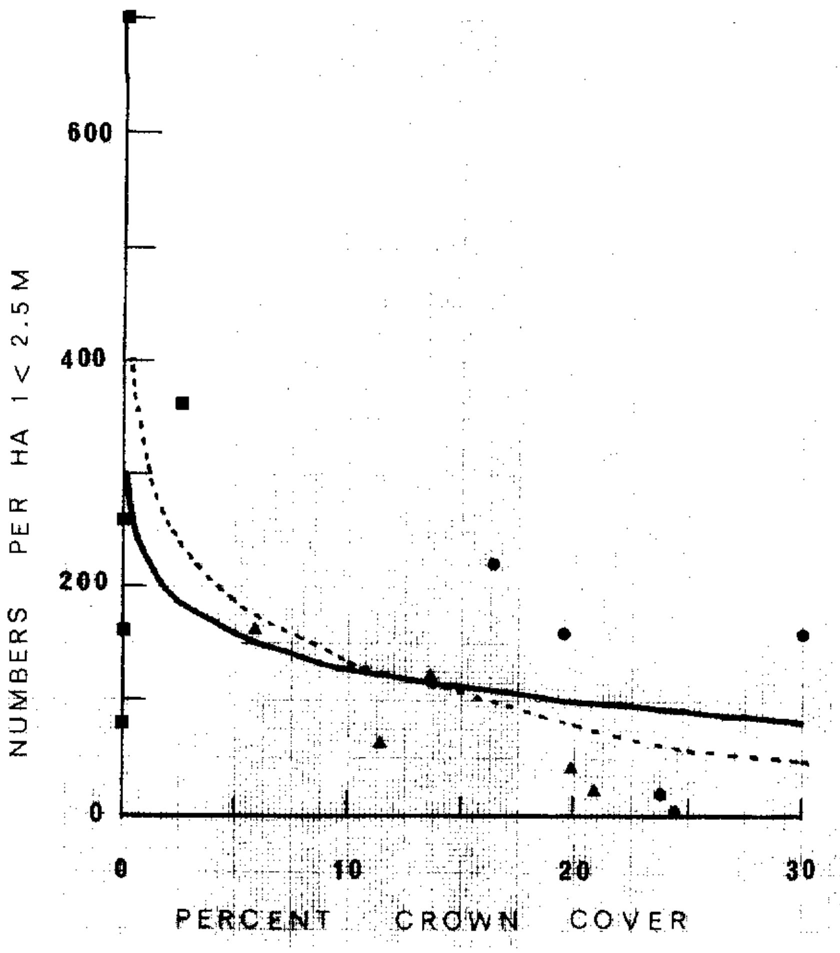

Figure 3. Stocking and Crown Cover Percentage.
Circles represent uncleared plot set; triangles the 1/3 cleared set; and squares the cleared plots. The solid line is the regression based on 15 plots, the dotted line that based on plot quarters (see text).

Individual Plot Descriptions 1978/1980

Cleared Areas

Plot 1 had fewest *Acacia aneura* (Table 1). Of the seven individuals only one exceeded 2m in height: this was a terete-phyll specimen in b quarter which put on 30cm in height between 1978 and 1980 by when it had reached 2.58m in height (Table 3). Three of the seven were of this phyll type, another three had short round phylls and one had half broad, long phylls. The latter was the slowest growing individual mulga. The mean increase in height over the period was 23.3cm for the terete phyll plants and only 12cm for the short round phyll specimens. Taller plants grew faster than shorter plants (Table 3). This plot had one *Acacia tetragonophylla,* one *Cassia nemophila* and several individuals of an *Eremophila* sp. There were four *Rhagodia drummondii* a number of *Ptilotus* sp; *Solanum lasiophyllum* was common, as were small Chenopods. Single specimens of *Exocarpos aphyllus* and of *Leichardtia australis* were noted.

Soil was generally clay loam, the mean of 5 soil depth to hardpan measurements was 60cm. Five cut stumps were recorded (Table 2) and there were 5 dead trees in the plot.

Plot 2 had 11 *Acacia aneura* of which 8 were of the short round phyll type, two were terete and one had half broad phylls. In contrast with plot 1 the terete phyll plants showed a mean height increase of 8.5cm compared with 22.9cm for those with short round phylls. However, the taller plants increased in height more than the shorter ones (Table 3). The tallest individual, a short round phyll (s-r) plant grew from 2.07m in 1978 to 2.49m in 1980. The only other shrub species present were small Chenopods, *Ptilotus* sp. and *Solanum lasiophyllum*

Soil was generally silty loam and soil depth averaged 40.2cm. There were 19 cut stumps in this plot and 9 dead trees. Most soils in the whole area were similar to plots 1 and 2 in texture.

Plot 3 had the highest stocking of obvious regrowth mulgas, with a total of 40 plants recorded at heights between 0.28 and 2.75m in 1978, and 0.23 and 2.82m in 1980. Several small plants showed signs of stress in 1980 and had lost foliage. Four different phyll types were distinguished:

s-r with 25 individuals, mainly clustered in quarters b, c (Fig. 4), these averaged 1.41m in 1978 and 1.54m in 1980;

terete (t) only two individuals in quarter a, between 1 and 2m tall. Both declined in height during the period between measurements;

half broad long (hb,l) with 11 stems, all but one of which occurred in the north-west quarter a (Fig. 4). These were taller, on average, than s-r plants, with mean heights of 1.76 in 1978 and 1.85m in 1980, and a lower mean increase in height of 9.3cm;

half broad (hb) only two individuals both in the north of the plot, one grew from 0.38 to 0.44m and the other from 1.61 to 1.75m.

On the whole plants less than 1m tall did not increase in height and the average increase in height of the taller plants was less than for the same classes in plots 1 and 2 (Table 3).

Two stems each of *Acacia tetragonophylla*, *Canthium lineare*, and *Exocarpus aphyllus* were present in this plot. Other shrub species included *Eremophila* sp., *Ptilotus* sp. and *Sida* sp.

Soil depth averaged 42cm. Fifteen cut stumps were recorded, mainly in plot quarter b (Fig. 4) and there were 6 dead trees in this plot.

TABLE 3. Crown Cover, Stocking✪and Growth Rates for Smaller Trees Cleared Area

Plot No.	Quarter	*Acacia aneura* <1.00 m				*Acacia aneura* 1<2.5 m				Percent Crown Cover >3 m tall.
		★Stems ha^{-1}	Mean Heights (m) 1978/9	Mean Heights (m) 1980	☆i (cm)	★Stems ha^{-1}	Mean Heights (m) 1978/9	Mean Heights (m) 1980	☆i (cm)	
1	a	80	0.83	0.86	3	0	-	-	-	-
	b	80	0.71	0.80	9	80	2.28	2.58	30	-
	c	80	0.48	0.61	13	80	1.62	1.88	26	-
	d	0	-	-	-	160	1.45	1.59	14	-
Means	plot no.1	60	0.673	0.757	8.3	80	1.70	1.91	21.0	-
2	a	0	-	-	-	0	-	-	-	-
	b	0	-	-	-	80	1.72	2.18	46	-
	c	80	0.84	0.82	neg	160	1.45	1.53	8.5	-
	d	160	0.67	0.77	10	400	1.55	1.81	25.4	-
Means	plot no.2	60	0.727	0.787	6.0	160	1.55	1.79	23.8	-
3	a	160	0.33	0.34	0.5	1200	1.59	1.67	7.7	-
	b	0	-	-	-	560	1.60	1.74	14.3	-
	c	160	0.55	0.53	neg	1040	1.67	1.84	16.6	-
	d	8	0.76	0.80	4	0	-	-	-	-
Means	plot no.3	100	0.504	0.504	0.0	700	1.62	1.75	12.3	-
12	a	400	0.53	0.50	neg	80	1.04	0.81	neg	-
	b	480	0.63	0.75	12.7	400	1.43	1.45	2.0	-
	c	320	0.54	0.57	2.3	400	1.83	2.01	18.6	0.8
	d	160	0.59	0.54	neg	560	1.55	1.63	7.6	9.6
Means	plot no.12	340	0.572	0.608	3.5	360	1.57	1.64	7.4	2.6
13✪	a	80	0.24	0.18	neg	160	1.67	1.75	15	-
	b	0	-	-		80	2.30	2.45	30	-
	c	0	-	-		640	1.61	1.69	16.6	-
	d	80	0.26	0.26	0	160	1.83	1.85	5	-
Means	plot no.13	40	0.25	0.22	neg	260	1.71	1.78	15.6	-
Overall means		120	0.565	0.597	3.2	312	1.62	1.75	13.3	0.5

✪ Stocking in the two size classes is as at 1978 (1979 for plot 13).

★ For entries against a, b, c, d the factor is 80, and for plot means 20.

☆ Height increment 'i' is for a two year period; plot 13 has been adjusted; 'neg' means that the second mean height was lower than the first.

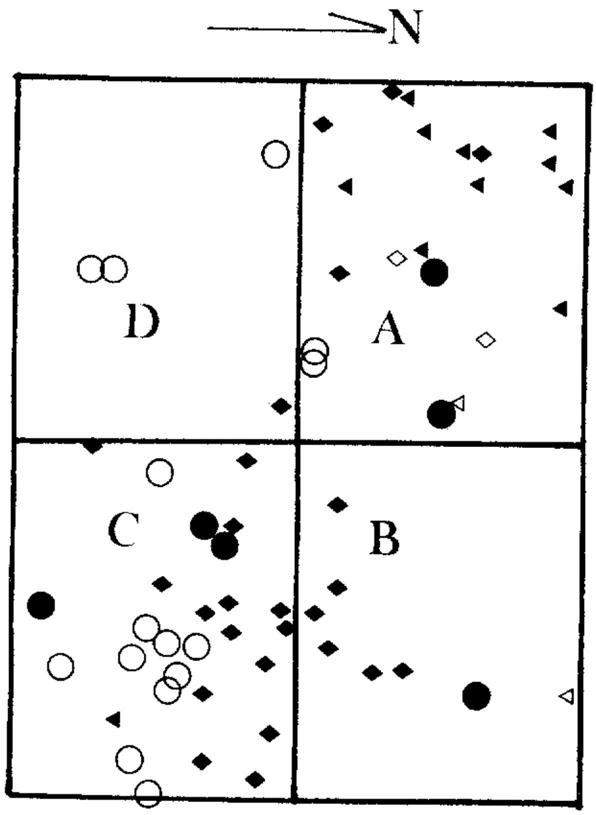

Figure 4. Diagrammatic representation of Plot 3 in cleared area. A, B, C, D represent plot quarters; open circles-stumps of felled trees; closed circles - dead trees. Mulga regeneration by four phyllode types: closed diamonds, short-round; open diamonds, terete; open triangles, half broad; closed triangles, half broad, long.

Plot 13. The 18 mulga here were of two phyll types: 8 were narrow (n) and 10 were hb. The former averaged about 1.5m whereas the latter were around 2m tall on average. The mean increases in height between 1979 and 1980 were 7.9 and 8.4cm respectively. One of each type were < 0.5m (Table 1) and these did not grow (Table 3). There were 13 stems between 1 and 2.5m tall, 7n and 6hb, representing the more vigorous regrowth. These increased in height, on average, by 8.6 and 6.3cm respectively over the one year period. Three hb plants > 2.5m may have originated prior to overwood thinning.

One *Acacia tetragonophylla* bush occurred in this plot. There were 18 cut stumps and three dead trees.

Plot 12. This plot had highest total numbers of mulga recorded. Two large trees, one of hb (6.6m) and one t (7.4) suggest the area was not treated in the same manner as plots 1-3, 13. These large trees had small crowns (Table 3). The mulga were in two main phyll classes, there were 25 stems of hb (many of which had been defoliated by caterpillars by September, 1980 and were stressed), and 14 of s-r. In addition to the large specimen of t referred to, there were also 2 specimens of hb,1. These latter showed no growth between 1978-1980. One each of hb and s-r < 0.5 died, most of the other small plants showed little or no growth. The s-r plants grew faster than the hb plants in all sizes viz

	Increments (cm) by classes (m)			
classes	≤0.5	0.5<1	1-2.5	>2.5<3.5
hb	neg(3)	neg(4)	2cm(13)	12cm(3)
s-r	2.8(4)	18(5)	25(3)	33(1)

(numbers contributing in brackets)

Two bushes of *Acacia tetragonophylla* were recorded in this plot. Average soil depth was 37.8cm. There were 9 dead trees present but no evidence of cut stumps.

One-Third Cleared Areas

Plot 7. Of the 16 mulga here the majority (9) had terete phyllodes, including all three >5m tall. Two of the latter had longer phyllodes than many of the smaller plants with terete phylls. There were 3 each of s-r and hb types, and one tree (3.9m) had broad, long (bl) phyllodes. The 5 t between 1 and 2.7m had an average height increment of 13cm during 1978-1980, the same as the average for all 8 between 1 and 2.5m (Table 4). The mean height change for plants <1m was 8.7cm, higher than for all other plots in this set. This may be related to the lower overall crown cover vis a vis other plots (Table 4), though as in the previous set the taller regeneration plants grew faster than the smaller plants.

Canthium lineare, *Ptilotus* sp. and *Leichardtia australis* were present in this plot. Mean soil depth was 39cm, 2 felled stumps were recorded and there were 17 dead trees.

Plot 8 again had t mulga as the most abundant (7 of 13) though none were taller than 3.8m. The tallest plants were the bl specimens with all three >5m tall. S-r was represented by 3 plants, 2 < 0.5m and one of 1.6m. The fastest growing individuals were 4 of t between 2.8 and 3.8m in 1978 which grew from an average of 3.12m to 3.46m in 1970. Two of t between 1.5 and 2.0m grew an average of 11cm, and the remaining plant of this phyllode type remained stationary at 28cm.

Other species present included *Eremophila* sp., *Rhagodia*, *Solanum lasiophyllum*, *Ptilotus* sp., *Leichardtia australis* and low Chenopods. Average soil depth was 43cm, there were 8 cut stumps and an additional 8 dead trees.

Plot 9 was the poorest overall in representation of smaller *Acacia aneura*. Of the 8 mulga present only 2 were less than 2m height. These were a t which grew from 1.69m to 1.75m over the two year period and an s-r 0.28 to 0.29. The largest trees were 3 bl all >6m tall. This plot had highest percentage crown cover for the set and this was well distributed across all quarters (Table 4).

Soil was a sandy clay loam, much deeper than elsewhere (>80cm). Two large *Acacia tetragonophylla*, 3 *Canthium lineare*, 2 *Exocarpus aphyllus* and 2 *Rhagodia* also contributed to effective competition restricting the opportunity for mulga seedlings to become established. Other species included *Leichardtia*

TABLE 4. Crown Cover, Stocking and Growth Rates for Smaller Trees One-Third Cleared Area

Plot No.	Quarter	*Acacia aneura* <1.00 m ★Stems ha^{-1}	Mean Heights (m) 1978/9	Mean Heights (m) 1980	☆i (cm)	*Acacia aneura* 1<2.5 m ★Stems ha^{-1}	Mean Heights (m) 1978/9	Mean Heights (m) 1980	☆i (cm)	Percent Crown Cover >3 m tall.
7	a	0	-	-		160	1.76	1.86	10	0
	b	0	-	-		240	1.71	1.94	22.7	0
	c	160	0.64	0.70	5.5	80	1.19	1.18	neg	20
	d	80	0.33	0.48	15	160	1.61	1.70	8.5	3.2
Means	plot no.7	60	0.537	0.623	8.7	160	1.63	1.76	13.0	5.8
8	a	80	0.31	0.34	3	160	1.60	1.71	11.0	18.4
	b	80	0.49	0.44	neg	0	-	-	-	9.6
	c	0	-	-	-	80	1.73	1.85	12	4.8
	d	80	0.28	0.28	0	0	-	-	-	12
Means	plot no.8	60	0.36	0.35	neg	60	1.64	1.76	11.4	11.2
9	a	0	-	-	-	0	-	-	-	20
	b	80	0.28	0.29	1	0	-	-	-	24
	c	0	-	-	-	80	1.69	1.75	6	15.2
	d	0	-	-	-	0	-	-	-	24
Means	plot no.9	20	0.28	0.29	1	20	1.69	1.75	6	20.8
10	a	240	0.19	0.19	0.3	80	1.59	1.68	9	0
	b	400	0.18	0.17	neg	0	-	-	-	4
	c	320	0.47	0.45	neg	160	1.28	1.37	9.5	40.8
	d	240	0.70	0.72	2.0	240	1.44	1.55	10.3	9.6
Means	plot no.10	300	0.363	0.361	neg	120	1.41	1.51	9.8	13.6
15✪	a	240	0.59	0.66	14	80	2.16	2.26	20	26.4
	b	320	0.28	0.30	3	0	-	-	-	17.6
	c	160	0.26	0.27	2	80	2.29	2.29	0	18.4
	d	400	0.43	0.46	4.8	0	-	-	-	16.8
Means	plot no.15	280	0.399	0.428	5.8	40	2.23	2.28	10	19.8
Overall means		144	0.389	0.418	2.89	80	1.63	1.74	11.15	14.2

australis, *Solanum lasiophyllum* and small Chenopods.

One felled stump was recorded and there were also 9 dead trees noted in this plot.

Plot 15. Three large bl mulga of >6m characterise this plot. In addition 8 small representatives of this type, between 0.16 and 0.80m, grew an average of 3.5cm in height 1979-1980. The other large tree is hb and this type is represented also by another 6 individuals between 2m and 4.7m tall, and two small plants which also averaged 3.5cm in growth. There were 2 small representatives of n which did not increase and three of s-r, two of which were less than 0.5m tall.

This plot also contained large numbers of *Acacia tetragonophylla* - 7 substantial bushes and several small plants. Several clumps of *Dianella revoluta* occurred in shady places close to large trees and two *Dodonaea* sp. were present. Three cut stumps and 19 dead trees were recorded.

Plot 10. This plot is perhaps more closely allied with the uncleared set. No cut stumps were noted; and 11 dead trees were present. However there were a number of mulga between 1 and 2.5mtall which showed height increases comparable with plot 15. Of the 28 *Acacia aneura* 12 were t, 11 were hb, 3 were bl and 2 were s-r. Of the 5 stems >4m tall in 1978, 3 were hb, there were one each of t and bl. The 6 stems of 1-2.5m were all t and averaged 9.8cm in height increase. Of the plants <1m in height 8 were hb and these increased by <1cm over the two year period; a further 5 were t which showed negative growth, one was bl which grew 1cm, and of 2 s-r one died and the other lost height.

One plant each of *Canthium lineare* and of *Exocarpus aphyllus* plus a number of small *Solanum lasiophyllum* were also present in this plot. Soil was mainly silty clay loam with a depth of 41cm.

TABLE 5. Crown Cover, Stocking and Growth Rates for Smaller Trees Uncleared Area

Plot No.	Quarter	*Acacia aneura* <1.00 m ★Stems ha^{-1}	Mean Heights (m) 1978/9	Mean Heights (m) 1980	☆i (cm)	*Acacia aneura* 1<2.5 m ★Stems ha^{-1}	Mean Heights (m) 1978/9	Mean Heights (m) 1980	☆i (cm)	Percent Crown Cover >3 m tall.
4	a	800	0.36	0.39	2.8	0	-	-	-	32
	b	160	0.70	0.81	11	320	1.40	1.52	12	7.2
	c	800	0.36	0.38	1.6	320	1.37	1.53	15.5	28
	d	80	0.75	0.95	20	0	-	-	-	11.2
Means	Plot no.4	460	0.408	0.446	3.7	160	1.39	1.52	13.8	19.6
5	a	80	0.78	0.41	neg	0	-	-	-	24
	b	240	0.33	0.32	neg	0	-	-	-	12
	c	320	0.45	0.48	2.3	0	-	-	-	35.2
	d	0	-	-	-	0	-	-	-	26.4
Means	Plot no.5	160	0.446	0.409	neg	0				24.4
6	a	80	0.09	0.10	1	0	-	-	-	34.4
	b	80	0.42	0.45	3	640	1.89	2.01	11.5	12.8
	c	80	0.41	0.43	2	0	-	-	-	23.2
	d	80	0.20	0.22	2	0	-	-	-	49.6
Means	Plot no.6	80	0.28	0.30	2	160	1.89	2.01	11.5	30.0
11	a	400	0.55	0.54	neg	80	1.87	2.00	13	17.6
	b	400	0.57	0.59	2.2	720	1.44	1.54	9.9	0
	c	80	0.61	0.67	6	80	1.93	2.13	20	0
	d	80	0.96	1.01	5	0	-	-	-	48
Means	Plot no.11	240	0.595	0.613	1.75	220	1.53	1.64	11.1	16.4
14	a	0	-	-	-	0	-	-	-	17.6
	b	80	0.63	0.63	0	80	2.15	2.37	22.0	17.6
	c	80	0.38	0.50	12	0	-	-	-	34.4
	d	80	0.12	0.08	neg	0	-	-	-	25.6
Means	Plot no.14	60	0.377	0.403	2.7	20	2.15	2.37	22	23.8
Overall means		200	0.447	0.466	2.02	116	1.65	1.77	12.44	22.8

Uncleared Areas

Plot 4. The average stand table for uncleared plots is u-shaped (Fig. 2) and the size class distribution of plot 4 exemplifies this. Of the 7 trees >5m tall the tallest 6 were all type bl, only one other plant, a small one, was of this type. The other tall tree was t, as were the two trees in the 4m class (Table 1). Six of the eight stems 1-1.99m tall were s-r and these grew from an average of 1.27m in 1978 to 1.39m in 1980. The tallest stem in this size class was t, and it grew from 1.87 to 2.20m making it the fastest growing individual. There were 5 stems of t less than 1m tall and these grew on average 4cm. The 14 stems of s-r in the same class averaged 2cm increase. Only four plants were designated phyll type hb and these grew from a mean height of 0.96m in 1978 to 1.04m in 1980.

Suppression of small plants by big trees is strongly suggested in this plot (Table 5).

Three *Acacia tetragonophylla*, four *Cassia nemophila*, four *Eremophila longifolia*, three *Exocarpus aphyllus*; a number of *Solanum lasiophyllum*, and *Eremophila* sp. with numerous small Chenopods complete the stand.

Three felled stumps were observed and there were 22 dead trees in the plot. Average soil depth was 35cm and the soil was a silty clay loam.

Plot 5 was the only plot inside the enclosure which had no cut stumps in it at all. There were 11 dead trees. Of the 8 large trees present 6 were phyll type bl and 2 were hb. Of the small plants 4 were s-r less than 0.4m tall and these showed no growth over the two year period. A further 3 were t, none of which grew, and one of which lost its leader and hence nearly 50 percent of effective height. Plot quarter a of Table 5 refers to this individual. The remaining *Acacia aneura* was hb which grew from 0.48 to 0.67m - this was 4m from the nearest large tree and all other "seedlings" were closer to large trees.

Mean soil depth for this plot was 44cm. There were 2 *Acacia tetragonophylla*, 5 *Eremophila* sp., 1 *Canthium lineare*, 3 *Exocarpus aphyllus* and a number of small chenopods present.

Plot 6 had more trees over 5m than all other plots. Of the 11 trees in this class 9 were bl and two were t. In addition one tree of 4.5m was also bl. The 3 smallest mulga were all s-r which grew only marginally over the two year period, the fastest growing individual <0.5m was t which grew from 0.42 to 0.45. Each of these four small plants was present in a separate plot quarter and hence appear as individuals on lines in Table 5. One individual of phyllode type n fell in the 3m class. All the remainder were t from 1.15 to 2.34m in 1978. These averaged (8 stems) 1.89m in 1978 and 2.01m in 1980 and were clustered in plot quarter b (Table 5).

This plot carried 4 large *Acacia tetragonophylla* and also had 4 *Exocarpus aphyllus*, 2 species of *Eremophila*, a lot of *Ptilotus* sp., *Sida* sp. and *Dianella revoluta*. There were 4 cut stumps, 15 dead trees and soil depth averaged 30cm.

Plot 14. Of the 12 trees of 4m or over 10 were of phyll type n, 1 of bl, and 1 of hb. The 3 trees in the 3m class were all hb. Of the two in the 2m class there was one each of bl and hb of which only the former increased in size 1979-1980. The three plants <1m all appear in Table 5, the one in quarter b was bl, the one in c was hb and the one in d was of type n. That in c, the only small plant to show any height change was 4m from the nearest large tree.

There were no cut stumps in this plot and only 6 dead trees. There was no *Acacia tetragonophylla* in this plot.

Plot 11. This plot was unusual in having a fairly high representation of trees in the 1m class. Of the 10 of this size 7 were s-r which grew from an average of 1.37m in 1978 to 1.47m in 1980. The other 3 were t, one of which died, the other two averaged 10cm height growth also.

Of the 7 larger trees >4m, four were of phyll type n, two of bl and one was t. The sole representative in the 3m class was t and of the 3 in the 2m class, 2 were s-r - these 3 averaged an increase of about 18cm in height with the t specimen having grown slightly faster.

Plants less than 1m grew much less, the 7 individuals of type s-r grew from a mean height of 0.54 to 0.56m whereas the 4 of type t grew from 0.76 to 0.77m. A single specimen of phyll type n remained the same at 0.33m.

There were 15 dead trees in this plot and one cut stump. Four *Canthium lineare*, two *Exocarpus aphyllus*, several *Eremophila* sp., *Solanum lasiophyllum* and *Leichardtia australis* were also present in this plot.

Average soil depth was 38cm to hardpan, and the soil was predominantly silty clay loam in texture.

Discussion

Despite considerable variations between individual plants the overall current average increments in height appear to be similar for the range of plots when comparable size classes are considered. The larger obvious regeneration is now growing faster than small "seedling" plants. It is possible that many of the low *Acacia aneura* could be of considerable age. These plants may have been able to survive in a suppressed condition for some time.

If we consider the set of larger regeneration present in plot 3 as typical for the bulk of the area then the change of mean height 1.62 to 1.75m (Table 3) over the 2 year period suggests that 26 years would have elapsed if the same rate of growth had consistently occurred. That it has not is obvious from other studies in the general region. Examination of the rainfall records since 1956 suggests that heavy summer rainfall in 1963 may have provided the impetus for widespread germination and seedling establishment. The 15 year period to 1978 would have then entailed an average annual increase of 10.8cm in height. This rate of increase in fact occurred, during the period of review, in plots 1 and 2. This study will be continued. The plots form a most useful set of precisely documented treatment.

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Voucher specimens of species mentioned are held in the WAIT collection, those listed in the introduction under collection numbers 1265-1277.

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THE STATUS OF TUART (*EUCALYPTUS GOMPHOCEPHALA DC.*) IN THE PERTH METROPOLITAN AREA

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Summary

A preliminary examination of *Eucalyptus gomphocephala* in the Perth metropolitan area suggests that increased frequency of fire is associated with changes which may lead to loss of this species in some areas. Inflammable exotic annual grasses are encouraged by fire and in turn lead to frequent fires which destroy tuart seedling regeneration and prevent the accumulation of material for ashbed regeneration. Trees are progressively damaged by frequent fire and become unable to set seed. Progressive crown deterioration by a number of environmental factors may be accelerated by frequent fire.

Introduction

Tuart (*Eucalyptus gomphocephala DC.*) occurs naturally within a coastal strip of Western Australia almost 500 km in length. It grows in magnificent stands at Ludlow, towards the southern end of its distribution, some 180 km south of Perth.

Tuart has been grown in a number of countries including Algeria, Chile, Cyprus, India, Israel, Italy, Morocco, Spain and the U.S.A. (California). Much information is available regarding its performance in Israel where early enthusiasm was generated following incomplete information regarding its natural distribution in Western Australia. For instance, it has been stated that Tuart is '*able to tolerate salt winds, highly alkaline or even slightly saline soils and is moderately drought resistant*' (Hall *et al* 1975). However in Israel it has proved disappointing '*it is not lime-resistant and suffers on high-lime soils from lime-induced iron deficiency and chlorosis. Near the coast it suffers from salt spray and in dry areas it is not drought resistant.*' (Karschon, pers. comm.).

Regeneration of Tuart can be achieved with care. A test area at Ludlow was burnt with a moderate intensity fire in May 1971. Seedlings were observed two months later and in greater number six months after the burn, when 20 cm high (Keene and Cracknell, priv. comm.). Early differences in size between plants on ashbeds and away from ashbeds reflected the well-known nutritional advantages of ash (Hatch 1960). By January 1972 seedlings on ashbeds were 30-38 cm high. There were many losses away from ashbeds where surviving seedlings were unthrifty, reaching only 10 cm high and suffering from intense grass competition (Keene and Cracknell, priv. comm.). Wildfire in 1974 killed very few of the regenerating Tuart on ashbeds, which had continued to grow rapidly (McKinnell, pers. comm.).

Maintenance of trees in urban environments is a different proposition from plantation management or manipulation of natural stands in large blocks. A cursory examination of Tuart in the vicinity of Perth suggests that in much of the greater metropolitan area Tuart is generally unhealthy and often moribund, and that smaller trees and seedlings are scarce.

This account presents some information on environmental parameters and discusses possible reasons for the apparent decline of Tuart in the Perth area.

Procedure

Twenty sites, each selected to include at least one large Tuart tree, were examined in Autumn 1978. These sites covered three latitudinal belts (Fig. 1) at the following localities -

(i) Burns Beach, 25 km north of Perth (10 sites)

(ii) Bold Park, west of Perth (6 sites), and

(iii) Thomas Road, 25 km south of Perth (4 sites)

A total of 76 Tuart trees were measured, crown health was scored on a six point scale from 0 (dead) to 5 (full crown) (Fox and Curry 1980).

The Burns Beach locality is less developed in terms of urbanisation than the others. Bold Park is an oasis of bushland in otherwise developed suburbia, and the Thomas Road locality, with much industrial development on the ocean side, has scattered suburban enclaves mingling with larger fringe rural usages.

Trees were measured within temporary plots of 50 x 50 m, shrubs and herbs were measured in sub-samples of 12-20 m^2.

Soil depth was determined in the field by pushing a metal T-bar into the ground to obtain an estimate of whether limestone occurred close to the surface. Soil samples were taken at 30 cm depth from all sites. In the laboratory pH, Ca (flame emission), moisture content and organic matter were determined. The presence of insect damage and signs suggesting fungal damage were noted, and the recent fire history of each area was elucidated.

Results

Site data

Site parameters are summarised in Table 1. The soils on the sample areas have been classified as the Cottesloe and Karrakatta Soil Associations which are components of the Spearwood Dune System (Bettenay *et al.*, 1960). The Cottesloe Association tends to have shallower soils over limestone, and lies closer to the ocean than the Karrakatta. No Burns Beach site had a hard calcareous layer

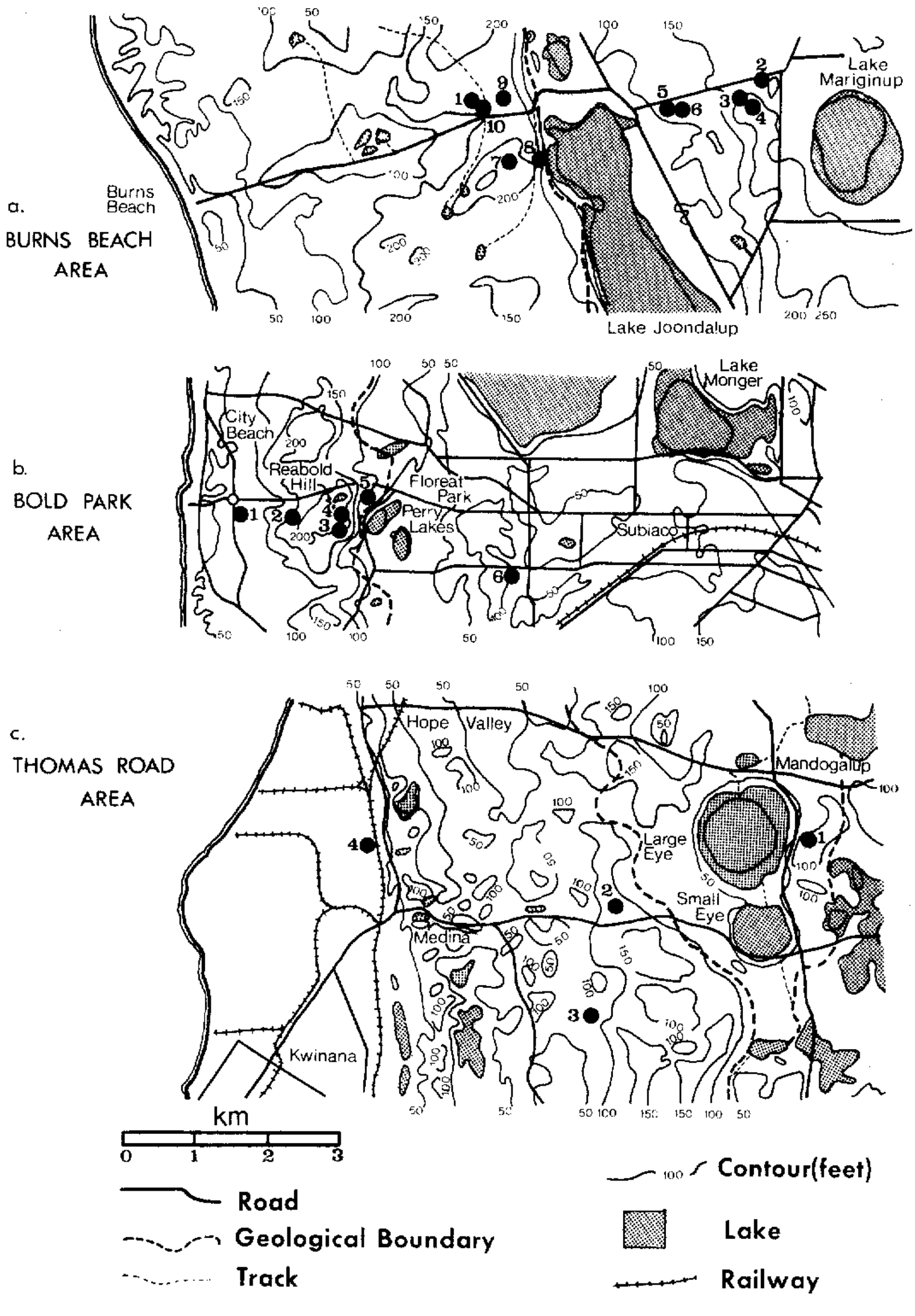

Fig. 1 Locality map showing sites examined
(After Geological Survey of Western Australia,1960)

TABLE 1 SUMMARY OF SITE PARAMETERS

SITE NO.	SOIL ASSOCIATION a	MOST RECENT FIRE (YEARS) b	ASPECT	SLOPE c	30 CM DEPTH SOIL SAMPLES pH	Ca $mg100g^{-1}$	PER CENT H_2O	OM	HEALTH OF TALLEST TUART (0-5)
Locality									
a. BURNS BEACH									
1	Ct	0	N	F	7.3	19	4	1.7	3
2	K	>5	0	F	6.9	14	2.4	1.3	4
3	K	4	N	S	7.0	11	4.1	1.2	1
4	K	4	NE	H	8.3	26	3.9	0.8	3
5	K	4	W	F	6.8	22	3.9	1.1	1
6	K	4	W	S	6.4	32	5.9	2.2	3
7	Ct	1	E	S	6.9	31	2.5	1.6	4
8	Ct	1-3	E	S	6.8	30	4.1	2.3	3
9	Ct	1-3	E	S	7.1	29	2.4	1.5	3
10	Ct	0	N	F	6.7	18	7.9	1.0	2
b. BOLD PARK									
1	Ct	>5	E	F	6.8	50	2.7	2.2	4
2	Ct	0	N	V	7.2	28	1.9	3.3	4
3	Ct	0	NE	H	7.0	70	0.6	2.2	3
4	Ct	1	SE	H	7.2	56	0.6	1.7	3
5	Ct	1	SE	S/V	7.2	18	0.8	1.6	5
6	K	>5	0	F	6.8	18	5.7	1.7	3
c. THOMAS ROAD									
1	K	2	W	S	8.1	7	1.1	7.2	4
2	Ct	0	SE	S	7.1	13	1.0	1.5	3
3	Ct	0	SE	S	7.4	203	1.1	3.7	4
4	Ct	0	0	F	8.2	158	7.2	5.8	5

a Ct Cottesloe, K Karrakatta (Fox and Curry 1980)

b 0 = burnt 1977/78, 1 = burnt one year earlier, etc.

c H hill, V valley, S slope, F flat

in the top 80 cm of soil and neither did sites 1, 5, 6 at Bold Park and sites 1, 2, 4 at Thomas Road.

The remaining sites, all in the Cottesloe Association, did have a calcareous layer closer than 80 cm to the surface. The shallowest soil was at Thomas Road site 3 (average depth 28 cm), a ridge site with surface limestone present in the area. Mean distance from the ocean for Cottesloe sites was 3.6 km, and for Karrakatta sites 7.4 km. Comparison of sites falling in the two soil associations, Cottesloe and Karrakatta, suggests that in addition to shallower soils the Cottesloe sites tended to have higher Ca values than did Karrakatta sites (Table 1).

Mean crown health scores and crown diameters of the tallest Tuart were greater for Cottesloe sites whereas mean height and stem diameters were greater for Karrakatta sites.

Soil organic matter shows some interesting relationships. Using Spearman's Rank Correlation for all 20 sites it showed significance at p 0.01 with crown diameter (.66; p.01 = .56) and crown health (.57); and at p 0.05 with calcium (.46; p.05 = .44) and negatively with shrub density (-.46) and species numbers (-.50).

