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SOME OBSERVATIONS ON EARLY DEVELOPMENT IN ACACIA ANEURA SEEDLINGS FROM DIFFERING LOCALITIES.

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Introduction

Variation between and within species of Acacia has been discussed by several authors (see reference list).

In a previous study attention was drawn to differences in phyllode size within and between Acacia aneura trees at a single location[10]. Phyllode size and shape has been considered a useful characteristic in distinguishing closely related species[15] from A. aneura. Within the species two general forms have been long recognized. Cannon[6] noted that phyllodes in one form are broad. He contrasted broad with narrow phyllodes as follows:

FORM	LENGTH (mm)	WIDTH (mm)	AREA (mm)
Broad	57	8	350
Narrow	55	2.5	100

Black[2] described typical Acacia aneura as having phyllodes 30-70 mm length and 1-2.5 mm broad. His variety latifolia in contrast had phyllodes 4-7 mm broad. The 'Charleville' variety which we described earlier[4] had mature phyllodes 25-28 mm in length, 3.9-5.3 mm in width and with mean surface area of 107-133 mm .

The total variability within the present taxon Acacia aneura is encompassed in Pedley's extremes[16]; 20-240 mm length, 0.9-12 mm width. As there is so much variation within Acacia aneura and this variation is complex and poorly understood, Pedley suggests that recognition of infraspecific taxa, such as Black's var. latifolia, is not possible at present. However it has been suggested that ecotypes associated with summer and winter rainfall regimes may exist.[13] Turesson (in Stebbins[21]) emphasises that differentiation into ecotypes is more likely in common wide-spread species than in rare or locally endemic species. Considerable variation in phyllode shape within A. melanoxylon[9] has been related to distance from the coast and to seasonal distribution of rainfall.

Differences exist within Acacia aneura populations in respect of legume type, seed weight and germination characteristics.[12] It is possible that further study will show that broad geographical/climatic trends exist in a similar fashion to those shown for Acacia harpophylla by Coaldrake.[8]

A study of seedling morphology is a useful tool in elucidating taxonomic relationships within Acacia[20]. In pinnate leaf species both the number and arrangement of leaflets are of interest, as well as the arrangement of the entire leaves.[19] Acacia with persistent pinnate foliage have been regarded as originating in moist areas, in contrast with those species which produce phyllodes early. Variation in juvenile leaf forms may be discussed in relation to species advancement, drought tolerance and in terms of developmental morphogenesis.

Reversion to juvenile foliage may occur in Acacia species.[7] We note this in Acacia saligna at Bentley, W.A. in association with the gall rust fungus Uromycladium tepperianum, but not to date in A. aneura. Cambage[5] noted reports of twinning in Acacia juniperina. A. aneura seeds occasionally produce 2 radicles. Attempts at following through the development of these abnormal seedlings (about 1 per cent of seed sown) have failed - either one or both radicles abort within a week or so of germination and both have usually died within 2 weeks. One interesting plant was observed in 1977 at Bentley. In this the usual alternate arrangement of the first pinnate leaves or eophylls, was replaced such that a pair of opposite pinnate leaves, each with two pairs of leaflets followed the cotyledons. These were followed by another pair of opposite pinnate leaves. The second pair were bipinnate with one having two pairs of opposite leaflets and the other having three pairs of opposite leaflets. The next leaf was phyllodinous in having a swollen petiole. This was also leafy with a bipinnate set of three pairs of opposite leaflets. The next leaf was entirely phyllodinous (E. Bunn, personal communication).

A certain amount of variation in seedling morphology as between batches of Acacia aneura seed suggested that a detailed examination of early develomental morphology could prove of interest. As it is always difficult to extrapolate results from different areas[18], it was considered desirable to use seed lots from sharply contrasting environments for this study.

Material Used in the Study

Some 300 seed of each of four Acacia aneura seed collections was sown in seedling trays containing coarse sand following hot water treatment. When cotyledons appeared 45 seedlings from each batch were carefully transplanted into compressed peat jiffy pots containing a modified UC 11B soil mix.[1] Seedlings were harvested and drawn to illustrate the progression of leaf and phyllode production over the following 3 months. All plants were housed in a greenhouse at Bentley. Water was given to bring pots to field capacity about twice a week. The period involved was July-October, when temperatures were rising.

Seed came from the following locations (prefix denotes batch in figures):

C. Queensland seed from Charleville Pastoral Station. Individuals raised from this seed have the same overall appearance, with blue-grey rounded, flat, phyllodes. Legumes not sighted. Location ~ 26°25 S, 146°13 E, collected ~ 1975. Viability of this seed has remained high[11] though seedling growth under glasshouse conditions at Bentley tends to be better in summer than in late winter/early spring. Mature phyllodes have been described in detail.[4]

L. Western Australian seed from Cosmo-Newberry, near Laverton. Individuals raised have the same overall appearance, with narrow short flattened phyllodes. Legumes not sighted. Location 28°00 S, 122°54 E, collected late 1975. Seedlings tend to be slow growing under glasshouse conditions. A range of germination studies has been undertaken with this material.[11]

LD. Western Australian seed from Leinster Downs. Seeds are much larger than the other batches used, the parent has flat but broader phyllodes than L and the legumes are large. Collection No. 2751, collected November 1979. The plant has some characteristics similar to A. craspedocarpa. Location 27°51 , 120°36 E.

P. Western Australian seed from West Angelas, in the Pilbara region. The parent trees have narrow to terete phyllodes. This locality is towards the north-western limit of the range of Acacia aneura. Location 23°05 S, 118°40 E, collected December, 1979.

Representative plants of each batch were harvested weekly. Typical, representative individuals from each harvest were pressed and drawn. Figures 1-6 illustrate leaf and phyllode development.

Results

On germination the cotyledons emerge and are carried above soil level by development of the hypocotyl. Radicle emergence occurs first and root extension is characteristically rapid. As the jiffy pots used were only 5 cm tall roots either came through the walls of the container or curled around the bottom within 4-6 weeks. Root morphology was not considered.

Cotyledons persisted to varying lengths of time. Retention was probably related more to individual development than to any sharp ecotypic difference. However, we note that persistence appeared to be less in Laverton and Leinster sets (7 wks) compared with the other two from lower latitudes (11-12 wks). Cotyledons in the Leinster set tended to be larger than the others (Figure 3).

The first eophylls emerged after the cotyledons. These had two to three pairs of opposite leaflets. Leaflets may be described as ovate, with entire margins, rounded to mucronate apices and with attenuate petiolated bases. The number of pairs of leaflets on the first eophyll showed some differences between sets. The Charleville plants were variable with more plants having two pairs of leaflets; one had two first eophylls, one with 4 and one with 6 leaflets (Figure 1, B). In the Laverton set all seedlings had 2 pairs of leaflets on the first eophyll but most plants also showed an extended petiole beyond the ultimate pair (Figure 2). The Leinster set had more plants with three pairs of leaflets on the first eophyll, than with two pairs. In the West Angelas set three pairs were more common though persistence of all three pairs beyond 4-5 weeks was infrequent.

Development of the second eophyll was more varied. Two extreme forms were observed

a) an opposite bipinnate leaf with 2-3 pairs of leaflets on each pinna, petiole narrow and similar in length to length of the pinnae (Figure 2, C and D; Figure 6, A and B)

b) a phyllodinous bipinnate leaf with the pinnae borne distal to a comparatively broad petiole (e.g. Figure 1, C and D; Figure 3, E and F, Figure 4, A and B; Figure 5, E and F). Two to three pairs of leaflets were also present.

The second form is perhaps better described as a transitional bippinate leaf rather than an eophyll. Both forms were present in seedlings of each set with rather more of a) present in the Laverton and West Angelas sets (86 and 89 percent respectively). On the other hand more of b) were present in the other two sets with 77 and 82 per cent in Leinster and Charleville sets respectively.

Leaflets of the second eophylls were about half the size of those on the first eophylls. The lower leaflets adjacent to each other but on opposing pinnae were consistently smaller than the rest of the leaflets. Leaflets were of similar shape to those of the first eophylls but were more cordiform than ovate. Second eophylls became conspicuous after 3 weeks in West Angelas and Laverton sets of seedlings, and at 5 weeks in the Charleville set and 6 weeks in the Leinster Downs set.

A distinctive third eophyll was produced in the Laverton and West Angelas sets with a petiole not quite as broad as the phyllodinous second leaf of the Leinster and Charleville sets. The first true phyllodes (with no leaflets) began to appear at 6 weeks in the Charleville and Leinster sets. In the case of the Leinster plants these were invariably the third post-cotyledonary leaves, whereas in the Charleville plants the third leaf was also a transitional of type b). In some of the Laverton plants a fourth leaf was also produced (Figure 2F) when it was of type b); in others the fourth leaf was a phyllode devoid of leaflets. The West Angelas set had a few individuals which carried very

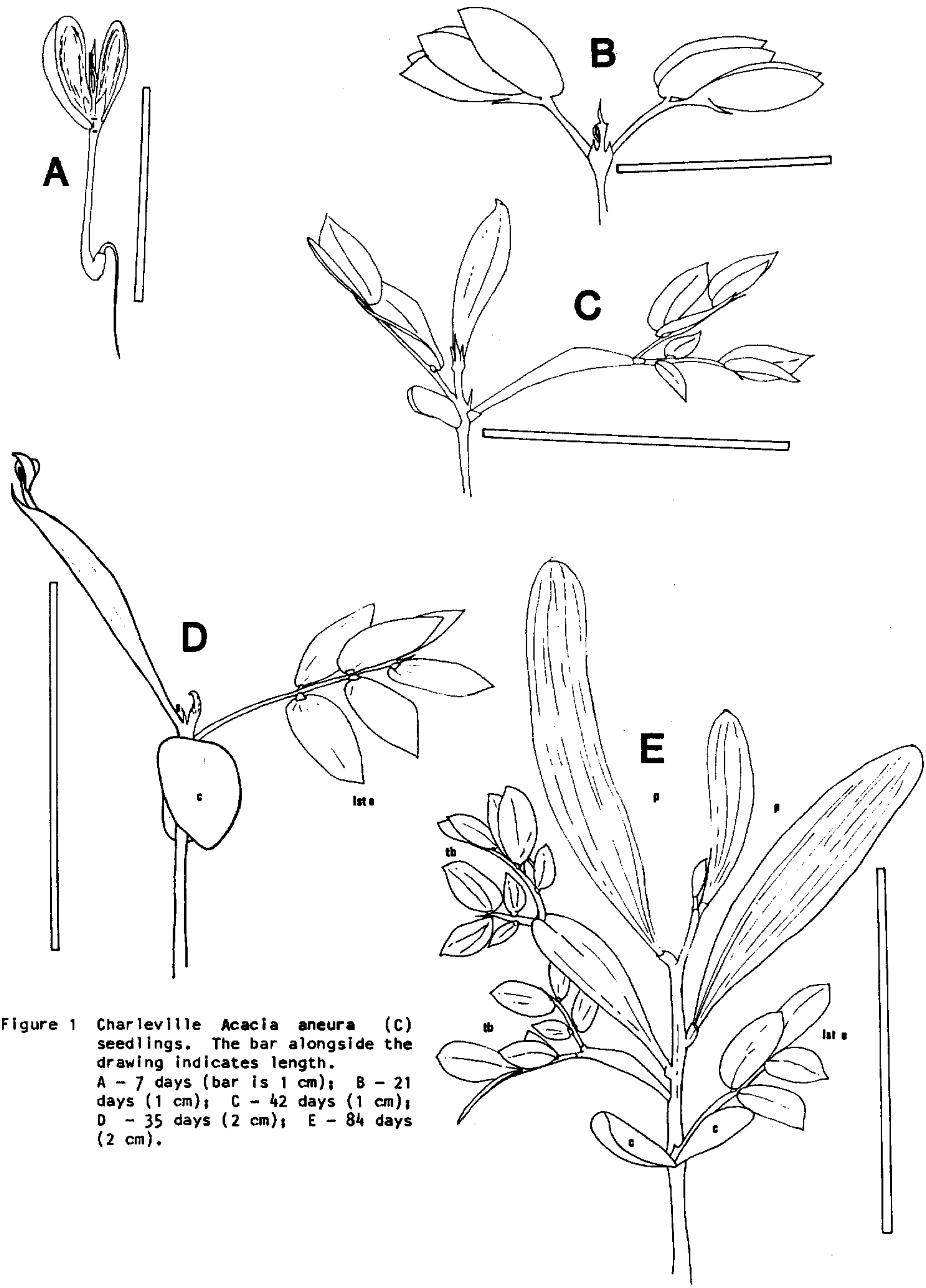


Figure 1 Charleville *Acacia aneura* (C) seedlings. The bar alongside the drawing indicates length.
A – 7 days (bar is 1 cm); B – 21 days (1 cm); C – 42 days (1 cm); D – 35 days (2 cm); E – 84 days (2 cm).

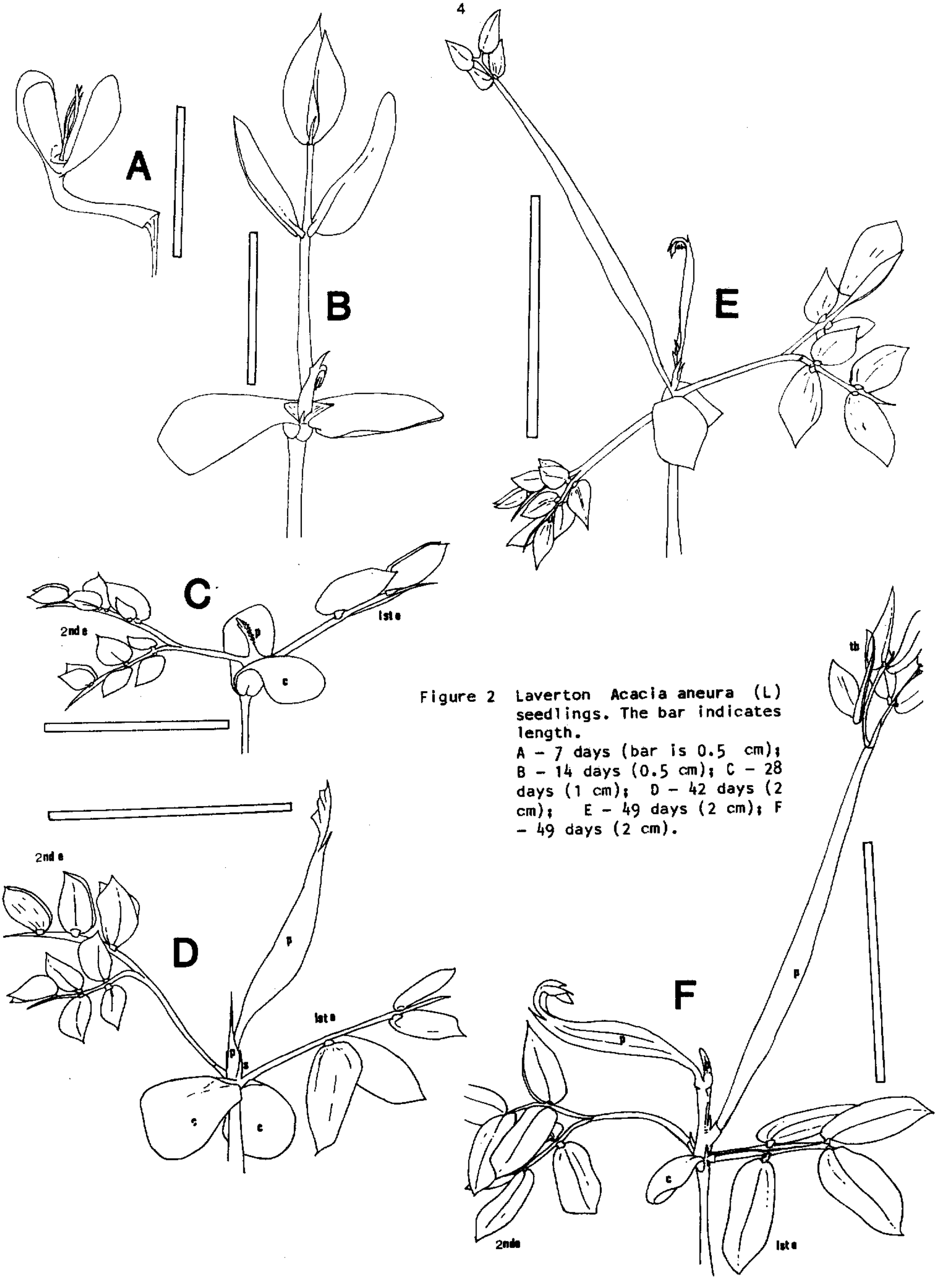


Figure 2 Laverton *Acacia aneura* (L) seedlings. The bar indicates length.
A – 7 days (bar is 0.5 cm); B – 14 days (0.5 cm); C – 28 days (1 cm); D – 42 days (2 cm); E – 49 days (2 cm); F – 49 days (2 cm).