Tuart showed a diminution in size from south to north (Fig. 2). There was a tendency for trees on hills to reach smaller dimensions than those on valley, sloping or relatively

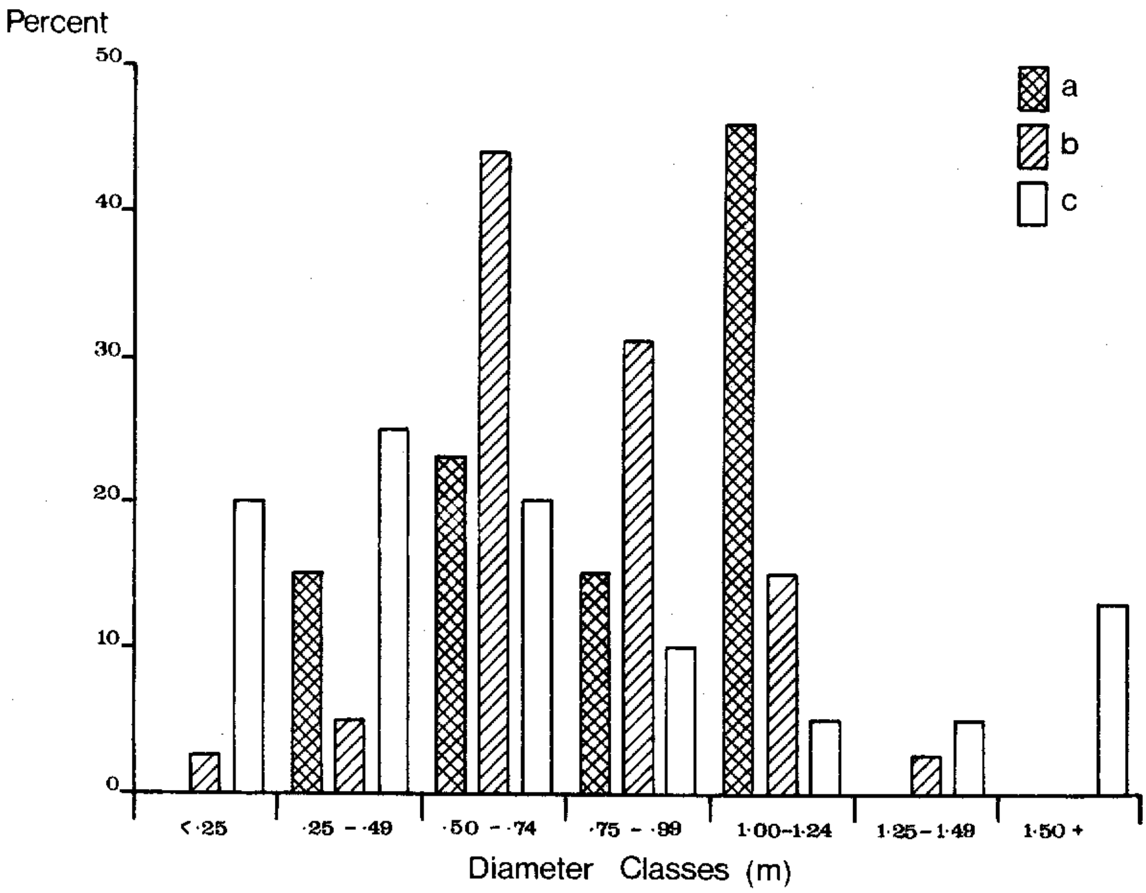

Fig. 2 Percentage of assessed trees in diameter classes
(a) Burns Beach (b) Bold Park (c) Thomas Road

flat sites (Table 1). In particular, smaller trees occurred at sites where limestone was noted in the upper soil profile.

Regeneration

Tuart regeneration was only observed at site 1, Thomas Road, where 10 stems of average height 1.5 m were recorded. This site may have been burnt at a fortuitous time, and, on the indefinite fire history information available, seems to have had a different fire record from all other sites (Table 1). It also had a higher density of shrubs and more recorded species than other sites in the same locality (Table 2) as well as the largest Tuart.

Macrozamia riedlei (Zamia) and *Xanthorrhoea preissii* (Blackboy) were the most frequently encountered 'shrub' species, present at 17 and 12 sites respectively. From carbon dating studies individuals of these species have been estimated to be of considerable age, 400 to 600 years, (Wycherley priv. comm.). Both species can readily produce new foliage after fires and appear to be able to withstand frequent fire for longer than most of the other shrub species found with Tuart. At Burns Beach sites 1 and 10, burnt in the 1977-78 summer, individuals of *Banksia attenuata, Casuarina fraserana* and *Jacksonia sternbergiana* only survived the fire when less than 1 m in height. Thomas Road site 4 had blackboy as the only shrub species left - this area had been burnt frequently and may have been burnt twice in 1977-78. There was only one record of blackboy from the Bold Park sites.

In the Bold Park locality, frequent fires have probably eliminated any Tuart seedlings that may have developed. These sites have a ground cover consisting largely of introduced species which compete strongly with any seedlings that germinate. Highly inflammable grasses are particularly abundant at Bold Park (Table 3) where the likelihood of suitable ashbeds being formed is now very small. Some three-quarters of the main park area was burnt in December 1977 and 60 per cent was burnt in the previous year.

Patches of dead vegetation were observed at sites 4, 7 and 9, Burns Beach. At site 4, dead specimens of *Jacksonia sternbergiana* occurred around the Tuart trees. At site 7, there was a circular patch of dead trees down-slope from the Tuart; both *Banksia attenuata* and *B. grandis* were dead, and the lower leaves of *Zamia* and *Jacksonia sternbergiana* were affected. At site 9, a small dead patch surrounded the Tuart.

TABLE 2 MAIN SPECIES PRESENT AT SAMPLED SITES

Species / Location Site	Burns Beach 1	2	3	4	5	6	7	8	9	10	Bold Park 1	2	3	4	5	6	Thomas Road 1	2	3	4
<u>Trees</u>	Numbers of stems																			
Eucalyptus gomphocephala	1	1	2	4	1	1	3	2	1	1	7	10	7	6	5	4	3	2	3	12
E. calophylla				1	3			2							15					
E. marginata			2	1		3	8	9	1		3	2				11				
<u>Subsidiary Trees</u>	Relative Abundance*																			
Casuarina fraserana	+						+		+				+	+		+				
Banksia attenuata	+	+	+			+	+	++			+	+	+			+	++	+		
B. grandis							+	+										+		
B. menziesii	+						+	+			+	+	+	+				+	++	
<u>Shrubs</u>																				
Xanthorrhoea preissii	++		+++	+++	+++	+++	+	++	+	++					+			+		++
Macrozamia riedlei		+	+	+	+	++	+		++	+	+	+	+	+	+	+	+++	++	+	
Dryandra sessilis							++	+	+++											
Jacksonia furcellata		+		+	++	++	+		++	+									+	
J. sternbergiana	+			+		+	++	+												
Melaleuca heugelii												+	+	+						
Acacia saligna			+					+	+	++						+				
A. cochlearis																+				
A. pulchella	+						+	+	++		+		+	+	+		+		++	
<u>Climber</u>																				
Hardenbergia comptoniana			+	+	+	+					+	+	+	+	+			+	+	
Number of shrub species	8	5	11	11	8	10	18	11	12	6	6	2	3	11	3	3	4	4	3	1
All species (including recorded herbs - incomplete)	10	6	14	16	10	12	22	13	18	7	13	12	15	18	14	14	18	11	10	7

* <10 individuals = +; 10-49 = ++; 50+ = +++

Crown Health

Very few trees were observed with complete crowns (score 5). Spearman's Rank Correlation for all sites showed crown health to be significantly correlated with crown diameter (.90; p 0.01 = .56) but not with stem diameter or height. There was a positive relationship with soil organic matter (.57) and a negative correlation with density of shrubs (-.62), especially numbers of Blackboy and Zamia (-.57).

The linear regression for crown health (CH) on crown diameter (CD, m) is:

$$CH = 1.43 + 0.16\ CD\ (r = 0.83).$$

Substitution of the crown diameter/stem diameter (SD, m) ratio for crown diameter gives a less significant relationship:

$$CH = 0.87 + 0.20\ \frac{CD}{SD}\ (r = 0.79).$$

However, incorporation of height (H, m) as another variable improves the estimation of crown health:

$$CH = -0.97 + 0.21\ \frac{CD}{SD} + 0.07H\ (r = 0.85).$$

This relationship is illustrated in Fig. 3.

Discussion

The importance of differences in calcium levels may be slight as Ca concentration at the soil surface is dependant upon past fire history. The levels are not as high as those reported by Hatch (1960) for the top 5 cm or so of ashbed soils. Surface soil is the most conveniently observable portion of the edaphic environment but it must be noted that Tuart is a deep-rooted species (Lamont and Lange 1976). Data presented on soil moisture and pH illustrate only the ranges within which Tuart was observed and not the status of Tuart.

Soil organic matter is influenced by litter-fall and breakdown. It is related negatively to fire and could be a useful index of soil fertility for sandy soils.

Seedling Regeneration

The general absence of Tuart regeneration suggests that in these open woodlands the species is vulnerable to fire. In particular, infestation with veld grass leads to frequent fires (Baird 1977). The pattern of

TABLE 3 MOST ABUNDANT HERB LAYER SPECIES IN BOLD PARK SITES

SPECIES	Site 1	2	3	4	5	6
Avena fatua (wild oats)	++	++	++	+	++	++
Erharta calycina (veld grass)	++	++		++		
Lagurus ovatus (Hare's tail grass)	+			++	+	+
Pelargonium capitatum (Stork's bill)	++	+	++	++	+	+

(++ abundant; + present)

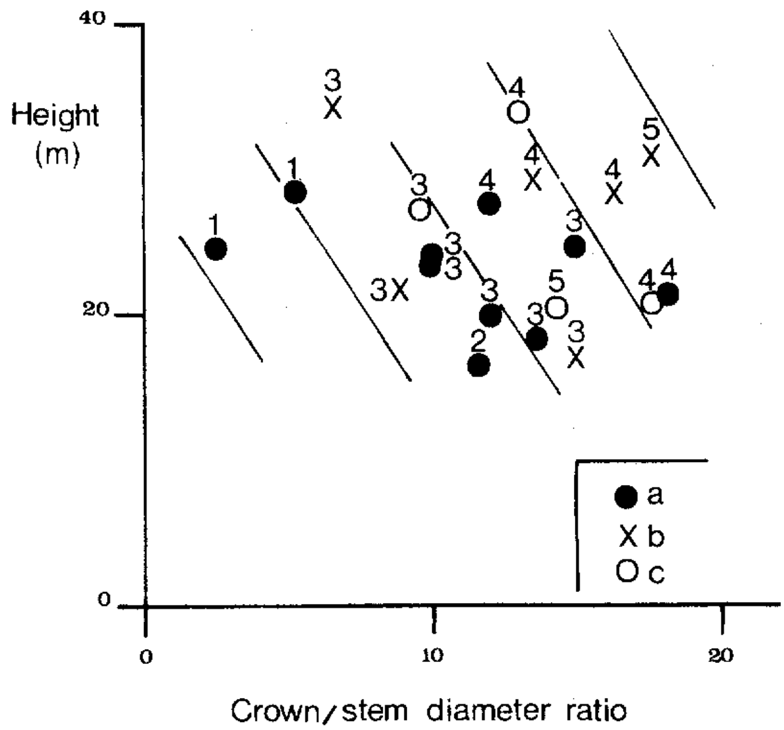

Fig. 3 Height and crown / stem diameter ratio for the tallest tree at each site. Numbers refer to crown health categories, and oblique lines to the regression surface.

Crown health= –.973+.211 C/S+.067 Ht (r=.853)

(a) Burns Beach (b) Bold Park (c) Thomas Road

infestation and consequent grass fires follows the pattern of development. Bold Park is most infested and most vulnerable while the Burns Beach sites are least affected.

The Thomas Road location shows a clear pattern of increased fire frequency nearer the coast. Site 4, in an industrial area, tends to be burnt annually; sites 2 and 3 in or near residential areas are burnt frequently while site 1, the only site with Tuart regeneration and somewhat remote from urbanisation, is burnt less frequently. At the time of the study (1978) the local Shire appeared to have no consistent policy regarding control burning. Areas were burnt off if considered to be a potential fire hazard at the discretion of the Shire employees.

The presence of old charred logs at site 1 suggests that the useful growth of young Tuart there may well have occurred on an ashbed. The more frequently burnt site 4 had a high pH but little prospect of regeneration as crowns were badly damaged and epicormic growth cannot provide seed for several years (Fox and Curry 1980). Repeated summer fires are likely to give much competition from annuals to any seedlings that germinate. Sites 2 and 3 are likely to become similar to Bold Park site 1, that is, densely covered in introduced annuals.

Evidence from Ludlow (*q.v.* above) suggests that after 3-4 years Tuart regeneration may be somewhat fire resistant, if it is able to persist.

Crown Health

Top die-back and death of larger trees may be initiated by a number of agencies, some of which will act in synergy. Crown condition may be affected by borers, fungal infection, fire, soil moisture changes, nutrient changes, loss of foliage to insects or atmospheric agencies and exposure. Each of these agencies is discussed in turn.

Borers

Correlation of crown health in the field with the level of insect infestation in the crown is difficult without lopping. Borer damage may be a significant cause of deterioration when large trees become isolated from crown fires. Woodborers on Tuart include the stem girdler *Cryptophasa unipunctata* (Xyloryctidae); the Tuart borer *Phoracantha impavida* (Cerambycidae) and *Culama* sp. (Cossidae). These have all been implicated in shoot damage leading to stagheadedness (Fox and Curry, 1980) though *P. impavida* seems to be the most important species.

Fungal Infection

Larger trees may be infected by wound parasites of the genus *Piptoporus*. An orange stain in exposed wood of trees at two sites in Bold Park was attributed to *Piptoporus* sp. and two species, *P. australiensis* (lower branches) and *P. portentosus* (upper crown wood), have been noted in King's Park (Hilton priv. comm.).

Armillaria mellea has been noted as causing death of old Tuart in King's Park, particularly in irrigated areas (Wycherley priv. comm.). The dead patches at sites 4, 7, and 9, Burns Beach may have been due to a fungal pathogen such as *Armillaria*. At these sites *Dryandra sessilis*, *Casuarina fraserana*, *Jacksonia furcellata* and *Xanthorrhoea preissii* were unaffected, and the Tuart was not in poorer crown health than at other Burns Beach sites.

Fire

Havel (1979) has noted the combined effect of fires and introduced weed species leading to canopy reduction throughout the main dune system on which Tuart is found. Fire may have greatest influence at any one time on the seedling Tuart present but cumulatively will lead to degeneration of large trees.

Trees at Bold Park site 1 showed no sign of recent fire damage, but most trees at the other sites of this locality showed extensive fire damage with some basal regeneration unlikely to survive, and previous epicormic crown growth burnt off again. At site 5, the best tree was in good condition but other stems had suffered damage in the past.

Tuarts at Burns Beach sites 3, 4, 5 and 6 suffered fire damage in the recent past (last fire four years earlier) from which they had recovered poorly by the time of assessment. Fires following Cyclone Alby (4th April, 1978) destroyed approximately 50 per cent of the crowns at sites 1 and 10, and only at sites 2 and 7 in the Burns Beach area were crowns in reasonable condition. Epicormic crown regeneration was scored at these sites and a Spearman's Rank Correlation suggested there was a strong relationship between crown regeneration and crown health score (.77; p. 01 = .75). Burning is partially controlled in this area - the Shire and the Forests Department maintain close liaison on burning practice. Baird (1977) in respect of King's Park suggests that Tuart deterioration is due to a complex of factors of which fire may not be the most important.

Soil Moisture Changes

Within the Spearwood Dune System water moves through cavities in the underlying calcareous deposits (Havel 1968). Replenishment of ground water through winter rainfall enables pumping of aquifers to continue and at present there is no evidence that lowered water tables have affected Tuart. Israeli experience quoted above suggests that drought is important. Havel (1979) notes that after a decade of mainly below average rainfall the effect of pumping on vegetation is difficult to separate from the natural, drought-induced drop in the ground water table. The Tuart trees at King's Park described by Beard (1967) declined in condition between 1962 and 1973 (Wycherley and Hatch 1974). Evidence of earlier decline from newspaper cuttings of 1938-39 suggests that periodic drought may affect conditions from time to time (Wycherley, priv. comm.). The dead patches discussed under 'fungal infection' may have been drought induced.

Nutrient Changes

No site studied had been subjected to nutritional changes.

Leaf Defoliators

A number of leaf-eating insects favour Tuart with their presence and may cause much damage to foliage, particularly on smaller trees

(Fox and Curry 1980). Defoliation by insects was not significant in the study reported here, apart from that to epicormic growth. Damage to epicormic growth was important at Bold Park.

Atmospheric Agencies

Cyclone Alby imparted scorch-like damage to residual foliage, mainly on the north sides, to trees at all sites of Burns Beach location, except site 5. Here the Tuart had a poor crown with few leaves, and many leaves on the ground. Symptoms were similar to those reported by Karschon (1963) for scorch due to wind-borne material. Leaf scorch was also evident on trees at site 1, Bold Park. This site was very close to the ocean and the damage was probably due to sea salt. Leaves were similar to the extreme case illustrated by Karschon (1964) with most damage on the west side of the trees.

This example is the only one where 'exposure' can be given as a causal agent. In this case destruction of surrounding vegetation and some landscape alteration has exposed trees to the westerly winds from the sea.

Beard (1967) has postulated that low-canopy dominance replaced high-canopy dominance in King's Park partly due to felling and partly due to fire. This scenario was associated with a later period of strict fire suppression during which the understorey species became dense. Increased competition for moisture led to the eucalypts dying back. In the present study healthy trees tended to have greater crown to stem diameter ratios and to be associated with fewer shrubs. As the fire history for the sites examined is not well known and the study has not taken place over a period of time it is not possible to disentangle the effects of fire, drought and other agencies. Nevertheless, fire is the main influence on degradation of Tuart woodlands as a whole (Fox and Curry 1980) and is especially critical in minimising the opportunities for regeneration to succeed.

Conclusions

As Tuart woodland in the coastal plain around Perth is developed it becomes subject to frequent fire. Whether this is a result of policy or due to vandalism is immaterial, as the effects are often the same: all land in the areas studied has a risk of frequent fire. Later when buildings are erected, fire gradually becomes excluded. In the in-between phase, it would be possible (by careful planning) to retain Tuart trees, though the undoubted hazard of having inflammable material around will daunt most developers and many individual prospective home-dwellers. The first stage of development is clearly the most critical for all areas. The establishment of exotic grasses encourages frequent groundfires inimical to the survival of young Tuart for whose survival the first summer after germination is critical. Frequent fires produce epicormic foliage which cannot then produce seed and also reduce the chances of ashbeds forming. Gradually the crowns will become sparser as branch wood is burnt. When large trees are somewhat isolated from crown fire, then borers may accentuate top dieback. Superimposed on these patterns are the probable, but difficult to quantify, effects of periodic drought.

Acknowledgments

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BIOMASS PRODUCTION OF VOLUNTEER NATIVE UNDERSTOREY ON BAUXITE MINED SITES

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Introduction

The main objectives of rehabilitation after mining are to restore the mined areas to maximum potential as water catchments, where this may be a current or anticipated land use and to restore them to an aesthetically acceptable state to be of value as a community recreational resource (this is particularly important in Jarrahdale which, owing to its proximity to Perth, is increasingly being used for recreational purposes). It is also important to re-establish a forest community that is a stable and balanced vegetation system that aids the conservation of the surrounding native forest.

The rehabilitation process involves the return of topsoil and the establishment of a permanent cover of vegetation to maintain long term stability of the landscape. The vertical pit slopes are reduced to slopes of less than one in two by bulldozing and blasting and pit floors are graded to create a surface of similar topography present before mining operations and one that will follow the undulations of the surrounding landscape. In general the top 400 mm of topsoil is returned to the pit floor. Deep ripping of the subsoil is carried out along the contours to relieve compaction brought about by previous mining activity; this process also facilitates improved root penetration through the underlying clay and it may help to reduce the occurrence of wind-throw during winter that may be a consequence of lack of penetration of roots of the trees. A number of eucalypts from the eastern states have been selected for rehabilitation programs for their commercial timber potential and their apparent resistance to jarrah dieback; local Darling Range eucalypt species including marri, wandoo and blackbutt have also been selected for current vegetation work. The establishment of these trees in monocultures is not sufficient to provide a balanced vegetation system. Much of the accumulated seed present in the topsoil before removal is depleted by handling and stockpiling. Direct seeding programmes have been proposed using native seeds from the jarrah forest to promote the colonization of mined areas with understorey.

The successful re-establishment of volunteer native understorey on mined areas has been suggested to be dependent on the method of topsoil treatment after mining activity. The most favoured topsoil handling treatment, currently, is double stripping whereby the top 5 cm is removed then freshly replaced after the next 5 cm is removed. Double stripping is the most costly treatment of topsoil but has been observed to yield successful regeneration of volunteer native understorey from seeds retained in the topsoil. Diversity and density measurements may indicate marked differences in the establishment of volunteer native understorey on differently treated topsoil.

Methods

During the mining period the soil may deteriorate with a loss in nutrients and the destruction of viable seeds. An adjacent undisturbed forest site was thus used for sampling as a control. It was assumed to be representative of the forest before mining activitites although, a lower grade of bauxite ore may occur under the remaining uncleared forest (as it was unsuitable for mining) and may support a slightly different composition of flora.

An existing topsoil handling field trial site at Jarrahdale (mine site no. 2) was used for sampling. It had been established in 1975 when seedlings of *Eucalyptus calophylla* were planted. The area of the mine site was approximately half stockpiled topsoil return and half fresh overburden return (double stripping). The stockpiled soil was spread in November, 1974 and the stockpiled soil with fresh overburden was spread in May, 1975. The pit was divided into 5 compartments bounded by 2-metre high contour banks; the two treatments alternate in a checkerboard arrangement over the area. Between two contour banks, half the area was stockpiled soil and the other half was double stripped (see Fig. 1). Two to five sample plots, each of 1 m^2, were set up within each of the sub-divisions depending on their size. The plots were located on the mid-line between contour banks and separated by approximately 30 paces; their exact positions were marked. Thirteen plots, in total, were established in each treatment area. A similar number was set up in the forest along a transect running downslope and at right angles to the contour banks of the mine site.

In each one metre square sample plot a visual estimate of percentage of ground cover was made as a total (plant + litter) and as plant cover only. Ground cover is important as an erosional control check. Visual estimates may be subject to some degree of personal bias, but this disadvantage was outweighed by the requirement for a rapid and easy assessment.

All green plant material present within the boundaries of the plot was clipped at ground level (applied to stems), placed in plastic bags and weighed by species using a spring balance; biomass was expressed as fresh weight of a species per metre square. Assessment of biomass by species may indicate the relative abundance and richness of species (diversity) and show the relative effectiveness of the type of rehabilitation. Dry weight may have been a more valuable measure of biomass excluding the effect of water loss from fresh material; however, time was limited and wet weight was a useful compromise. To avoid the problems of over-estimation or under-estimation of biomass per m^2, before clipping material, plant foliage was clipped following the 1 m^2 boundary of the quadrat. Thus, an individual with only part of its canopy in the 1 m^2, but not the main shoot, had only the foliage in the 1 m^2 included. Surface leaf litter was collected, weighed and recorded (only surface leaves were included, along with dead plants, but partially decayed material was exluded as it was moist and covered with soil which would contribute a considerable additional weight giving a mis-representation of biomass of litter present).

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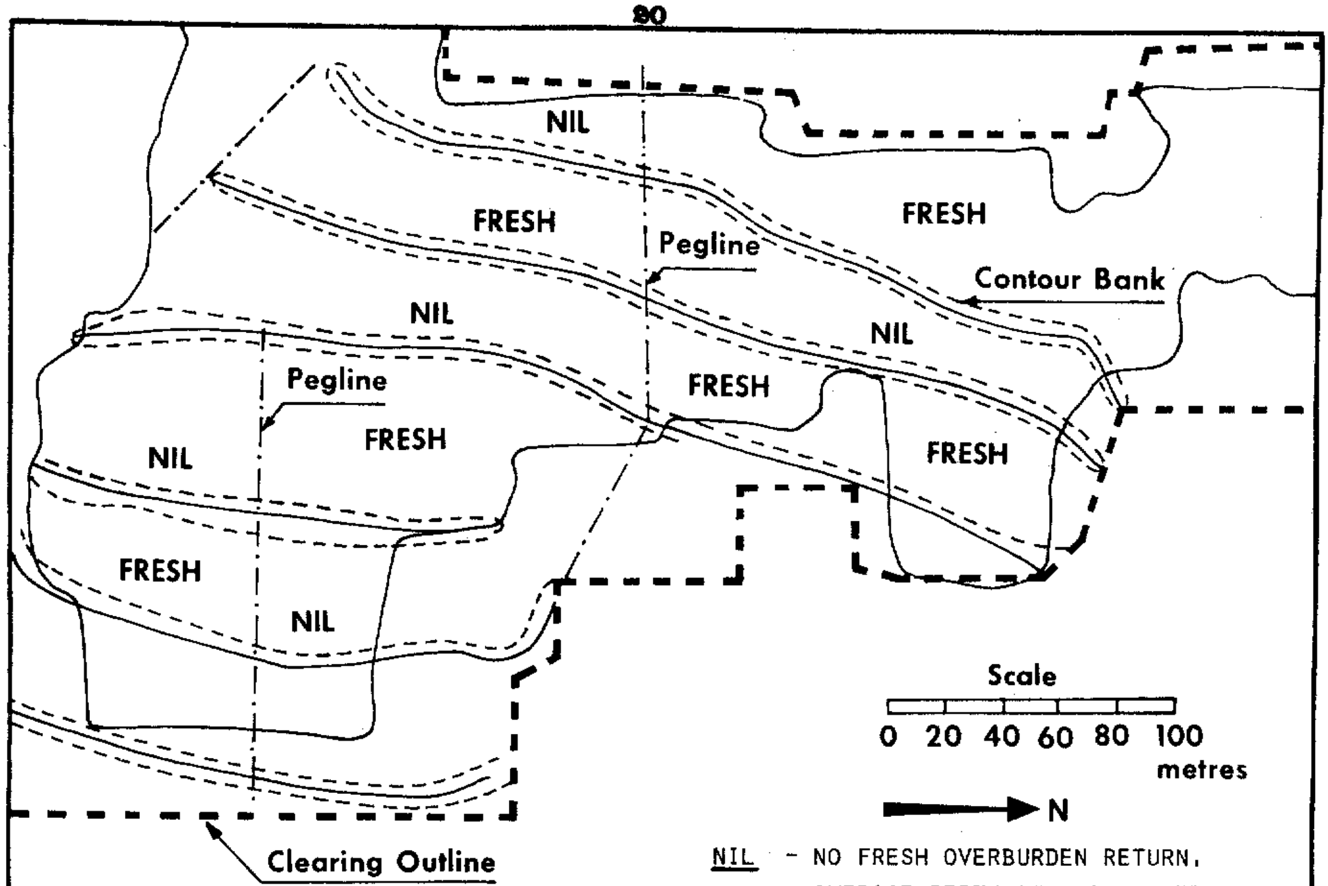

NIL - NO FRESH OVERBURDEN RETURN. AVERAGE DEPTH OF STOCKPILED SOIL 40CM SPREAD NOVEMBER 1974.

FRESH ~ 5 CM - FRESH OVERBURDEN TAKEN FROM NEWLY CLEARED AREA AND SPREAD MAY 1975. OVER 40 CM STOCKPILED SOIL (PIT AREA 9.9 HA)

FIGURE 1.

LAYOUT OF FIELD TRIAL USED IN THE STUDY OF *EUCALYPTUS CALOPHYLLA* PLANTED IN 1975.

Collections of material of one species weighing less than 10 g, or one individual of a species were recorded as "present" (assumed to make a relatively insignificant contribution to the total biomass for the purpose of the study). Understorey was classified as any plant from moss to shrubs of shoulder height (as occurs for *Acacia pulchella*. A field herbarium was made for the identification of unknown species; as well, flowering species were collected and pressed.

Table 1 Biomass production and groundcover of forested and rehabilitated mine sites

(Average values given, standard errors in brackets)

SITE	BIOMASS (g) Plant	Litter	COVER (%) Plant	Litter
Forest	235.0 (36.5)	261.5 (36.7)	64.2 (4.0	33.8 (3.9)
Double stripped topsoil	386.4 (94.2)	97.5 (23.3)	33.8 (4.6)	10.8 (2.8)
Stockpiled topsoil	66.7 (14.5)	25.0 (12.0)	7.8 (1.6)	5.9 (3.0)

Values calculated for individual plots, each of thirteen, one metre square plots.

Results

Results are presented in Tables 1 -3 and species area curves are illustrated in fig. 2.

Diversity was estimated using the Shannon-Weiner Index of Diversity[9] which is a function of the population proportions of the several species[7]. Two components of diversity included in Shannon's formularare: a) species richness; b) relative abundance (equitability)[8]. The formula is,

$$H' = -{}^{s}_{i=1}\, n_i \log n_i \quad \text{(Decits)}$$

where n_i = total number of individuals of the ith species.

N = total number of individuals in the sample.

Index of Equitability, J',

$$J' = \frac{H' \text{ (Decits)}}{\log s}$$

where s = total number of species

$$\log s = H'_{max}$$

Biomass production and groundcover

Plant (live) biomass tended to show slight variation in the three sites, the double stripped topsoil site showing the most variation (Table 1). The average values indicated that biomass production was highest in the double stripped topsoil, approximately six times the average biomass production in stockpiled topsoil. Overall, the individuals tended to be smaller in the forest than in the rehabilitated sites[10]; a number of larger individuals were encountered, particularly in the double stripped area, which contributed to a higher average value of production and significantly added to variability of biomass production. Litter biomass decreased markedly from forest to stockpiled areas by a factor of ten; litter biomass average value for the double stripped site was approximately one third of the value for the forest site. Litter biomass tended to be more variable in stockpiled topsoil. From observation, the nature of the litter indicated that the overstorey was the major contributor on all sites, but canopy cover in the forest was densest, yielding considerably higher litter biomass.

Plant (live) cover showed relatively small variation in the three sites. Average values displayed a halving of cover from the forest to double stripped sites; live coverage on stockpiled areas was approximately one quarter of the live cover in double stripped areas.

Much of the live cover on the stockpiled site was attributable to a few large individuals with minimal spread. Average litter cover was highest in the forest, decreasing by one third on double stripped topsoil and, again, was reduced to half in stockpiled topsoil. Generally, litter tended to occur in patches under overstorey in the stockpiled site and was in higher concentration in the ripped depressions (as was also observed in the double stripped site). On double stripped sites, litter seemed to be more evenly spread and was associated with the larger individuals of the overstorey; it was observed that a considerable area of ground remained uncovered.

Species diversity

Species numbers on mature forested and three-year-old double stripped sites were similar; the average values showed slight variability. (Table 2). Diversity index values indicated a lower diversity for the double stripped site. During sampling, on the double stripped site a few individuals were encountered only once with a number of species commonly occurring.

Table 2 Species numbers, diversity and equitability indices for forested and rehabilitated mine sites.

SITE	Average Species/plot	H'	E
Forest	9.5 (1.6)	1.42	0.88
Double stripped topsoil	7.7 (0.8)	1.19	0.76
Stockpiled topsoil	3.8 (0.7)	1.35	0.95

On the stockpiled site, sampling yielded a smaller number of different species with similar frequencies of occurrence. For these reasons, it was apparent that the equitability component was most strongly reflected in the Shannon-Weiner diversity indices; this trend was also evident in the equitability indices (Table 2).

Estimates of species diversity using biomass production by species showed the diversities of the forested and double stripped sites to be very similar as compared with the difference between values displayed in Table 2. Similar equitability indices reflect a similar eveness of distribution of species, but also reflect a more uneven distribution of species biomass within one site. The proportion of species biomass (individual biomass) was apparently more strongly reflected in the diversity indices by the estimation used above.

Discussion

In general, the species - area curve shows the relationship between the number of species encountered as the area of the sample plot changes. It is an indication of whether the sample area was sufficiently large to be representative of the stand. This minimum size requirement of the sample is termed the "minimal area" which is related to the number of species which occur as the sample size increases[3].

Usually, a nested arrangement of sample plots is used, but in the present study the sample plots were non-contiguous. The Braun-Blanquet concept of minimal area is related to the area at which the species - area curve becomes approximately horizontal[3]. According to Kershaw[3], if true homogeneity existed, then minimal area would be a valid concept. Thus, homogeneity and minimal area may be related.

Comparison of the species - area curves for the forested and rehabilitated mine sites (Fig. 2) revealed that the number of new species was tending to drop off with an increase in the sampling area, particularly in the stockpiled site. It was apparent that the minimal area was not displayed for forested and double stripped sites, but it was reached in the stockpiled area. For this reason, it may be possible that sampling was insufficient in these areas and that species numbers and diversity indices may have been underestimated; that is, the sample taken was not necessarily sufficiently large enough to be representative. As the minimal area was apparently determined for the stockpiled topsoil site, and as there was a degree of homogeneity of vegetation over the site (attributable to initial even spreading of topsoil containing seed and initial pattern of planting of tree seedlings) it was likely, in this case, that the minimal area concept is valid for application in rehabilitated mine sites. Its exact position may be more difficult to determine for forested and possibly double stripped areas where species richness was likely to be higher.

The main objective of the present study was to show which of the two topsoil handling treatments yielded the most successful re-establishment of volunteer native understorey in terms of density and diversity measurements. The density of vegetation or groundcover was important for checking erosional control; diversity indices (incorporating the frequency of occurrence of species in one method, see Table 2, and incorporating the proportions of individual species in another method, see Table 3) reflected the degree to which the rehabilitated site was established towards a mature forest community when compared against the existing jarrah forest climax community.

The differences in biomass production, groundcover and species diversity between double stripped soil and forested sites may be mainly attributable to their differing stages of development (different stages of maturity). After three years, the double stripped area supported about half the cover of mature forest sites[10]. Peet[5,6] found the cover in a jarrah forest, over a wide area, was 40 percent. Live cover recorded in the present work showed that forest cover varied from 60-68 percent. The considerable difference in the values may be attributable to inherent personal bias included in visual estimates[3]. Tacey[10] from his work proposed that groundcover was fairly rapidly approaching forest levels in the mine sites, where sufficient seed was present in a position from which it could germinate and establish.

Table 3 Species diversity and equitability indices for forest and rehabilitated mine sites.

Biomass production by species was used for diversity index estimation.

SITE	Diversity Index, H'	Equitability Index, E
Forest	0.84	0.67
Double stripped topsoil	0.82	0.60
Stockpiled	0.60	0.57

Litter cover on forest sites was three times that on double stripped sites and six times that on stockpiled sites. Tacey[10] recorded forest litter cover to be six times as great as double stripped cover. The presence of a larger overstorey biomass in the jarrah forest site would have made a significant contribution to the litter. Hatch[2] (see also Bevege[1]), recorded the half life of litter in the jarrah forest as 2.7 years; thus, maximum level of litter buildup would not be expected in the

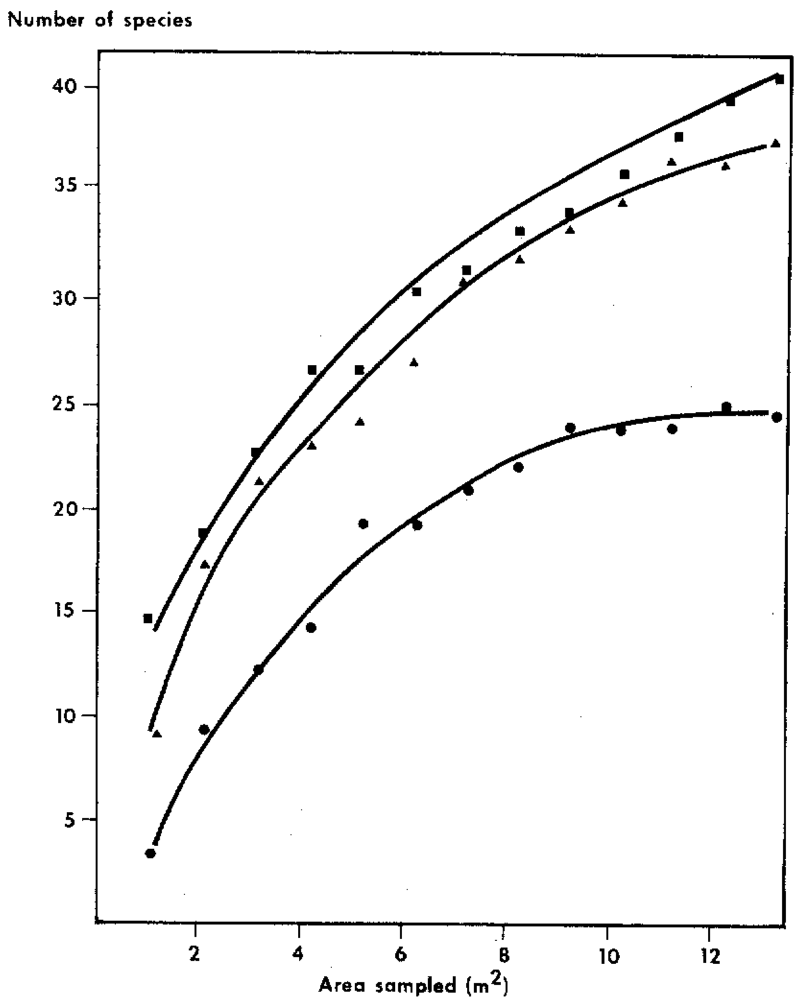

Fig. 2 Species area curves for (a) jarrah forest plots ■——■ (b) double stripped topsoil ▲——▲ (c) stockpiled topsoil ●——●

three year old rehabilitated site. The forest would be expected to provide the best check on erosion and the effective control of erosion in double stripped areas to be approaching this as the litter builds up. After three years, the stockpiled area seemed to have made very little significant progress in litter cover or plant biomass increases. It was suggested by Tacey[10] that improvements to vegetative cover in early years of rehabilitation could be made with the introduction of additional techniques such as mulching, use of agricultural legumes or direct seeded native understorey. The sowing of subterranean clover has also been suggested. Six weeks after germination on mine sites, it was found to establish complete groundcover[10].

Rehabilitated mine sites may be regarded as mainland habitat islands. They could be considered as secondary forest growth as mentioned in MacArthur[4]. The areas have had an initial input of species: planted *E. calophylla* (in area studies) seedlings; respread topsoil with a germinable seed load. This initial input provided the colonizer understorey species which tend to dominate the site. Such species as *Acacia pulchella, Trimalium ledifolium, Kennedia prostrata* and *K. coccinea*, from observation, constituted the most important pioneer species.

In addition, it was observed that these species were not as abundant in the jarrah forest. Like islands, in early stages of development, the mine sites are characterised by small species numbers with a few colonizers dominant. Chance immigration of plant species into the area may occur from the surrounding forest. As the community passes through the stages of succession, it may reach the climax level of the forest and the "island habitat" may eventually be indistinct.

Conclusions

It was evident, from the data collected to date, that double stripped topsoil handling treatment yielded the more successful re-establishment of volunteer native understorey in terms of its contribution to groundcover and species diversity. Double stripping may be considered to represent a means of returning a range of jarrah forest species to rehabilitated sites[10].

A continuous monitoring of the rehabilitated mine sites will be necessary to ascertain the long-term success of double stripping in returning a jarrah forest that may be of use to the community as a recreational resource or it may be useful as a water catchment area.

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GERMINATION CHARACTERISTICS OF SOME SPECIES OF *EUCALYPTUS* FROM THE HAMERSLEY PLATEAU, PILBARA REGION

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Introduction

This paper reports comparative germination records for seven species of *Eucalyptus* which are found on the Hamersley Plateau of the Pilbara Region, as defined by Beard[2]. The seed was collected in December 1979 and the germination studies were undertaken between March and June 1980 at Bentley.

Species Recorded from the Hamersley Plateau

Seed was collected from within a study area of c. 25 km radius, centred on a hill located at 118° 40' east and 23° 05' south. The seven were as follows (collection numbers in brackets).

1 *E. dichromophloia* F.Muell. (2714)
2 *E. gamophylla* F.Muell. (2718)
3 *E. kingsmillii* Maiden et Blakely (2731)
4 *E. leucophloia* Brooker (2700)
5 *E. oleosa* F.Muell. ex Miq. (2720,2728, 2729,2744)
6 *E. patellaris* F.Muell. (2743,2745)
7 *E. setosa* Schau. (2712)

Separate germination tests were undertaken on seed from each of the collections listed. A specimen of each is housed in the herbarium of the Biology Department of the Western Australian Institute of Technology. Notes pertaining to each of these species are included below under 'Germination Studies'.

Beard[2] found seven species of sufficient importance in the Pilbara Region to be used in mapping. These were numbers 1, 2, 4 and 5 of the above seven together with the following three

E. camaldulensis Dehnh. ('River(red) Gum')
E. microtheca F.Muell. ('White-stemmed Coolabah')
E. sp. aff. *aspera* F.Muell. (*aspera* is 'Brittle Range Gum')

This gives a total of ten for species of reasonably common frequency. Of these I have not seen *E. camaldulensis* in the Hamersley Plateau where it does occur in gorge bottoms[2]. It is a wide ranging species[5], the most widespread of all eucalypts, occurring generally across the north of Australia[7]. Both this species, the River Gum, and *E. microtheca* are said to have photosensitive seed[9], a property which may have caused errors had these species been included in the tests described below. *E. microtheca* was present in the study area (collection 2662) lining major (lower) drainage channels with sandy creek beds. This species may have displaced *E. camaldulensis* in the study area, a region of comparatively high altitude. It is noted in passing that the name *E. microtheca* formerly referred to the 'Flooded Box' of the Kimberley[1,3] and *E. coolabah* Blakely & Jacobs was reserved for the Pilbara occurrence. The amalgamation renders *E. microtheca* almost as widely distributed (across the north of Australia) as *E. camaldulensis*[7].

The tenth identity *E.* sp. aff. *aspera* has been noted at Marandoo[8] and is said by Beard to have handsome white bark[2]. *E. aspera* occurs from the Kimberley to Mt. Isa in Queensland, it has greyish foliage and is a small crooked tree[1] It is not unlike *E. setosa*, to which it is very closely related[3], but has smaller fruits. It is possible that *E.* sp. aff. *aspera* and *E. setosa* may easily be confused in the field though the bark colour should distinguish them.

Several other identities have been noted from the region of the Hamersley Plateau. These are as follows:

E. sp. aff. *calycogona* Turcz. (*calycogona* is 'Gooseberry Mallee')
E. sp. aff. *dumosa* A.Cunn. ex Schau. (*dumosa* is 'Congoo Mallee'[3])
(private comm. Ian Pound);

and from Marandoo[8]:

E. terminalis F.Muell. ('Inland Bloodwood'[1])
E. trivalvis Blakely ('Victoria Spring Mallee'[3]).

Of these four the species *E. calycogona* and *E. dumosa* both have southern distributions[3,5]. It is possible that the very variable *E. oleosa* (see below) may have provided field specimens resembling these two. The *E.* sp. aff. *dumosa* may, alternatively, be the same as the *E. trivalvis* from Marandoo. *E. trivalvis* and *E. dumosa* are consecutive species in Blakely's list[3].

E. terminalis is also known as 'Long-fruited Bloodwood'[3] and may be distinguished from *E. setosa* by its long fruit stalks (pedicels). While peduncles in both are of similar length, the pedicels of *E. setosa* are shorter.

E. leucophloia[4] was formerly *E. brevifolia* F.Muell. and the name change may cause some confusion.

Germination Studies

Seed was extracted from capsules by drying at 40°C. Microscopic examination was utilised to determine seed from sterile material (chaff) and seeds were counted into 4 batches of 50 for each collection number. In the case of *E. dichromophloia* two tests were undertaken as the first result (34 percent germination overall) was considered disappointing.

Each batch of 50 seeds was arranged on filter paper over moist vermiculite in a glass petri dish. The dishes were then placed in controlled temperature cabinets kept in darkness at 10°, 15°, 20° and 25°C for a period of 60 days.

The dishes were inspected daily, any germinated seedlings (defined as 2mm of growth) being counted and removed.

For each species some general remarks are given together with a table of germination measurements, a figure including a sketch of the seed, the young seedling, and a graph showing the time course of germination. In each graph the four temperatures are designated by dots for 10°C, by dashes for 15°C, by dot/dash for 20°C and by solid lines for 25°C.

Each table gives nine different 'germination measurements'. These are as follows[6]:

1. Final percentage germination, the total percentage that had germinated by 60 days from the start.

2. The number of days required to achieve the final percentage germination.

3. Germination rate as a measure calculated by summing the product of germinants and days from the start and then dividing the sum by the total number of germinants (each germinant used once only)

i.e. $$\frac{n_1 \times t_1 + n_2 \times t_2 \ldots\ldots\ldots n_x \times t_x}{\Sigma_x^1 n}$$

4. Peak value is the highest value of cumulative percentage germinated over number of days from commencement, that is, a measure of steepness of the germination gradient illustrated in the figures.

5. M.D.G. (or mean daily germination) the final percentage germination over the number of days taken for the last recorded germinating seed.

6. G.V. (or germination value) combining rate of germination and viability:

G.V. = Peak Value x Mean daily germination.

7. Energy $\% \frac{7}{28}$. Germinative energy used as an expression giving a measure of the strength of seed. This is obtained by taking the percentage that germinated in 7 days over the percentage that germinated in 28 days times 100.

8. Germinative capacity as the percentage of seed that had germinated at 28 days.

9. Vigour combines the last two

$$\text{vigour} = \frac{\text{germinative energy}}{\text{germinative capacity}}$$

and may be considered as an objective measure of "fitness" at least for seed of high viability.

1. *Eucalyptus dichromophloia*

This species is known variably as 'Bloodwood'[2], 'Variable-barked Bloodwood'[1] or 'Red-barked Bloodwood'[3]. It is a small tree with a small urn-shaped fruit and rough bark. Beard records it[2] from a variety of habitats viz. riverain woodland with *E. camaldulensis* and *E. microtheca*; lower slopes and plains with *Triodia pungens* and *E. setosa*; and with *E.* aff *aspera* on drainage of basalt hills. It is typical of Beard's association 4 'Tree steppe' with *Triodia pungens*[2]. *E. dichromophloia* occurs across northern Australia[7] and its name refers to two-coloured bark-old bark being typically reddish brown, scaly and persistent whereas newly exposed surfaces (in some regions at least) are smooth and whitish[7]. The red bark distinguishes it from *E.* sp. aff. *aspera*.

The seed is comparatively large[9] and winged; seedling growth is also faster than the other species tested (Fig. 1). Seed viability was low, 34 and 40 per cent germinated respectively in two tests. This was possibly due to the collection including old fruit which may have persisted on the tree for some time. Germination was most rapid at 25°C though more seed germinated at 20°C and the total germination was similar for 15 and 25°C. Lower temperature (10°C) depressed and prolonged the rate of germination (Table 1).

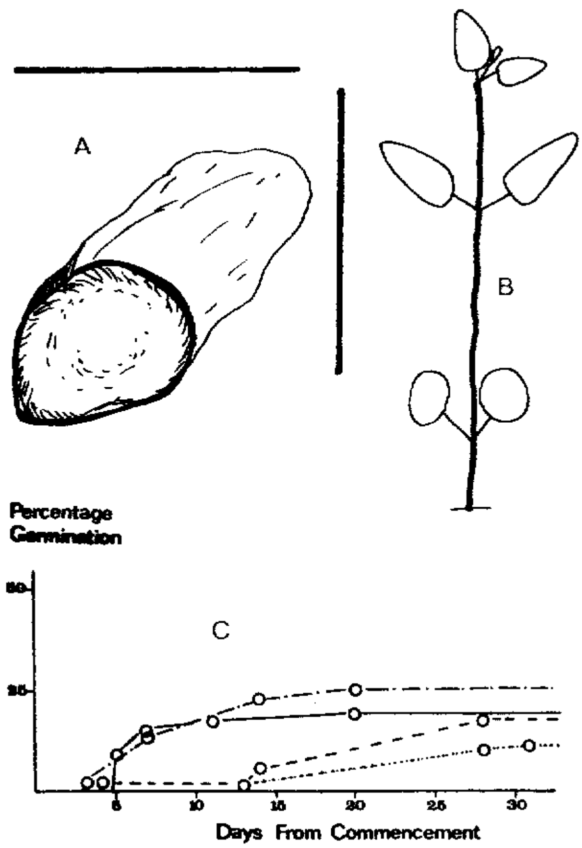


Figure 1. *Eucalyptus dichromophloia*

A seed, bar scale is 5mm length,
B seedling, six weeks from germination, vertical bar is 5cm in length,
C time course of germination at four temperatures (see text).

Table 1. *E. dichromophloia* germination
Collection 2714

Germination Measurement	Temperature (°C) 10	15	20	25
1. Final % germination	12	18	25	19
2. Days to 1	31	28	20	20
3. Germination rate	23.3	17.8	9.2	6.9
4. Peak value	0.39	0.68	2.00	2.17
5. M.D.G.	0.39	0.65	1.25	0.95
6. G.V.	0.15	0.44	2.50	2.06
7. Energy % $\frac{7}{28}$	0	11	48	74
8. Germinative capacity %	10	18	25	19
9. Vigour	-	0.6	1.9	3.9

(2 tests each of 50 seed per temperature, all measurements combined.)

2. *Eucalyptus gamophylla*

E. gamophylla has been referred to as 'Twin-leaved Gum'[3]. It is a glaucous mallee with smooth white mealy bark and silvery narrow leaves[3]. It is a component of Beard's association 7 'Shrub steppe' with *Triodia basedowii*. It also occurs with *E. leucophloia* and *Triodia wiseana*.

The seed is elongated and narrow (Fig. 2). Viability averaged 44 per cent and germination was most rapid at 25°C, declining in rate through the temperatures used in the test. Lower temperatures depressed and prolonged germination (Table 2).

Table 2. *E. gamophylla* germination
Collection 2718

Germination Measurement	Temperature (°C) 10	15	20	25
1. Final % germination	36	40	50	50
2. Days to 1	20	16	12	8
3. Germination rate	12.3	9.0	6.5	5.1
4. Peak value	2.46	3.20	5.25	7.67
5. M.D.G.	1.80	2.50	4.17	6.25
6. G.V.	4.43	8.0	21.9	47.9
7. Energy % $\frac{7}{28}$	0	30	56	96
8. Germinative capacity %	36	40	50	50
9. Vigour	-	0.8	1.1	1.9

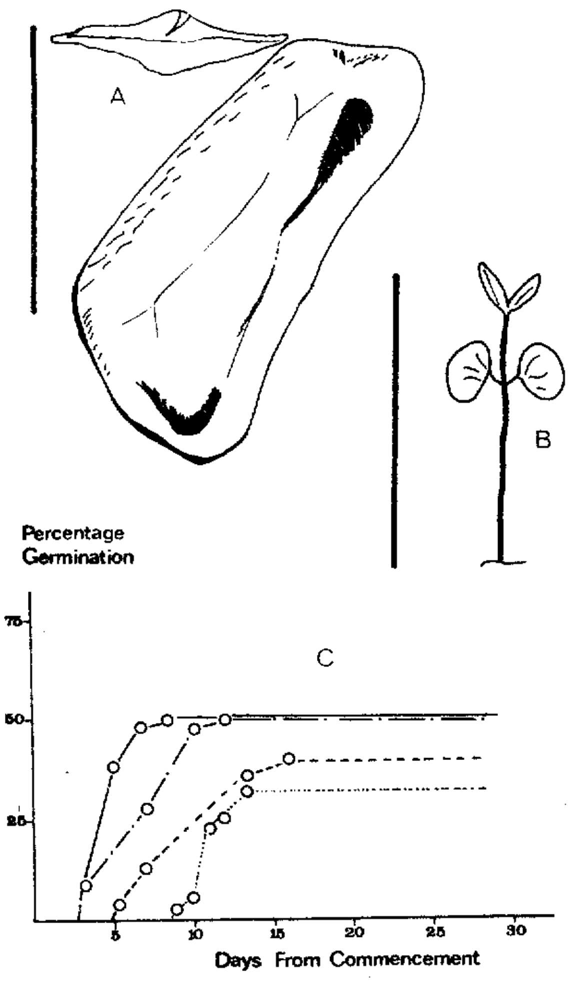


Figure 2. *Eucalyptus gamophylla*

A seed, surface and side view, vertical bar is 2mm,
B seedling six weeks from germination, vertical bar 5cm,
C time course of germination at four temperatures.

3. *Eucalyptus kingsmillii*

'Kingsmill's Mallee'[1] was collected from the summit region of Mt Bruce in 1932. It occurs on many of the mountain summits in the Hamersley Plateau as a wide spreading bushy mallee 3-5 m tall. Beard[2] notes it occurring with *E. gamophylla* and *E. leucophloia* though it is often locally dominant.

There is some confusion between this species and two other similar, closely related, species. Chippendale[5] notes that *E. pyriformis* Turcz. (the 'Pear-fruited Mallee'[1]) occurs in a narrow zone from the Murchison River south to Goomalling, usually in sandy soil in flat or gently undulating heathland. *E. youngiana* F. Muell. ('Large-fruited Mallee'[5]) occurs to the east of the Goldfields, some 150 km north and east of Kalgoorlie. Blakely's Mt Keith description of *E. kingsmillii* is probably *E. youngiana*[3].

The seed is somewhat angular and had high viability in this study, though it is not easy to maintain seedlings. Both cotyledons and first leaves are narrow (Fig. 3). The rate of germination was fastest at 20° followed by 15°C, suggesting that this species may have a lower optimum germination temperature compared with most other species.

Table 3. *E. kingsmillii* germination
Collection 2731

Germination Measurement	Temperature (°C) 10	15	20	25
1. Final % germination	92	100	100	94
2. Days to 1	45	26	16	25
3. Germination rate	20.6	10.4	8.4	11.4
4. Peak value	3.20	6.83	7.82	5.50
5. M.D.G.	2.19	3.85	6.25	3.76
6. G.V.	7.0	26.3	48.9	20.7
7. Energy % $\frac{7}{28}$	0	36	42	26
8. Germinative capacity %	72	100	100	94
9. Vigour	-	0.4	0.4	0.3

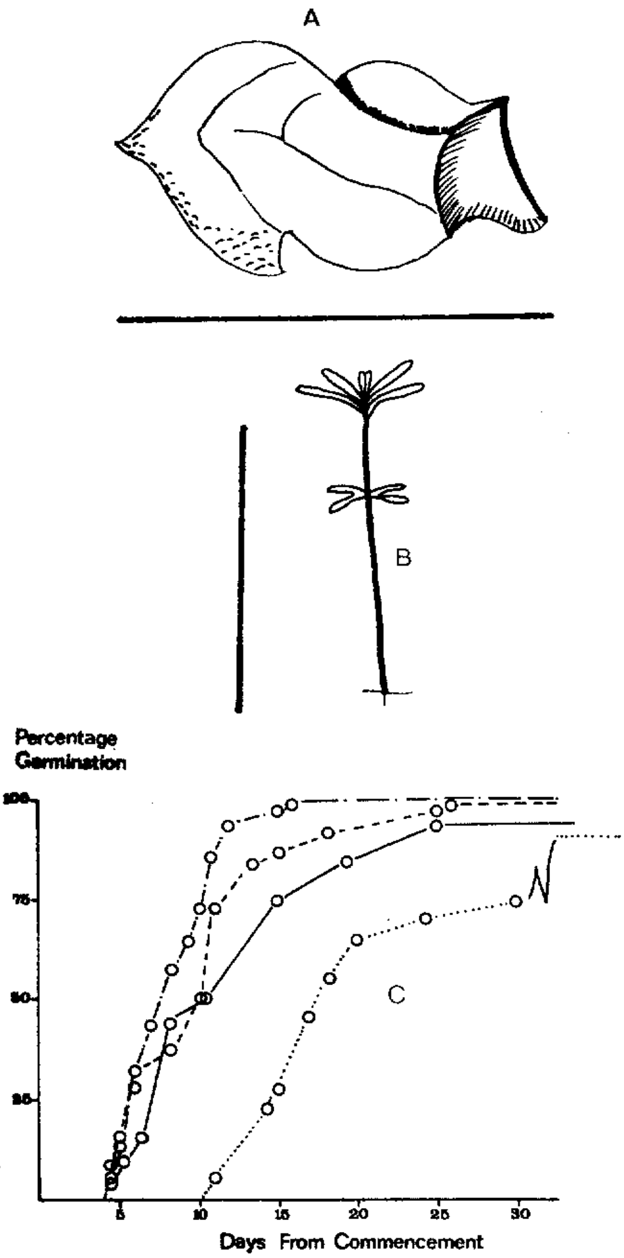


Figure 3. *Eucalyptus kingsmillii*

A seed, bar scale is 3mm length,
B seedling five weeks from germination, vertical bar 5cm,
C time course of germination at four temperatures (note maximum germination at 10°C was 92%, 42 days after commencement).

4. *Eucalyptus leucophloia*

The well accepted common name for this species is 'Snappy Gum' believed to be due to its brittleness[3]. However Brooker[4] in describing the species records the aboriginal name 'Migum' as used in the Pilbara. It was until recently confused with *E. brevifolia*[4] which is confined to the Kimberley of Western Australia and adjacent areas of the Northern Territory. *E. leucophloia* occurs between latitudes 20 and 23°S in the Pilbara and also in the Northern Territory and Queensland between latitudes 16 and 21°.[4] The name '*leucophloia*' refers to the white powdery bark, often black spotted[4].

Snappy Gum features in Beard's[2] association 3 'Tree steppe' with *Triodia wiseana* on basalt hills and ranges of jaspilite and dolomite, particularly on shallow stony soils. *E. gamophylla* is a frequent associate[2,4] and *E. terminalis* and *E. trivalvis* are also found with it[4].

Trees are stout though not large, with well developed boles often large in relation to the height. Blackened branch stubs are frequently seen testifying to past fire damage.

Seed, seedling and time course of germination are illustrated in Figure 4, while germination measurements are summarised in Table 4.

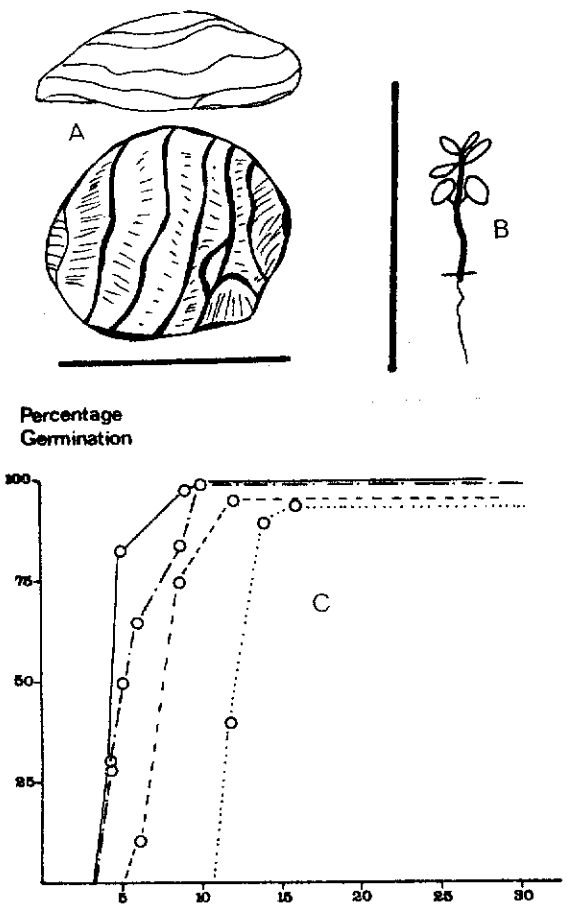


Figure 4. *Eucalyptus leucophloia*

A seed, surface and side view, bar scale is 1mm long,
B seedling eight weeks from germination, vertical bar 5cm,
C time course of germination at four temperatures.

Table 4. *E. leucophloia* germination

Collection 2700

Germination Measurement	Temperature (°C)			
	10	15	20	25
1. Final % germination	94	96	100	100
2. Days to 1	16	12	10	10
3. Germination rate (mean days)	12.8	8.3	6.0	5.1
4. Peak value	6.43	9.25	11.0	16.4
5. M.D.G.	5.88	8.0	10.0	10.0
6. G.V.	37.8	74.0	110	164
7. Energy % $\frac{7}{28}$	0	10.4	74	94
8. Germinative capacity %	94	96	100	100
9. Vigour	-	0.1	0.7	0.9

Seed viability was high (the fruits were all the current crop and evensized) and germination was rapid. Best results were achieved at 25°C with a drop in germination values through the range of temperatures used. At the higher temperatures over 50 per cent of seed germinated within 5 days.

5. *Eucalyptus oleosa*

Specimens were assigned to var. *oleosa* as described by Chippendale[5]. The four specimens from which seed was taken were variable in form, but were all mallees with shiny bark and an abundance of fruit. Each was taken from a different site within the study area ranging from a lower mountain slope, rocky creeks and valley floor. The commonly accepted name for E. *oleosa* var. *oleosa* is 'Giant Mallee'[1,3,5].

While it has not generally been noted from the Pilbara (cf above authors) Beard[2] mapped it in Kumarina Hills of the Upper Ashburton, mainly in drainage.

Fig. 5 gives average values for the seed germination from the four parent trees. There were no significant deviations from the general pattern illustrated, and germination values (Table 5) were similar. Three collections gave 100 per cent viability at all four temperatures: 2728 averaged 93 per cent viability. In each case germination rate was fastest at 25°C (item 3) with the values recorded being 8.6, 7.2, 4.5 and 4.5 compared with the overall mean of 6.3. Vigour of seed subjected to 25°C was highest in each case: 0.62, 0.70, 0.96 and 0.83 respectively compared with the mean of 0.8.

Mean daily germination (M.D.G.) on average (item 5 of Table 5) was greatest at 25°C reflecting the greater spread of days to final germination (item 2) when batches are amalgamated. The ranking of M.D.G. for each batch was as follows:-

2720 $\frac{15}{20}$ > 25 > 10

2728 25 > 15 > 20 > 10

2729 25 > 20 > 15 > 10

2744 25 > 15 > 20 > 10

The averaged responses are thus similar to those given for *E. leucophloia* which differed mainly in having higher peak values.

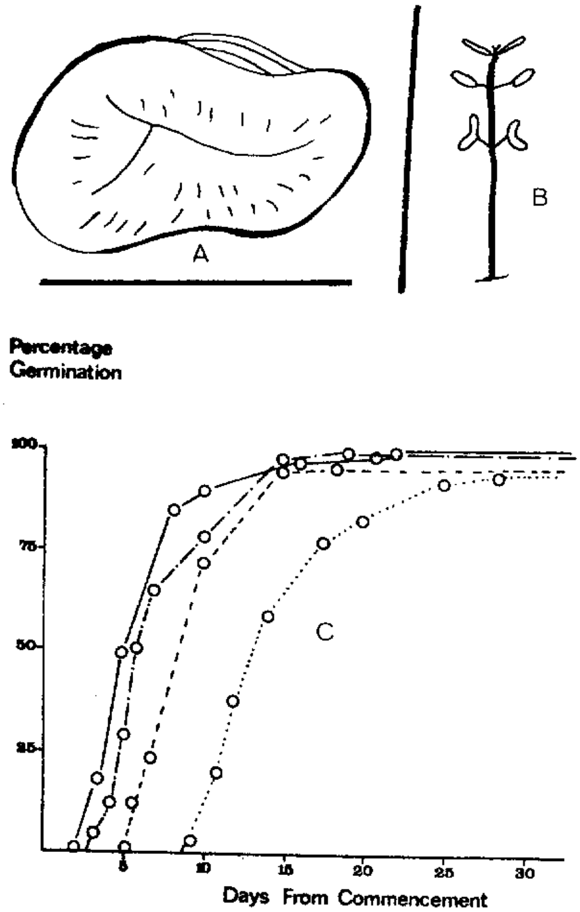


Figure 5. *Eucalyptus oleosa*

A seed, bar scale is 1mm,
B seedling eight weeks from germination, vertical bar 5cm,
C time course of germination at four temperatures, data averaged for seed from four different parent plants.

Table 5. E. *oleosa* var. *oleosa* germination
Collections 2720, 2728, 2729, 2744

Germination Measurement	Temperature (°C)			
	10	15	20	25
1. Final % germination	98	97	100	100
2. Days to 1	36	19	18	22
3. Germination rate	15.2	9.5	7.6	6.3
4. Peak value	4.57	7.25	9.1	11.1
5. M.D.G.	2.71	5.08	5.56	4.52
6. G.V.	12.4	36.8	50.6	50.1
7. Energy % $\frac{7}{28}$	0	25	64	78
8. Germinative capacity %	94	97	100	100
9. Vigour	-	0.3	0.6	0.8

(Data presented are means or sums of 4 tests each of 50 seed, per temperature regime, from 4 parent trees.)

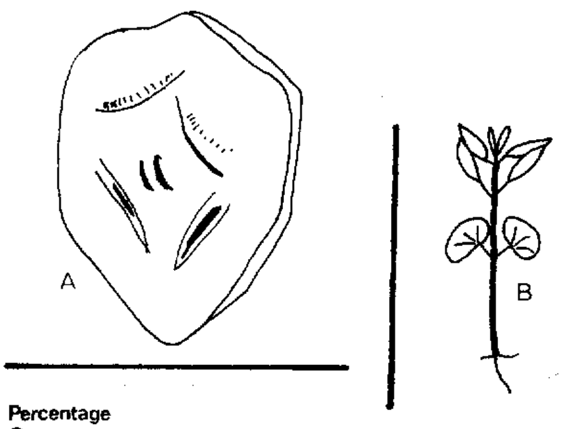
6. *Eucalyptus patellaris*

'Weeping Box'[1,3] is found through much of northern Australia[1] but is uncommon[3]. It is a tall, spreading tree of weeping habit 6-12 m tall with dirty grey bark and with leaves characteristically grey green. In the study area seed was taken from two trees found on the banks of a narrow sandy creek in hilly country.

In Fig. 6 performance of both seed lots are illustrated. Collection 2745 averaged 76 per cent germination, whereas 2743 gave only 58 per cent. Although the trees were close together (c. 20m apart) fruit development was more complete in the former at the time of collection. The averaged data presented in Table 6 suggest that germination was greatest at 20°C. However the actual percentages for each were as follows

	10	15	20	25°C
2743	44	68	64	56
2745	84	70	81	70

and the narrow spread of 6 of the 8 curves in Fig. 6 point to relative insensitivity of germination response to temperature compared with the other six species examined.



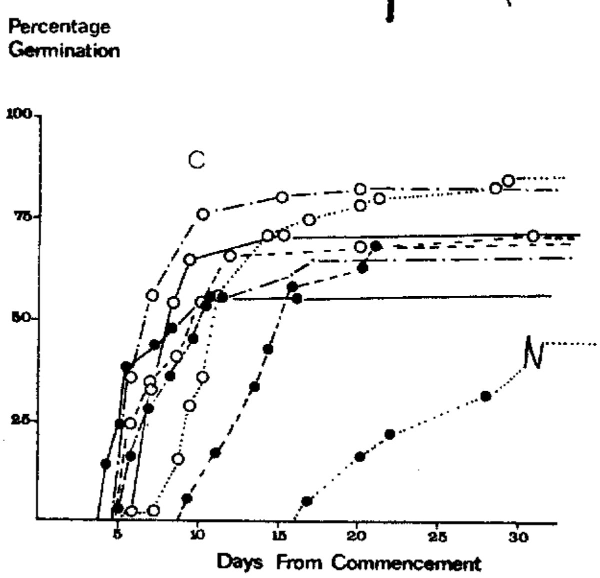


Figure 6. *Eucalyptus patellaris*

A seed, bar scale is 2mm,
B seedling six weeks from germination, vertical bar 5cm,
C time course of germination at four temperatures, open circles coll. no. 2745, closed circles coll. no. 2743. (Note for the latter maximum germination at 10°C was 44%, 48 days after commencement.)

Table 6. *E. patellaris* germination
Collections 2743, 2745

Germination Measurement	Temperature (°C)			
	10	15	20	25
1. Final % germination	64	69	73	63
2. Days to 1	48	26	20	16
3. Germination rate	17.5	11.5	8.2	7.4
4. Peak value	2.55	3.88	6.59	6.25
5. M.D.G.	1.33	2.65	3.65	3.94
6. G.V.	3.4	10.3	24.1	24.6
7. Energy % $\frac{7}{28}$	1.8	24.6	57.5	58.7
8. Germinative capacity %	56	69	73	63
9. Vigour	0.03	0.4	0.8	0.9

(2 sets of tests combined from 2 different parent trees.)

7. *Eucalyptus setosa*

This small to medium-sized, well branched, often crooked, tree is known as 'Rough-leaved Bloodwood'[1,3]. It may be distinguished from *E. dichromophloia* by its larger, urn-shaped fruits. Leaves are thick opposite, hairy and tend to being triangular in shape; they are stem clasping[3]. Bark is rough and scaly. Rough-leaved Bloodwood is found over much of northern Australia. In the Pilbara Beard[2] has noted its occurrence with *E. dichromophloia* and *Triodia pungens* on lower slopes and plains.

Overall germination patterns (Table 7) were very similar to *E. leucophloia* (Table 4). At 25°C however germination of *E. setosa* was exceptionally rapid with all germinants recorded within 4 days. The spread of temperature response (Fig. 7) suggests that 20-25°C contains the optimum range for this species. Of the species with high viability only this one reached 1.0 or more for vigour.

The seed is winged (Fig. 7) as in *E. dichromophloia*.

Table 7. *E. setosa* germination
Collection 2712

Germination Measurement	Temperature (°C)			
	10	15	20	25
1. Final % germination	90	96	96	90
2. Days to 1	17	14	14	4
3. Germination rate	12.4	7.1	4.2	3.7
4. Peak value	6.14	9.75	18.5	22.5
5. M.D.G.	5.29	6.86	6.86	22.5
6. G.V.	32.5	66.9	127	506
7. Energy % $\frac{7}{28}$	0	68.8	93.8	100
8. Germinative capacity %	90	96	96	90
9. Vigour	-	0.7	1.0	1.1

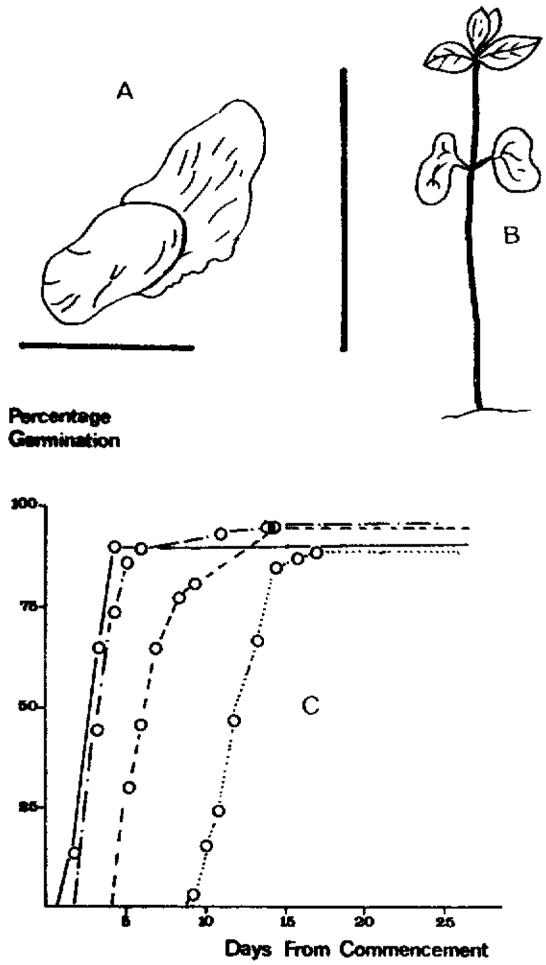


Figure 7. *Eucalyptus setosa*

A seed, bar scale is 3mm,
B seedling seven weeks from germination, vertical bar 5cm,
C time course of germination at four temperatures.

Acknowledgments

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Staff of the W.A. Herbarium are thanked for their assistance in naming specimens.

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A GROWTH AND COMPETITION STUDY INVOLVING THE SYMPATRIC SPECIES *ACACIA ANEURA*, *A. CRASPEDOCARPA*, *A. LINOPHYLLA* AND *A. PRUINOCARPA* IN POT TRIAL

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Summary

Mulga (*Acacia aneura*), while often forming more or less pure stands, or maintaining a position of general dominance over much of the vegetation zone in which it occurs does have a number of associate species. Three of these are: *A. craspedocarpa* often found on creek lines with a bush-like appearance or a straggly main stem in older specimens; *A. linophylla* almost invariably a shrub with no main stem, pre-eminently a plant of sandy soils; and *A. pruinocarpa* often found on better-watered sites and forming a tree emergent above mulga.

A set of pots with four different 'soils' was planted with four individual seedlings each, in various combinations of these four species in August 1978. The trial was maintained for exactly one year in a shade house giving approximately 70 percent of daylight, at the Western Australian Institute of Technology, Bentley. All plants were then harvested and measured.

Growth in pot trial tended to reflect the ecological preferences of the species in nature. The 'heavier' soil media produced greatest growth and highest relative yield totals. Height and numbers of phyllodes are examined as predictors of dry matter production.

Introduction

The distribution patterns within Western Australia of the four species *Acacia aneura* F. Muell. ex Benth., *A. craspedocarpa* F. Muell., *A. linophylla* W.V. Fitzg. and *A. pruinocarpa* Tindale, based on herbarium records, by map-sheet occurrence[9], are illustrated in Fig. 1. In general terms the other three species fall within the range of *Acacia aneura*.

All are found in the Murchison region[5] and of the four species *Acacia craspedocarpa* has both the smallest and most compact range while the distribution of *A. pruinocarpa*, at least on present knowledge, is most disjunct. Common names are as follows

A. aneura	mulga
A. craspedocarpa	hop mulga[14], thadangu[10]
A. linophylla	bowgada[10]
A. pruinocarpa	gidgee[1]

Acacia aneura

Mulga is said to grow at its best on plains with red-earth loamy soils overlying a siliceous hardpan[5]. It tends to be of low stature on very stony soils and areas which shed water. To the north of its' range it tends to occur in valleys or water gaining sites. In Queensland at its eastern limits of distribution in moister regions it occurs predominantly on massive earths, extending onto other soil types with increasing aridity[11].

Cannon[7] noted that in arid regions competition is not so much for space and light, of which there is abundance, but rather for moisture. Melville[10] has illustrated the pattern of regrowth around a parent tree of *Acacia aneura* and he has shown that larger regrowth occurs furthest from the parent. A similar phenomenon has been illustrated more recently at Mileura[8]. There is undoubtedly strong root competition, for water, between young plants and well established individuals.

All three of the other species may be found in association with mulga, and, on occasion, three of the four may be found together though the differences in site preferences between the species are such that it is not possible to find all four in close association. *Acacia pruinocarpa* is not often found with *A. craspedocarpa*. The following notes summarize the kinds of environment where joint occurrences of two or more of the four species have been noted.