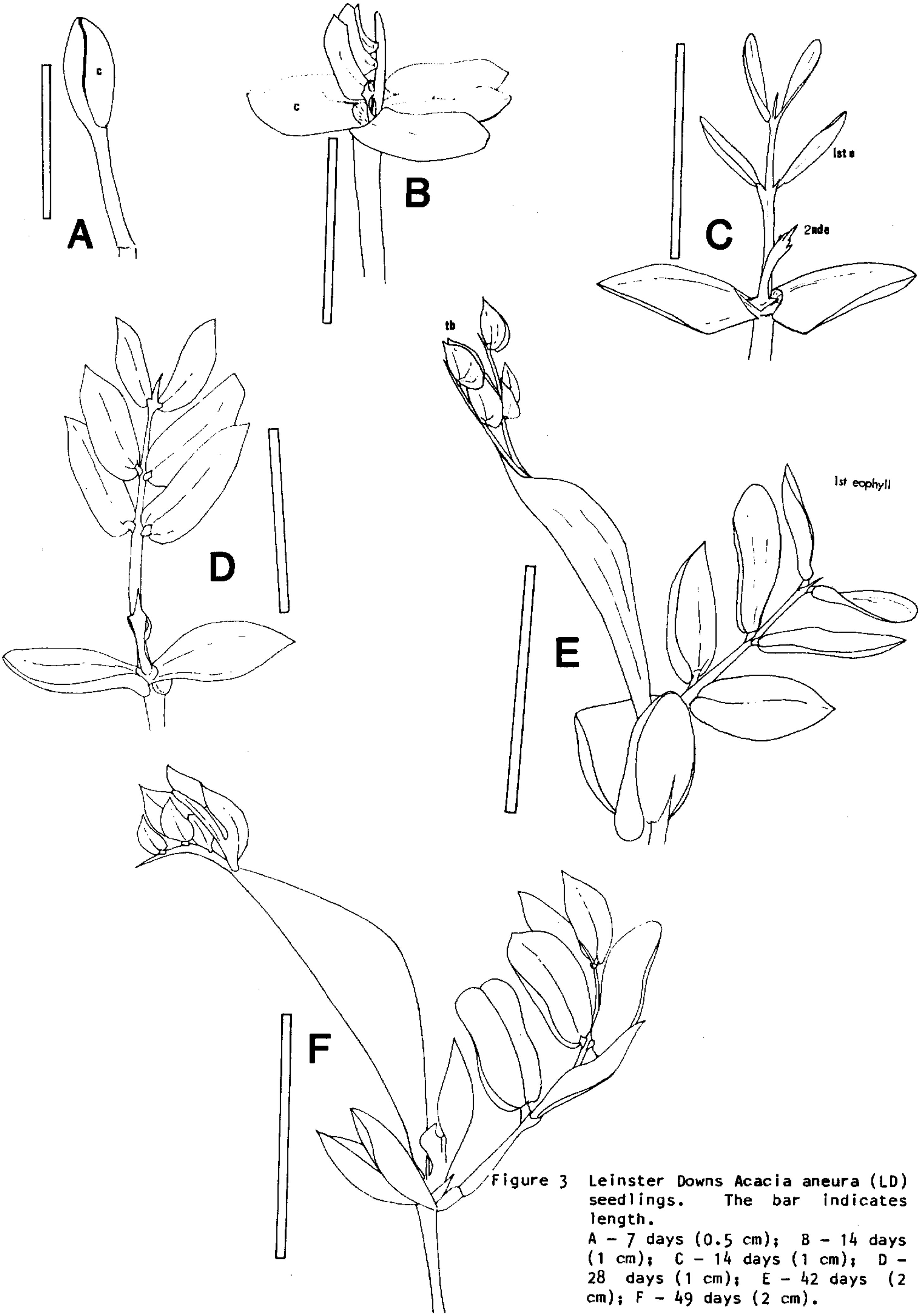
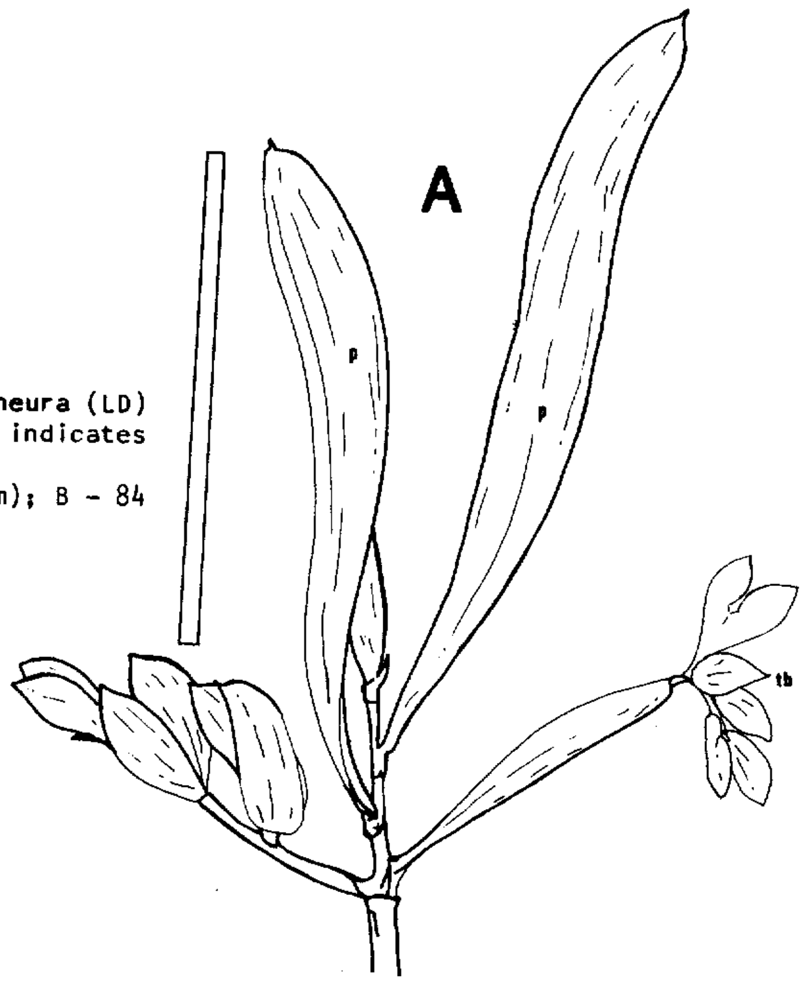
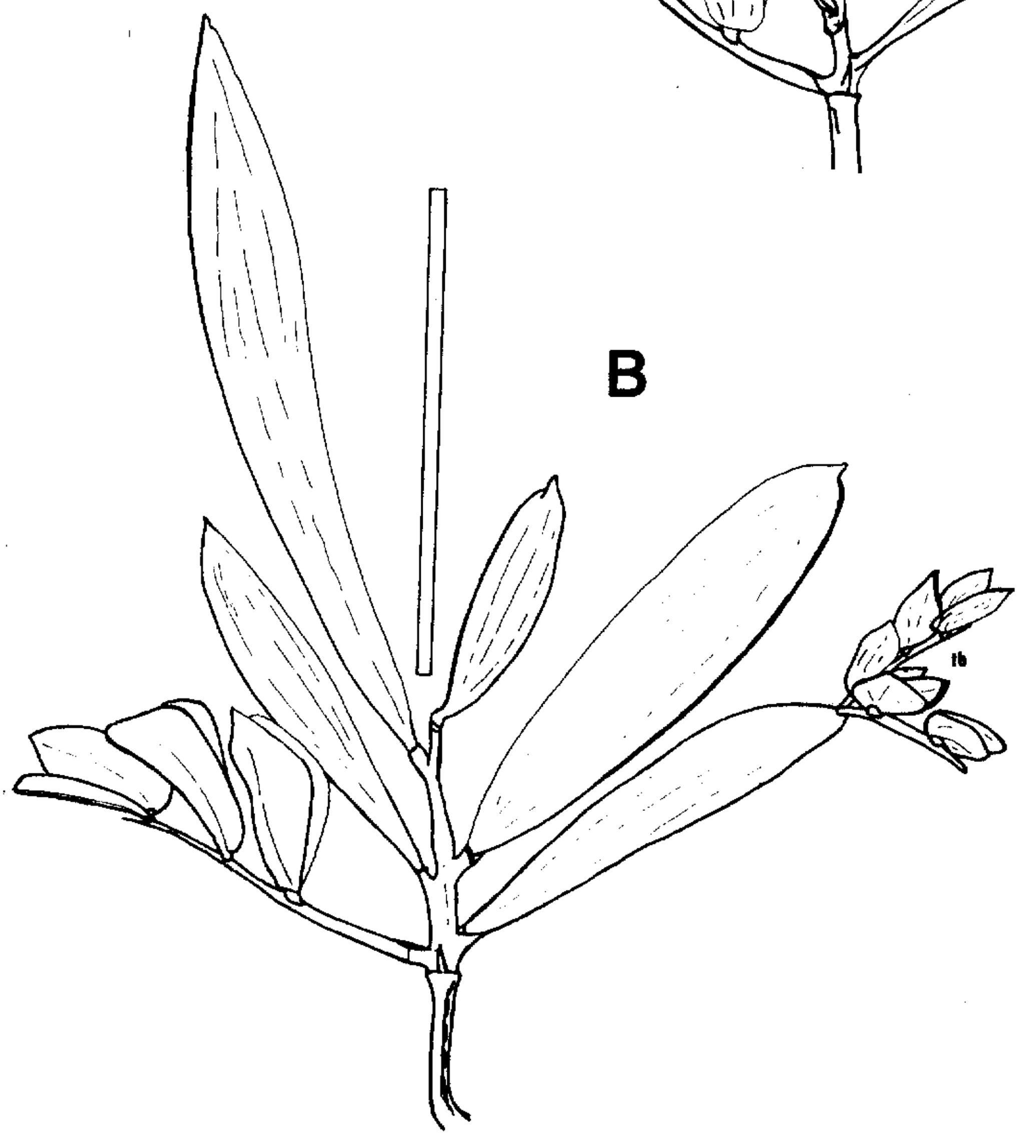


Figure 3 Leinster Downs *Acacia aneura* (LD) seedlings. The bar indicates length.
A – 7 days (0.5 cm); B – 14 days (1 cm); C – 14 days (1 cm); D – 28 days (1 cm); E – 42 days (2 cm); F – 49 days (2 cm).