Acacia craspedocarpa

Acacia craspedocarpa has been described as an undershrub by Beard of 2m height or less[5], to 3m height[14] and to 5m[10]. It does not reach the same stature as do *Acacia aneura* and *A. pruinocarpa*; nevertheless larger individuals seem eventually to attain fair sizes though the species maintains a spreading shrubby habit. It occurs in thickets, in almost pure communities on flood plains in the Murchison[10], and there is general agreement that its main habitats are along margins of definite stream lines, in broad watercourses and as a component of fringing communities[14].

In the Gascoyne *Acacia craspedocarpa* occurs with *A. aneura* on clay over calcareous hard pan on the Warri Rangeland Type (R.T.) and also on alluvial plains of Three Rivers R.T. with *Acacia aneura* and *A. pruinocarpa*[13]. It is found as an understory to *A. aneura* on drainage lines of the Carnegie Salient[2]. *A. craspedocarpa* favours deeper red earths in drainage tracts of the Wiluna-Meekatharra area where Speck[12] recorded it in the west and centre of his study area in three floristic communities characterised by mulga of 3-7m in height. One of these communities was restricted to saline alluvial plains in Cunyu Land System (L.S.).

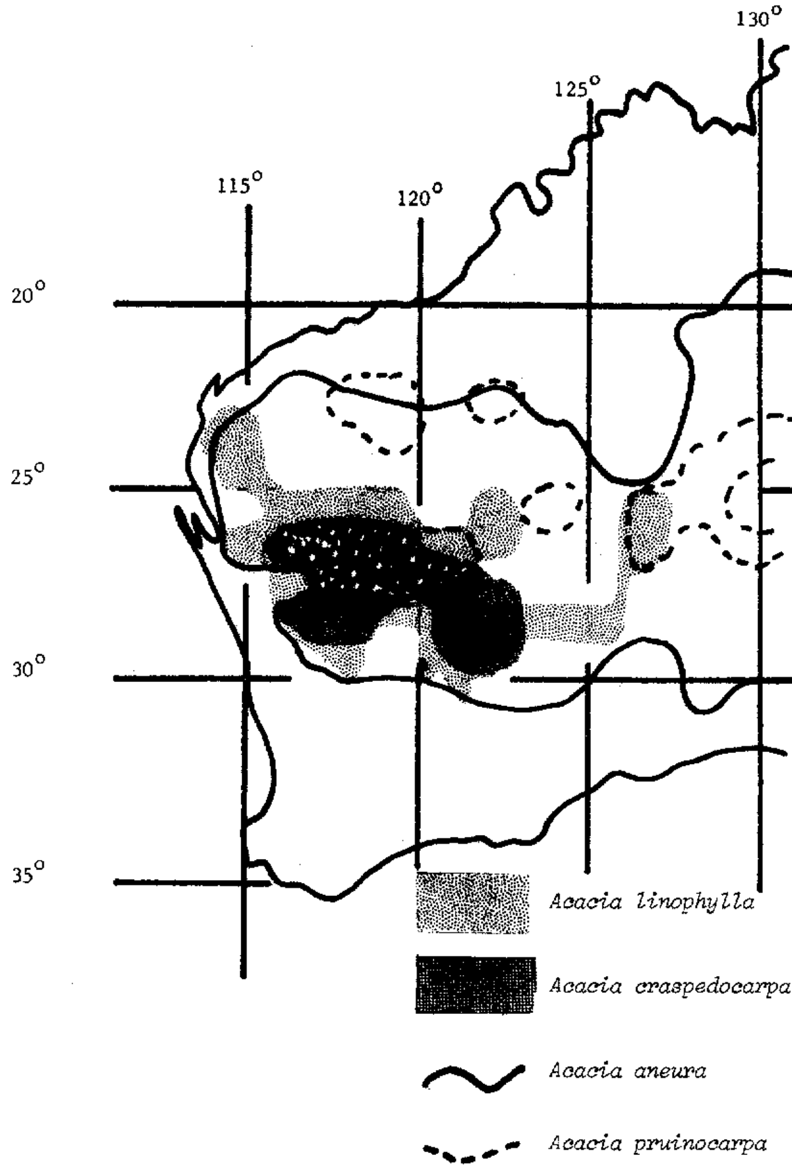

Figure 1. Distribution of four *Acacia* species in Western Australia (after Hnatiuk and Maslin 1980)

Acacia linophylla

In the case of *Acacia linophylla* Cannon[7] observed that the small size of individuals and the large amounts of dead wood present attest to the difficult conditions under which the species lives. This species is readily recognised by its globular shape with erect fine terete phyllodia[10]. It is typically a shrub branched from the base with a spreading bushy habit. It occurs on two main habitats desert sands and sand plains or on siliceous rocks[5]. In the main part of its distribution it is characteristic of the sand plains of the Bullimore L.S. where *Triodia basedowii* is commonly present. Speck's community 54 is described as *Acacia aneura* - *Acacia linophylla* - *Triodi basedowii* and this consists of a dense low tree layer of mulga to 4m with scattered taller individuals of *Acacia pruinocarpa*, tall shrubs of A. *linophylla* and low shrubs of *Eremophila leucophylla*[12]. These three Acacias also occur together in Winmar and Macadam R.T. of the Gascoyne[13] on sand and in groves/intergroves.

Acacia linophylla occurs on sand ridges of the Carnegie Salient[5], in sandy interdunes and locally in sandhills, into the Gibson Desert[2], and is probably one of the principal species of the shrub steppe of the Little Sandy Desert[4]. In the Gascoyne it is found on sand with mulga on Bidgemia, Divide, Lyons, Mantle and Woramel R.T.'s and on sand banks in Jamindie, Flood and Bubbagundy R.T.'s[13]. Some of the red sands overlie calcareous subsoils with loam at depth and a calcareous hardpan. Beard has so described *Acacia linophylla* occurrence at Gindalbie from where it spreads east to the edge of the Great Victoria Desert[3].

Speck described four *Acacia aneura*-*Acacia linophylla* communities (his 39-42) on rocky hills and slopes of greenstone and sandstone[12]. In the Gascoyne Ranges it occurs on Mount Augustus[4] a sandstone massif[5]. It has also been reported as an undershrub to mulga on ridges of the Kennedy Range (Moogooloo R.T.) and also on schist and gneiss hills of the Agamenon and Peak Hill R.T.'s[13].

Acacia pruinocarpa

Tall gidgee is found in the Murchison and Gascoyne plains and *Acacia pruinocarpa* is generally of shorter stature on slopes and hills of the Pilbara. Gidgee occurs in mulga woodlands and mulga groves, in wide flat watercourses and stony alluvial plains. On favourable sites it may reach 12m in height[14].

In addition to the Bullimore L.S. occurrence mentioned above Speck[12] recorded A. *pruinocarpa* as an important member of four other communities:-

Community 7	Gidgee - *Acacia aneura*-*Eremophila fraseri*
Community 8	Gidgee - A. *aneura*-E. *fraseri*-*Danthonia bipartita*
Community 11	Gidgee - A. *aneura*-A. *tetragonophylla*
Community 73	*Eucalyptus aspera* fringing community.

C7 an open mulga woodland has gidgee to 7m tall and occupies lower slopes of the Wiluna L.S. C8 has diffuse mulga groves with scattered taller gidgee on shallow soils, stripped crests and slopes of the Fisher L.S. C11 is an open woodland on deeper soils of alluvial plains and fans in Cunyu, Jundee, Sodary, Wiluna and Yandil L.S.'s. The last of these 4, C73 occupies drainage channels of the Wiluna L.S. north of Meekatharra.

Acacia pruinocarpa is found in groves on Frederick R.T., on floodplains of the Clere R.T. and on wandarrie banks of Landor R.T., all of the Gascoyne[13]. It also occurs in the Carnegie Salient[2,4] and on level plains north of Wiluna[5]. It is a rare associate of mulga in the Great Sandy Desert region[1], it occurs particularly south of Lake Mackay on rising ground, and also in steppe parkland of the Gibson Desert[1,2], particularly on hilltops. It is often stunted on slopes of quartzitic ranges in the Warburton region with some occurrence on interdunes between sandhills. It is occasionally present on basalt of the Warburton Range and on the sandy plains around the ranges[2]. It is present on calcrete areas near Lake Austin[5].

Other Gascoyne localities are described by Beard[4] as loam flats and higher hills of the Teano Range. It occurs also on stony plains of Jamindie, Kurubuka and Winmar R.T.'s[13].

Further north it occurs in the Yabalgo Plain on summit plateaux[5] and well into the Pilbara on hard, red, alkaline soils in the Oakover valley, and on outwash plains of the Fortescue[4]. In the Hamersley Plateau *Acacia pruinocarpa* is found in gorge bottoms, valley plains and also on the better soils of the basalt hills around Mt Tom Price. It also occurs in the Kumarina Hills to the south of the Hamersley Range, with some occurrence on red sand with calcrete nodules[4].

The Pot Trial

Seed of the 4 species was sown and germinated in June 1978. The *Acacia aneura* seed was ex Charleville, Queensland (courtesy of the Queensland Department of Primary Industry). Seed of the other three species was collected in the Meekatharra area in late 1977. Red sand of the Bullimore L.S. and red (loam) earth of the Bigida L.S. were obtained from Yeelirrie. These two were used as potting media for transplanted seedlings alone and in 50 per cent mixture. A fourth medium was commercially supplied coarse sand. The latter was used to simulate establishment and early growth in drainage areas. The mixture served to provide an intermediate arid country mix.

The soils were placed in standard 5 inch plastic pots, in equal quantities (750cc), with the base lined internally with vermiculite. Sufficient soil and seedlings were available to provide a set of 40 pots with ten different species combinations of four seedlings with one pot of each combination allocated to each of the four soil media. The arrangement is illustrated in Table 1.

Table 1. Arrangement of seedling mixtures and soil type, showing survivors and losses over 12 months.

Pot Sets	Soil Medium: Coarse sand 1	Desert sand 2	Mixture (50% of 2 & 4) 3	Desert loam 4
1	PPPP	PPPP	PPPP	PPPP
2	PPPA	PPPA	PPPA	PPPA
3	PPAA	PPAA	PPAA	PPAA
4	PAAA	PAAA	PAAA	PAAA
5	AAAA	AAAA	AAAA	AAAA
6	LAAA	LAAA	LAAA	LAAA
7	LLLA	LLLA	LLLA	LLLA
8	CCCC	CCCC	CCCC	CCCC
9	CCCA	CCCA	CCCA	CCCA
10	CCAA	CCAA	CCAA	CCAA

Survivors at twelve months P, A, L, C

Percentage Loss by Species

	1	2	3	4
P A. *pruinocarpa*	30	30	30	40
A A. *aneura*	24	0	6	12
L A. *linophylla*	50	50	25	75
C A. *craspedocarpa*	44	11	11	0

All pots were labelled and placed in a shade house in the second week of August 1978, in random positions. Adequate water was supplied by supplementing natural rainfall during the cooler months such that the pots did not dry out. In the warmer months the pots were watered at least every third day to bring moisture content up to field capacity. No replacements were made for losses and pots were repositioned every fortnight.

All pots were harvested in the second week of August 1979. Plants were washed free of the soil media and measured for shoot height and root length, after drying with paper towels. Fresh weight and dry weight, after 48 hours at 60°C, were recorded for each individual surviving plant.

Reference to Table 1 shows that four combinations of A. *pruinocarpa* and A. *aneura*, 3 of A. *craspedocarpa* and A. *aneura* and 2 of A. *linophylla* and A. *aneura* were used. In addition set 5, all *Acacia aneura*, was available for use in comparison with the mixtures in calculating relative yield[6].

Survival

Survivors and losses are summarized in Table 1. Overall loss of seedlings was greatest in coarse sand (32.5 per cent) followed by desert loam (22.5 per cent). Losses in the mixture of desert loam and sand, and in desert sand were the same, at 15 per cent. *Acacia aneura* seedlings survived the experiment as a whole better than the others, losing only 10 per cent of total seedlings. Survival of *Acacia craspedocarpa* was 83 per cent, A. *pruinocarpa* 68 per cent and *Acacia linophylla* was the poorest performer overall with only 50 per cent of seedlings surviving. The latter two survived better in coarse sand and desert sand than in desert loam. *Acacia linophylla* survived best in the mixed desert soil and worst in desert loam, and in each of the 1:3 and 3:1 mixtures with *Acacia aneura* only 50 per cent of the A. *linophylla* survived.

Acacia pruinocarpa survivals were more or less uniform across the soils with a slightly poorer performance in desert loam where survivors were 60 per cent. Survivals of A. *pruinocarpa* in competition with A. *aneura* were best at 1:3 where A. *pruinocarpa* survived in each soil. Survival was 75 per cent in both 3:1 and 2:2 mixtures, but only 50 per cent survived in 4:0, with survivals uniformly 2 per pot across all soils. Of the 8 combinations of 3 or more A. *pruinocarpa* per pot in only 2 (3:1, both sands) did more than 2 individuals of this species survive.

Acacia craspedocarpa survived well in all soils except the coarse sand. Survival was particularly good in desert loam, however only one loss occurred in each of desert sand and the mixture. Survival was high in both 3:1 and 2:2 mixture with *Acacia aneura*, where only one plant died in each, and in both cases that was in coarse sand. Most losses of A. *craspedocarpa* occurred in the 4:0, where only in desert loam did all four plants survive.

Acacia aneura showed greatest losses in coarse sand (4 of 17 died), none were lost in desert sand, 1 from the loam/sand mixture set and two from desert loam. There were no losses in mixture with *Acacia craspedocarpa* at 1:3 and 2:2. Three losses each occurred in mixtures with A. *pruinocarpa* and A. *linophylla*, of which 2 of each were in coarse sand and one of each in desert loam. Of the three species grown at 4 seedlings to a pot *Acacia aneura* was the most successful with only one loss.

Growth of *Acacia aneura* seedlings

Measurements of the 61 *Acacia aneura* seedlings which survived to harvest are summarised in Fig. 2. Soils are numbered in the same sequence as given in Table 1. Total individual plant dry weight (top and root combined) is illustrated as the dependent variable with shoot (stem and phyllodes) dry weight, number of living phyllodes, and height as independent variables. This presentation ignores the effects of competition and serves to describe the range of growth achieved by *Acacia aneura* in the trial and to relate growth in terms of dry weight to other growth indices as between the four soil types. It will be noted that the scales for the constituent graphs 1, 2 and 3 of Fig. 2 representing coarse sand are different from the others. Levels of dry matter production, height and numbers of phyllodes retained with soil treatment one were all much lower than for the other three soils. Scales on Fig. 2 for soils 2, 3 and 4 are the same.

Greatest individual dry weight was achieved in soil 3 (mixture) at 1.77g from a pot containing two small survivors of (three planted) A. *pruinocarpa*. The same soil also produced another A. *aneura* of 1.50g from a pot containing 2 well grown A. *craspedocarpa* at 0.93 and 0.58g, plus another mulga of 0.73g. The next most productive soil was desert loam (soil 4) and it is of interest to note that for similar total dry weights those plants grown in desert loam tended to have a higher proportion of tops than plants grown in the mixed soil (cf Fig. 2, 7 and 10). Dry matter production was least in coarse sand but many of the A. *aneura* grown in desert sand produced dry matter well within the range for the two better soils.

Mean dry weights of individual plants by soil medium are shown in Table 2. Growth differences between soils were significant at p0.001.

The proportion of dry matter in shoots compared with roots (expressed as shoot/root ratio or S/R) may be inferred from Fig. 2. For coarse sand smaller plants had S/R > 1 whereas larger plants had S/R < 1. The means trend was <1 for both desert sand and desert loam, whereas for the mixture S/R was >1.

Phyllode numbers did not exceed 5 in coarse sand, the highest number was recorded in desert loam (18) on a plant of dry weight 1.13g from a pot containing one survivor of (three planted) A. *pruinocarpa* and two plants from the mixed soil had 16 phyllodes. The trends evident were for higher phyllode numbers at a given weight in desert sand and at larger weights for plants grown in desert loam. The latter tended to have more phyllodes at a given weight than plants grown in the mixed desert soil.

Root lengths have not been summarised here as the pot size restricted vertical extension considerably. Under this restriction *Acacia aneura* typically produces coiled roots in the bottom of the pot. Unravelling and linear measurements are scarcely indicative of what might occur in the field or with taller pots. Height extension however has been taken into consideration, on the assumption that root extension restriction is unlikely to affect height growth in the short term provided adequate moisture is available. Tallest individuals of *Acacia aneura* were recorded in desert loam where 3 individuals exceeded 10cm, with the tallest at 12.0cm. One individual reached

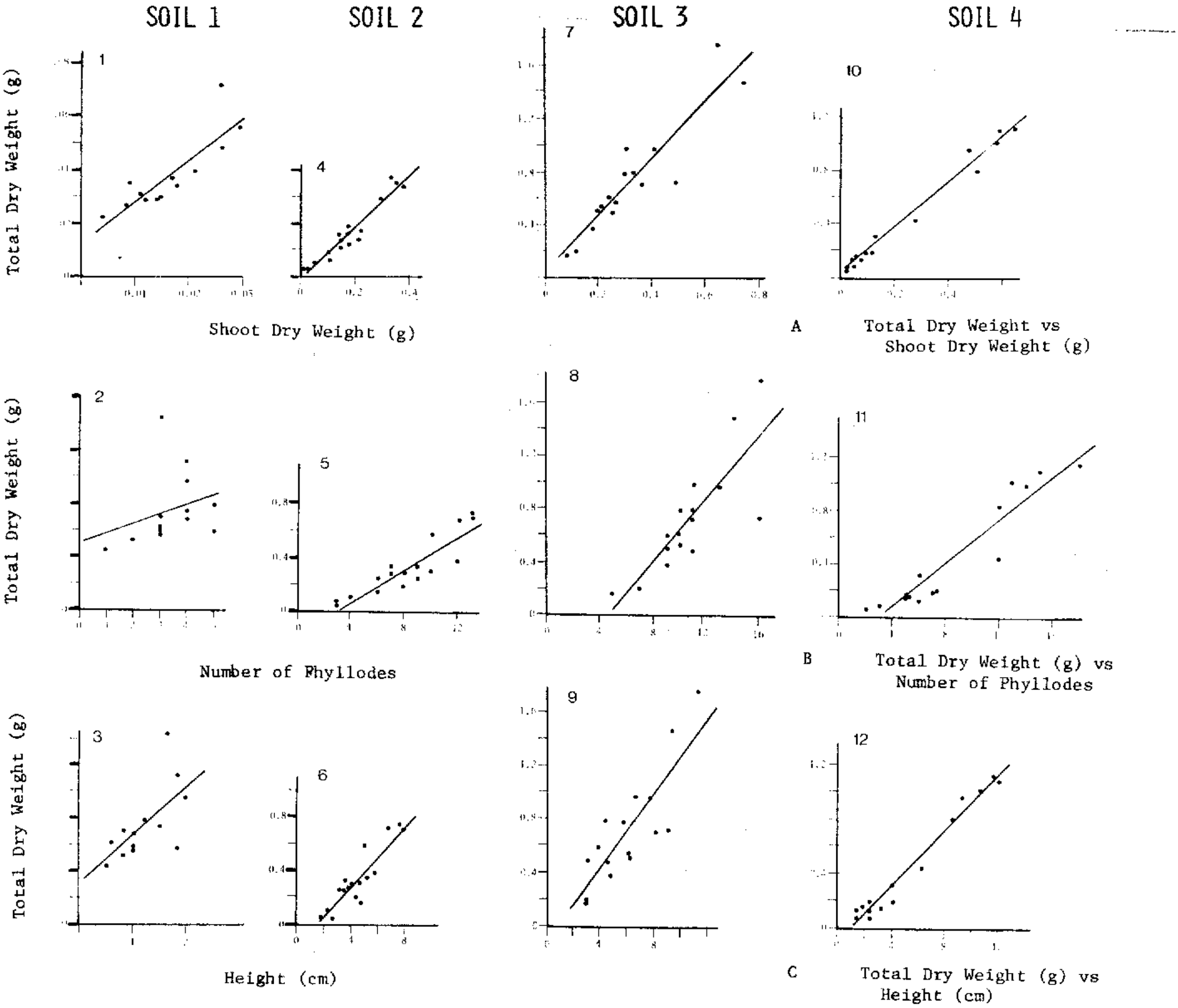

Figure 2. Individual plant measurements and regression lines for *Acacia aneura* seedlings grown in 4 soil types.

11.1cm in mixed desert sand/loam. At a given dry weight the overall trend was for plants grown in the mixed soil to have fewer phyllodes than those in desert sand or desert loam.

The linear regression equations for *Acacia aneura* illustrated in Fig. 2 are as follows:

Soil 1 CS (n=13)

(1)TDW = .013 + 1.535 SDW r = .852***
(2)TDW = .026 + .004 NP r = .288NS
(3)TDW = .016 + .018 H r = .643*

Soil 2 DS (n=17)

(4)TDW = -.022 + 2.019 SDW r = .974***
(5)TDW = -.179 + .062 NP r = .898***
(6)TDW = -.167 + .110 H r = .911***

Soil 3 MIX 2/4 (n=16)

(7)TDW = .038 + 2.159 SDW r = .921***
(8)TDW = -.537 + .117 NP r = .818***
(9)TDW = -.132 + .143 H r = .832***

Soil 4 DL (n = 15)

(10)TDW = .039 + 1.718 SDW r = .992***
(11)TDW = -.244 + .081 NP r = .950***
(12)TDW = -.118 + .105 H r = .985***

in addition we may note for combined soil treatments:

Soils 2, 3, 4 (n=48)

TDW = .017 + 1.989 SDW r = .951***
TDW = -.316 + .089 NP r = .869***
TDW = -.147 + .122 H r = .881***

All soils (n=61)

TDW = .012 + 2.009 SDW r = .962***
TDW = -.271 + .085 NP r = .895***
TDW = -.124 + .119 H r = .908***

Significance level of correlation coefficient
r *p0.05; **p0.01: ***p0.001

In each case shoot dry weight is a more accurate predictor of total dry weight than either height or phyllode number. However the latter two can be objectively determined without seedling destruction and may thus be more useful for rapid estimation or for comparative non-destructive sampling.

Taking the model incorporating both height and numbers of phyllodes as determinants of total dry weight, viz:

Total Dry Weight = a+b(height) + c(number of phyllodes) i.e. TDW = a+bH+cNP the following set of regression equations is obtained:

Soil 1 CS (n=13)
TDW = .016 + .018H + .0001NP
r = .643*

Soil 2 DS (n=17)
TDW = -.195 + .066H + .028NP
r = .927***

Soil 3 Mix 2/4 (n=16)
TDW = -.400 + .085H + .057NP
r = .859***

Soil 4 DL (n=15)
TDW = -.150 + .088H + .015NP
r = .987***

and combining soil treatments

Soils 3, 4 (n=31)
TDW = -.245 + .062H + .050NP
r = .899***

Soils 2, 3, 4 (n=48)
TDW = -.258 + .072H + .041NP
r = .898***

All soils (n=61)
TDW = -.204 + .074H + .035NP
r = .919***

It may be noted that for coarse sand the two variable expression is identical in a, b and r to that for the linear regression of total dry weight and height. Clearly taking account of phyllode numbers has added nothing to the prediction of dry weight based on height for this soil. Plants from this soil had lowest standard deviation in relation to mean weights (Table 2).

For all other cases the combination of height and number of phyllodes gives a more efficient estimate of total dry weight than each separately. With all plants combined the differences are minor, as will be discussed below.

Table 2. Dry matter production. Mixed *Acacia* species competition

Species	Soil Medium: Coarse sand 1	Desert sand 2	Mixture (2&4 50%) 3	Desert loam 4	Significance, variance ratio
	Mean Dry Weights Individual Plants (g)				
A. pruinocarpa	0.079	0.139	0.187	0.203	F 3.08 *
SD	0.038	0.090	0.084	0.108	
A. aneura	0.038	0.333	0.725	0.455	F 11.41 ***
SD	0.014	0.223	0.421	0.414	
A. linophylla	0.261	1.032	1.257	1.824	F 47.85 **
SD	0.051	0.057	0.157	-	
A. craspedocarpa	0.109	0.418	0.777	0.687	F 6.49 **
SD	0.052	0.327	0.332	0.302	
	Total production, mean per pot, by soil medium				
	0.211	1.201	2.290	1.605	F 11.02 ***
SD	0.084	0.567	1.170	1.023	

Significance of variance ratio F * p0.05; ** p0.01; *** p0.001

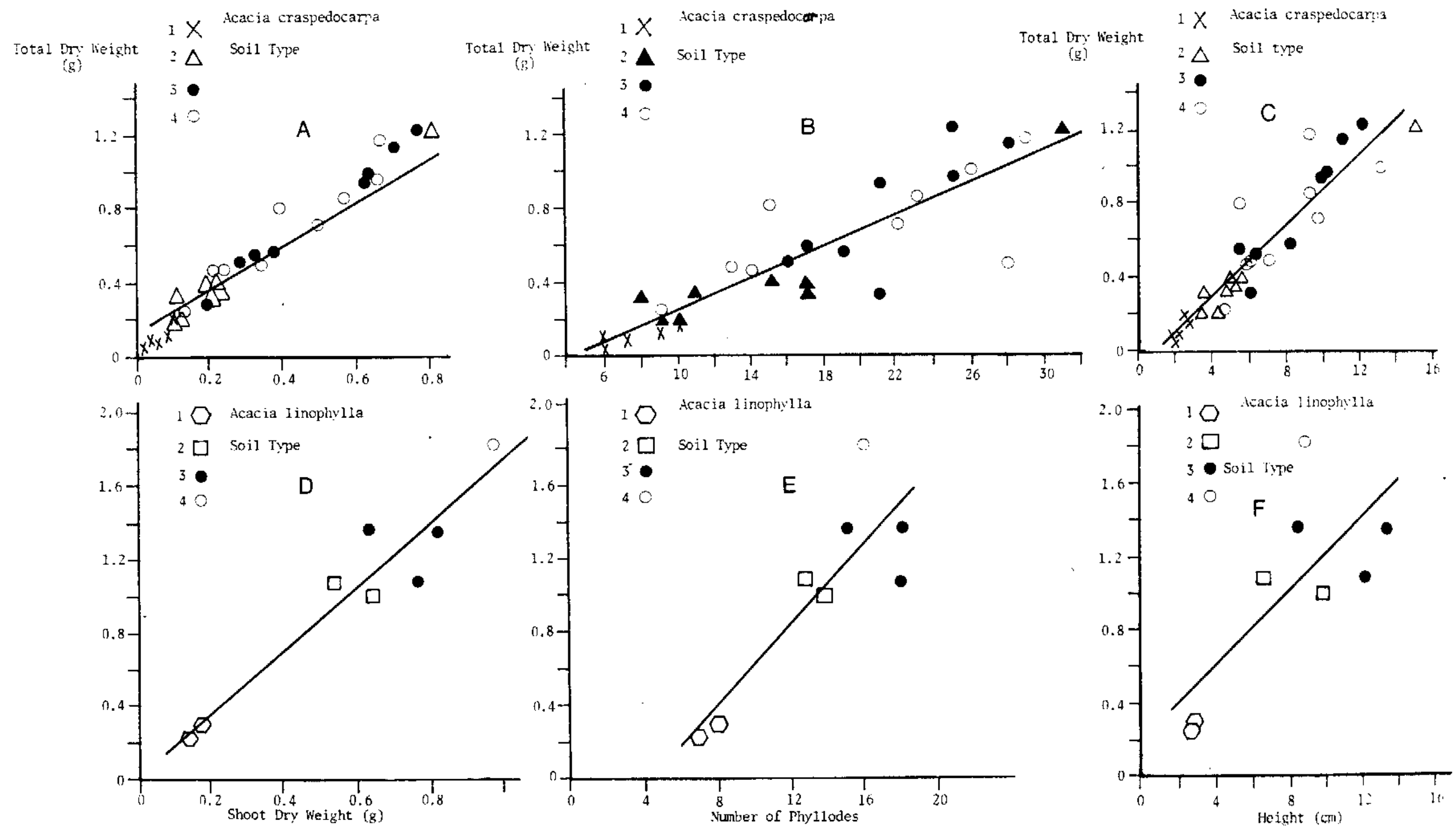

Figure 3. Individual plant measurements and regression lines for, above, *Acacia craspedocarpa*: A, total dry weight (TDW) and shoot dry weight; B, TDW and number of phyllodes; C, TDW and height; and, below, *Acacia linophylla*: D, TDW and shoot dry weight; E, TDW and number of phyllodes; F, TDW and height.

Soil types as follows 1, coarse sand; 2, desert sand; 3, mixture of 2 and 4; 4, desert loam.

Comparative Dry Matter Production

In Table 2 we have noted that *Acacia aneura* performed best in mixed desert soil, followed by desert loam then desert sand and finally coarse sand. The same pattern is seen for *Acacia craspedocarpa*. *A. linophylla* and *A. pruinocarpa* performed best, on average, in desert loam, followed by the mixture and then by the other two soil media as for *A. aneura*. All of the differences were significant at p0.05 or better. Total overall production per pot reflected the performance of *A. aneura* and *A. craspedocarpa* which between them accounted for 91 of the 126 surviving plants.

A. linophylla produced greatest mean plant weight in each soil, followed consistently by *A. craspedocarpa*. Then came *A. aneura* and *A. pruinocarpa*, with the exception of coarse sand where *A. pruinocarpa* plants produced greater dry matter than *A. aneura*.

Relative to the highest overall mean pot production of 2.29g in desert mixture the other soils were desert loam 70 percent, desert sand 52 percent and coarse sand 9 percent.

The constituent graphs of Figs. 3 and 4 illustrate total dry weight production in *Acacia craspedocarpa*, *A. linophylla* and *A. pruinocarpa* in similar fashion to *Acacia*

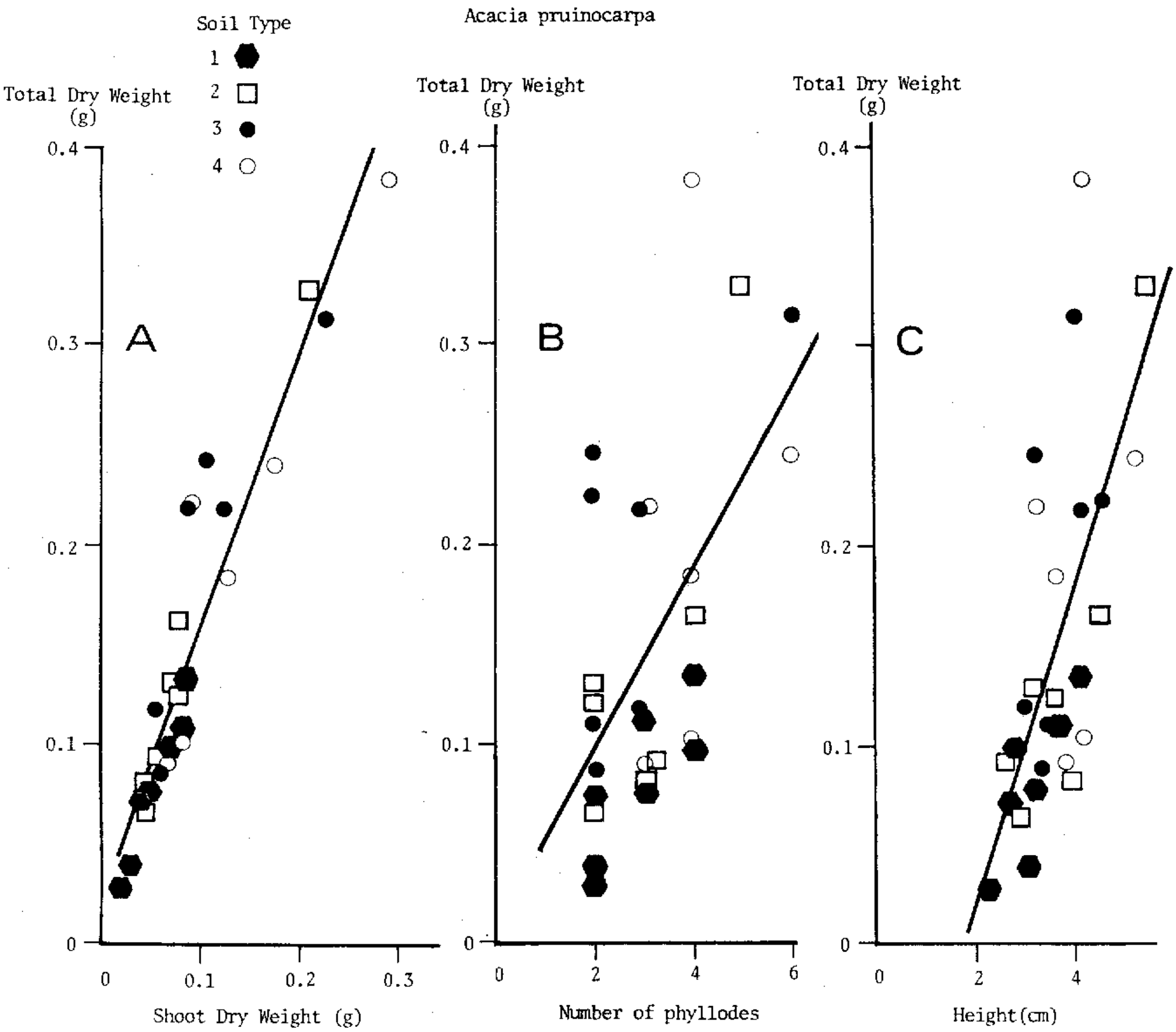

Figure 4. Individual plant measurements and regression lines for *Acacia pruinocarpa*.
Total dry weight (g) and A, shoot dry weight; B, number of phyllodes; C, height (cm).
Soil types as follows 1, coarse sand; 2, desert sand; 3, mixture of 2 and 4; 4, desert loam.

aneura in Fig. 2. Again it will be noted that different scales have been used to emphasise the ranges of production achieved as between species, and here that soil medium is given by symbols as fewer individual plants were available.

With *A. craspedocarpa* more of the heavier individuals were found in the desert soil mix. One individual in desert sand attained 1.20g dry weight, this was the largest of three survivors of a set of four planted. This individual with S/R of 2.1, attained a shoot height of 15cm and had 31 phyllodes at harvest. The other 7 individual survivors in desert sand were clustered at the lower end of the graphs with a tendency to have more phyllodes for a given dry weight than individuals from the other soil media.

Acacia craspedocarpa plants generally had S/R of >1, though the smallest plants, grown in coarse sand had ratios much closer to 1 than larger plants. The two largest individuals from desert soil mixture were 1.23g, S/R 1.67, 25 phylls 12.1cm tall, from a pot of 3/4 survivors; and 1.14g, S/R 1.64, 28 phylls, 11cm tall, from a set of 4 survivors three of which were *A. craspedocarpa*, the fourth *A. aneura*. The largest individual from the desert loam soil attained a total dry weight of 1.17g with a shoot/root ratio of 1.33, it had 29 phyllodes and was 9.2cm. This was from a set of 4 survivors, 3 *A. craspedocarpa* and one *A. aneura*.

Taking a relative total dry weight of 100 for the desert soil mixture plant of 1.23g, the relative values of heaviest individuals from the other three soils were 97.6 for desert sand, 95.4 for desert loam and 14.4 for coarse sand. This compares with 41.8, 64.2 and 4.1 respectively for *Acacia aneura*.

The best individual *Acacia linophylla* grew in desert loam. This attained 1.82g total dry weight with a shoot/root ratio of 1.14, 16 phyllodes and a stem height of 9.1cm (Fig. 3). However there were more survivors in the desert soil mixture where three individuals potted with an *Acacia aneura* all survived and produced individual total dry weights of 1.36, 1.34 and 1.08g compared with the *A. aneura* at 0.72g. The best *A. linophylla* in desert sand attained 1.07g where two out of 3 survived with one *A. aneura*. Two survived in coarse sand giving 0.30 and 0.23g total dry weight. Performance of *A. linophylla* in coarse sand was better than the other species where greatest individual total dry weights were 0.13g for *A. pruinocarpa*, 0.18g for *A. craspedocarpa* and 0.07g for *A. aneura*. Shoot/root ratio for *A. linophylla* exceeded 1 and (apart from the single plant from desert loam) number of phyllodes and shoot height increased steadily with total dry weight.

With a relative total dry weight of 100 for the *A. linophylla* desert loam plant, the relative values of heaviest individuals from the other soils were 74.5 for desert mixture, 58.8 for desert sand and 16.3 for coarse sand. A total of 5 individuals exceeded 1.0g total dry weight compared with 4 each of *A. aneura* and *A. craspedocarpa*.

Performance of *Acacia pruinocarpa* was poor in all 4 soil media, compared with the other three species, though it did produce a heavier plant in coarse sand than did *Acacia aneura*. The performance of *A. pruinocarpa* in terms of total dry weight was best in desert loam where an individual survivor (of three planted) reached 0.38g in a pot containing an *A. aneura* of 1.13g. However this individual had only 4 phyllodes and was only 4.2cm tall. The best individual from desert sand attained 0.33g, being one of two survivors of a set of 4 planted. This had 5 phyllodes and reached 5.4cm in height. In desert soil mixture an individual attained 0.31g (2 *A. pruinocarpa* survivors with 1 *A. aneura* of 1.77g) with 6 phyllodes and a height of 4cm. The shoot/root ratios for these three *A. pruinocarpa* were 3.0, 1.75 and 2.40 respectively. Shoot/root ratios were >1 in all cases.

Relative greatest dry weights by soil were as follows: desert loam 100, desert sand 85.2, mixture 81.5, coarse sand 34.6.

Table 3 shows relative values of heaviest individuals of all species compared with the largest *Acacia linophylla*.

Table 3. Relative Values of Heaviest Individuals in Relation to *A. linophylla*.

	Coarse sand	Desert sand	Mixture	Desert loam
Acacia aneura	3.9	40.1	96.7	62.2
A. craspedocarpa	9.7	65.8	67.4	64.4
A. linophylla	16.3	58.8	74.5	100.0
A. pruinocarpa	7.3	17.9	17.2	21.1

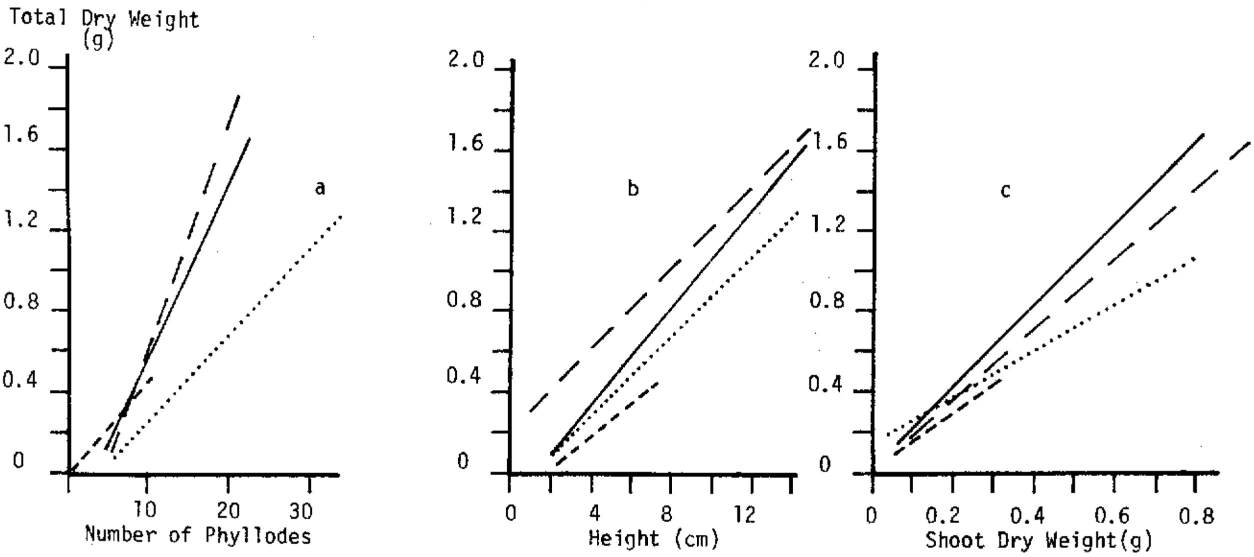

Figure 5. Regression lines for main growth parameters, all soils combined (i.e., Figs. 2-4), for each species ________ *Acacia aneura;* .... *Acacia craspedocarpa;* _ _ _ _ _ *Acacia linophylla;* ---------- *Acacia pruinocarpa.*

Prediction of Dry Matter Production

The data for all surviving plants have been analysed to produce the regression lines of total dry weight with number of phyllodes, height and shoot dry weight presented in Fig. 5.

The regression equations for Fig. 5 are as follows:

(a) Total dry weight (TDW) and number of phyllodes (NP)

A. aneura	TDW = .085 NP - .271,r= .90	***
A. craspedocarpa	TDW = .043 NP - .180,r= .88	***
A. linophylla	TDW = .109 NP - .464,r= .85	**
A. pruinocarpa	TDW = .045 NP + .010,r= .58	**

(b) Total dry weight and height (H)

A. aneura	TDW = .119 H - .124,r= .91	***
A. craspedocarpa	TDW = .098 H - .100,r= .93	***
A. linophylla	TDW = .099 H + .215,r= .74	*
A. pruinocarpa	TDW = .079 H - .137,r= .65	***

(c) Total dry weight and shoot dry weight (SDW)

A. aneura	TDW = 2.01 SDW + .012,r= .96	***
A. craspedocarpa	TDW = 1.15 SDW + .130,r= .83	***
A. linophylla	TDW = 1.74 SDW + .012,r= .95	***
A. pruinocarpa	TDW = 1.36 SDW + .027,r= .93	***

Numbers: *A. aneura* 61; *A. craspedocarpa* 30; *A. linophylla* 8; *A. pruinocarpa* 27.

Significance level of correlation coefficient r *p0.05; **p0.01; ***p0.001

The most efficient predictor overall is shoot dry weight, however, as we have noted above, this involves destructive sampling and for rapid visual assessment it seems that height would be a useful indicator for total dry matter production in *A. aneura*, *A. craspedocarpa* and *A. pruinocarpa*. The fourth species, *A. linophylla* has comparatively long phyllodes and a less definite stem apex. With this latter species number of phyllodes apparently predicts dry matter production more efficiently than does height though the small number of plants involved may have produced anomalous results. Use of number of phyllodes in *A. aneura* and *A. craspedocarpa* is almost as efficient as height, but in *A. pruinocarpa* height is clearly to be preferred. Phyllode retention in *A. pruinocarpa* tended to be poor, the range in numbers being between 2 and 6.

Relative Yield

Relative yield totals for *A. aneura* with *A. pruinocarpa* and with *A. craspedocarpa* at different proportions for each of the soil media, are illustrated in Fig. 6. The method used follows the replacement series principle.[6]

Taking *Acacia pruinocarpa* in soil 1 (coarse sand) as an example the pot planted with 4 seedlings of *A. pruinocarpa* produced 0.23g dry weight. This is given a value of 1.0 to the left of the diagram and the weights of *A. pruinocarpa* obtained from the three other species mixtures available (i.e. 3 *A. pruinocarpa*, 1 *A. aneura;* 2 *A. pruinocarpa*, 2 *A. aneura;* 1 *A. pruinocarpa*, 3 *A. aneura*), are scaled relative to 0.23g as 1.0. The resulting points are plotted as solid squares and joined with a broken line terminating at zero to the right hand side of the diagram. Similarly the coarse sand pot planted with 4 seedlings of *A. aneura* produced 0.14g dry weight and this is given a value of 1.0 to the right of the diagram corresponding to the vertical axis labelled *A. aneura* 1.0/*A. pruinocarpa* 0. *A. aneura* weights from the three pots containing coarse sand, in which *A. aneura* and *A. pruinocarpa* were grown in mixture are scaled relative to 0.14g as 1.0. The resultant points are plotted as solid diamonds and joined with a dashed line terminating at zero to the left hand side of the diagram. The solid line joining the solid square at 1.0 on the left hand vertical axis and the solid diamond at 1.0 on the right hand axis, represents the total dry matter production per pot.

For *Acacia pruinocarpa* it may be seen that highest relative yield totals were achieved in each case with the planted species mixture of three *A. pruinocarpa* with one *A. aneura*. The greatest relative yield over all species combinations was attained with desert loam (soil 4) where *A. aneura* produced greater dry weights with fewer numbers of plants. This

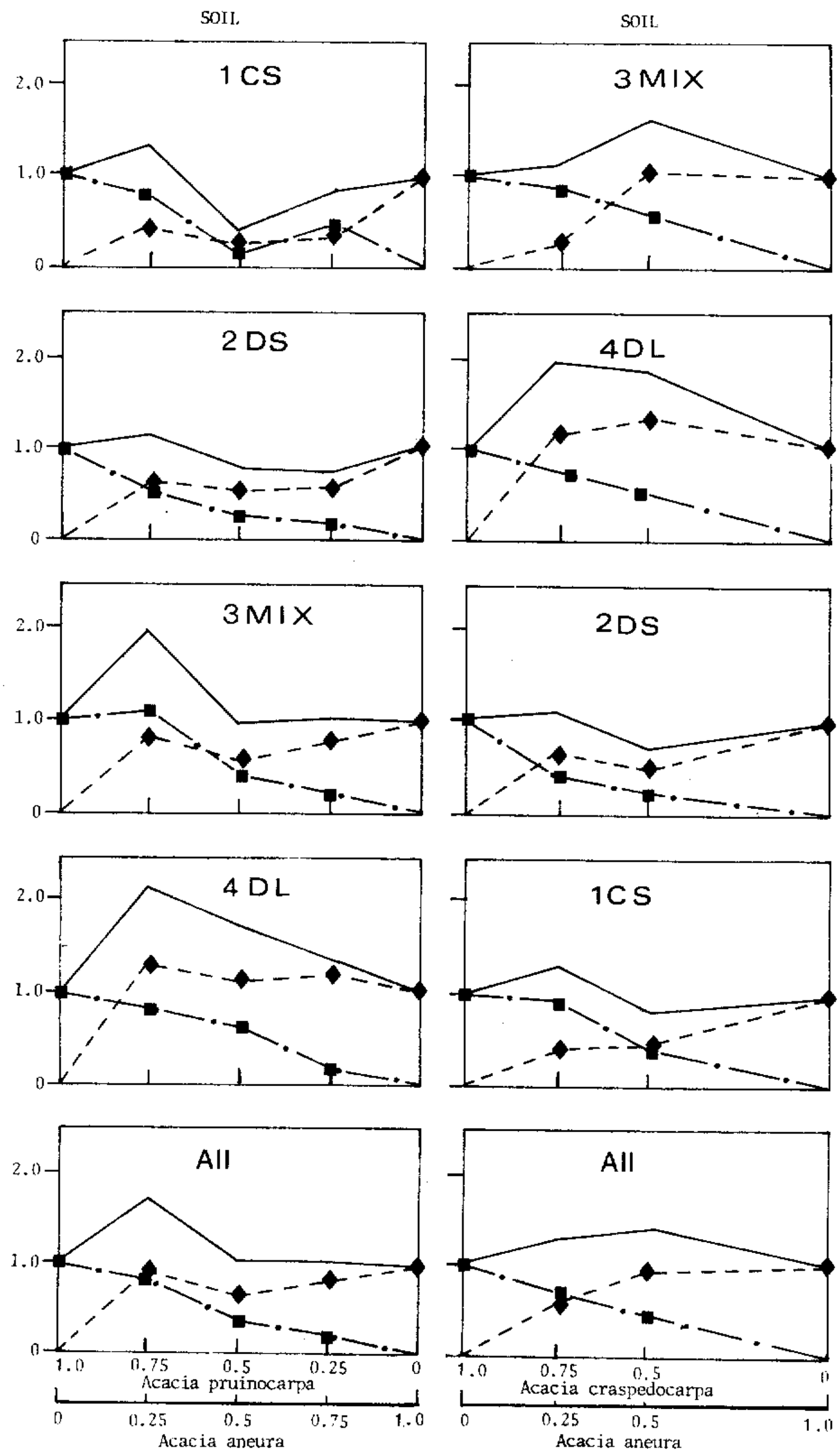

Figure 6. Relative Yield Totals for *Acacia aneura* with *A. pruinocarpa* and *A. craspedocarpa* expressed separately for each soil treatment. Dashed line in each case is the yield of *Acacia aneura*.

was the only soil where the relative yield total greatly exceeded 1.0 for the 0.5/0.5 mixture. In the 0.5/0.5 mixtures *A. pruinocarpa* was uniformly poor over all soils in comparison with *A. aneura*.

In the case of *A. craspedocarpa* in mixture with *A. aneura* (also Fig. 6) highest relative yield total was also attained with desert loam. In both desert loam and the desert soil mixture relative yield totals exceeded 1.0 for both species mixtures of 3 *Acacia craspedocarpa*, 1 *A. aneura* and 2 *A. craspedocarpa*, 2 *A. aneura*.

The small number of surviving *Acacia linophylla* precluded an analysis of its performance against *A. aneura* by separate soil mixtures.

A slightly different presentation is given in Fig. 7 which ignores the differences between soil media and compares the overall mean values for *A. aneura* four plants to a pot against the other species.

Table 4. Means and Totals for Dry Weight Yield by Species for Sets of Four Pots

Species mixture (No. of Plants)	Dry weight yields (g) Plant mean	Total all pots	Pot mean
(4)A. *aneura*	0.28	4.19	1.05
(2)A. *aneura*	0.49	3.93	0.98
(2)A. *craspedocarpa*	0.49	3.45	0.86
	Total	7.39	1.85
(1)A. *aneura*	0.59	2.36	0.59
(3)A. *craspedocarpa*	0.49	5.38	1.35
	Total	7.74	1.94
(4)A. *craspedocarpa*	0.62	7.45	1.86
(3)A. *aneura*	0.31	3.36	0.84
(1)A. *pruinocarpa*	0.10	0.40	0.10
	Total	3.76	0.94
(2)A. *aneura*	0.45	2.68	0.67
(2)A. *pruinocarpa*	0.11	0.64	0.16
	Total	3.32	0.83
(1)A. *aneura*	0.91	3.66	0.91
(3)A. *pruinocarpa*	0.15	1.36	0.34
	Total	5.02	1.25
(4)A. *pruinocarpa*	0.21	1.65	0.41
(3)A. *aneura*	0.34	3.37	0.84
(1)A. *linophylla*	1.06	2.12	0.53
	Total	5.49	1.37
(1)A. *aneura*	0.34	1.03	0.26
(3)A. *linophylla*	1.01	6.06	1.51
	Total	7.09	1.77

The mean dry weight of the four pots planted with four *Acacia aneura* was 1.05g and this was used to give a relative value of 1.0 (solid circles to the left of each of Fig. 7 A-C). The relative value of the mean dry weight for the sets of 4 *A. craspedocarpa* of 1.78 was derived from the actual yield of 1.86g (Table 4). Weights of each species in the mixtures are entered as proportions of the same relative value and summed as for Fig. 6 to give total dry weight yields relative to *A. aneura* alone.

Four *A. craspedocarpa* outgrew four *A. aneura* by 78 percent and the combinations of 3 *A. craspedocarpa*, 1 *A. aneura*; and 2 *A. craspedocarpa*, 2 *A. aneura*; produced 84 and 76 percent more dry weight respectively than *A. aneura* did alone (Fig. 7). A combination of the two species appears able to make more efficient use of resources than *A. aneura* alone and *A. aneura* makes a proportionately greater growth contribution in mixture.

A comparison of Fig. 7A and B suggests that *A. aneura* can grow more efficiently with *A. craspedocarpa* than it can with *A. linophylla*. This is mirrored by a comparison of actual yields (Table 4). Under the conditions of the experiment *A. pruinocarpa* competed least efficiently with *A. aneura* (Fig. 7C).

Discussion and Conclusions

Statistical precision in the experiment reported was precluded by a lack of replication, and losses of some plants may have distorted mean values. As a preliminary study of comparative growth and competition several trends deserve emphasis.

Combinations of *A. aneura* and *A. craspedocarpa* produced greatest overall growth though *A. linophylla* individuals were consistently heavier than those of other species. While too few examples were available it was noteworthy that *Acacia linophylla* survivals were fewest in desert loam, a soil on which it does not attain dominance in nature.

A. aneura and *A. craspedocarpa* grew best in desert soil mixture, whereas the other two did so in desert loam. The order of individual growth was *A. linophylla* > *A. craspedocarpa* > *A. aneura* > *A. pruinocarpa*, across all soils.

Highest relative yield totals were obtained in desert loam which probably reflects a greater supply of growth factors in this medium.

Acacia pruinocarpa has proven difficult to grow in the nursery at Bentley. Lack of success with multiple plant pots may point to an allelopathic problem with this species. Root odour for *A. pruinocarpa* is intense, red leaf colour is common and phyllodes tend to dry off, with many seedlings remaining small. Its performance by soil medium was consistent with what may have been expected from its known distribution.

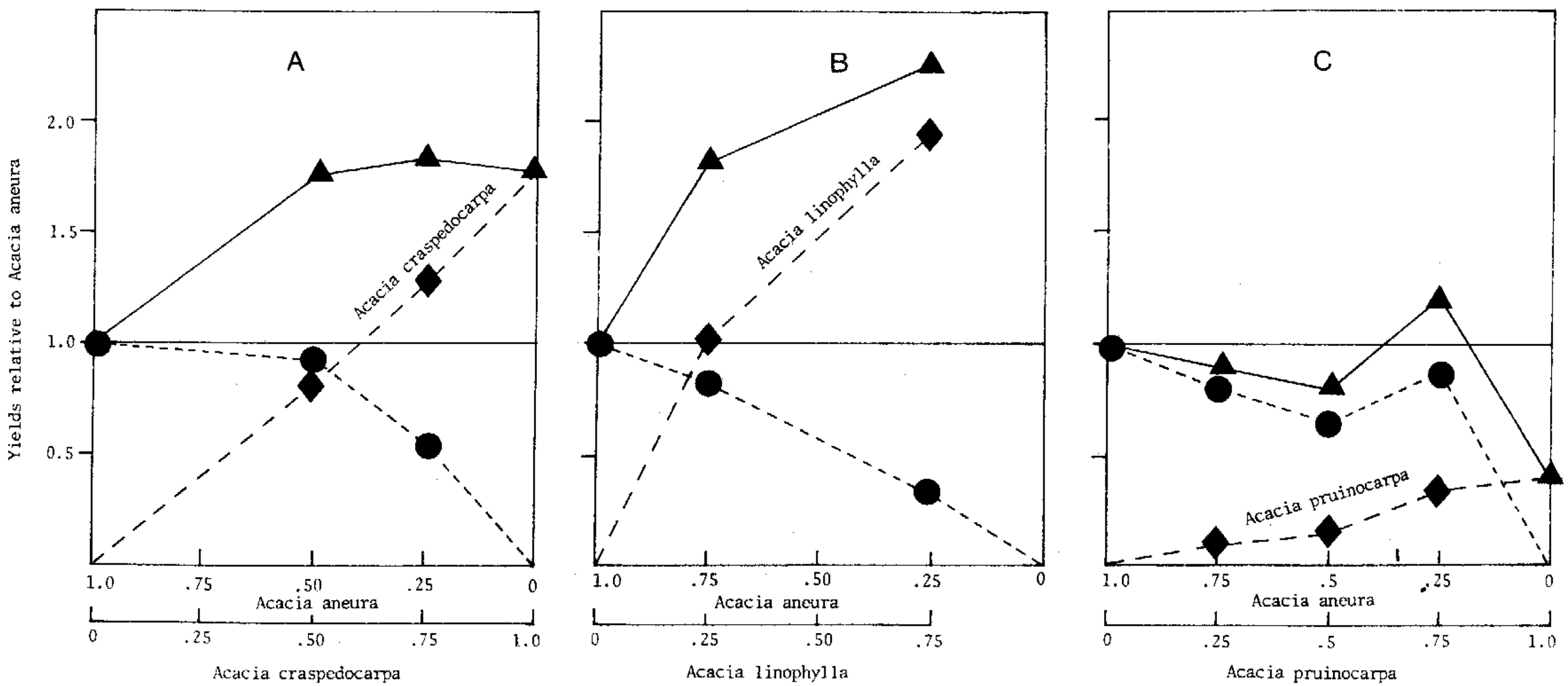

Figure 7. Dry weight yields relative to *Acacia aneura* at four plants per pot, means of all soil treatments ▲ total, ● *Acacia aneura*, ◆ competitor. A, *Acacia craspedocarpa*; B, *A. linophylla*; C, *A. pruinocarpa*.

Mean production in desert sand was about half of that obtained in mixed desert soil. Surviving *A. linophylla* were at least twice as heavy as individuals of other species grown in desert sand. The remarkable performance of *A. linophylla* in desert loam (Table 2) was based on only one individual.

Acacia aneura plants attained greatest weights in mixed desert soil, due to higher S/R ratio. At given weights this mixed soil produced plants with fewer phyllodes than did desert loam, where the tallest individuals occurred.

Plant height appears to be a useful indicator of dry matter production in all except *Acacia linophylla*.

Acknowledgements

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CHANGES IN A STAND OF *ACACIA ANEURA* CAUSED BY A HAIL STORM

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Introduction

Hail damage is one environmental factor which is believed by many people to be responsible for the death of *Acacia aneura*[1] Davies observed a stand of trees at Mileura Station where hail stripped off phyllodes and broke twigs in December 1965[3]. Several trees died but a number slowly regenerated and flowered in 1968.

Two areas at Sherwood Station have been examined recently for regeneration following death of trees by hail damage[4].

The present paper describes the short term effects of a hail storm on the *Acacia aneura* stems in a sample plot of 0.4ha at Altona, Yeelirrie Station (Fig. 1).

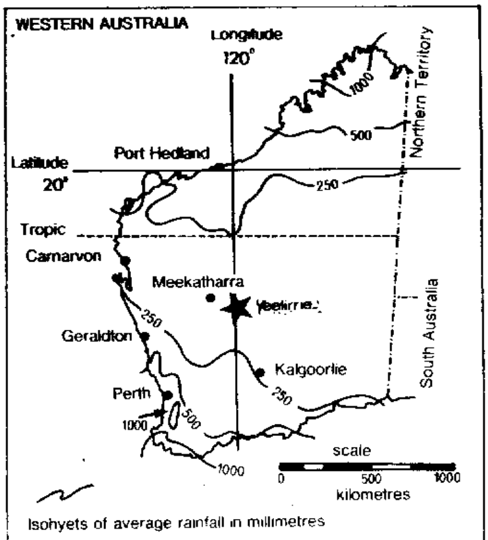


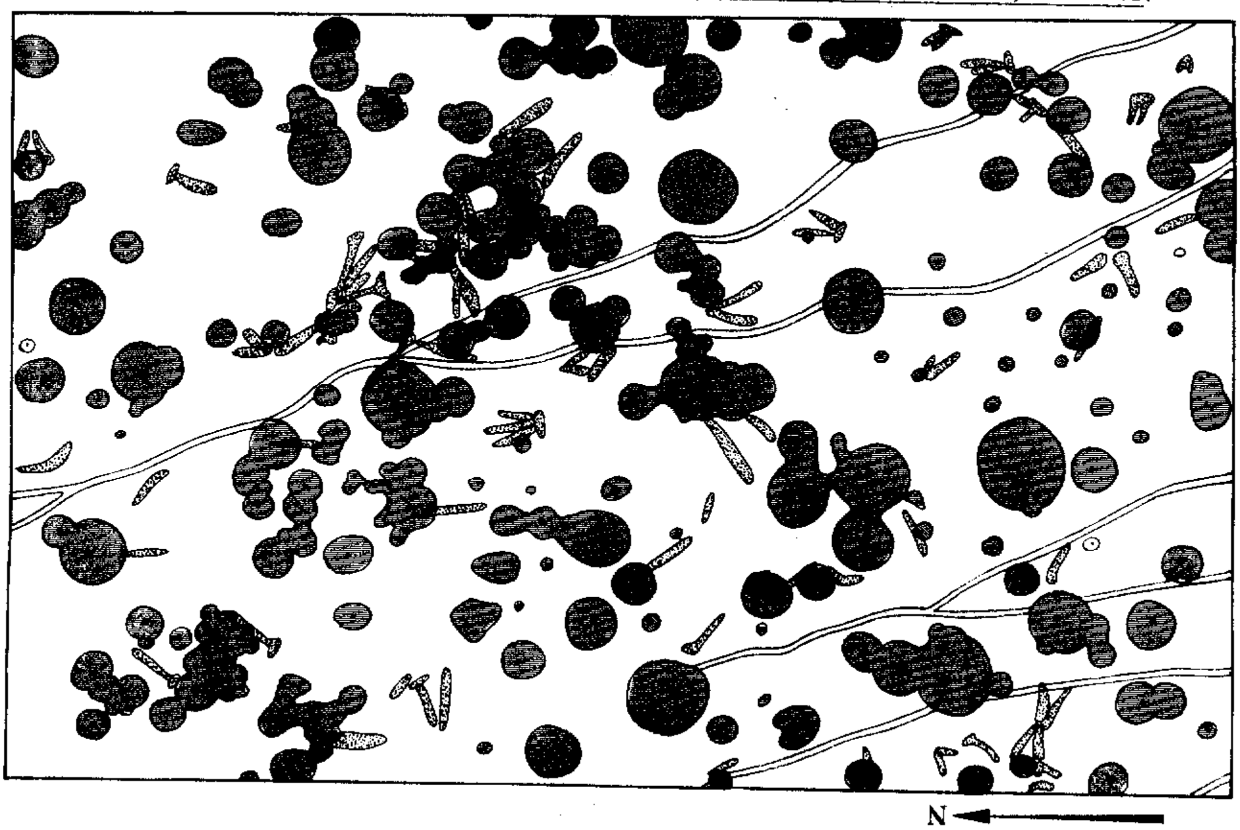
Figure 1. Location Map, Yeelirrie.

The Study Site

A number of plots of size 0.05ha have been established at Yeelirrie to investigate the effects of de-stocking on *Acacia aneura*[5,6]. A larger area was selected, established and all trees measured in July 1977 to study long term stability in conjunction with the de-stocking investigations. The plot size selected was 50 x 80m. An account of spatial pattern in *Acacia aneura* within this study site has been published elsewhere.[7]

Measurements at establishment were for height, crown diameter and stem diameters at 1.3m from the ground. All plants were classified by phyllode type.

Figure 2. Crown cover, surface dead wood and old sheep tracks, Altona Plot, Yeelirrie.



Hail fell in the area on December 17th 1978 flooding the nearby roads and stripping much of the foliage from trees in a broad belt across (west to east) the lower part of the station (pers. comm. Bob Biggs). A brief visit was made to the area on February 23rd 1979, a rather longer inspection was made on May 15th 1979, but it was not until the middle of July 1979 that the plot was totally re-measured, on 13-14th of that month, exactly two years after the plot was first established.

Figure 2 shows the canopy cover of the mulga trees, dead wood and old sheep tracks. Crown cover in the area was 19.6 percent at July 1977. Measurements for a total of 319 individual plants are available for both July 1977 (pre-hail) and July 1979 (post hail). A summary of numbers by height size classes and by eight sub-plots of 0.05ha is given in Table 1.

Table 1. Stems of *Acacia aneura* present in 1977 and 1979, by 1977 size classes

Height Size Class (m)	Numbers of Stems in $500m^2$ sub plots — Sub-plot 1	2	3	4	5	6	7	8	Total Stems
< 0.5	13	1	3	6	14	3	12	6	58
0.5-0.99	14	-	-	11	1	3	3	4	36
1.0-1.99	19	4	6	11	2	4	7	3	56
2.0-2.99	9	3	16	6	1	8	8	7	58
3.0-3.99	7	4	21	9	5	4	-	6	56
4.0-4.99	4	6	11	-	5	5	-	1	32
5+	1	3	2	2	6	4	3	2	23
Totals	67	21	59	45	34	31	33	29	319

Apart from *Acacia aneura* the only perennial species of any significance in the area (and these are ignored here) were a few *Acacia tetragonophylla* and *Eremophila* sp. aff. *leucophylla*.

Pre-Hail Stand Dimensions

Total number of *Acacia aneura* per ha was 798 exactly double the average stocking of 40 perimeter plots at Yeelirrie reported earlier[6]. The smallest height classes (<1.0m) and the tallest (>4.0m) were present in proportions between 35 and 100 percent more than the average for the perimeter set. The intermediate height classes (1.0 to 3.99m) were very well represented with an average of 165 percent more stems than the perimeter set average.

Tall trees tended to be more scattered than the intermediate sizes, which were often clumped[7] (see also Fig. 2). The mean height overall in 1977 was 2.30m with a range between 0.08 and 5.75m. The corresponding mean crown diameter was 1.77m with a range of 5.76m, between 0.14 and 5.90m. Crown diameters are plotted with height in Fig. 3. Many of the smaller plants had a crown/height ratio >1.0, that is data lying above the dotted meridian line, whereas the majority of stems >2m in height had a crown/height ratio of <1.0. Ranges within size classes increased considerably with size. This was more pronounced for crown diameter than height. Whereas trees of >4.0m tall had a crown diameter range of the order of 3.5m (1.5 to 5+m), those trees with crowns of >4.0m across had a range in height of about 2.5m (4m and over) (Fig. 3).

The 1977 measurements were taken in a period of drought[6]. Many of the smaller plants were not thriving, and some of the intermediate sized stems had suffered drying off of leading shoots.

Visual Effects of Hail

At the brief inspection of February 23rd 1979 many of the taller trees were particularly bare with respect to foliage left in the crowns. Considerable amounts of leaf material were present on the ground and at least 10 newly germinated *Acacia aneura* seedlings were present in groups under three or four different parent trees. These seedlings had grown to about 10cm and presumably originated from the stimulation provided by the soaking received on December 17th two months earlier. These seedlings were not marked. It was anticipated that germination would continue and that a number could be tagged later on.

New foliage had appeared on plants of 10-30cm in height and many of these were in much better condition than at plot establishment.

Individuals with terete foliage in this region tend to have upward sweeping branches with narrow crowns when heights are between 1.5 and 3m or so. These plants and others in the same height range showed a certain amount of bark damage to branches and many twiglets at the tops of branches had been snapped off. There was little evidence of new foliage on trees with narrow phyllodes generally.

In contrast many of the smaller to intermediate sized trees with broader phyllodes showed the presence of new foliage. It seems likely that these individuals had lost proportionately more of their original foliage than had plants with narrower phyllodes. The latter appeared to have retained more phyllodes than those with broader leaves.

On May 15th 25 perimeter trees of 2-6m in height were assessed, exactly 5 months after the hail storm. Of the 25 assessed, 20 had smaller crowns than 22 months earlier while 5, which had presumably suffered less from hail damage, had larger crowns than at plot establishment. The assessment suggested that a total of 8 trees had more or less recovered foliage, 4 showed extensive twig damage still evident and a further 7 had not recovered very well.

By this time a lot of *Leichardtia australis* seedlings and sucker shoots had sprouted and commenced twining into perennial plants.

An attempt was made at assigning a percentage damage value to each individual tree assessed. These percentage values ranged from 0 to 40 percent for an individual with a broken centre crown. None of the 25 trees assessed had greater apparent damage than this. Values could only be given in the series 1, 5, 10, 15, 20, 25, 30 and thereafter in 10 percent ranks.

The percentage change in crown diameter between July 1977 and May 1979 was calculated and the two sets of percentages plotted. With the exclusion of the 5 trees which showed an increase in crown diameter, the scatter of data was tested against a range of equations and the best fit was a linear relation of the form $y = a + bx$

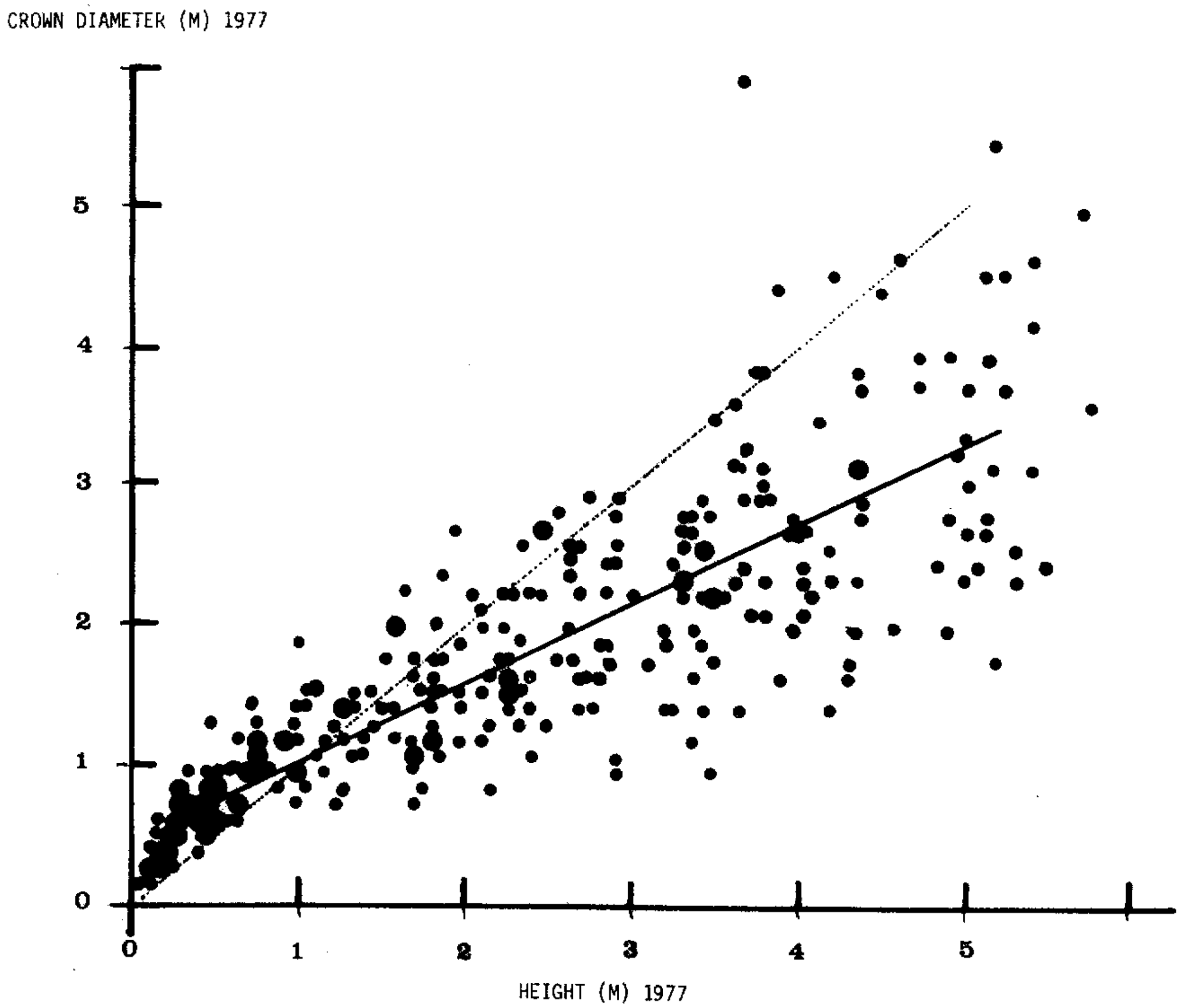


Figure 3. Crown diameter and height (m) for *Acacia aneura* at July 1977.

Solid line is the linear regression CD = 0.45 + 0.57H, r 0.85. Dotted line joins equi-diameter/height points. Small filled circles represent individual stems, larger circles show coincidence of two or more individuals.

where y was percentage change in crown diameter (CD) and x was visually assessed percentage damage (DAM). For the 20 trees which showed a decrease in crown diameter the regression was CD = 2.05 + 0.52 DAM. The correlation coefficient of 0.65 was highly significant.

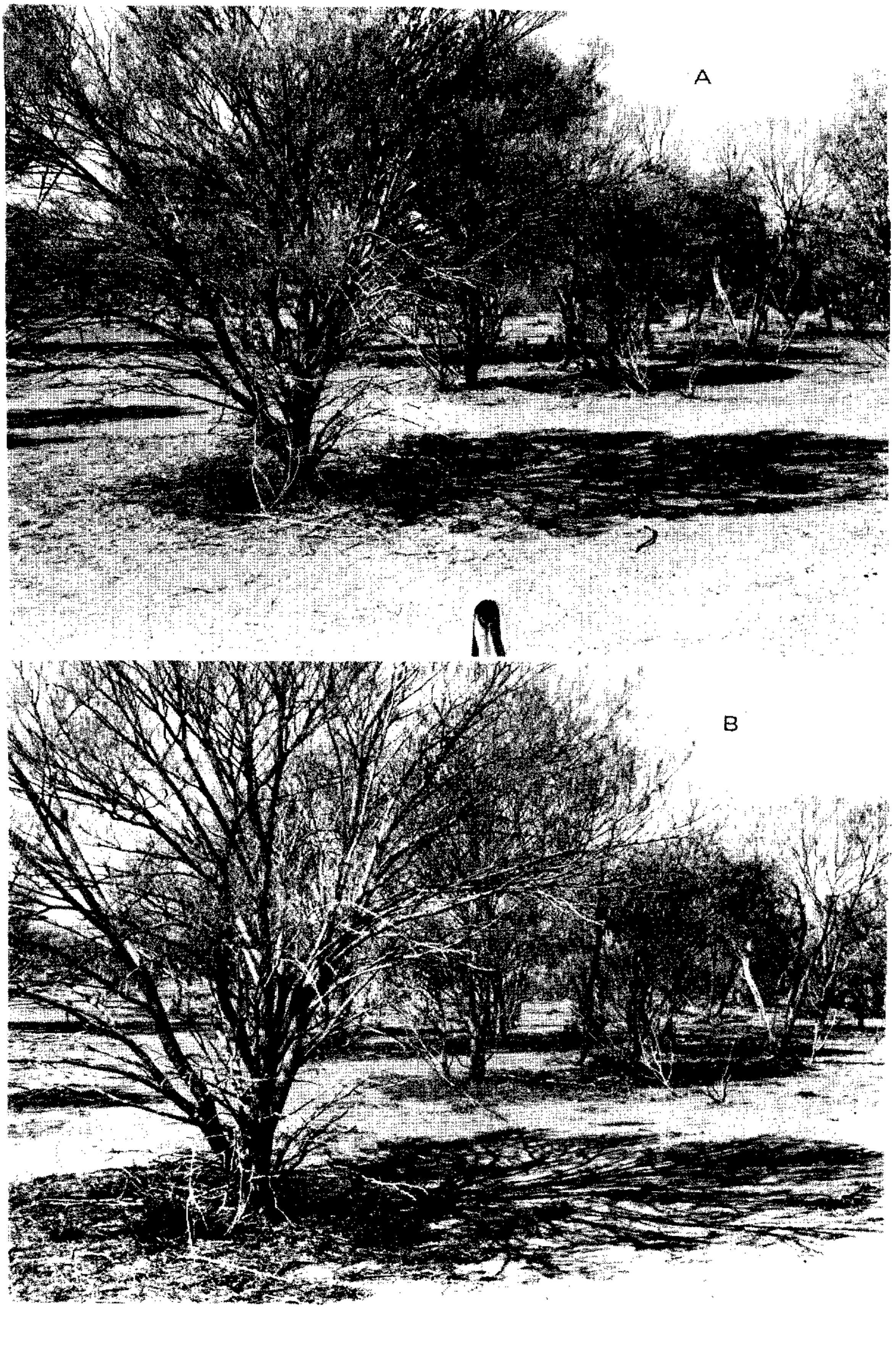
Despite the rather arbitrary nature of its assessment it was considered that this method of categorizing damage would be useful for a subsequent whole plot re-measurement.