Figure 4 Leinster Downs *Acacia aneura* (LD) seedlings. The bar indicates length.
A - 56 days (bar is 2 cm); B - 84 days (2 cm).





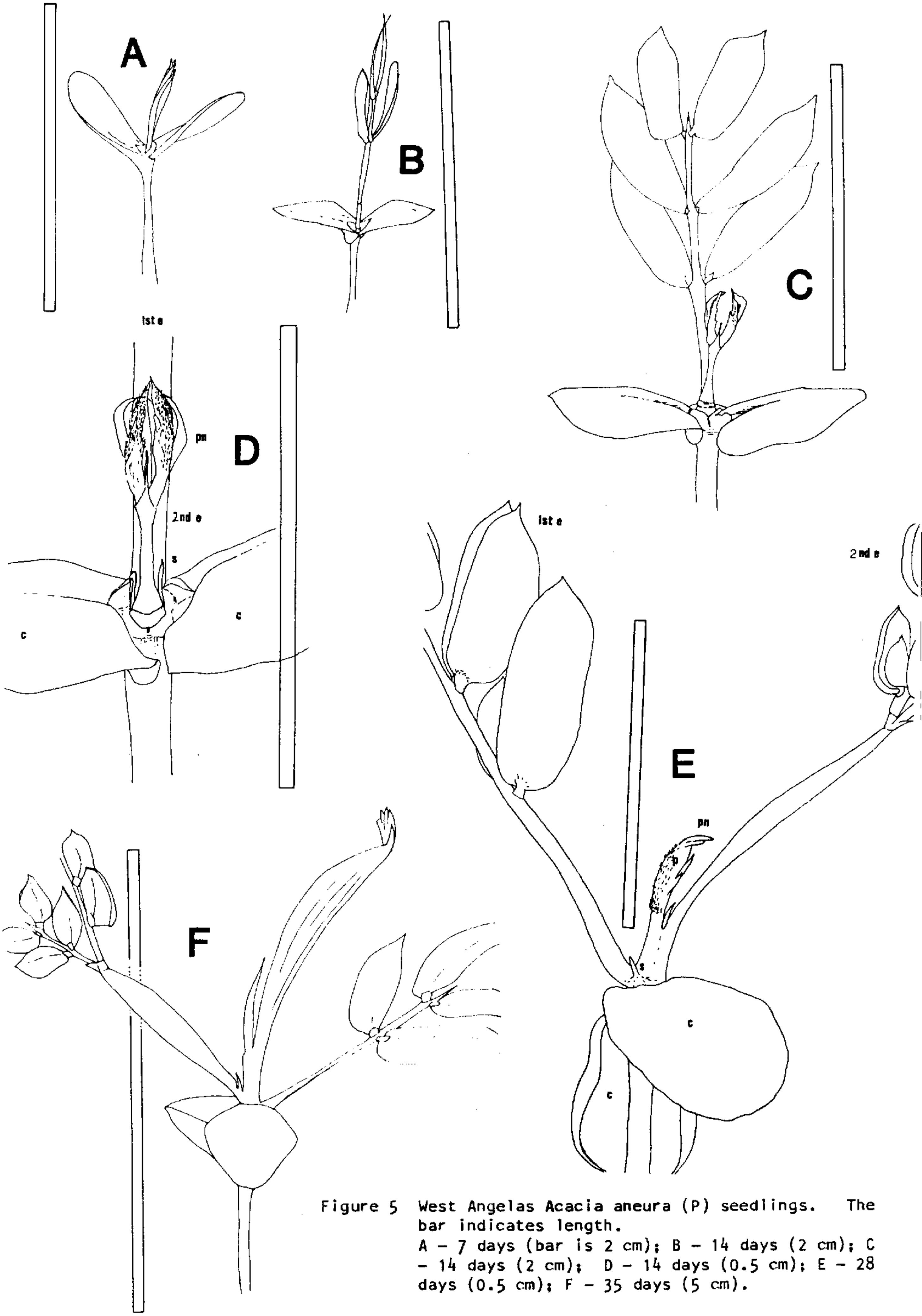


Figure 5 West Angelas *Acacia aneura* (P) seedlings. The bar indicates length.
A – 7 days (bar is 2 cm); B – 14 days (2 cm); C – 14 days (2 cm); D – 14 days (0.5 cm); E – 28 days (0.5 cm); F – 35 days (5 cm).

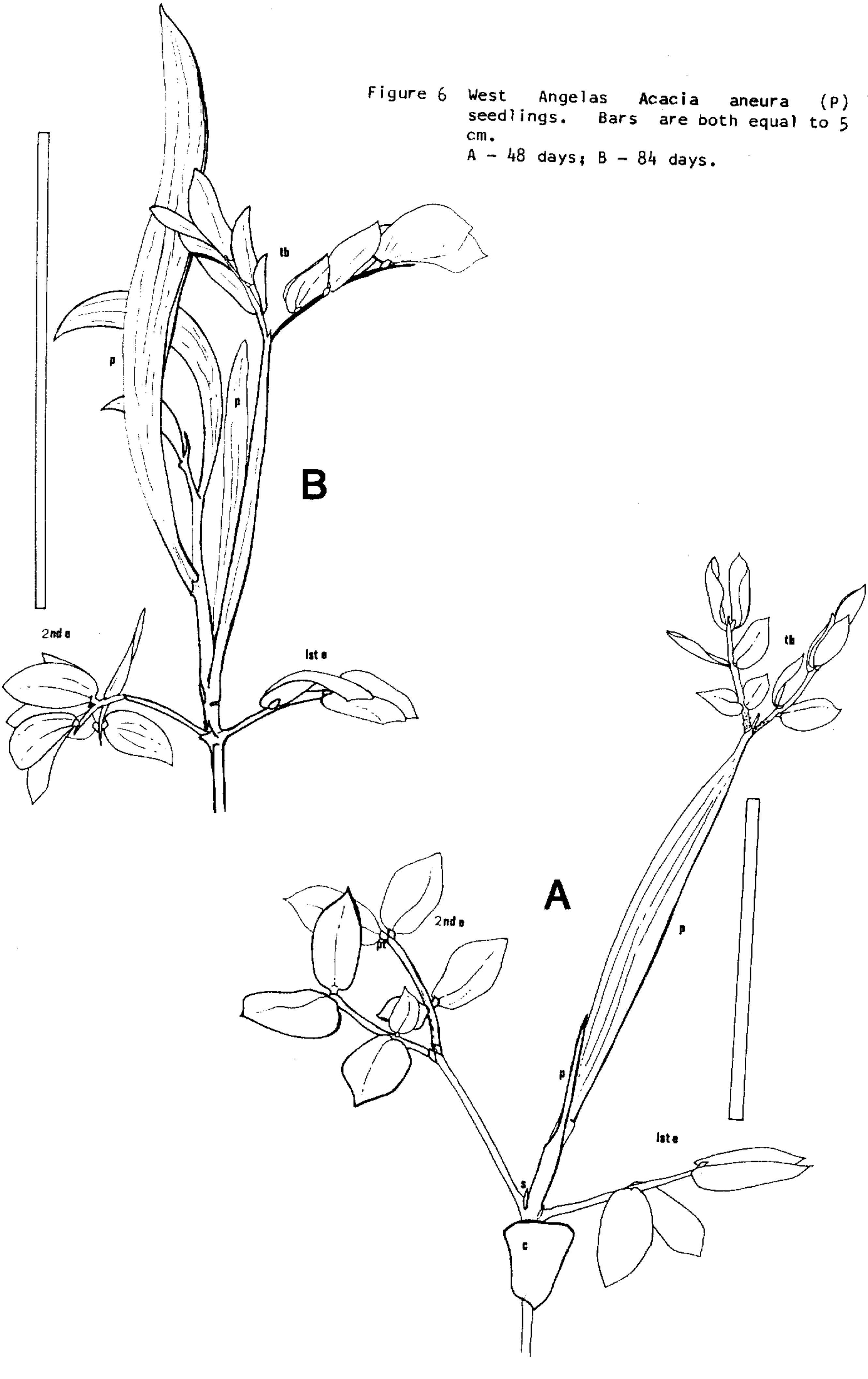


Figure 6 West Angelas **Acacia aneura** (P) seedlings. Bars are both equal to 5 cm.
A - 48 days; B - 84 days.

small, early deciduous, leaflets on the fourth post-cotyledonary leaves.

The West Angelas plants produced greatest dry matter in the first four weeks. Harvests at four weeks gave the following mean dry weights in mg

P	West Angelas	46
LD	Leinster	28
L	Laverton	22
C	Charleville	8

The Charleville plants continued to grow poorly with only 20 mg reached at 6 weeks. Many plants died before the eighth week (end of August). The Leinster seedlings grew more strongly than the others and overtook the West Angelas set by 6 weeks. Mean dry weights of 75 mg per plant were attained by 7 weeks in the Leinster set, 12 weeks in the West Angelas set and 14 weeks in the Laverton set.