There was little trend evident when percentage crown diameter loss was plotted against tree height, and similarly with crown diameter. At this partial measurement the mean height of measured trees was 3.95m compared with 3.64m at plot establishment, while mean crown diameter had fallen away from 2.79 to 2.61m.

Re-measurement of the complete plot is dealt with below. At this point attention is drawn to the photographs shown in Fig. 4. The upper one was taken at plot establishment and the lower at complete re-measurement two years later, and 7 months after the hail storm. The large tree to the left is tree 1 of sub-plot 5, it has long narrow phyllodes and was 3.7m tall at both measurements. In 1977 its crown diameter was 5.9m and this had fallen to 5.25m by July 1979, a loss of 11 percent. The lower photograph shows considerably more litter on the ground under the tree, thinner foliage in the crown and less shadow cast than does the upper photograph.

Figure 4. View across the plot from the middle of the western edge looking to the south east.

A July 15th, 1977, B July, 14th, 1979.



Post-Hail Stand Dimensions

The sad omission from this report is an account of the fate of newly germinated seedlings reported above. By July 1979 there were no seedlings in the north western sector under the trees where seedlings had been observed in February. It is possible that root competition here was too much especially in view of the continued comparatively droughty conditions. Crisp[2] has reported that mulga seedlings tend to occur clustered among and associated with stands of dead trees. It may be presumed that had the damaged trees concerned been killed then these seedlings may have survived.

Diligent searching of the entire plot did produce a total of 13 live seedlings which had not previously been recorded. These were mainly in the east of the plot and they tended to occur in-between large *Acacia aneura* trees. The size range of these seedlings was from 4-37cm in height and mean height was 17.5cm. The larger individuals (33, 36 and 37 cm) may have been missed at plot establishment though the smaller ones (4, 4, 7, 8 and 9cm) were definitely recent additions. It will be interesting to see whether this cohort can survive root competition. New additions are not dealt with further in this account.

The mean height at July 1979 was 2.35m, an overall average increase of 0.05m over the two year period. Of the 319 individuals present in 1977 and 1979 the shortest was 0.10m in 1979 and the tallest 5.80m giving a range of 5.7m. The corresponding mean crown diameter was 1.77 - no change from 1977, though many individuals had lost diameter, as noted above. The losses were reflected in the range which had fallen to 5.40 (from 5.76) between 0.15 and 5.55m (from 0.14 and 5.90m).

Crown diameters are plotted with height in Fig. 5. Much the same sorts of generalisations apply as for the data of Fig. 3 (see above), however the differences in ranges with increased size had become even more marked by July 1979. Trees of >4.0m tall had now reached much greater range, of the order of 5m (0.5 to 5+m), and trees with crowns >4.0m diameter now had a smaller range in height than they had in 1977, of about 2m (3.7m and over). The overall relationship between crown diameter and height as shown by the linear regression is not dissimilar to the pre-hail status (Fig. 3) despite these general effects. If both linear regressions were plotted on the same graph, that for 1979 would be just below that for 1977 but more or less parallel to it.

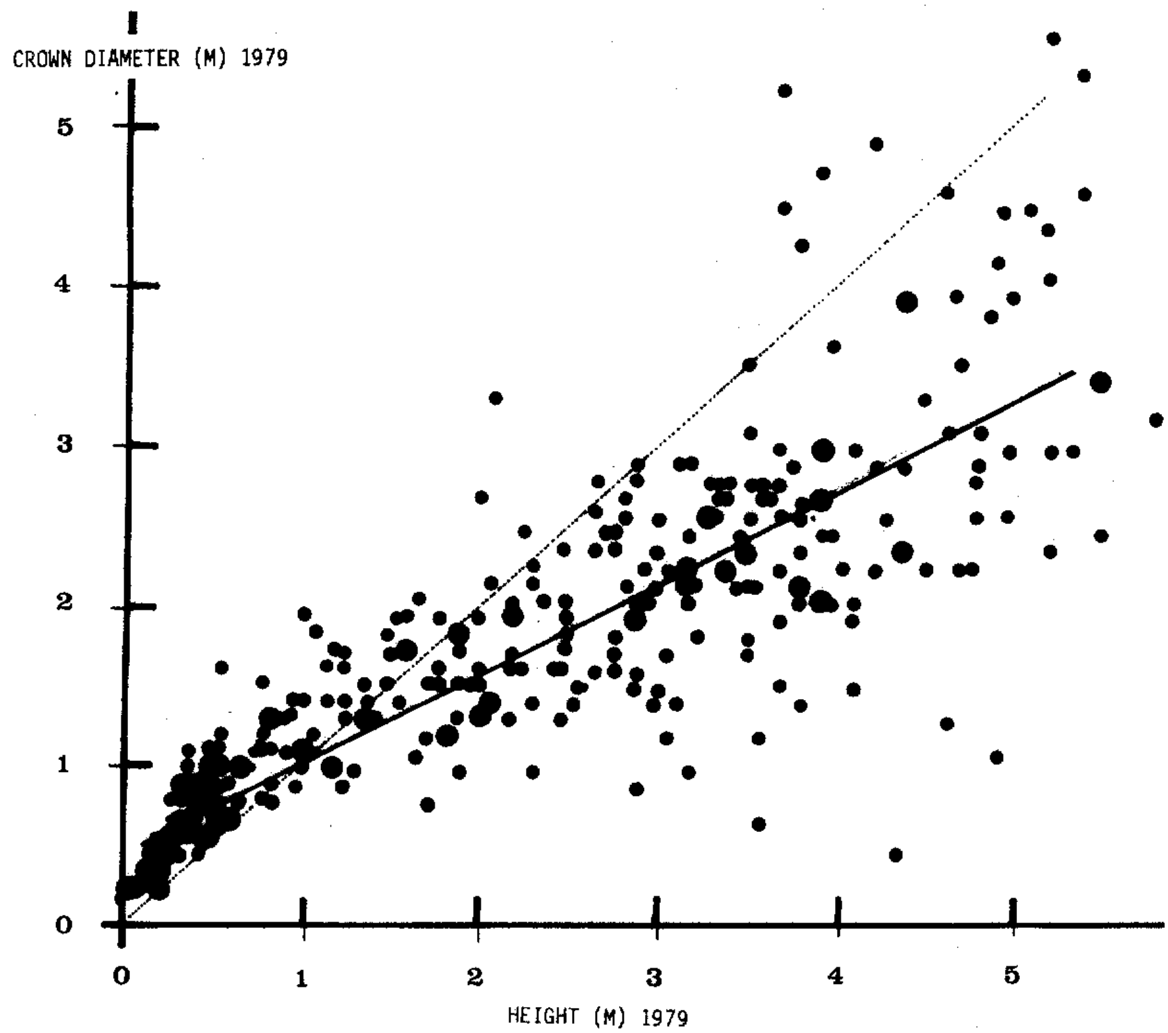


Figure 5. Crown diameter and height (m) for *Acacia aneura* at July 1979.

Solid line is the linear regression $CD = 0.43 + 0.57H$, r 0.83. Dotted line joins equi-diameter/height points as for Fig. 3.

Table 2 Mean Values of Height, Crown Diameter, Shaded Category and Percentage Crown Damage for all stems by size classes

Measurement	<0.5	0.5-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	5.0+	Totals
	Height Classes at July 1977 (M)							
Number of stems	58	36	56	58	56	32	23	319
Height 1977	30.24	71.64	153.29	250.52	354.38	440.31	523.48	230.16
S.E.	1.47	2.44	4.13	3.69	3.15	5.01	4.46	8.89
Height 1979	33.07	76.86	162.96	268.50	354.38	433.75	515.0	234.97
S.E.	1.67	3.41	4.84	4.33	3.20	5.96	6.79	8.73
Percentage change	9.4	7.3	6.3	7.2	0	-1.5	-1.6	2.1
Crown diameter 1977	52.14	97.25	138.89	191.52	250.79	286.03	342.26	177.05
S.E.	2.94	4.23	5.45	6.93	11.18	15.77	20.63	6.03
Crown diameter 1979	52.62	99.56	145.43	192.21	247.61	281.25	338.35	177.35
S.E.	3.33	4.53	5.42	7.25	10.99	15.63	22.94	5.97
Percentage change	0.9	2.4	4.7	0.4	-1.3	-1.7	-1.1	0.2
Shaded Category	2.66	2.75	2.54	2.29	1.89	1.94	1.70	2.30
S.E.	0.23	0.23	0.18	0.17	0.14	0.19	0.15	0.08
Percentage Crown damage	9.72	16.06	11.21	13.78	13.02	18.41	30.44	14.38
S.E.	1.65	3.16	2.18	1.93	1.19	3.17	4.74	0.90

Changes of height and of crown diameter within height classes are shown in Table 2. On average trees in height classes of <3.0m tall showed some positive height increment. As a percentage of 1977 height the change was greatest in the smallest class. Trees >4m tall show an apparent, small, loss in height. At first sight this might be taken as attributable to hail damage but it must be emphasised that for trees of >4m tall height measurements were taken with a clinometer, the accuracy of which was probably of the order of plus or minus 10cm for a 5m tree i.e. ± 2%.

Despite a great amount of damaged twiglets from the December hail, by July most trees had made some growth. Little or no height growth would be anticipated for the larger, more or less mature individuals, whereas the small to intermediate size class trees would have been expected to show some height change. On the whole we may conclude there was no real loss of height due to the hail. The 1979 height was highly correlated with that of 1977. The linear regression was:

$$1979 \text{ Height} = 9.90 + 0.98 \text{ (1977 Height)}$$

with $r = 0.995$.

In the case of crown diameter all classes of >3m width showed some apparent loss of crown. For a tree with crown of 3.5m a 1.3 percent "loss" amounts to 4.6cm. This amount is also probably well within the bounds of experimental error considering the method used. For the plant of 1.5m crown diameter a 4.7 percent increase amounts to 7.1cm, and for the trees in the 1<2m class in 1977 some real crown growth must be accepted as having taken place. The 1979 crown diamter (CD) was highly correlated with that of 1977. The linear regression was

$$1979 \text{ CD} = 8.28 + 0.96 \text{ (1977 CD)}$$

with $r = 0.965$.

The summarised data set then may well conceal trends. In the following sections notice is taken of 'damage' as described above, and this is examined within size classes. Finally here attention is drawn to the values under 'shaded category' of Table 2. Integers were assigned to each of the 319 individuals such that:

1. described a mulga standing alone and thus free of shade, or one which stood well above any neighbours;
2. was assigned to a singleton standing within a few metres of another singleton;
3. was given to trees at the edges of clumps such that some part of their crown area, at least, projected away from other stems;
4. was used for those individuals within larger clumps and shaded from the sides;
5. described those plants in large clumps and lower than their neighbours.

Table 2 suggests a not unexpected general trend of decreasing mean value with increasing tree height for this parameter. The (negative) linear correlation was:

$$\text{Shade} = -0.2 \text{ (1977 Height)} + 2.8,$$

with $r = -0.257$. The 1979 heights gave exactly the same values for a, b and r. Similar negative correlations were found with crown diameter, e.g.

Shade = -0.4 (1977 CD) + 3.0,

with r = -0.326.

Damage by Height Classes

The question of whether taller trees suffered more hail "damage" than shorter trees may be examined by reference to Fig. 6 and the lower section of Table 2. The positive slope of the regression line suggests that taller trees suffered more damage, though the angle of slope is not pronounced. Clearly some individuals with a lot of damage were short plants, others were tall. Of those with 50 percent or more of visually assessed damage only 4 of the 15 concerned exceeded 4m in height (Fig. 6).

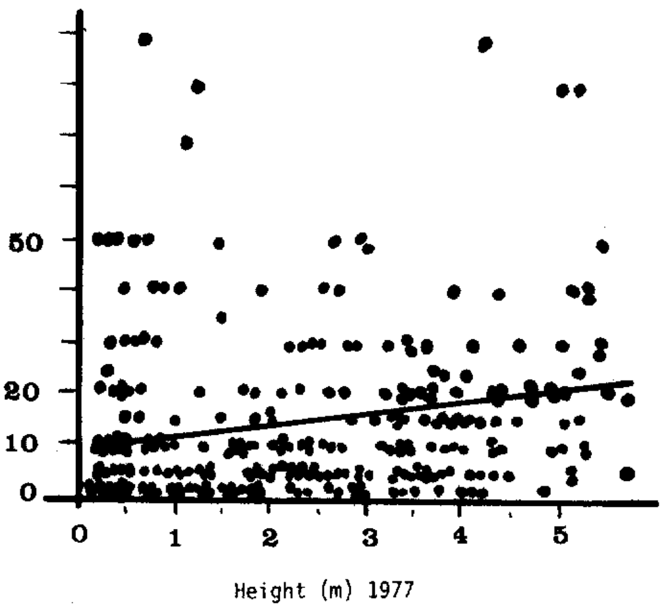


Figure 6. Percentage crown damage visually assessed July 1979 against height in metres as at July 1977.

Solid line is the linear regression.

C.Dam.% = 9.20 + 2.25 Ht.

r = 0.221, p0.00003

However the mean percentage crown damage for trees of 5.0m + (23 individuals) was higher than that for all other height classes at 30.4 percent (Table 2). The main bulk of the stand table differed little from the overall mean (i.e. >0.5 to <5.0m). The smallest 58 plants as a group had the lowest average crown damage percentage.

Crown damage percentage was more closely correlated with height (Fig. 6) than with crown diameter (Fig. 7). The relationship, in this case a negative correlation, between percentage crown damage and shaded category was even less significant viz:

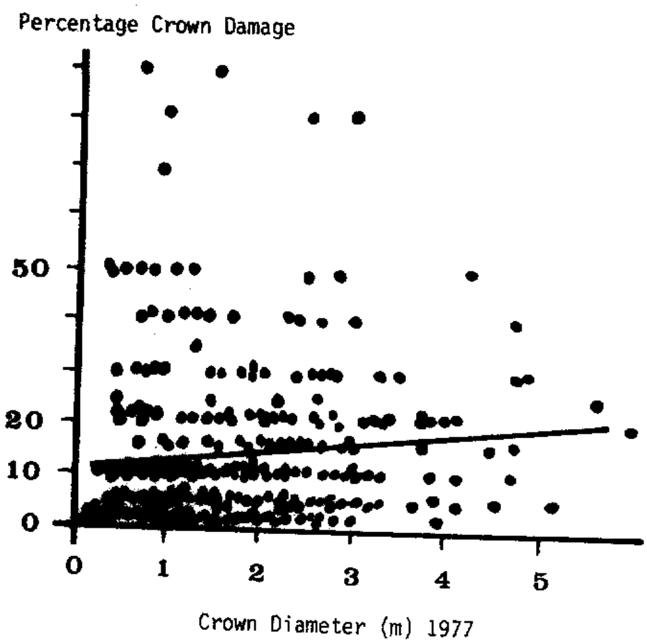


Figure 7. Percentage crown damage visually assessed July 1979 against crown diameter in metres as at July 1977.

Solid line is the linear regression.

C.Dam.% = 11.49 + 1.63 C.Diam.

r = 0.109, p0.026

C.Dam.% = -0.99 Shade + 16.67

with r = -0.084, p0.068.

Damage by Phyllode Type

The general visual observations given earlier suggested some possibility of different effects of hail on *Acacia aneura* stems of differing phyllode type. Earlier observations[6] have pointed to differing susceptibilities to drought. The range of phyllode types in mulga is so great that it would be reasonable to examine the differential response to hail damage.

Within the study site six main phyllode types have been recognised[7]. These are illustrated in Fig. 8 and their locations are plotted on Fig. 9 which uses the same raw data as did Fig. 2.

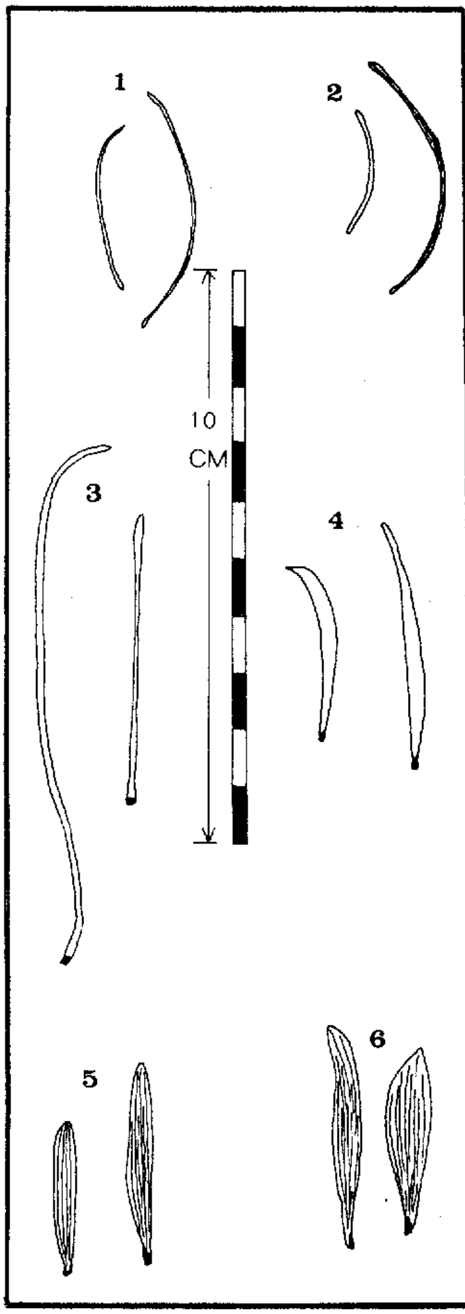
Dimensions of the phyllodes by shapes are as follows:

more or less terete	30-40mm long x <1mm width;
short and narrow	20-40 x 1mm;
long and narrow	50-90 x 1mm;
half-broad	30-45 x 1-3mm;
three-quarters broad	25-35 x 3-5mm;
broad	35-50 x 5-8mm.

A set of pre- and post-hail photographs of foliage for 6 individual trees appears as Fig. 10. Numbers by phyllode type and summarised dimensions are given in Table 3.

Figure 8. *Acacia aneura* phyllode shapes in Altona Plot.

1. more or less terete;
2. short and narrow;
3. long and narrow;
4. half-broad;
5. three-quarters broad;
6. broad (cf var. *latifolia*).



1. More or less terete

This form though very distinctive in shape as well as foliage was one of the two least common types. Only one of the 15 stems exceeded 3.0m in height. The mean height increased from 1.22m in 1977 to 1.27m in 1979. The corresponding change in crown diameter was from 1.32 to 1.34m. All three stems >2m high suffered substantial crown damage (Table 3) and the plants in the 2m class were more shaded than the average for that height class.

Smaller trees (0.5<2m) suffered less damage than the average for those size classes and these were more isolated. This type accounted for <5 percent of plants overall. It had the highest proportion (40 percent) of its stems with little or no damage, and accounted for 9 percent of the 67 individuals in this category.

The relationship between percentage crown damage and 1977 height was significant at p0.15

$$CD\% = 9.1 + 3.6\ (1977\ \text{Height}),\ r = 0.29.$$

Percentage crown damage and crown diameter were not at all significantly related ($p>0.4$).

2. Short and narrow

This form accounted for 15 percent of all mulga in the plot. Five trees exceeded 4m in height. The mean height of all stems increased from 1.70m in 1977 to 1.74m in 1979. Crown diameter increased from 1.44 to 1.48m over the period.

The 22 stems between 1 and <3m incurred substantially less crown damage than the means for the height classes involved. However, the three trees >5m had a much higher mean percent damage than the mean for the 23 in this class. The smaller plants were more shaded than most, but those in the 1m class (and this form accounted for 16/56) were more isolated than the mean for the class.

This form had 31 percent of its stems showing little or no damage and accounted for 22 percent of the individuals in this group. The relationship between percentage crown damage and 1977 height was significant at p0.09

$$CD\% = 9.4 + 2.7\ (1977\ \text{Height}),\ r = 0.20$$

whereas percentage crown damage and crown diameter were not correlated.

Tree d of Fig. 10 (sub-plot 7, no. 16) was 2.46m tall in 1977 and 2.50m in 1979. Its crown diameter was 2.34m at both measurements and crown damage was assessed at 5 percent.

3. Long and narrow

Numbers were similar to the previous type but no trees exceeded 5m and there were no seedlings recorded. The mean height of all stems increased from 2.31m in 1977 to 2.41m in 1979. This was the second best mean height increment. However the foliage specimen illustrated, that of tree f in Fig. 10 (sub-plot 8, no. 30), was 2.10m in 1977 and 1.99m in 1979. It suffered a lot of end twig damage as illustrated, damage was recorded at 5 percent. Its crown measurements were 2.02m and 1.94m respectively. The type means for crown diameter were 1.88 and 1.91 for the two dates. Neither height nor crown diameter could be said to be related to percentage crown damage.

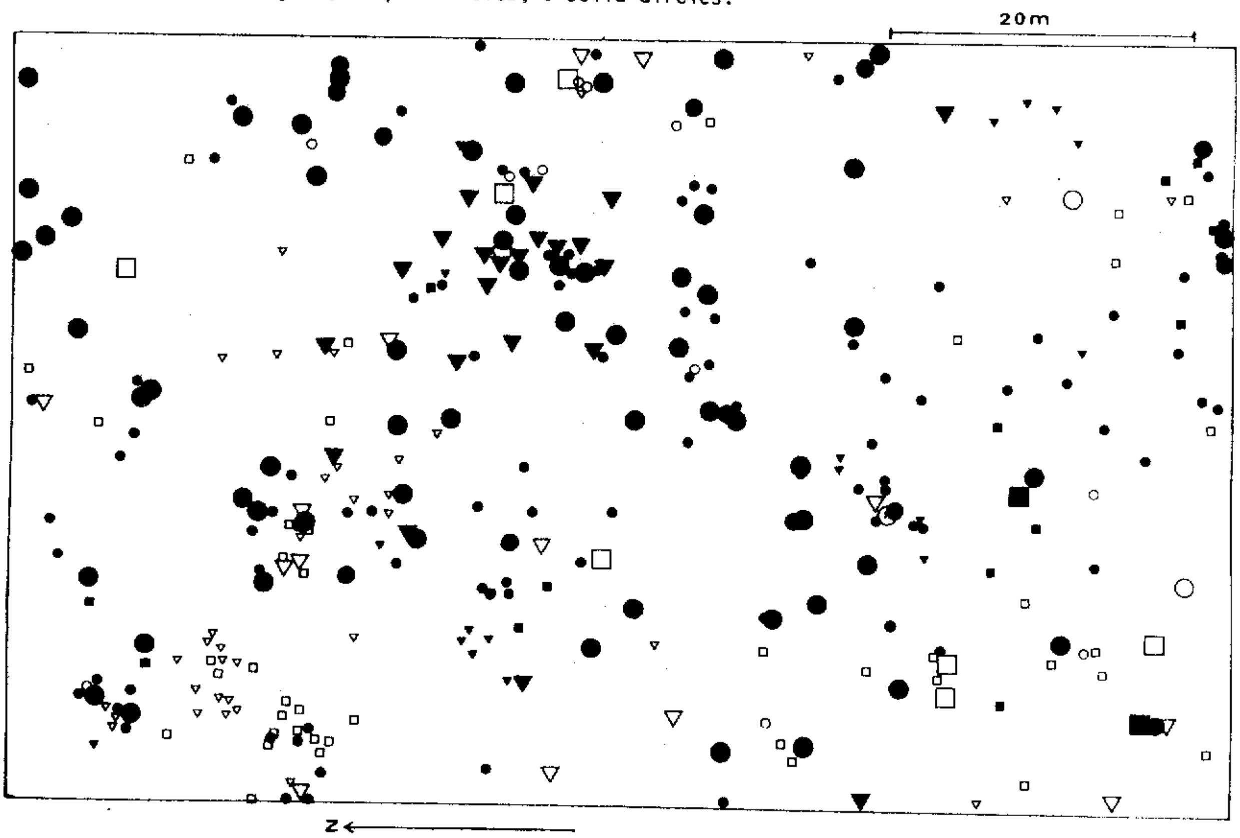
Trees in height classes were not different from the means for all trees (Table 3) except that the 5 smallest individuals were more shaded than the rest.

Table 3 Numbers of stems with average shade category and percentage crown damage averaged by phyllode type and 1977 height class.

Leaf Class	Height Classes 1977 (m) 0.5	0.5-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	5.0+	Total
1. Stems	5	5	2	2	-	-	1	15
average shade category	2.2	2.6	3	2.5	-	-	1	2.4
average % damage	13.0	9.0	2.5	27.5	-	-	25	13.4
2. Stems	10	9	16	6	3	2	3	49
average shade category	3.3	2.4	2.1	2.3	1.0	3.0	2.3	2.4
average % damage	10.5	21.1	8.4	6.7	16.7	7.5	45.0	14.0
3. Stems	-	5	21	11	9	4	-	50
average shade category	-	3.8	3.0	2.0	1.9	2.3	-	2.6
average % damage	-	20.0	10.2	15.0	15.0	17.5	-	13.9
4. Stems	3	4	5	11	11	6	-	40
average shade category	2.0	3.0	1.8	2.0	1.8	2.2	-	2.1
average % damage	3.3	6.3	5.0	14.6	6.8	20.0	-	10.6
5. Stems	4	-	2	7	1	-	-	14
average shade category	4.0	-	4.0	2.6	4.0	-	-	3.3
average % damage	5.0	-	10.0	10.7	0	-	-	8.6
6. Stems	36	13	10	21	32	20	19	151
average shade category	2.4	2.5	2.3	2.5	1.9	1.7	1.6	2.1
average % damage	9.4	16.2	21.0	14.1	14.5	19.0	28.4	16.3
All Stems	58	36	56	58	56	32	23	319
average shade category	2.7	2.8	2.5	2.3	1.9	1.9	1.7	2.3
average % damage	9.7	16.1	11.2	13.8	13.0	18.4	30.4	14.4

Figure 9. Distribution of *Acacia aneura* stems by phyllode types and size classes, Altona Plot, Yeelirrie.

Large symbols stems >3m height; smaller symbols <3m height.
Phyllode types (see text) 1 solid squares, 2 open squares, 3 open triangles, 4 solid triangles, 5 open circles, 6 solid circles.



4. Half-broad

Size distribution was similar to the preceeding type but with fewer stems in the 1m height class and several smaller plants present. The mean height in 1977 was 2.60m and this increased to 2.66m by 1979. Corresponding crown diameters were 1.90 and 1.80, representing a mean decrease of almost 5 percent. Trees in the 1<3m height classes were more isolated than individuals of the other types.

Overall percentage crown damage was the second lowest amongst the 6 types represented and plants < 1m were least damaged amongst the types.

However the 6 trees of >4m incurred greater average damage than did trees in this class for other types apart from type 6.

A reasonable linear relation existed between percentage crown damage and height

CD% = 3.4 + 2.8 (1977 Height)
r = 0.21, p0.10

but not for crown damage and crown diameter.

5. Three-quarters broad

This type was least frequent of the six and none exceeded 4.0m in height. The mean height increased from 1.81m to 1.97m, the greatest mean change recorded amongst phyllode types. In 1977 mean crown diameter was 1.56m and this increased to 1.65m by 1979.

The type is illustrated by tree e of Fig. 10. This individual did not suffer much from the hail, crown damage was recorded as nil. It grew in height from 2.90m in 1977 to 3.10m in 1979 and its crown also showed an increase from 2.56m to 2.90m (sub-plot 8, no. 5).

The type as a whole suffered less crown damage than the other 5 (Table 3) although 6 of 14 stems had in excess of 5 percent damage. Despite the quite different phyllode shape and tree form, its behaviour in relation to the hail was not unlike the other scarce type (No. 1).

There was no linear relation between crown damage and height, but percentage crown damage and crown diameter achieved significance at p0.18 (r = 0.26)

CD% = 2.9 + 3.6 (1977 Cr. Diam.)

6. Broad (cf var. *latifolia*)

Nearly half of all the mulga in the study area (47.3 percent) were of the broad-leaved variety. Consequently rather more precision is to be expected with the analysis in respect of this type. There was little change in overall mean height between measurements: 2.57m in 1977 and 2.59m in 1979. The mean crown diameter fell away marginally after the hail storm but the mean value to two decimal places was 1.87m at both times.

Three specimens are illustrated in Fig. 10. These are tabulated in Table 4.

Table 4. Broad-phyll specimens, Fig. 10

Tree	Heights		Crown Diameter		Percentage Crown Damage
	1977	1979	1977	1979	
	(m)		(m)		
a	4.35	4.40	4.15	3.90	20
b	4.40	4.40	3.10	2.83	20
c	3.95	3.75	2.65	2.83	15

All three show bunched new leaves apparently shorter and more rounded than those carried prior to the hail storm.

Crown damage percentage was significantly correlated with both height and crown diameter viz.

CD% = 10.2 + 2.4 (1977 Height)
r = 0.28 p<0.001

CD% = 11.1 + 2.8 (1977 Cr. Diam.)
r = 0.21 p<0.01

Partitioning of data by height classes detracts from this apparent elegance, as also may be expected from Figs. 6 and 7. For example with respect to percentage crown damage and height

a. Trees <2m, n = 59, r = 0.21, p0.06
b. Trees 2<4m, n = 53, r = 0.5, p0.4
c. Trees >4m, n = 39, r = 0.24, p0.07

That is damage tended to be spread across all sizes of trees with this phyllode type.

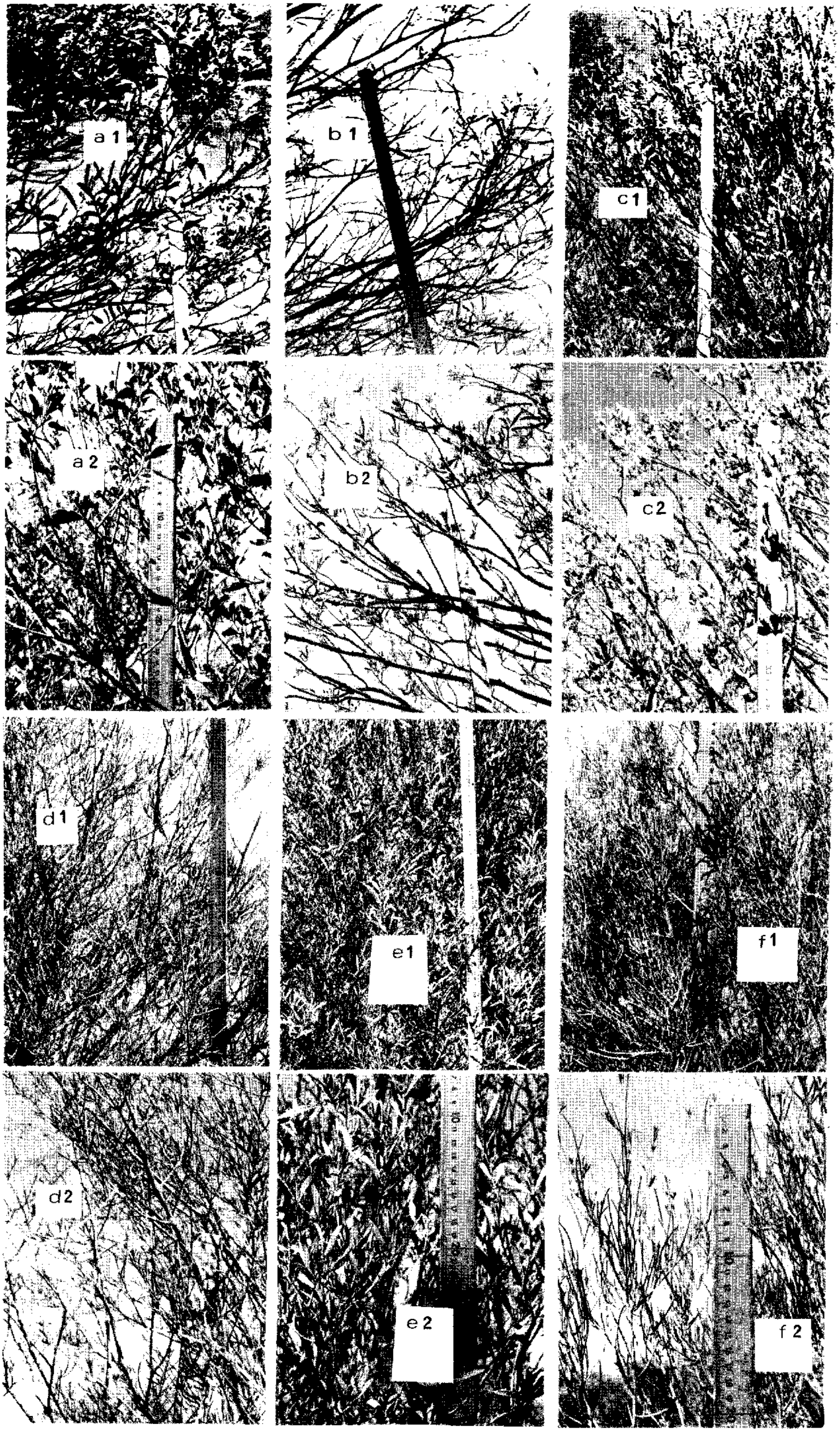
The level of crown damage tended to mirror the overall means for all types, the only exception being that a rather higher percentage mean damage occurred in type 6 trees in the 1<2m height class (Table 3). Two-thirds of all stems had 5 percent or more crown damage compared with the overall plot mean of 58 percent with this level. It seems plausible that the greater surface area exposed to the hail would have given a higher chance of individual phyllodes being hit and damaged than in other types.

Opposite

Figure 10. Photographs of the foliage of individual trees (a, b, c, d, e, f) taken in 1977 (1) and 1979 (2), both in the month of July.

Tree	Type (Fig. 8)	Collection No.
a	6	799
b	6	801
c	6	802
d	2	803
e	5	804
f	3	805

Sizes are given for each in the text under the type commentaries.


a1
b1
c1
a2
b2
c2
d1
e1
f1
d2
e2
f2

Conclusions

No trees have died to date in the study area discussed. Soon after the hail damage the visual impression was that many trees would die. Coming after a long period of drought the hail would have removed a lot of scarcely functioning phyllodes and at the same time given a major boost to the soil moisture status. New growth was produced fairly rapidly and much of the apparent crown loss could not readily be measured.

Estimates of percentage damage are clearly very general approximations which must be treated with some caution. However, all the evidence suggests that damage was not concentrated on particular sizes of trees, but occurred through all categories. A clear result of hail was a certain, at least temporary, distortion of individual tree height/crown ratios which may well affect longer term survival chances for those individual trees severely affected.

It remains to be seen whether the 'shock' induced phyllodes will survive and function as well as those pre-existing. The photographs presented suggest that some leaf shape change occurred in respect of the broader phyllode types.

The quite distinctive 'more or less terete' form of mulga in this area clearly has different levels of tolerance to hail than does the more abundant (successful?) broad-leaf variety.

The early boost to seedling germination resulted in disappointing recruitment and establishment. However, a basis does exist for sustained observations of the set of seedlings which originated from the hailstorm disturbance.

Acknowledgements

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PRELIMINARY INVESTIGATIONS INTO GERMINATION AND ESTABLISHMENT OF SANDALWOOD, *SANTALUM SPICATUM* (R.Br.) DC.

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Introduction

Sandalwood is part of the history of Western Australia and the first recorded export of this aromatic wood was in 1845. The amount of sandalwood exported has fluctuated greatly, and still varies from year to year depending on the demand.

Santalum spicatum (Fig. 1) is the major aromatic species in Western Australia. This is a very slow growing species requiring 70-90 years to attain a commercial size of 127mm to 200mm diameter. This is in comparison with *S. album*, the commercial sandalwood in India, which can attain a size of 150mm diameter in 7 years under ideal conditions and 10-20 years in more rigorous conditions (G. Hughes and P.C. Richmond, pers. comm.).

This preliminary study is part of a major investigation into the germination and establishment of *S. spicatum*, with a view to producing seedlings and host plants suitable for field planting.

Distribution

There are four species of the genus *Santalum* distributed throughout Australia.

S. spicatum is mainly found in, and distributed throughout most of the state of Western Australia. It is not found in the Kimberleys or in the extreme south-west of the state. The main areas of remaining natural stands of sandalwood are the Eastern Goldfields and north of the Murchison River to Carnarvon. Rainfall patterns which affect the soil structure and plant associations have an indirect effect on the distribution of sandalwood. The broad distribution of the trees is dependent on the presence of suitable endemic host plants (e.g. *Acacia* sp.).

S. lanceolatum (plum bush) does contain oil and has been exploited commercially, to a limited extent. Sandalwood flour from *S. lanceolatum* is mixed with that from *S. spicatum* and used in the production of joss sticks. This species is found mainly in the extreme north with a few specimens as far south as Leonora. (Underwood, 1954).

S. acuminatum (quandong) and *S. murrayanum* (bitter quandong) are distributed widely throughout the eastern states. In Western Australia, *S. acuminatum* has a wide distribution throughout the southern half of the state, and *S. murrayanum* a more limited distribution in the south-west and wheat belt areas (Beard, 1970).