Discussion

Seedling morphology in **Acacia aneura** has been described by Cambage[5], Preece[17] and Carr and Burdon[7].

Cambage noted that the usual sequence of development in Acacia is that cotyledons are followed by one simply-pinnate leaf (which we have referred to as the first eophyll) and that this is followed by a varying number of alternate, abruptly bipinnate leaves. On the first leaves the common petioles are stalks, but these gradually become more dilated until finally they have no bipinnate leaves on their tips. Cambage illustrated (his Plate II) the development of Acacia aneura showing the first leaf with 4 leaflets, the second leaf bipinnate with 2 x 4 leaflets and the third phyllodinous with 2 x 6 leaflets. Subsequent leaves were phyllodes with no leaflets. His description is as follows

> Leaf 1, abruptly pinnate, usually slow in developing petiole 5-7 mm long, pale green glabrous; leaflets 2 pairs, petiolule sometimes 1 mm long obovate-oblong, often mucronate, with sometimes a few hairs on margin, 6 to 9 mm long, 3 mm broad, upper side green, underside paler, midrib distinct, especially in dried specimens, secondary nerve and lateral venation more obscured, rachis about 6 mm long, pale green, glabrous excurrent, stipules reduced to small scales.

One seedling was reported[5] with an opposite pair of pinnate leaves, each with 2 pairs of leaflets.

> Leaf 2, bipinnate, petiole in some cases slightly dilated, about 1 cm long, pilose, excurrent, leaflets two to three pairs, in some cases not strictly opposite, light green.

> Leaf 3, bipinnate, petiole sometimes vertically flattened up to 3 cm long with two distinct nerves, the more prominent one being close to the lower margin, and extending directly to the base of the pinnae, sprinkled with fine hairs; leaflets three pairs, mucronate, margins often obscurely ciliate; rachis pilose or almost glabrous, excurrent.

> Leaf 4 may be a narrow phyllode about 4.5 cm long, 3 mm broad, with an oblique or recurved hispid point, finely striate, but with 2 nerves and especially the lower, more conspicuous than the rest, sometimes minutely hoary and more distinctly so when first appearing.

Cambage also recorded a seedling with 3 cotyledons.

Preece showed that more pinnules were produced in the first 4 seedling leaves of A. **aneura** raised at 30-35°C than in seedlings raised at 20°C. In the latter the fourth and subsequent leaves were generally phyllodinous.[17] At the higher temperature the fourth leaf was usually bipinnate.[7] Dissection of the embryo revealed that it possesses 4 foliage leaves: leaf 1 is pinnate, with 4 leaflets; leaf 2 is bipinnate; leaves 3 and 4 are primordial. Carr and Burdon contrasted seedlings from Cobar district, New South Wales with seedlings from Charleville, Queensland.[7] The Cobar plants were 'broad-leaved', probably diploid, and leaf 3 usually exhibited a phyllodinous rhachis. By contast the Charleville 'broad-leaved tetraploid form' produced seedlings in which the third leaf was entirely phyllodinous in >60 per cent of seedlings. It is possible that our 'Charleville' type is of the same origin as our results are similar. An examination of ploidy levels in relation to phyllode size and shape would be most interesting.

The studies of Preece, and Carr and Burdon suggest then that, firstly, within an ecotype more leaflets are likely to be produced at higher temperatures. Secondly seedlings from plants with broader phyllodes produce fewer leaflets prior to phyllode differentiation. Our present results lend additional credence to the latter rule in that earlier phyllode production occurred in the two broader phyllode sets, those from Charleville and Leinster Downs. Glasshouse temperatures were constant for all four sets so that it could be presumed that any differences were genetical and not necessarily due to environmental levels. Greater numbers of lealets produced in the Laverton and West Angelas sets at comparatively low late winter/early spring temperatures suggests that the pattern of differentiation from primordia may well differ between **Acacia aneura** populations from different regions. Although the Laverton set was the most southerly in origin, that from West Angelas was from the lowest latitude of the four. Pre-adaptation to the temperatures experienced seems an unlikely explanation for increased leaflet numbers.

Boke[3] has reviewed the range of historical views regarding the derivation of the phyllode. From an analysis of histogenesis in Acacia **longifolia, A. decurrens** and **A. melanoxylon** Boke supports the theory that phyllodes are homologous with the petiole-rachis of a pinnate foliage leaf. It was suggested by Cambage[5] that the bipinnate form may be ancestral. It was found in Acacia **farnesiana** a species common to Africa, Asia, America and Australia, and also in **A. myrtifolia** a widespread Australian species. If the widespread distribution is indicative of the more ancient forms, then perhaps the species with a single pinnate leaf following the cotyledons are more recent. If they have developed more recently and have lost one pinnate leaf then, Cambage suggests, it may be reasonable to expect that the newer form will sometimes revert to the original or ancestral type. His unusual A. aneura seedling may have been such an example, one which on the basis of our present observations seems to be well within the range of variability experienced within sets. Li[14] examined seedling morphology in Acacia confusa. He considered this species to be more recent due to the reduced second eophyll. The views of Cambage and Li suggest that perhaps the Acacia aneura forms with broader phyllodes are more advanced, in the sense of a more recent origin.

The glasshouse grown plants were subjected to occasional water stress due to inherent problems in experimental design. It is possible that the Charleville plants may have been less able to tolerate the water stresses imposed. These came from the sample area with highest mean annual rainfall (515 mm). Rainfall at the other sites being 221 mm (Laverton); 215 mm (Leinster Downs) and 317 mm (West Angeias). The study suggests there is little to support the notion of summer and winter rainfall ecotypes in terms of seedling development.

Conclusions

There are differences in seedling morphology for Acacia aneura populations both comparatively close geographically as well as those much further apart. In sets with broader adult phyllodes the second eophyll tends to be more phyllodinous and non-leafy phyllodes appear sooner. This tendency is not related to the number of leaflets on the first eophyll and appears to be independent of temperature. Plants producing more leafy phyllodes may be considered to be more ancestral and if this holds true then the narrow phyllode types may be more ancient forms than plants with broader phyllodes.

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THE IMPORTANCE OF SOIL VARIABLES ON ESTABLISHMENT OF CAKILE MARITIMA ON PERTH BEACHES

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Introduction

The sea rocket, **Cakile maritima** (ssp. **baltica**) is the primary colonizer of Perth beaches. It may grow closer to the tide line than any other vascular plant.[3] It is found 30-40 m into the dunes only where the foredune is missing due to disturbance.

Cakile maritima is native to shores of the Mediterranean sea but has been introduced to Australia, North America and New Zealand.[4] It is believed to have been introduced to Western Australia in the late nineteenth century, with the first formal record dating from 1897.[1,16]

Cakile maritima can be described as a facultative annual as it is able to survive for more than one year if conditions are favourable.[8] The mature plant is relatively small (20-60 cm tall and wide) and has weak, erect to prostrate stems. Leaves are succulent and deeply lobed, or entire. The flowers have four, white to purple petals. Seedlings are usually present in winter and mature plants in summer, but demography of this species is greatly influenced by rainfall, temperature and level of mineral nutrients.[17]

The study reported here was designed to determine the importance of season, salinity, nutrients and water on the establishment of **C. maritima** in the zone between the high water mark and the seaward edge of the incipient foredune.

Materials and Methods

Soil samples were taken from beaches at Yanchep, Cockburn Sound and Warnbro in the vicinity of Perth (Figure 1). Five sites were randomly selected for sampling at the Yanchep and Warnbro Beach areas whereas the ten at Cockburn Sound were selected near industrial facilities to represent man-disturbed sites.

Sand was collected from each site on two occasions representing the summer soil present before the first winter rains (May) and winter soils thoroughly leached by winter storms and rains (August). The centre of each site was set at 5m above high tide level and sand was collected to a depth of approximately 20 cm.

Seedling plants, with the first pair of leaves less than 1 cm long, were collected in late August from the sea drift zone at Cockburn Sound adjacent to Site C1. Five 760 ml capacity pots of each sand sample received three seedlings each. Fibreglass wool was placed in the drainage holes to prevent loss of sand. Each set of five pots was placed on a tray enclosed in a plastic bag in a heated glasshouse. Water was supplied by sub-irrigation using 2l of deionised water every 10 days which was sufficient to prevent pots drying out at any stage.

During weekly inspection of plants, significant numbers of aphids, red-legged earth mites and white cabbage moth grubs were noted. These were physically removed at first. When this was seen to be ineffective the plants were sprayed with a 0.6 per cent solution of "Blue Cross Aphid and Pest Spray".

Effects of nitrogen and chloride

After five weeks of growth, five pairs (summer and winter) of soils were selected for further treatment. These were three soil pairs from Cockburn Sound and one each from Yanchep and Safety Bay.

The five pots within each sample tray were assigned to the following five treatments:

a) control
b) ammonium nitrate added (0.045 g)
c) sodium chloride added (2.06 g summer pots, 4.11 g winter pots)
d) ammonium nitrate and sodium chloride added (as above)
e) leachate not returned (see below).

Each pot was leached with 300 ml of deionized water. This quantity represented that required to bring the pot soil to field capacity. In treatment a) the leachate was returned directly and in e) it was discarded and 300 ml of deionized water used instead.

Analysis of plant material

Eleven weeks after first planting the seedlings, all plants were harvested.

Tops and roots were separated, washed and fresh weight determined. The number of seed pods on each plant was also counted. The tops were put in an oven for one week at 80°C and their dry weight determined. Mean fresh weight, dry weight and number of seeds per plant were calculated (Tables 1,2). Succulence was measured as fresh/dry weight ratio and percentage moisture by

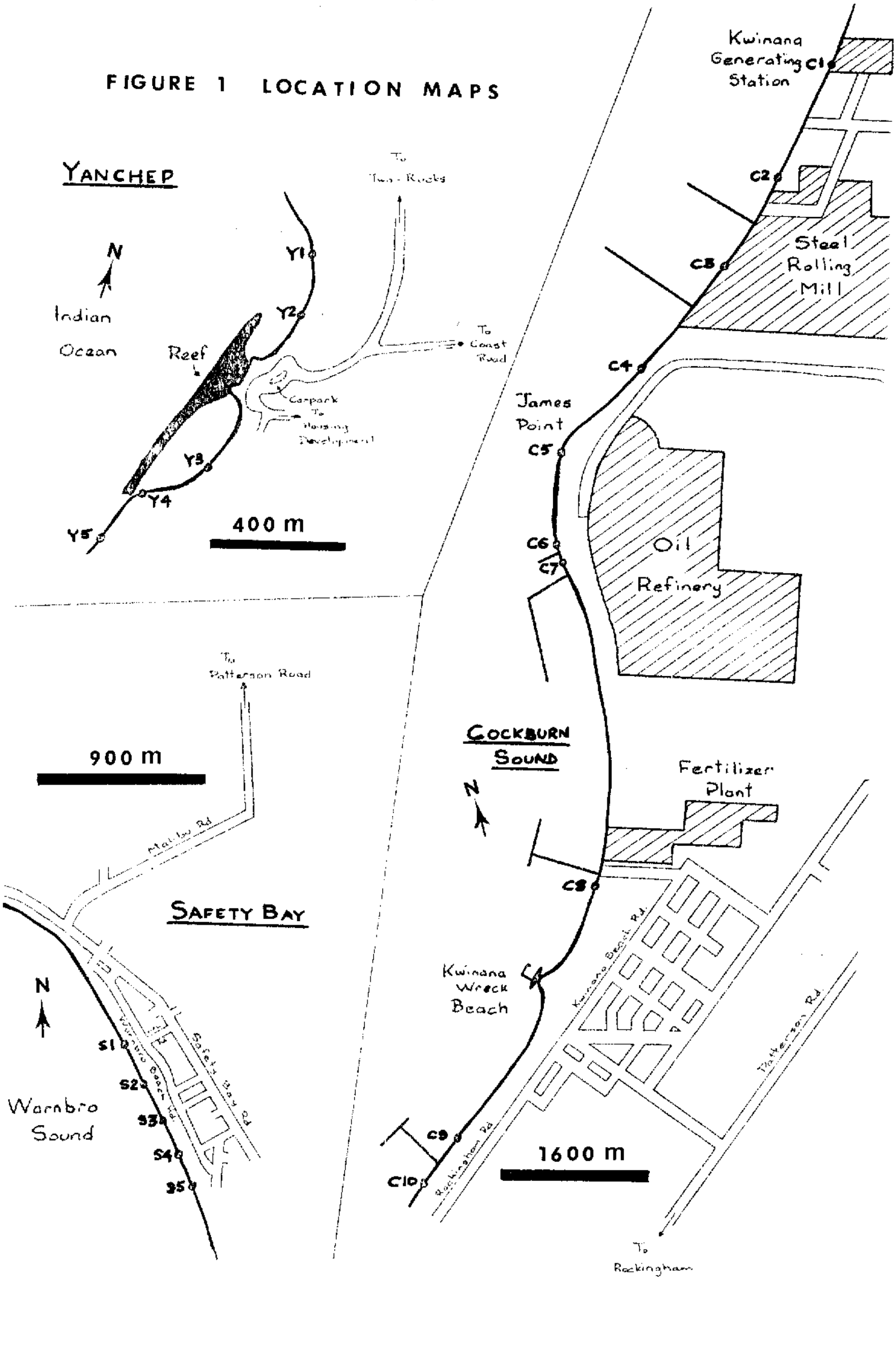
$$\frac{\text{fresh wt} - \text{dry wt}}{\text{fresh wt}} \times 100$$

Soil analysis

Each soil was assayed for nitrogen, phosphorus, chloride, calcium and pH using the methods of Chapman,[7] Anon[2] and Parker.[12]

Nitrogen and phosphorus were extracted with 1N KCl and the resulting solutions were coloured and analysed colorimetrically. Water extracts were used to determine pH and chlorine concentrations. The pH was measured with a glass electrode and chloride concentration with a chloridometer.

FIGURE 1 LOCATION MAPS



The heavy metals and calcium were extracted in a 1N NH_4Cl solution, made up to the average pH of the soil with 1N NaOH. The resulting solutions were analysed by atomic absorption spectrophotometry.

Results

Most of the plants progressed from the cotyledonary stage through to anthesis and, in some cases, fruit maturation, within the eleven week growing period.

a) Growth Indices

Growth was measured weekly by using the average leaf number per plant in each sample. This variable was found to be a good growth index, as a highly significant Pearson correlation coefficient ($p > 0.001$) was obtained between the leaf number and final top fresh weight, top dry weight and total fresh weight at the end of the experiment.

Leaf number was used, along with other growth characteritics, to determine the pattern of growth for **Cakile maritima.** The initial protracted cotyledonary stage was followed by a period of rapid leaf number increase. Total cotyledon loss, leaf abscission, flowering, decline in leaf number, stem elongation and fruit set then occurred successively. The cycle repeated itself following fruit set, when axillary secondary growth of leaves occurred (Figure 2).

Table 1. Comparison of mean growth in summer and winter in seven soils from Cockburn Sound. Results of analysis of variance are given.

Variable	Summer Mean	Winter Mean	Sig.
Top fresh wt (g)	0.78	0.86	NS
Top dry wt (mg)	73	106	NS
Root fresh wt (g)	0.18	0.22	*
Total fresh wt (g)	0.96	1.08	NS
Total deaths	6	1	*
Time to cotyledon loss (wk)	8	6	**
Leaf number	6.20	6.89	NS
Time to first leaf loss (wk)	7	5	**
Time to max. leaf no. (wk)	11	9	*
Time to flower (wk)	>12	7	**
No. fruits	1	16	**
Final height (cm)	6.1	15.7	**
% moisture	90.3	86.7	**
Succulence	10.31	7.66	*

NS not significant

* significant at 5% level

** significant at 1% level

*** significant at 0.5% level

**** significant at 0.1% level

(critical values,)

b) Winter versus summer growth

Plants in summer soils were shorter and less mature than those in winter soils, especially those from Cockburn Sound (Tables 1-3). However, statistical tests showed that whereas the events within the growth pattern and succulence varied significantly between these soils, the final biomass and leaf number did not. Plants growing in winter and summer soils from Cockburn Sound had the greatest growth when compared with those from Safety Bay and Yanchep.

Table 2. Comparison of mean growth in summer and winter in seven soils from Safety Bay. Results of analysis of variance are given.