Materials and Methods

a. Germination of seed

i. Seed collected from Jeedamya, Narrogin, west of Menangina and Yeelirrie was shelled and the hard endocarp was cracked. The seeds were then placed in plastic bags with vermiculite that had been treated with 5.5% benlate solution. The bags were sealed and placed in an incubator at 25^{o}c. This experiment was set up during the first week of August, 1980.

ii. Seed collected from Narrogin was shelled and the hard endocarp cracked. The seeds were then dusted with thiram and representative samples were planted in vermiculite or peat moss treated with 5.5% benlate solution. Trays of seeds in each of the soil types were placed in one of the following: glasshouse with mist system; dark (trays contained in plastic bags) or incubator at 25^{o}c (trays contained in plastic bags).

This experiment was set up during the first week of November 1980.

All bags and trays were checked at regular intervals for germinating seeds. From section (i), once the radicle was approximately 2cm long, the seedlings were potted in a mixture of sand, loam and humus (3:1:2). Seeds from section (ii) will be planted in pots when of a suitable size.

b. Development of haustoria

Santalum spicatum seedlings were placed in pots with the following potential host plants *Acacia aneura*, *A. cyclops*, *A. saligna*, *Albizia lophantha* and *Eucalyptus camaldulensis*. The trial pots were set up in January 1980 and plants were removed from their pots and examined for development of haustoria in May 1980. The plants were to be placed in larger pots after examination, so the roots and soil were disturbed as little as possible.

S. spicatum and *A. aneura* seedlings were potted together in March 1979 and harvested in April 1980.

c. Addition of nutrients

One year old *S. spicatum* seedlings, which had been grown with *Acacia acuminata* as hosts, were placed in pots with a soil mixture of sand and loam (3:1) and then treated in the following ways:

i. 7 pots were left untreated - control.

ii. 7 pots were each given combined nitrogen (as ammonium sulphate) at the level of 50kg,ha^{-1} (0.2g per pot).

iii. 6 pots were each given combined nitrogen at the level of 100kg,ha^{-1} (0.4g per pot).

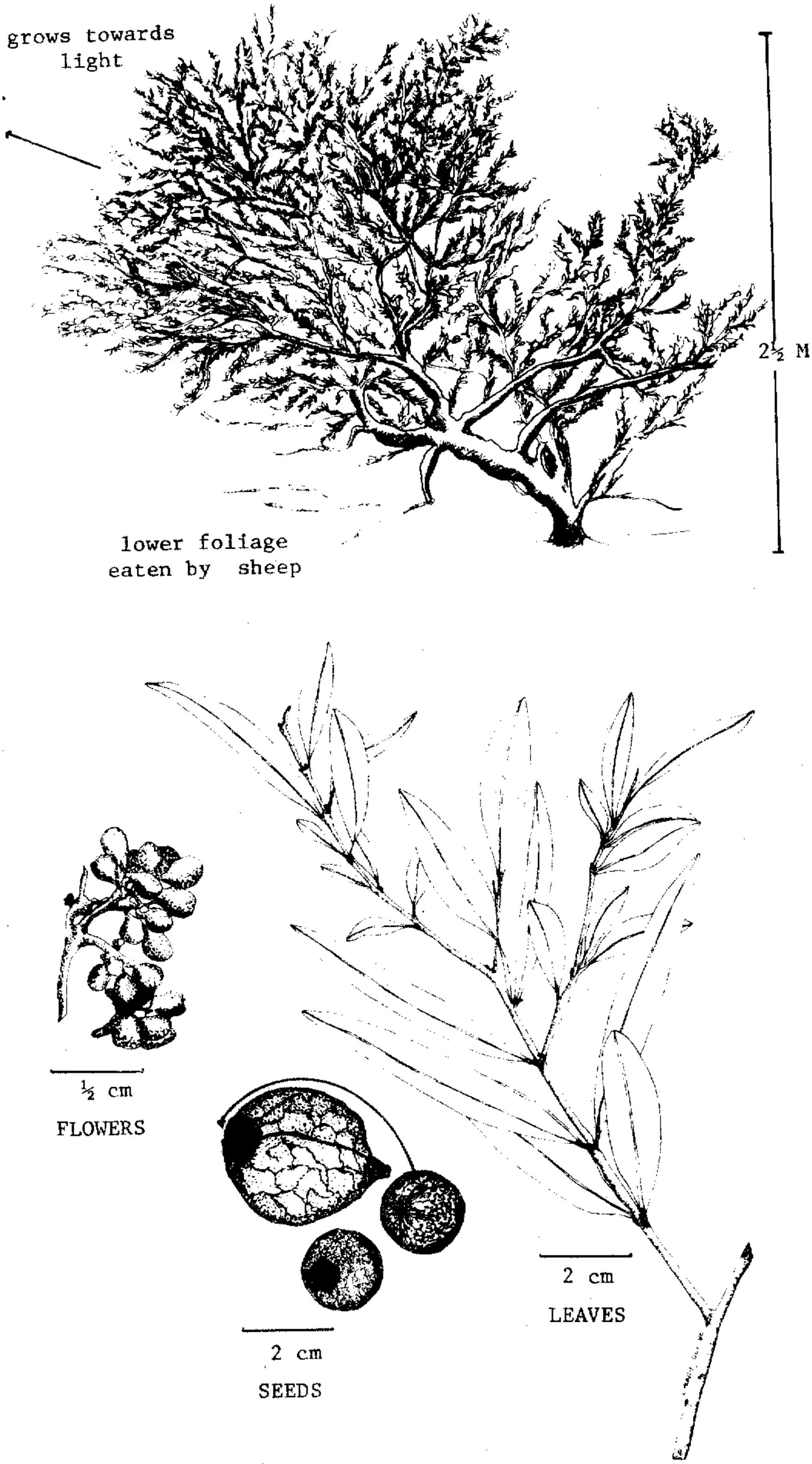

Figure 1 SANTALUM SPICATUM
(Sandalwood Tree)

The plants were watered twice a week with de-ionised water and checked for general health and leaf colour. Plants were harvested after 2 months and analysed for total nitrogen content. The seedlings were treated at the beginning of August 1980 and harvested in the first week of October 1980.

d. Nutrients and host plants

Sandalwood seedlings were planted with the following hosts: *Acacia aneura*, *A. cyclops*, *A. saligna*, *Albizia lophantha* and *Eucalyptus camaldulensis*. Each of 13 pots set up was given ½ teaspoon osmocote (slow-release fertiliser), and the plants were watered twice a week with de-ionised water and checked for general health and leaf colour. The plants were harvested after 2 months and both sandalwood seedlings and host plants were analysed for total nitrogen content. The osmocote was added to the plants in the third week of August 1980 and plants were harvested in the third week of October 1980.

e. Transplant of naturally regenerated seedlings

During a field trip to Leinster Downs Station in early July 1980, numerous *S. spicatum* seedlings were found around the base of a parent tree. Twelve (12) of the seedlings were transplanted to areas adjacent to the parent tree. The seedlings were watered the following day and rain fell the day after. The seedlings were then left and checked in early December.

Results

a. Germination of seed

The percentage germination of seed from sections (i) and (ii) is shown in Table 1. The germination of Narrogin seeds in section (ii) is not complete as this experiment is still in progress at the time of writing. Section (i) was terminated after 60 days and it is possible that more seed may have germinated if the experiment had continued for a longer period of time.

Results from section (ii) may be more meaningful as a larger number of seeds were planted, than in section (i).

b. Development of haustoria

In all pots, the development of the root systems was very dense, making it difficult to positively identify haustorial connections. The observations were further complicated by the fact that seedlings were to be replanted in larger pots, so the root systems were disturbed as little as possible.

Obvious haustoria were developed within 20 weeks between *S. spicatum* and *A. aneura* and within 12 months between *S. spicatum* and *E. camaldulensis*.

As none of the sandalwood seedlings planted with the other possible hosts were alive by December, 1980, it is not known whether haustorial connections were made between *S. spicatum* and *A. cyclops*, *A. saligna* or *Albizia lophantha*.

Table 1. Germination of *S. spicatum* seeds under various environmental conditions.

(i)

Day no.	% Sandalwood seeds germinated			
	Jeedamya	Narrogin	Menangina	Yeelirrie
0	0	0	0	0
11	0	0	0	6
13	0	0	0	13
14	10	0	0	13
19	10	0	20	26
25	10	10	30	60
29	20	10	30	60
35	30	10	30	60
39	40	20	30	60
42	40	20	30	73
47	40	30	30	73
54	40	30	30	80
60	40	30	30	80

(ii)

Day no.	% Narrogin Sandalwood seeds germinated					
	Glasshouse		Dark		Incubator 25°c	
	V	P	V	P	V	P
0	0	0	0	0	0	0
28	0	0	3.2	0	0	0
29	0	0	4.2	0	3.9	0
34	2.0	4.3	14.3	4.5	3.9	0
35	2.0	4.3	15.5	4.5	4.0	0
36	2.0	4.3	18.0	4.5	8.9	25.0
41	2.0	4.3	18.0	4.5	8.9	25.0

V = vermiculite
P = sphagnum peat moss

Table 2. Dry weight and nitrogen content of sandalwood seedlings treated with ammonium sulphate.

Plant no.	Control		$50kgha^{-1}$ nitrogen		$100kgha^{-1}$ nitrogen	
	Dry wt.(g)	%N	Dry wt.(g)	%N	Dry wt.(g)	%N
1	-	-	-	-	-	-
2	-	-	-	-	1.17	0.86
3	-	-	-	-	-	-
4	1.87	0.84	0.89	1.00	-	-
5	1.31	0.95	1.06	1.30	-	-
6	-	-	0.88	0.83	0.48	1.57
7	0.91	0.65	-	-	-	-

All plants with no dry weight or %N given died during the first 4 weeks of the experiment.

c. Addition of nutrients

The application of ammonium sulphate had little effect on the general appearance of the *S. spicatum* seedlings and the leaf colour remained yellow. The nitrogen analyses showed a slight increase in the %N with addition of higher levels of ammonium sulphate. Of the total number of seedlings set up, 55% were dead by the time of harvesting. Dry weight and %N results are shown in Table 2 but insufficient data was available for meaningful statistical analysis.

d. Nutrients and host plants

The *S. spicatum* seedlings and their host plants were harvested 2 months after treatment with osmocote. They were analysed for total nitrogen and the results are shown in Table 3.

Table 3. Nitrogen content of sandalwood seedlings and various host plants treated with osmocote.

Host		%N (Host)	%N (*S. spicatum*)
Acacia aneura	1.	0.37	0.39
	2.		0.58
	3.		0.48
	4.		-
	5.		-
	6.		-
A. cyclops	1.	0.81	0.30
	2.		1.31
A. saligna	1.	0.76	0.18
	2.		-
Albizia lophantha	1.	0.95	0
	2.		1.89
Eucalyptus camaldulensis		0.24	0.24

All host plants were alive at the time of harvesting but 30% of the sandalwood seedlings had died. The leaf colour of *S. spicatum* seedlings did not change significantly between the start and the end of the experiment.

e. Transplant of naturally regenerated seedlings

Between transplanting in early July and inspection in early December, all the 12 transplanted seedlings had died. However, the seedlings remaining, undisturbed and close to the parent tree were still alive and growing well.

Discussion

All experiments and results outlined in this report are preliminary and more detailed work needs to be done with larger numbers of *S. spicatum* seedlings.

However, several observations can be made regarding the germination and growth of the sandalwood seedlings.

Shelled and cracked seeds started to germinate approximately 10 days after planting, and an 80% germination rate was achieved 60 days after planting. This percentage of germination was found only in the Yeelirrie seed, but it is possible that more seeds from the other areas could have germinated if the experiment had continued for a longer time period. Hirano (1977) records time periods of 26-324 days for the germination of *S. album* and 75-824 days for germination of *S. paniculatum*.

Germination of the Narrogin seed started 28 days after planting and the rates of germination varied with the different environmental conditions. Many of the seeds in peat moss rotted within 2 weeks of planting, possibly due to excess moisture retained in the soil. No conclusions can be drawn about the ideal conditions for germination of the Narrogin seed, as this section of the experiment is still in progress.

Trials carried out by the W.A. Forestry Dept. have shown that haustorial attachment between the *S. spicatum* seedling and the host roots occurs about 6 months after germination. The results recorded here indicate that attachment took place within 5-12 months of germination. Barber (1906) reported that haustoria started to develop as soon as the root system started to branch, and the young roots attached themselves to rocks, bits of bark and even to other roots of the same plant. Development of the haustorium was dependent on it attaching itself to a suitable host root.

The addition of combined nitrogen (as ammonium sulphate) or the slow release fertiliser, osmocote, had little effect on the sandalwood seedlings over a period of two months. The leaves of both control and experimental seedlings remained yellow. Hirano (1977) found that ammonium sulphate and osmocote had no effect on the growth of *S. album*, *S. haleakalae* and *S. paniculatum* seedlings. However, the plants did respond to the addition of chelated iron and this appeared to be essential to the establishment of the seedlings without a host plant.

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EARLY RESPONSE TO FERTILISER TREATMENT BY THREE SPECIES OF *EUCALYPTUS* OF INTEREST IN BAUXITE MINING REHABILITATION

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Introduction

In returning bauxite pits to vegetative cover it is desirable to achieve rapid early growth. Early establishment is necessary so that the plants may be able to withstand the conditions imposed by hot summers in Western Australia's mediterranean climate.

Any fertilisation regime adopted should assist establishment and early growth. Success may be assessed in the field by survival rate, comparative early growth or other parameters which may provide growth indices.

A range of species has been planted in bauxite pits in former Jarrah forest of the Darling Range on completion of mining. More recently it has become desirable to concentrate efforts on those species which, in various ways, show best adaptation to the newly created environments.

Three of the species which have been considered as very useful are *Eucalyptus maculata* Hook., *E. saligna* Sm. and *E. wandoo* Blakely. The latter is found in the Range and further inland on clay soils and will possibly do reasonably well on the exposed pallid zone clay of mine-floors. The other two from the eastern states have performed well in numerous trials.

This note reports comparative early growth of these three species in pot trials conducted at Bentley in the Spring-early Summer of 1978.

Methods

Sets of one hundred and twenty container grown small seedlings of each of *Eucalyptus maculata* (Spotted gum), *E. saligna* (Sydney blue gum) and *E. wandoo* (Wandoo) were potted in 12.5cm diameter plastic horticultural pots containing Jarrah forest topsoil fumigated with methyl bromide. Each set was then divided into six treatment sub-sets of 20 plants such that mean plant heights did not differ significantly (p0.05) between treatments. Fertiliser was then added to treatment sets as follows:

1. Control (nil)
2. Basal (N,P,K,Zn,Mo,Cu)
3. Minus N (P,K,Zn,Mo,Cu)
4. Minus P (N,K,Zn,Mo,Cu)
5. Minus K (N,P,Zn,Mo,Cu)
6. Minus trace elements (N,P,K)

Nitrogen (N) was in the form of ammonium nitrate at an equivalent to field application of 115kgha^{-1}; phosphorus (P) as superphosphate at 340kgha^{-1}; potassium (K) as potassium sulphate at 115kgha^{-1}; zinc (Zn) as zinc sulphate at 50gha^{-1}; molybdenum (Mo) as sodium molybdate at 20gha^{-1}; and copper (Cu) as copper sulphate at 100gha^{-1}.

These fertiliser levels correspond to standard field applications. The pots were placed in the field trial area at Bentley in late July. All plants were watered regularly to the same extent. Plant heights were recorded each week. The experiment was terminated in late October after 92 days of growth. At this stage 10 individual plants of each species from each treatment were harvested and washed free of soil, dried in paper towels and weighed to give total plant fresh weight. The plants were then pressed and placed in an oven at 60^{o}c for 48 hours. Total dry weight was obtained. The plants were then divided into top and roots so that shoot and root dried weight could be determined. Leaf area of each plant was determined with a planimeter.

The results were analysed to determine whether any significance could be attached to differences in growth patterns between fertiliser treatments.

Results

Summaries of mean values for *E. maculata*, *E. saligna* and *E. wandoo* are presented in Tables 1-3 respectively. The parameters include final plant mean height for all 20 plants, mean height increment over 92 days for all plants and the best 10 increments averaged. For the 10 harvested plants the values are for total plant mean fresh weight and dry weight; dry shoot and root weights separately; and mean leaf area. In addition the fresh/dry weight and shoot/root dry weight mean ratios are also given. Fig. 1 gives means and standard deviations relative to control results for each of fresh weight, dry weight, root weight, shoot weight, and leaf area.

At the start of the experiment the *E. saligna* plants were taller than the rest, at a mean height of 37.7cm compared with 24.3 for *E. wandoo* and 17.4cm for *E. maculata*. This pattern of difference was maintained at termination when mean heights were 40.0, 26.7 and 19.7 for the three species respectively.

As mentioned above there was no significant difference at p0.05 between mean heights by treatments at the start. The tables show that this was also true at the time of harvest. Only for *E. maculata* was there a difference of interest (p0.10). In this species height ranking at the start was

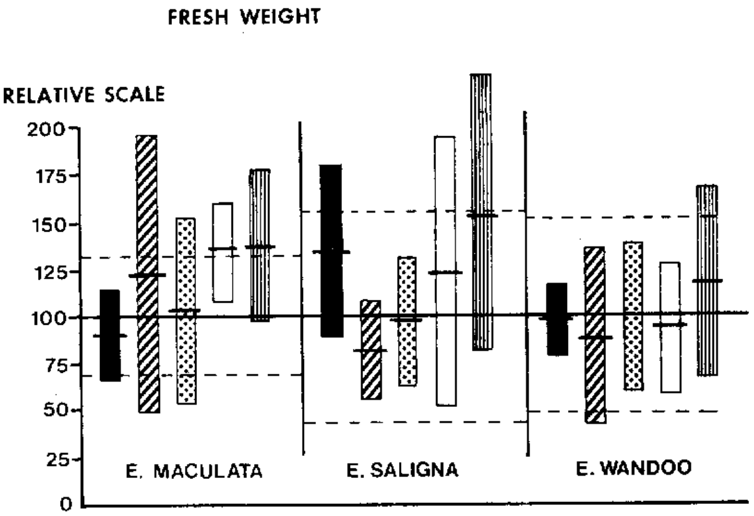
-P> -K> - Traces > -N> Basal > Control

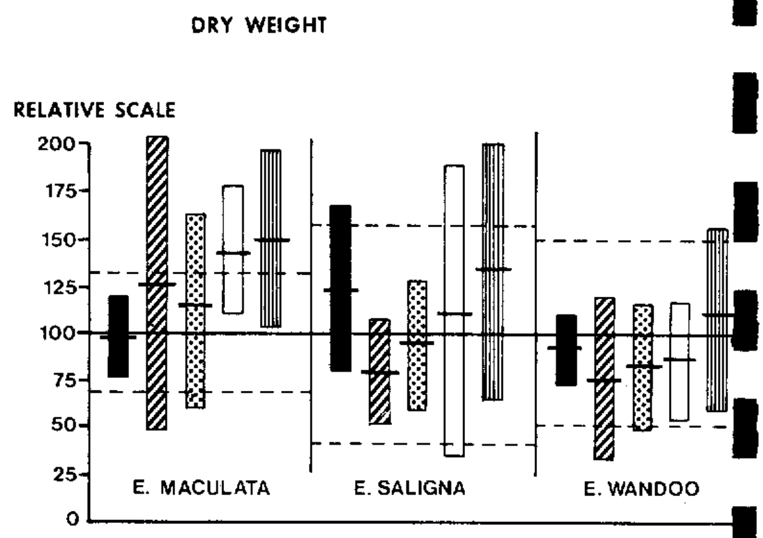
and at the end

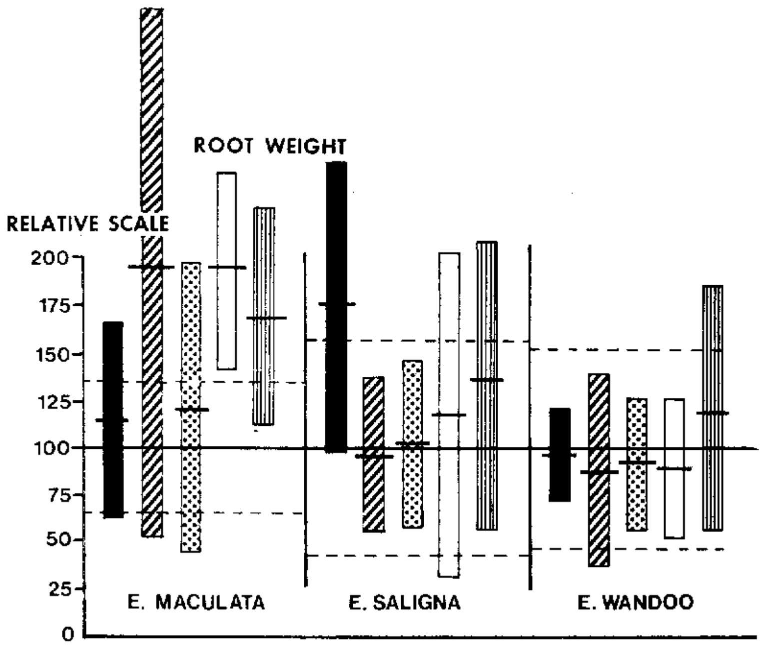
-P> - Traces > -K> -N> Control > Basal

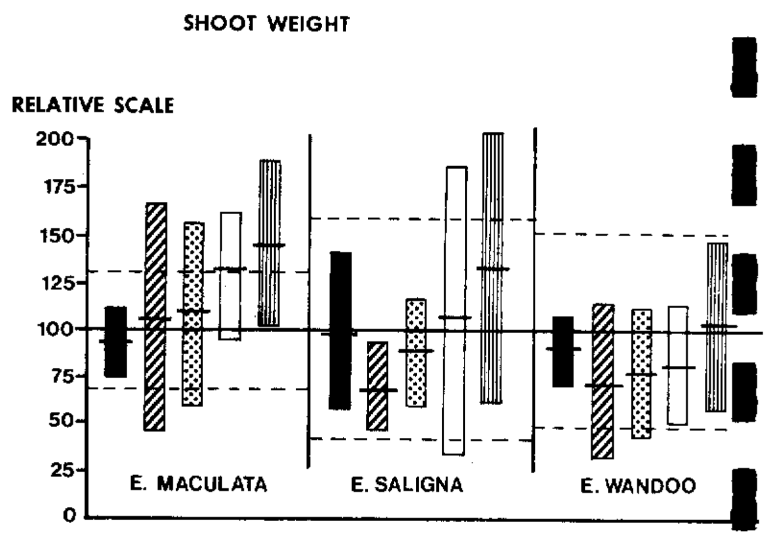
These shifts in ranking are of little significance in themselves. However it is perhaps of note that for *E. saligna* the -P treatment shifted from fifth place at the start to second place at the end. Also in *E. wandoo* -P moved from fourth to first ranking. In *E. wandoo* the -N treatment had second greatest mean height at the start and was lowest at termination.

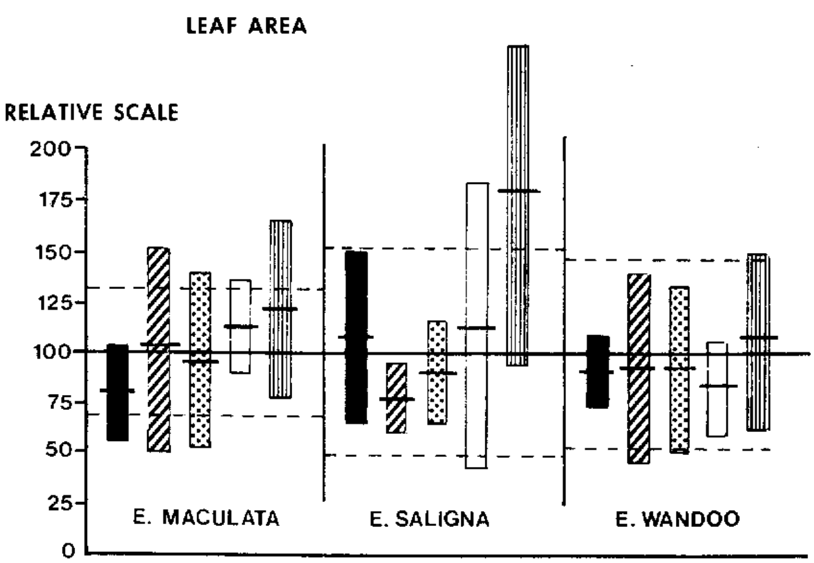
Analysis of height increments (which ignore differences, even if not significant, in starting mean heights) produces more interesting results. Indeed the significance level (p0.001) of differences in height increment is greater, for all species, than for any of the other parameters examined.











Dashed horizontal lines represent standard deviations for control treatments.

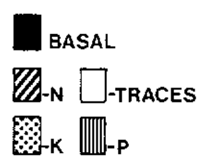


FIGURE 1: A, FRESH WEIGHT; B, DRY WEIGHT; C, ROOT WEIGHT; D, SHOOT WEIGHT; AND E, LEAF AREA; AT FINAL HARVEST (92 DAYS), MEANS AND STANDARD DEVIATIONS OF FERTILISER TREATMENTS, RELATIVE TO CONTROL (NO FERTILISER) AT 100 FOR ALL THREE SPECIES.

Table 1. Summary of 92 day harvest measurements *Eucalyptus maculata*

Harvest Values	Fertiliser Treatment						Significance		
	Control	Basal	-N	-K	-Traces	-P	F	D	LSD
Height (cm)	18.43	18.36	18.51	20.41	20.64	21.54	2.29*	3.70	2.53
Height increment (cm)	1.93	1.66	1.36	2.49	2.71	3.26	4.90****	1.24	0.85
Best 10 increments (cm)	2.73	2.59	2.13	3.46	3.71	4.55	5.33****	1.60	1.08
Fresh weight (g)	8.59	7.72	10.57	8.91	11.70	11.73	1.97*	5.07	3.43
Dry weight (g)	2.39	2.33	3.00	2.69	3.44	3.57	2.21*	1.48	1.00
Dry shoot weight (g)	1.86	1.72	1.99	2.05	2.42	2.68	2.27*	1.00	0.68
Dry root weight (g)	0.53	0.61	1.02	0.64	1.02	0.89	2.84**	0.54	0.36
Fresh/dry weight ratio	3.6	3.3	3.5	3.3	3.4	3.3	-	-	-
Dry shoot/root weight ratio	3.5	2.8	2.0	3.2	2.4	3.0	-	-	-
Leaf area (cm^2)	94.2	75.2	95.7	90.8	104.5	116.2	1.46NS	47.5	32.2

Table 2. Summary of 92 day harvest measurements *Eucalyptus saligna*

Harvest Values	Fertiliser Treatment						Significance		
	Control	Basal	-N	-K	-Traces	-P	F	D	LSD
Height (cm)	37.02	41.01	38.90	39.96	41.00	41.90	0.46NS	10.8	7.21
Height increment (cm)	1.25	1.28	1.65	1.72	2.91	5.33	14.92****	1.56	1.04
Best 10 increments (cm)	2.04	1.98	2.56	3.04	3.98	7.13	23.11****	1.69	1.15
Fresh weight (g)	12.29	16.50	9.89	12.09	15.19	18.94	2.56**	8.69	5.90
Dry weight (g)	3.90	4.84	3.06	3.65	4.27	5.23	1.43NS	2.78	1.89
Dry shoot weight (g)	2.64	2.60	1.87	2.36	2.81	3.50	1.48NS	1.85	1.96
Dry root weight (g)	1.26	2.24	1.20	1.30	1.46	1.73	2.21*	1.11	0.75
Fresh/dry weight ratio	3.2	3.4	3.2	3.3	3.6	3.6	-	-	-
Dry shoot/root weight ratio	2.1	1.2	1.6	1.8	1.9	2.0	-	-	-
Leaf area (cm^2)	104.8	115.0	81.6	95.1	117.4	185.2	4.13***	74.4	50.5

(Notes: Significance F is variance ratio from analysis of variance, followed by level of significance: NS not significant; * p0.1; ** p0.05; **** p0.001
D is difference for significance at p0.05 with Tukey test; and LSD is the least significant difference between any two means at p0.05).

In the case of *E. maculata* (Table 1) greatest significance, apart from height increments, lay in dry root weight differences with -N and - Traces giving greatest dry root weights. The range in -N however was greater than for all other measurements graphed (Fig. 1). These dry root weights also influenced shoot/root ratio. On the whole the -P and - Traces treatments gave best results relative to control.

E. saligna exhibited greatest significance in leaf area differences (Table 2). Here the -P treatment produced far and away the greatest leaf area relative to control (Fig. 1). However this treatment was also responsible for greatest leaf area in the other two species. Fresh weight differences in *E. saligna* were significant at p0.05 and here again the -P treatment gave the best results relative to control.

Fertiliser response in *E. wandoo* was poor. Of all five parameters illustrated in Fig. 1 only the -P treatment gave better results than did the control. The other fertiliser treatments depressed growth relative to control. Shoot weight and leaf area were only very slightly better in -P than in control.

The fresh/dry weight ratio in *E. wandoo* was lower on the whole than in the other species (see Table 4 for overall comparisons). *E. wandoo* also produced greatest fresh weight, dry weight, dry shoot weight and leaf area, on average, compared with the other two species.

Table 4 Mean values, all treatments by species at 92 days for the harvest values of Tables 1-3.

Harvest Values	Species		
	E. maculata	*E. saligna*	*E. wandoo*
Height (cm)	19.7	40.0	26.7
Height increment (cm)	2.2	2.4	2.3
Best 10 increments(cm)	3.2	3.5	3.1
Fresh weight (g)	9.9	14.1	14.9
Dry weight (g)	2.9	4.2	5.2
Dry shoot weight(g)	2.1	2.6	3.7
Dry root weight(g)	0.8	1.5	1.5
Fresh/dry weight	3.4	3.4	2.9
Dry shoot/root weight	2.8	1.8	2.5
Leaf area (cm^2)	96	117	124

Discussion

The greatest range in mean heights at time of harvest was in *E. saligna* (4.9 cm). This may be compared with 2.3cm in *E. maculata* and only 0.6cm in *E. wandoo*, despite the latter being taller plants than *E. maculata*. The generally low levels of difference in *E. wandoo* suggest that this species can grow, at least in early stages, in the short run, as well in forest topsoil alone as with added fertilisers.

Control plants had highest shoot/root ratio in all three species. For *E. maculata* and *E. saligna* this was coupled with higher root weights achieved with added fertiliser. In *E. wandoo* however both root and shoot weights tended to be lower with fertiliser (except for the -P treatment) and the shoot weights more so. The generally greater dry weight production in *E. wandoo* suggests that this species should be able to establish itself in the early stages better than the other two, even without fertiliser added.

If growing *E. wandoo* is seen as a desirable aim and the objective of using fertilisers is seen as that of stimulating early growth then the results presented here suggest the need for further nutrition experiments with this species.

The use of the standard basal fertiliser is satisfactory with *E. saligna* in that it promoted more dry weight growth in roots than other treatments and also provided almost as much total weight as did its nearest competitor, -P, which showed a much greater range (Fig. 1). The latter produced more leaf area but this may not be desirable through the first one or two summers until root growth is well established.

Table 3. Summary of 92 day harvest measurements *Eucalyptus wandoo*

Harvest Values	Fertiliser Treatment						Significance		
	Control	Basal	-N	-K	-Traces	-P	F	D	LSD
Height (cm)	26.79	26.45	26.37	26.70	26.79	26.99	0.03NS	5.33	3.65
Height increment (cm)	1.69	2.11	1.46	3.22	2.43	2.61	5.20****	1.14	0.83
Best 10 increments (cm)	2.25	3.10	2.11	4.34	3.43	3.47	6.41****	1.38	0.93
Fresh weight (g)	15.03	14.70	12.85	15.06	14.15	17.66	0.68NS	8.00	5.43
Dry weight (g)	5.76	5.29	4.40	4.69	4.90	6.31	1.02NS	2.94	1.99
Dry shoot weight (g)	4.25	3.82	3.10	3.27	3.52	4.47	1.10NS	2.16	1.47
Dry root weight (g)	1.51	1.46	1.30	1.41	1.38	1.84	0.77NS	0.90	0.61
Fresh/dry weight ratio	2.6	2.8	2.9	3.2	2.9	2.8	-	-	-
Dry shoot/root weight ratio	2.8	2.6	2.4	2.3	2.6	2.4	-	-	-
Leaf area (cm^2)	131.7	121.2	119.2	119.9	108.1	141.4	0.52NS	66.3	45.0

(Notes: Significance F is variance ratio from analysis of variance, followed by level of significance: NS not significant; **** p0.001

D is difference for significance at p0.05 with Tukey test; and LSD is the least significant difference between any two means at p0.05).

The results with *E. maculata* were much less clear cut. Despite attempts at giving all plants equal access to water, the high ranges (Fig. 1) associated with the -N treatments for *E. maculata* suggest that some nutrient leaching may have distorted the growth patterns. The closeness of the basal fertiliser response to that of control suggests that perhaps best results will not accrue to use of the basal mixture.

Acknowledgements

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VARIATION IN *ACACIA ANEURA* - NOTES ON SPECIMENS FROM GINDALBIE

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Introduction

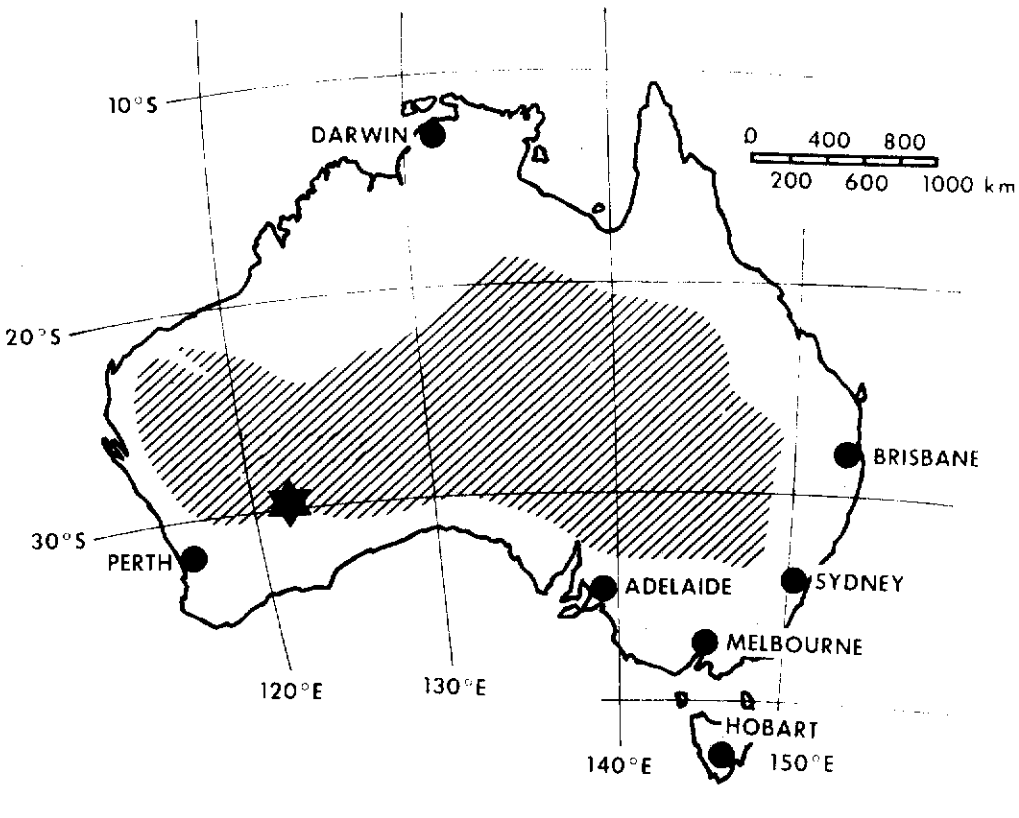
In this paper a description of pods, seed weight and germination characteristics is given in respect of *Acacia aneura* material collected from 10 trees at Gindalbie (121°46' E, 30°17' S) in November, 1979. This locality is to the south of the distribution of *A. aneura* in Western Australia (Fig. 1). A long term study of the progeny from selected individual *Acacia aneura* trees has been commenced. The material described forms a component of the study.

The original diagram of Mueller illustrates[1] three twiglets of *Acacia aneura* with phyllodes from terete to narrowly linear and curved. Black[2] gave the range of phyllode dimensions as 3-7cm long x 1-2.5mm wide with a broad leaf variety 4-7mm wide. He described pods as 2-3.5cm long and 7-14mm broad. More recently Pedley[10] has enunciated the range of phyllode dimensions as from 2-17(-24)cm long x 0.9-8(12)mm wide. Pedley considered the recognition of Black's variety *latifolia* as not at present warranted. Pedley gave pod dimensions as 2.5-5cm long x 7-13mm wide, with a prominent wing along the upper margin. Seeds were described as about 5mm long by 3mm wide.

Coaldrake notes consistent differences over the geographic range of *Acacia harpophylla* in seed weight, viability and rate of germination[4]. This species differs from mulga in its ability to germinate readily without prior treatment. The present study differs from Coaldrake's in that here the concern is with variation at the same geographical locality.

In mulga field studies it has been the practice to record trees by phyllode type. Some evidence is available to suggest that trees with broader phyllodes are more resistant to drought than other forms[7] and also that narrow phyllode forms may grow faster than others, at least in respect of post-fire regeneration[6]. It has not been possible until recently to obtain sufficient seed from individual parent trees such that seed or germination characteristics could be determined with any precision[8]. This study represents the first attempt at examining differences in seed weight and in germination characteristics within *Acacia aneura*.

Figure 1. Location of Gindalbie (shown by six-pointed star), in relation to the distribution of *Acacia aneura* within Australia (after Nix and Austin 1973).



General Characteristics: Phyllode and Pod Dimensions

In comparing properties of individual plants it is most important to compare like with like. A procedure for selection of leaves pods and flowers in some South African *Acacia* species emphasises this[12]. A detailed study of phyllode size in mulga has confirmed the need for comparable samples to be used in this species[5].