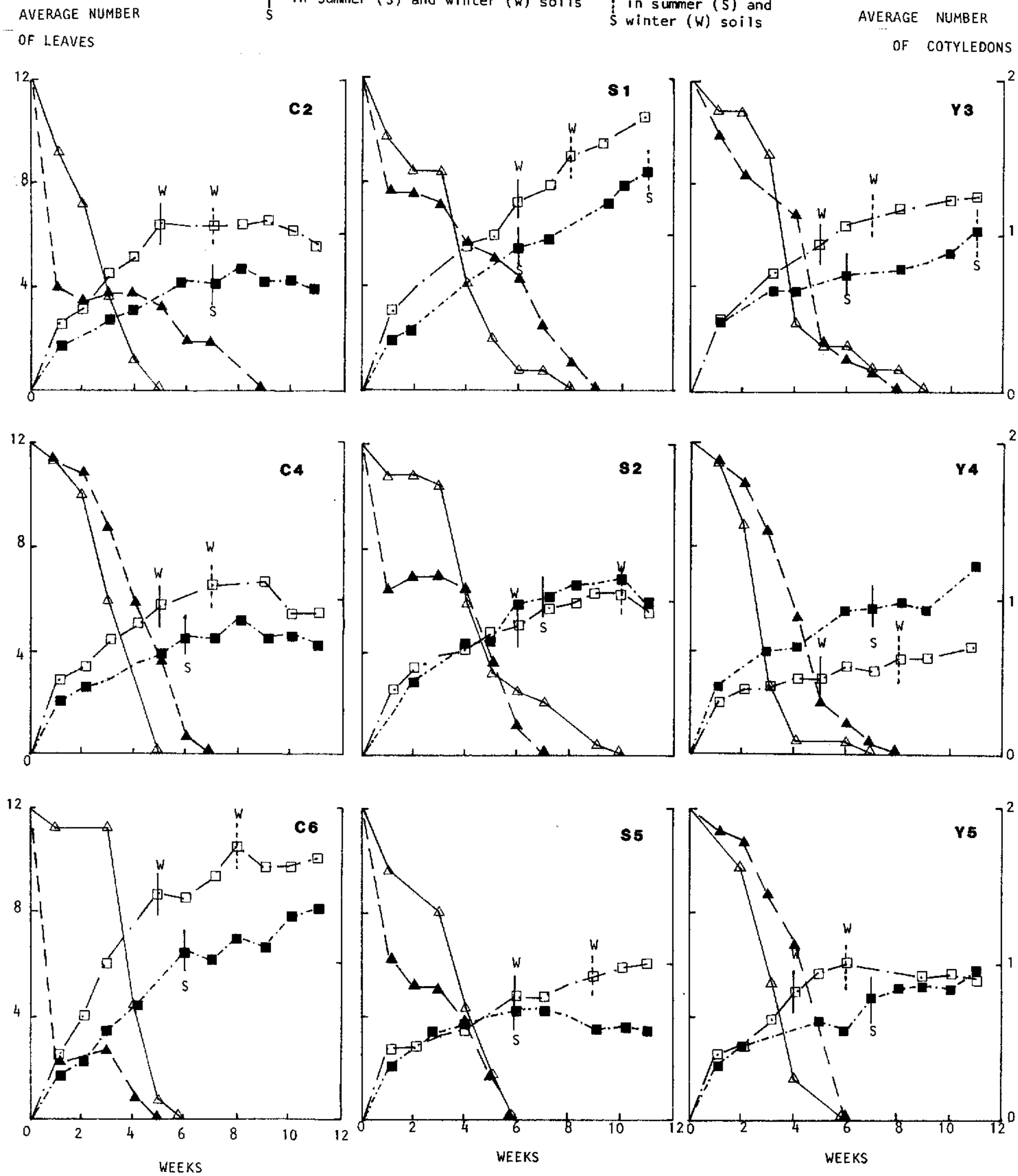
Variable	Summer Mean	Winter Mean	Sig.
Top fresh wt (g)	0.55	0.71	NS
Top dry wt (mg)	50	76	*
Root fresh wt (g)	0.16	0.28	NS
Total fresh wt (g)	0.71	0.99	NS
Total deaths	4	2	NS
Time to cotyledon loss (wk)	9	8	NS
Leaf number	5.22	6.10	NS
Time to first leaf loss (wk)	7	7	NS
Time to max. leaf no. (wk)	10	10	NS
Time to flower (wk)	>12	10	**
No. fruits	0	3	NS
Final height (cm)	4.7	7.8	*
% moisture	90.6	89.5	NS
Succulence	10.89	9.31	NS

c) Soil factors

The soil analyses are summarised in Tables 4-6. T-test and variance ratio statistics comparing seasonal soils, showed that chloride levels were consistently higher in summer; particularly at Cockburn, pH and N availability were higher in winter for two study areas, and water content and levels of phosphorus and calcium only varied significantly in one study area.

To gauge the effect of soil factors on growth of **Cakile maritima** in this experiment a stepwise multiple regression was used.[11] The major soil factors for all study sites and seasons combined were availability of water and levels of nitrogen and chloride (Table 7). Nitrogen was most highly and positively correlated with final leaf number, maximum leaf number, top, root and total weights, while chloride was most highly correlated with succulence (positive), total number of deaths (positive) and final height (negative).

FIGURE 2. Growth curves for seedlings grown in soil samples from Cockburn Sound (C2, C4, C6); Safety Bay (S1, S2, S5) and Yanchep (Y3, Y4, Y5)
Average number of cotyledons per plant ▲- - -▲ summer soils, △——△ winter soils,
Average number of leaves per plant ■·—·—■ summer soils, □—·—□ winter soils.
W | S Weeks to initial leaf abscission in Summer (S) and winter (W) soils
W ⋮ S Weeks to anthesis in summer (S) and winter (W) soils



The water content of the soil correlated best with number of weeks to flowering, leaf abscission and maximum leaf number (all negative) and percentage moisture in the tops (positive).

Table 4. Comparison of mean pH, chloride, N, P and Ca availability and water content before and after watering in Cockburn Sound soils.

Variable	Summer Mean	Winter Mean	Sig.
pH	9.73	9.54	NS
Cl (meq /l)	131.5	31.8	**
N (mg/kg)	47	66	NS
PO_4 (mg/kg)	10	9	NS
Ca (mg/kg)	310	260	*
Water content:			
before watering	4.1	3.8	NS
after watering	27.3	29.6	*

Table 3. Comparison of mean growth in summer and winter in seven soils from Yanchep. Results of analysis of variance are given.

Variable	Summer Mean	Winter Mean	Sig.
Top fresh wt (g)	0.68	0.43	NS
Top dry wt (mg)	0.61	0.60	NS
Root fresh wt (g)	0.20	0.25	NS
Total fresh wt (g)	0.88	0.68	NS
Total deaths	1	1	NS
Time to cotyledon loss (wk)	10	8	NS
Leaf number	6.92	5.87	NS
Time to first leaf loss (wk)	8	6	***
Time to max. leaf no. (wk)	12	10	NS
Time to flower (wk)	> 12	8	***
No. fruits	0	8	**
Final height (cm)	6.3	11.1	*
% moisture	90.8	85.6	***
Succulence	11.04	6.98	***

Table 5. Comparison of mean pH, chloride, N, P and Ca availability and water content before and after watering in Safety Bay soils.

Variable	Summer Mean	Winter Mean	Sig.
pH	9.28	9.55	**
Cl (meq /l)	90.9	35.0	**
N (mg/kg)	32	60	*
PO_4 (mg/kg)	12	12	NS
Ca (mg/kg)	290	320	NS
Water content:			
before watering	3.6	3.7	*
after watering	27.7	29.0	NS

Table 6. Comparison of mean pH, chloride, N, P and Ca availability and water content before and after watering in Yanchep soils.

Variable	Summer Mean	Winter Mean	Sig.
pH	9.70	10.38	*
Cl (meq /l)	89.6	12.2	***
N (mg/kg)	35	45	*
PO_4 (mg/kg)	12	14	NS
Ca (mg/kg)	270	280	NS
Water content:			
before watering	3.6	1.7	**
after watering	20.4	24.3	NS

Figures 3-7. Growth of seedlings in soils obtained in summer and winter from Cockburn Sound (C1, C7, C8), Safety Bay (S3) and Yanchep (Y2) with the addition of ammonium nitrate and sodium chloride.