In the present case the phyllode material was not specifically collected for analysis. The basis of selection was that each individual tree had abundant seed, and that a range of phyllode shapes between individuals would be covered. Caution in describing phyllodes for *Acacia aneura* was expressed by Everist (quoted by Coaldrake[4]). However generalisations are given here for want of more data, in respect of the 10 individuals. Fig. 2 gives phyllode shapes and Table 1 summarises the general range of lengths and widths for phyllodes and pods.

Phyllode dimensions are within the ranges given by Pedley[10], with ranking by phyllode mean width as follows:

$7>2>10>1>3>6>{}^{8}_{9}>4>5$

where number 7 is the broadest and number 5 the narrowest phyllode.

Pod dimensions are close to those reported by Pedley[10] though number 2 tends to be rather wider than his range indicates. Diagrams of pods are given in Fig. 3A and B.

Ranking by overall size (mean length x width, of the ranges of Table 1) is as follows:

$2>10>9>7>4>{}^{3}_{6}>8>{}^{5}_{1}$

Figure 2. Phyllode shapes of the 10 specimen trees of *Acacia aneura* from Gindalbie. Letters a to j represent specimens 1-10 respectively. Vertical bars are 5cm tall.

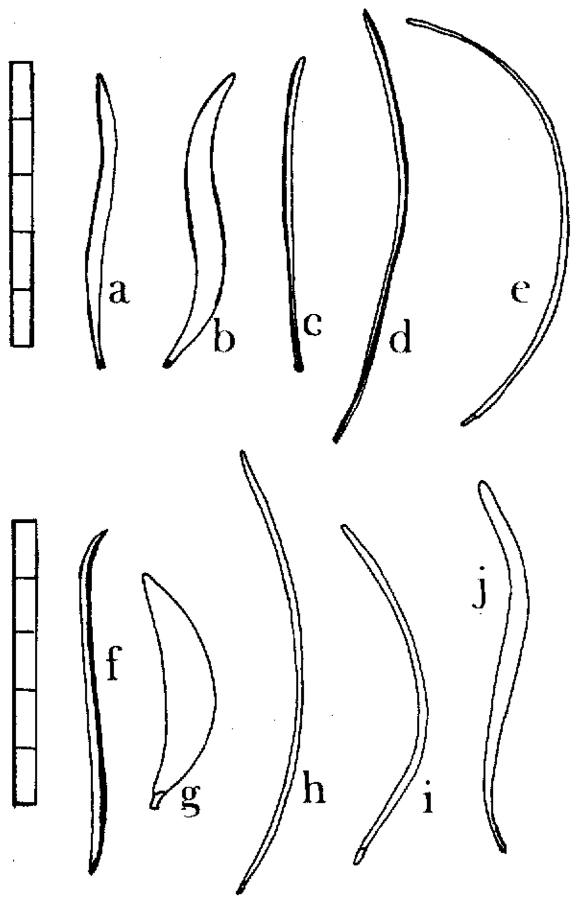


Table 1. Phyllode and pod characteristics of 10 specimens of *Acacia aneura* from Gindalbie.

No.	Collection	Phyllode Length	Phyllode Width	Pod Length	Pod Width
		(All dimensions in mm)			
1	2786	32-48	2-3	15-26	6- 9
2	2787	36-56	3-5	14-30	10-14
3	2788	33-76	2	16-30	7- 8
4	2789	40-80	1-1.5	22-32	6- 8
5	2790	52-75	1-1.2	18-30	6- 7
6	2791	50-62	1.5-2	12-24	8-11
7	2792	30-50	7-9	12-26	10-13
8	2793	55-92	1-1.5	15-26	7- 9
9	2794	33-58	1.5-2	15-25	11-13
10	2795	30-72	2.5-3	15-32	10-12

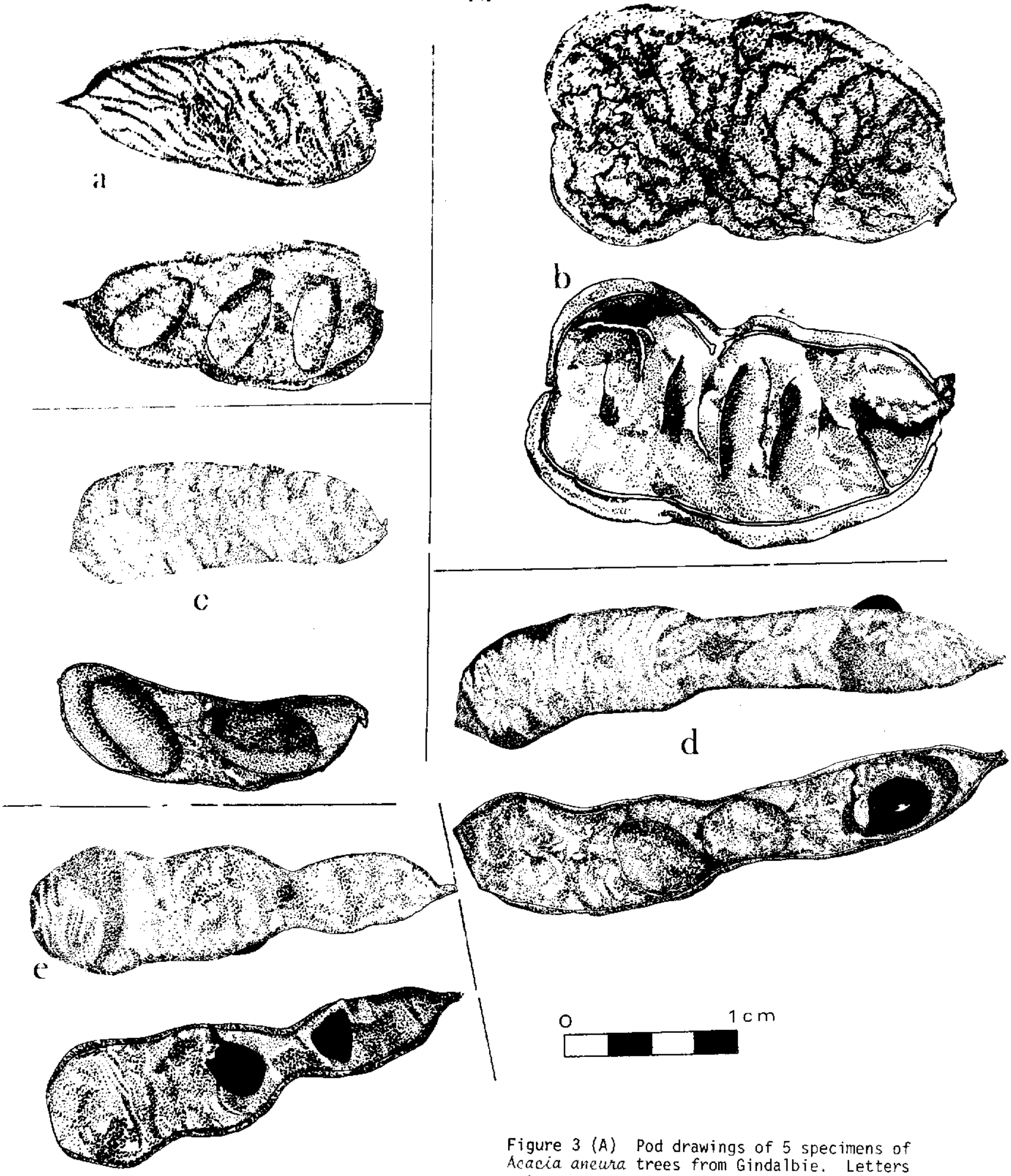


Figure 3 (A) Pod drawings of 5 specimens of *Acacia aneura* trees from Gindalbie. Letters a to e represent specimens 1-5 respectively.

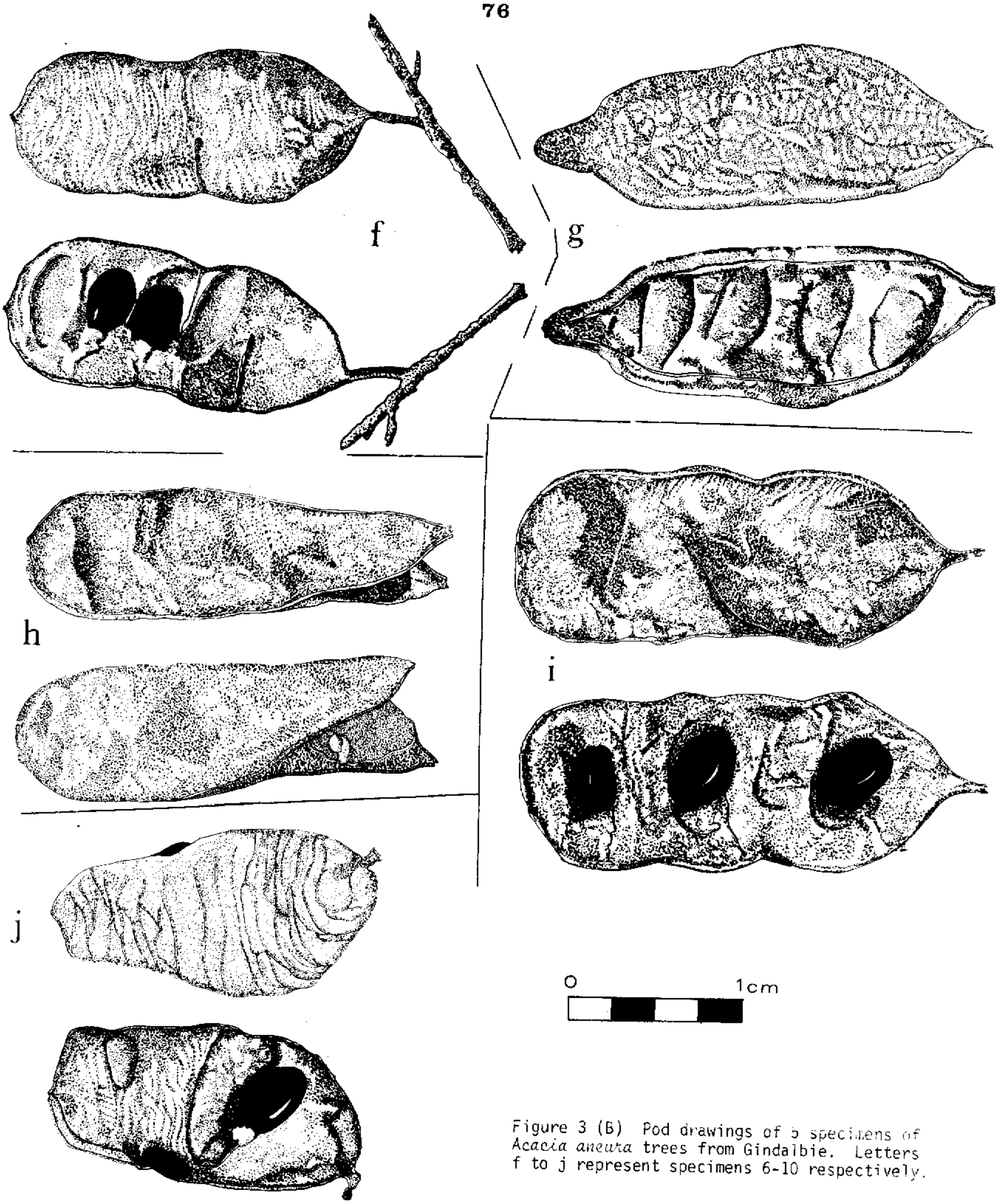


Figure 3 (B) Pod drawings of 5 specimens of *Acacia aneura* trees from Gindalbie. Letters f to j represent specimens 6-10 respectively.

Seed Weight

Seed weight within a species is clearly determined partly by environmental conditions and partly by genetical variation. Individual seeds may have low weight due to incomplete development. Insect damaged seeds, if not detected, may also contribute to lower weights. It is also possible that in comparing tree with tree the particular site conditions, principally in mulga the amount of soil moisture present in the ground during seed development and maturation, may influence the overall mean weight of seeds.

Seed weight was not used as a parameter by Ross and Morris[12]. In *Acacia harpophylla* however seed of heavier weight has been reported from an area with higher rainfall compared with seed from an area of lower rainfall[4].

An earlier study of mulga seed[8] suggested that within a batch, lighter seed tended to be less viable and to take longer to germinate than heavier seed. In that study the seed was of mixed parent origin but probably all of the same general leaf type. All progeny from the Laverton source reported have produced phyllodes akin to Gindalbie specimen 6 (Fig. 2, f).

A certain proportion of mulga seed is 'soft' and will germinate without heat pre-treatment[11]. Whether this characteristic is related to seed weight is not known.

All seed after extraction from pods was seived to remove small immature or undeveloped seed. Batches of 100 seed per specimen tree were individually weighed. During weighing any insect damaged seed were discarded. Seed weight characteristics for each batch are summarised in Table 2 and seed weight histograms are presented in Figure 4.

Mean seed weight ranking is

7
5>3>10>9>8>6>4>1
2

from heaviest to lightest.

The range of mean weights is from 7.11-17.70mg, with extreme values lying between 1.4 (number 1) and 25.2 (number 5)mg.

The overall mean percentage distribution by weight classes for the 10 samples (Fig. 4,k) approaches the expected normal distribution. However there are difficulties in characterising a tree with the use of 100 seed. For example the two batches of seed used for number 2 are summarised in Table 3.

Table 3. Tree 2 (2787) separate seed batches

Parameter	Batch a	Batch b	Combined
Mean wt(mg)	11.0	9.4	10.2
Minimum	8.0	1.7	1.7
Maximum	14.3	14.4	14.4
Range	6.3	12.7	12.7
1000 seed weight (g)	10.97 ± 0.28	9.35 ± 0.42	10.22 ± 0.38
No. of seed kg^{-1}	91,000 ± 2,300	107,000 ± 4,800	97,900 ± 3,700

These data suggest that considerable spread of mean values is likely (at least with some seed batches) and that both means and ranges calculated with t,p0.05 may be too precise to characterise all of the seed from a tree. Nevertheless the ranking given above is at least a useful approximation of one set of differences between individual trees.

Table 2. Seed Weight characteristics of 10 specimens of *Acacia aneura* from Gindalbie.

No.	Collection	Individual Seed Wt. (mg) Mean	Minimum	Maximum	Range	1000 seed wt (g) ± Range	No. of seed per kilogram ± Range
1	2786	7.11	1.4	10.3	8.9	7.11 ± 0.36	140,700 ± 7,200
2	2787	10.22	1.7	14.4	12.7	10.22 ± 0.38	97,900 ± 3,700
3	2788	16.13	11.9	22.7	10.8	16.13 ± 0.48	62,000 ± 1,800
4	2789	9.81	1.8	17.2	15.4	9.81 ± 0.57	102,000 ± 6,000
5	2790	17.70	11.6	25.2	13.6	17.70 ± 0.72	56,500 ± 2,300
6	2791	10.26	5.6	16.1	10.5	10.26 ± 0.49	97,500 ± 4,700
7	2792	10.28	6.2	14.8	8.6	10.28 ± 0.38	97,300 ± 3,600
8	2793	12.40	6.7	21.0	14.3	12.44 ± 0.50	80,400 ± 3,200
9	2794	12.63	2.1	18.7	16.6	12.63 ± 0.81	79,200 ± 5,100
10	2795	13.70	3.4	19.4	16.0	13.70 ± 0.62	73,000 ± 3,300

Note: Range at p0.05 (95% probability) calculated from standard error x t (=1.98) as a percentage of mean. All are sets of 100 seed except number 2 where 200 seed were used

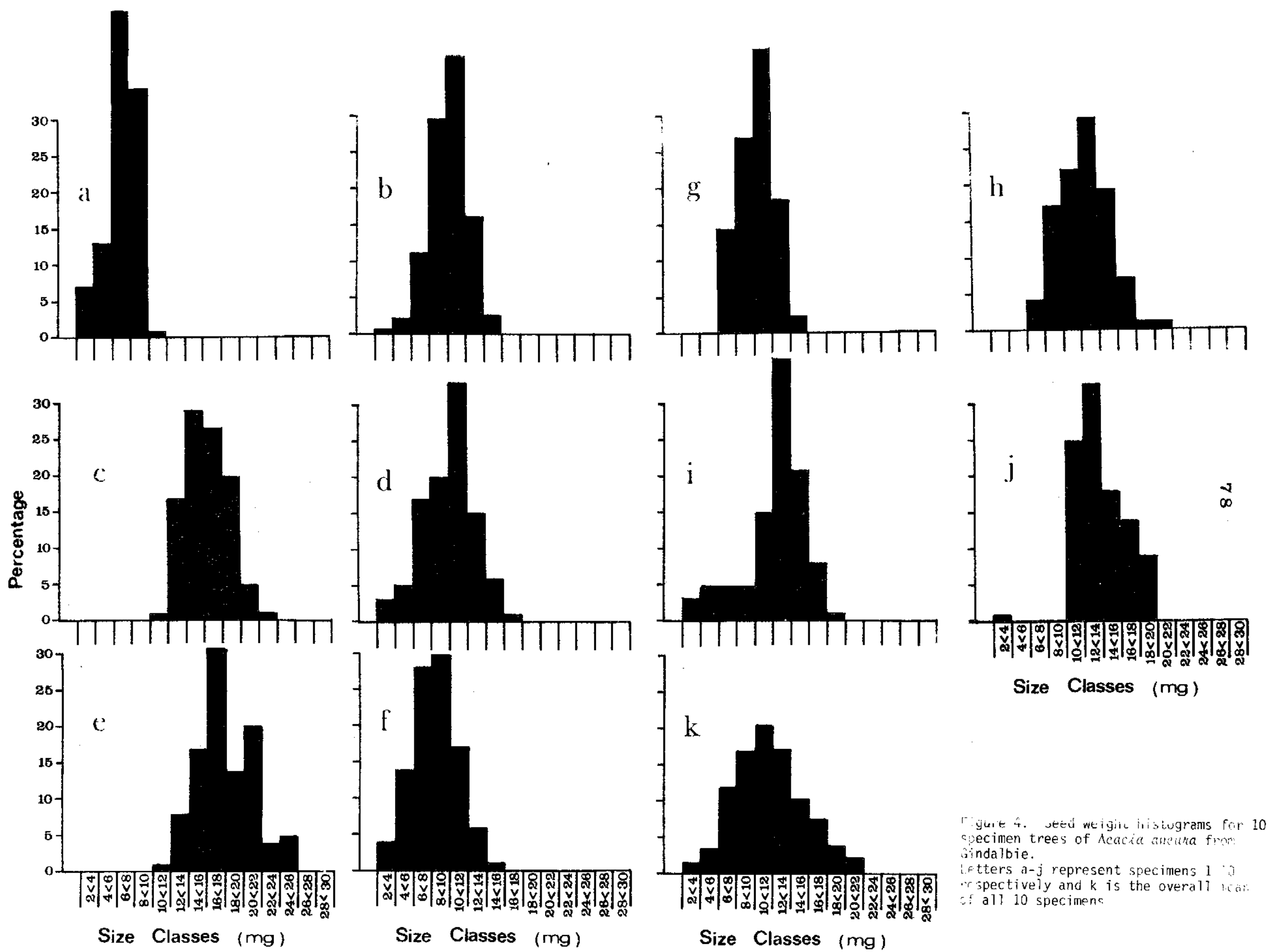


Figure 4. Seed weight histograms for 10 specimen trees of *Acacia aneura* from Gindalbie.
Letters a-j represent specimens 1-10 respectively and k is the overall mean of all 10 specimens

Germination Characteristics

Apparently good, undamaged seed of each specimen was arranged in 4 sets of 50. Each set of 50 seed was placed in a test tube to which boiling water was added sufficient to cover the seeds and half fill the tube. The test tubes were left to cool to room temperature. The seeds were then arranged on a filter paper over moistened vermiculite in a petri dish. Benlate was added to the surface to minimise fungal infection. These simple standards serve to provide a practical set of uniform treatment[13]. One petri dish with seed of each specimen was then placed in controlled temperature cabinets, one dish to each of four cabinets. These cabinets were maintained in darkness at 10, 15, 20 and 25^{o}c respectively for a period of 60 days (slightly longer in the case of specimen 1).

The dishes were inspected daily and all seeds with 2mm or more of radicle showing were removed and counted as germinants. The daily records of germination have been used to produce graphs showing the time course of cumulative germination (Figure 5). From the records of germination and the graphs nine different germination characteristics have been produced. These are presented below with brief notes on each specimen.

The nine characteristics are defined as follows:

1. Final percentage germination is the total percentage of seed germinated to the time that dishes were removed from the cabinets.

2. The number of days required to achieve the final percentage germination.

3. Germination rate is a measure calculated by summing the products of germinants and days from the hot water treatment. The sum is then divided by the total number of germinants. Each germinated seedling is used once only:

$$\frac{(n_1 \times t_1) + (n_2 \times t_2) \;........ nx \times tx}{\Sigma_x^1 n}$$

4. Peak value is the highest level of cumulative percentage germinated divided by number of days from hot water treatment. It is thus a measure of the steepness of the germination gradient illustrated in Fig. 5.

5. M.D.G. is mean daily germination. It is obtained by dividing the final percentage germination by the number of days taken for the last recorded germinant.

6. G.V. is germination value. This combines rate of germination and viability such that G.V. = Peak Value x M.D.G.

7. Energy % 7/28. Here germinative energy is used as an expression giving a measure of the 'strength' of the seed. This is obtained by taking the percentage that had germinated by 7 days divided by the percentage that germinated by 28 days, times 100.

8. Germinative capacity is the percentage of seed that had germinated at 28 days from hot water treatment.

9. Vigour combines energy and germinative capacity such that

   $$\text{vigour} = \frac{\text{germinative energy}}{\text{germinative capacity}}$$

   It may be considered as an objective measure of 'fitness', at least for seed of high viability.

Seed of half of the specimens germinated fastest at 25^{o}c and four of these produced most germinants at the higher temperature (numbers 1,5,6,10). However three specimens produced more germinants at 20^{o}c (numbers 3,4,9), one did so at 15^{o}c (number 8) and two (numbers 2 and 7) produced most germinants at the lowest temperature, 10^{o}c. These latter had broader phyllodes than the others (Fig.2).

Of some interest is the fact that the specimens which gave the highest germination percentages showed a definite trend of increased percentage with increased mean seed weight, viz

specimen	1	4	9	10	5
%g at 25^{o}c	80	*	86	98	98
Overall percentage g	64	69	(60)	80.5	89.5
Mean seed wt (mg)	7.1	9.8	12.6	13.7	17.7

It must be noted here that specimen 4 had 100 percent germination at 20^{o}c and specimen 9 had 94 percent germination at 20^{o}c.

The other one to produce best results at 20^{o}c was number 3 with 66 percent. These three had an inverse relation of seed weight and percentage germination at 20^{o}c, viz

specimen	4	9	3
%g at 20^{o}c	100	94	66
mean seed wt (mg)	9.8	12.6	16.1

Individual characteristics

A brief summary of the salient features of each specimen follows.

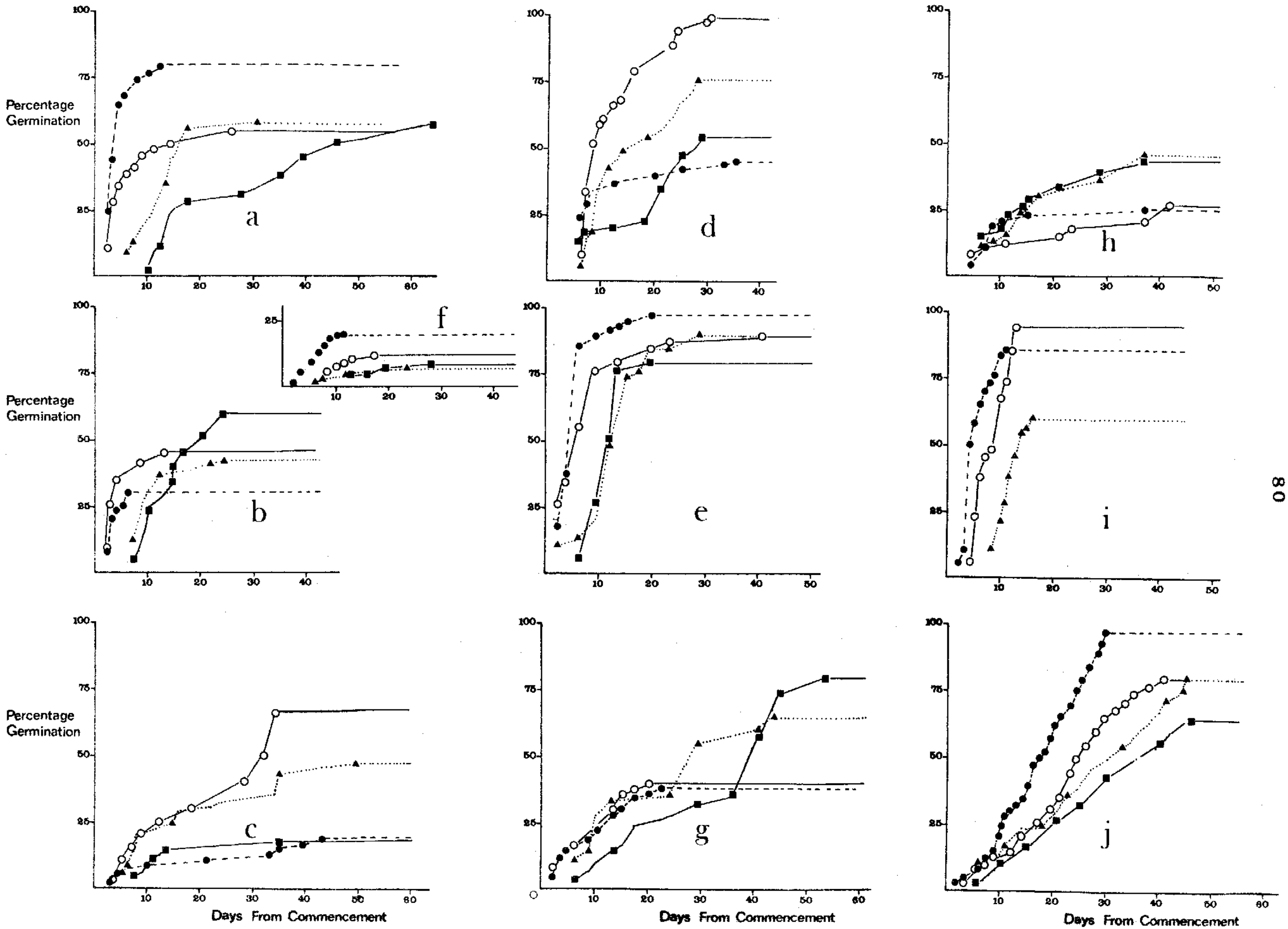


Figure 5. Time course of cumulative germination for sets of 50 seed at four temperatures from 10 specimens of *Acacia aneura*. Letters a to j represent specimens 1-10 respectively. Symbols as follows: dashed line and filled circles 25^{o}c; solid line and open circles 20^{o}c; dotted line and f[illegible] tri[illegible]les 15[illegible] solid li[illegible] and filled s[illegible]s 10[illegible]

1. Collection 2786

The erect slightly curved phyllodes terminate in a blunt point. The pod also has a point to it. The main difference between this and all the others however is the very low mean seed weight (Table 2) which is coupled with a low range between lightest and heaviest seed. Despite low seed weight 80 percent germination was achieved at 25°c (Table 4) and this specimen had the fourth best overall viability with a mean percentage germination of 64 percent. Mean pod area is the smallest of the set of 10. This individual is best adapted to the 25°c regime and is perhaps most closely allied to number 10 which has a similar pod shape and also a similar phyllode width.

Table 4. Germination Characteristics
Specimen 1 Collection 2786

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	64	58	54	80
2. Days to 1	78	31	26	13
3. Germination rate	32.4	13.3	6.2	3.9
4. Peak value	1.6	3.3	8.5	16.5
5. M.D.G.	0.8	1.9	2.1	6.2
6. G.V.	1.3	6.2	17.7	101.5
7. Energy % 7/28	-	21.4	77.8	92.5
8. Germinative capacity %	30	56	54	80
9. Vigour	-	0.38	1.44	1.16

2. Collection 2787

The large pod distinguishes this specimen. This specimen has been mentioned above as performing well at 10°c. A close inspection of Fig. 5(b) and Table 5 reveals that germination commenced more quickly at higher temperatures, but continued for longer at lower temperatures such that while twice as many seedlings germinated at 10°c as at 25°c, it took them four times as long to do so.

Table 5. Germination Characteristics
Specimen 2 Collection 2787

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	60	42	43	30
2. Days to 1	24	24	13	6
3. Germination rate	11.9	10.0	4.0	3.5
4. Peak value	2.8	3.0	8.9	6.7
5. M.D.G.	2.5	1.8	3.3	5.0
6. G.V.	6.9	5.3	29.6	33.4
7. Energy % 7/28	6.7	28.6	86.9	100
8. Germinative capacity %	60	42	43	30
9. Vigour	0.11	0.68	2.00	3.33

It is similar in phyllode to specimen 7 and may be described as broadly curved, but has a much broader pod than 7. Mean seed weight is similar to numbers 6 and 7 further supporting the notion of a close affinity to the latter. The seed weight histogram is similar to the mean of all specimens, but with few in larger sizes.

3. Collection 2788

Narrow phyllodes with black tips and also black new phylls are a feature of number 3. Pod shape is not unlike number 1 but texture is more papery, similar to 4 and 5. Mean seed weight is the second heaviest but germination was poor with 36.5 percent overall. Best germination occurred at 20 and 15°c. As mentioned above its germination performance puts it with numbers 4 and 9, but of the two it is much closer to 4 (Fig. 5, Tables 6 and 7) despite having a mean seed weight almost double that of number 4.

Table 6. Germination Characteristics
Specimen 3 Collection 2788

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	16	46	66	18
2. Days to 1	35	49	34	43
3. Germination rate	13.0	19.0	23.3	21.7
4. Peak value	1.1	2.5	2.2	1.0
5. M.D.G.	0.5	0.9	1.9	0.4
6. G.V.	0.5	2.4	4.3	0.4
7. Energy % 7/28	28.6	43.8	40.0	60
8. Germinative capacity %	14	32	40	10
9. Vigour	2.04	1.37	1.00	6.00

4. Collection 2789

This specimen has narrow, sweepingly curved phyllodes. Mean pod area is similar to number 3 with which it also has some germination similarities. The seed weight histogram is similar to the mean of all 10 specimens, though it has only the second lightest seed. Mean phyllode length is average but width is second narrowest with only number 5 being narrower. The papery pods are similar to both 3 and 5.

Germination averaged 60 percent overall with best results at 20 and 15°c and highest germination value at 20°c (Table 7).

Table 7. Germination Characteristics
Specimen 4 Collection 2789

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	54	76	100	46
2. Days to 1	28	28	31	34
3. Germination rate	16.9	14.0	12.1	10.7
4. Peak value	2.6	3.8	6.7	4.3
5. M.D.G.	1.9	2.7	3.2	1.3
6. G.V.	5.0	10.4	21.5	5.7
7. Energy % 7/28	33.3	18.4	37.5	66.7
8. Germinative capacity %	54	76	96	42
9. Vigour	0.62	0.24	0.39	1.59

5. Collection 2790

The narrow sweeping curved phyllodes are very similar to number 4, indeed this pair are probably closest in phyllode shape and dimensions. Pod area is slightly less than number 4 but with a similar texture and elongated shape.

Mean seed weight is heaviest of all sets, with only number 3 approaching it (Table 2). The seed weight histogram is well to the right of the mean (Fig. 4). Best germination was at 25°c but germination was uniformly high at a mean of 89.5 percent, the best of the 10 specimens examined, with high germinative capacity (Table 8).

Table 8. Germination Characteristics
Specimen 5 Collection 2790

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	80	90	90	98
2. Days to 1	19	28	41	19
3. Germination rate	11.6	12.8	7.7	5.5
4. Peak value	5.9	4.9	13.0	14.3
5. M.D.G.	4.2	3.2	2.2	5.2
6. G.V.	24.6	15.8	28.6	73.9
7. Energy % 7/28	5.0	13.3	61.4	87.8
8. Germinative capacity %	80	90	88	98
9. Vigour	0.06	0.15	0.70	0.90

6. Collection 2791

Phyllodes are narrow curved at the end. Pod shape and area is closest to number 8 but seed weight mean is very close to numbers 2 and 7. Germination was the poorest of all specimens at a mean of only 11 percent, with best performance at 25°c (Table 9). This tends to suggest that perhaps seed weight at 10.26mg represents imperfect growth - if so we should have to discount germination trends for half the specimens (Table 2) a proportion to be rejected at this stage in favour of a genetical explanation.

Table 9. Germination Characteristics
Specimen 6 Collection 2791

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	8	6	11	19
2. Days to 1	27	23	17	11
3. Germination rate	16.4	13.3	10.2	5.8
4. Peak value	0.4	0.3	0.8	2.1
5. M.D.G.	0.3	0.3	0.7	1.7
6. G.V.	0.1	0.1	0.5	3.7
7. Energy % 7/28	-	33.3	-	73.7
8. Germinative capacity %	8	6	11	19
9. Vigour	-	5.55	-	3.88

7. Collection 2792

The broad obtusely curved phyllodes are the broadest of the set. Number 2 is close but with longer, narrower phyllodes. Mean seed weight is very close to numbers 2 and 6. Overall germination rate was 55.5 percent with 80 percent germinating at 10°c. Had the experiment been terminated at 20 days, then the order would have been 20>25>15>10°c instead of the pattern at 45 days of 10>15>20>25°c (Table 10). The pod is distinctively tipped (Fig. 3B, g) and seed weight is similar to numbers 2 and 6.

Table 10. Germination Characteristics
Specimen 7 Collection 2792

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	80	64	40	38
2. Days to 1	54	43	20	22
3. Germination rate	24.1	20.3	9.4	9.8
4. Peak value	1.6	2.8	4.0	3.5
5. M.D.G.	1.5	1.5	2.0	1.7
6. G.V.	2.4	4.2	8.0	6.1
7. Energy % 7/28	7.1	20.8	40.0	36.8
8. Germinative capacity %	28	48	40	38
9. Vigour	0.26	0.43	1.00	0.97

8. Collection 2793

This specimen has narrow phyllodes very similar to number 9 but slightly narrower and up to twice as long (Table 1). Pods are not unlike number 3 but softer and perhaps closer to 5. Overall germination was poor at 34.5 percent, with best total germination at 15°c but the 10 and 15° results have little between them so that the overall pattern is not unlike that of number 7. Low germinative capacity was recorded (Table 11). Seed weight is intermediate and close to number 9, with the seed weight histogram (Fig. 4, h) very close to the overall mean.

Table 11. Germination Characteristics
Specimen 8 Collection 2793

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	42	46	26	24
2. Days to 1	37	37	42	37
3. Germination rate	16.0	19.1	20.3	9.1
4. Peak value	2.0	1.8	2.0	2.3
5. M.D.G.	1.1	1.2	0.6	0.7
6. G.V.	2.3	2.2	1.2	1.5
7. Energy % 7/28	36.8	27.8	55.6	45.5
8. Germinative capacity %	38	36	18	20
9. Vigour	0.97	0.77	3.09	2.27

9. Collection 2794

Narrow curved phyllodes similar to 8 but shorter. Pod large and robust, broader than 8.

Overall germination at 60 percent with the best performance at 20 and 25°c though the early trend was for 25°c to germinate fastest. This set was unique in that seed at 10°c did not germinate (Table 12) and the seed set at 15°c took a considerable time to start. Germinative capacity was high and the germination value for 25°c almost as high as for number 1.

Seed weight is the fourth heaviest of the set of 10.

Table 12. Germination Characteristics
Specimen 9 Collection 2794

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	0	60	94	86
2. Days to 1	28	16	13	11
3. Germination rate	-	11.7	8.4	5.3
4. Peak value	-	3.9	7.2	12.5
5. M.D.G.	-	3.8	7.2	7.8
6. G.V.	-	14.5	52.3	97.8
7. Energy % 7/28	-	-	48.9	81.4
8. Germinative capacity %	-	60	94	86
9. Vigour	-	-	0.52	0.95

Note: Means for two lots of seed tested.

10. Collection 2794

Long broadish phyllodes, in fact the third broadest after numbers 7 and 2. Seed weight is third heaviest after 5 and 3 at 13.7mg. Overall percentage germination was second highest after number 5, at 80.5 percent. This seed took a lot longer to reach maximum germination than numbers 5 and 9.

Mean pod size is similar to (but intermediate between) specimens 2 and 9.

Table 13. Germination Characteristics
Specimen 10 Collection 2795

Germination Measurement	Temperature (°c) 10	15	20	25
1. Final %	64	80	80	98
2. Days to 1	46	45	41	30
3. Germination rate	25.1	25.3	21.7	17.3
4. Peak value	1.3	1.7	2.1	3.2
5. M.D.G.	1.4	1.7	1.9	3.2
6. G.V.	1.8	3.0	4.1	10.0
7. Energy % 7/28	15.8	21.7	16.1	13.0
8. Germinative capacity %	38	46	62	92
9. Vigour	0.42	0.47	0.26	0.14

Conclusions

A consideration of seed weight, leaf shape and germination behaviour suggests that numbers 2 and 7 stand apart from the others. These broad phyll trees of very similar mean seed weight both produced highest germination at 10°c.

There was some tendency for higher germination with increased mean seed weight, particularly in the series 1,9,10,5 which ran across the range of phyllode types.

Early indications based on observation of seedling growth are that the progeny of each individual is more or less uniform and that phyllode type may be ranked similarly to the parents.

The study continues.

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