○ Control

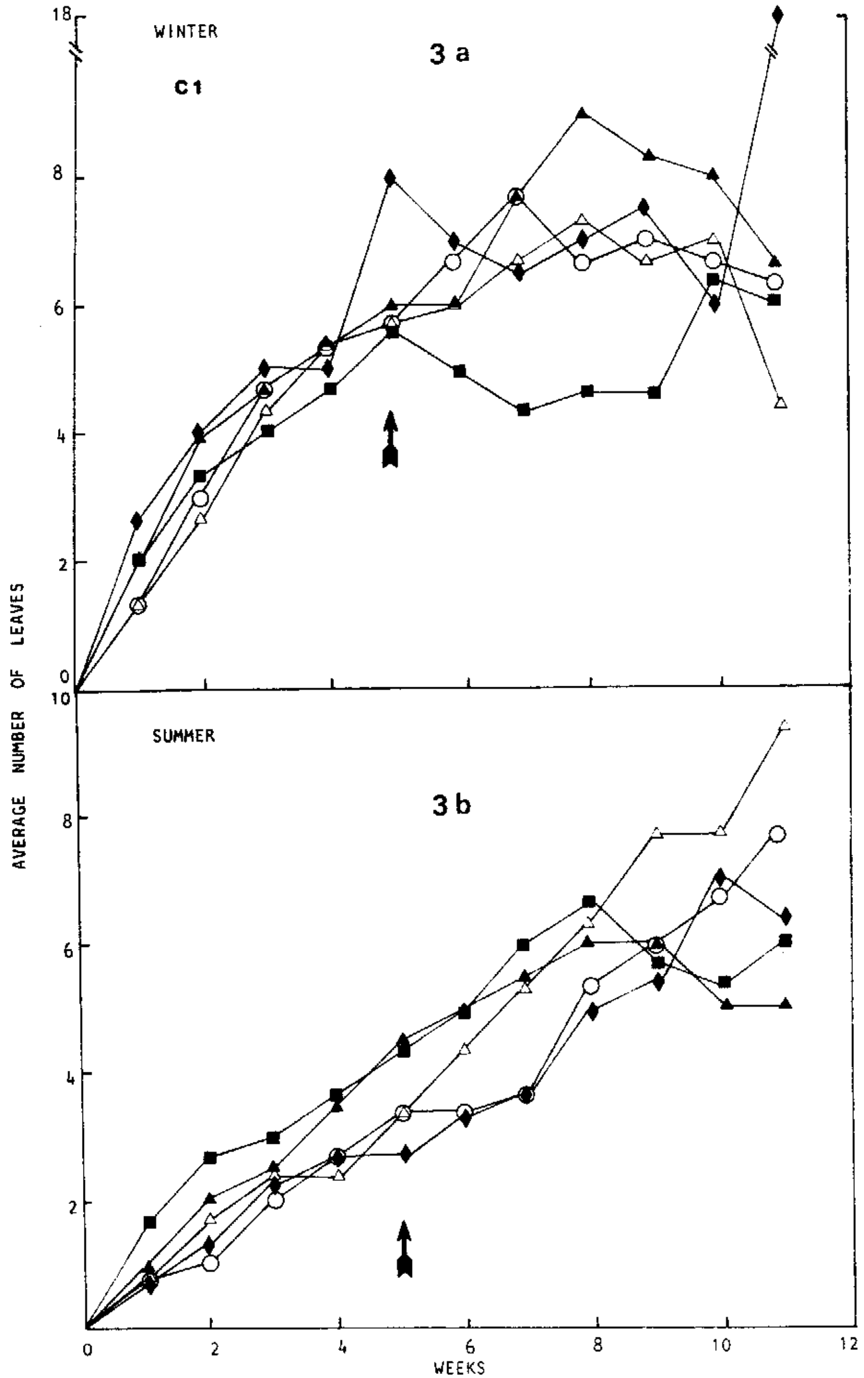
▲ NH_4NO_3 Added

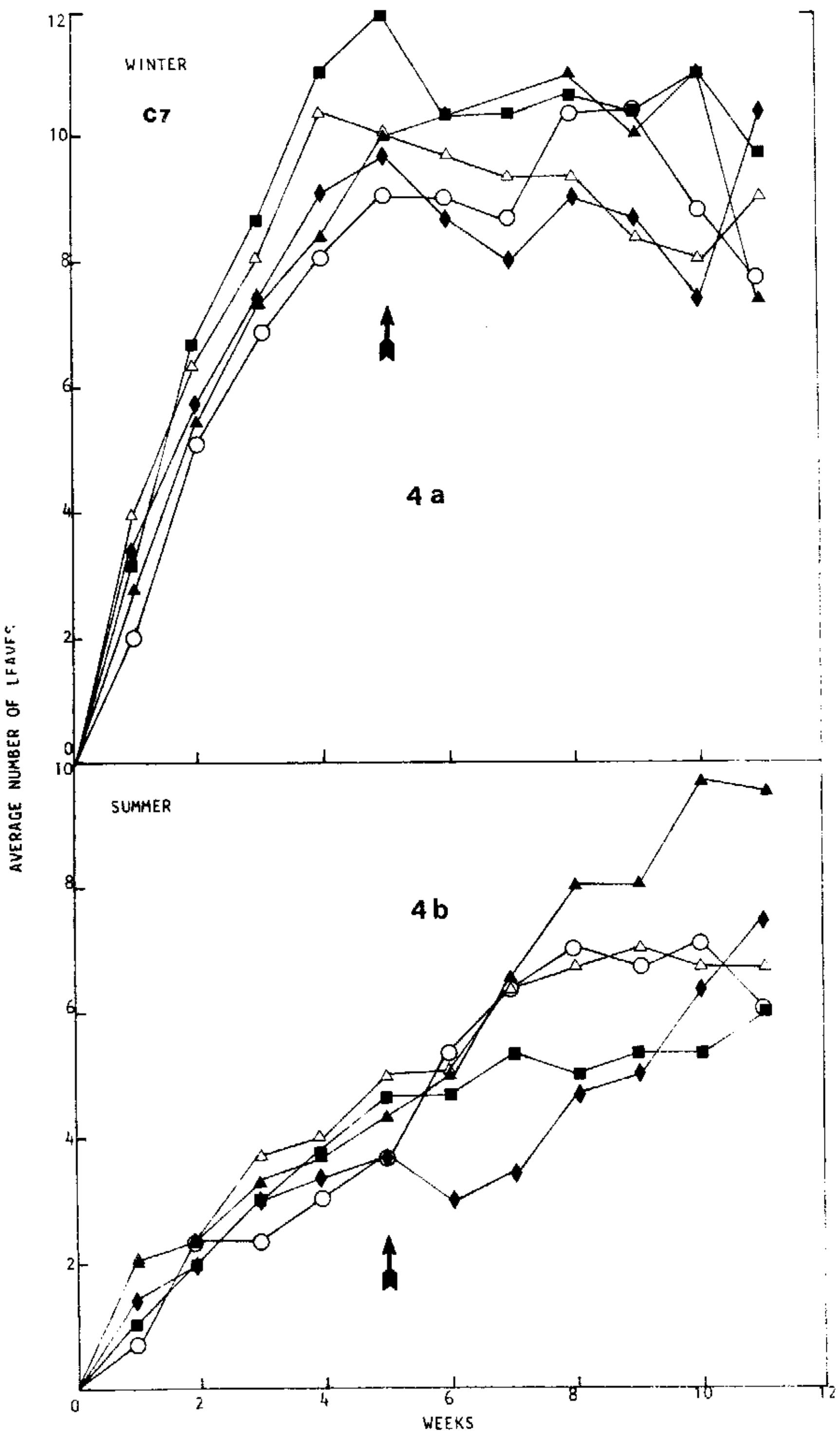
■ NaCl Added

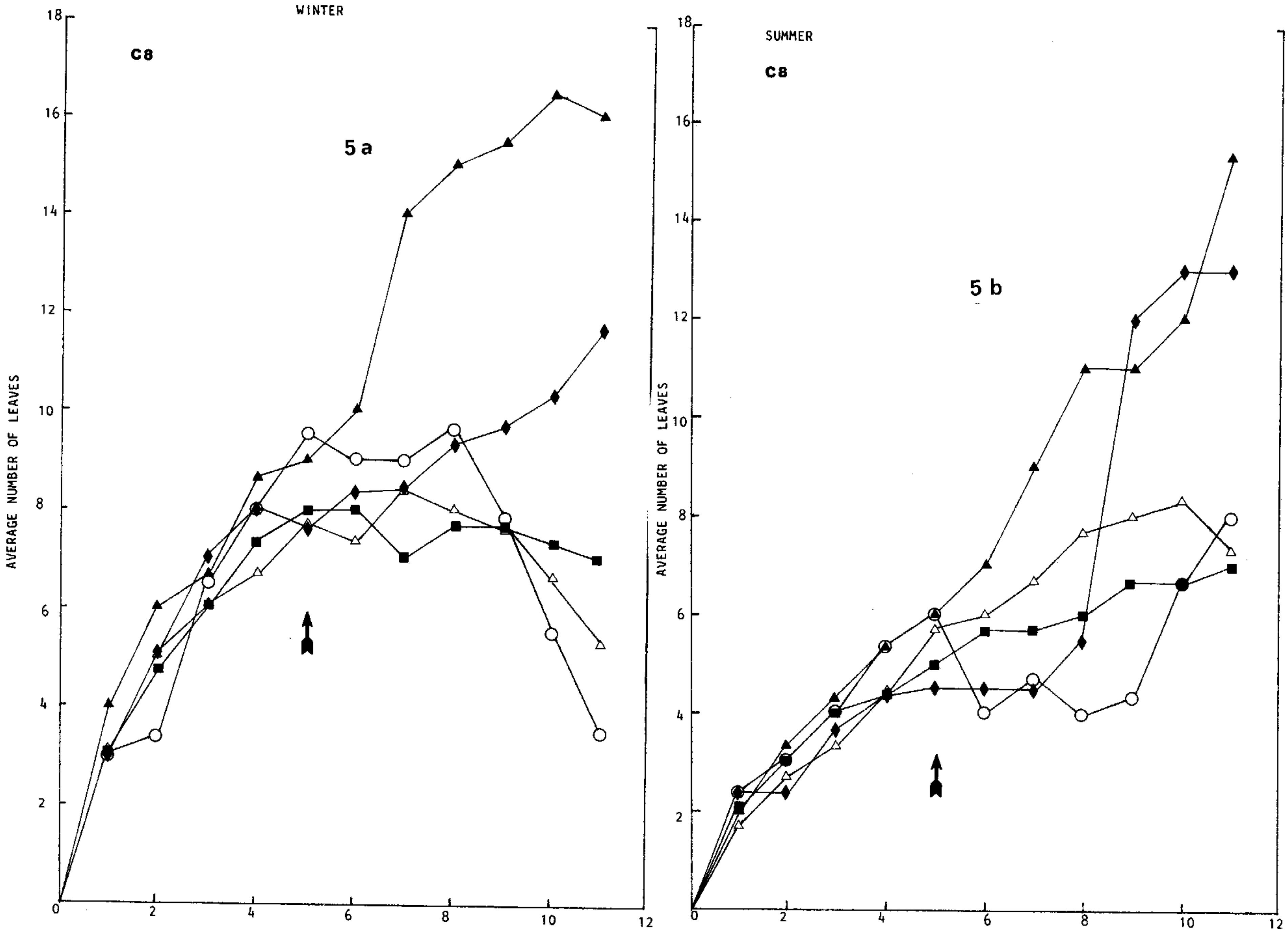
◆ NH_4NO_3 and NaCl Added

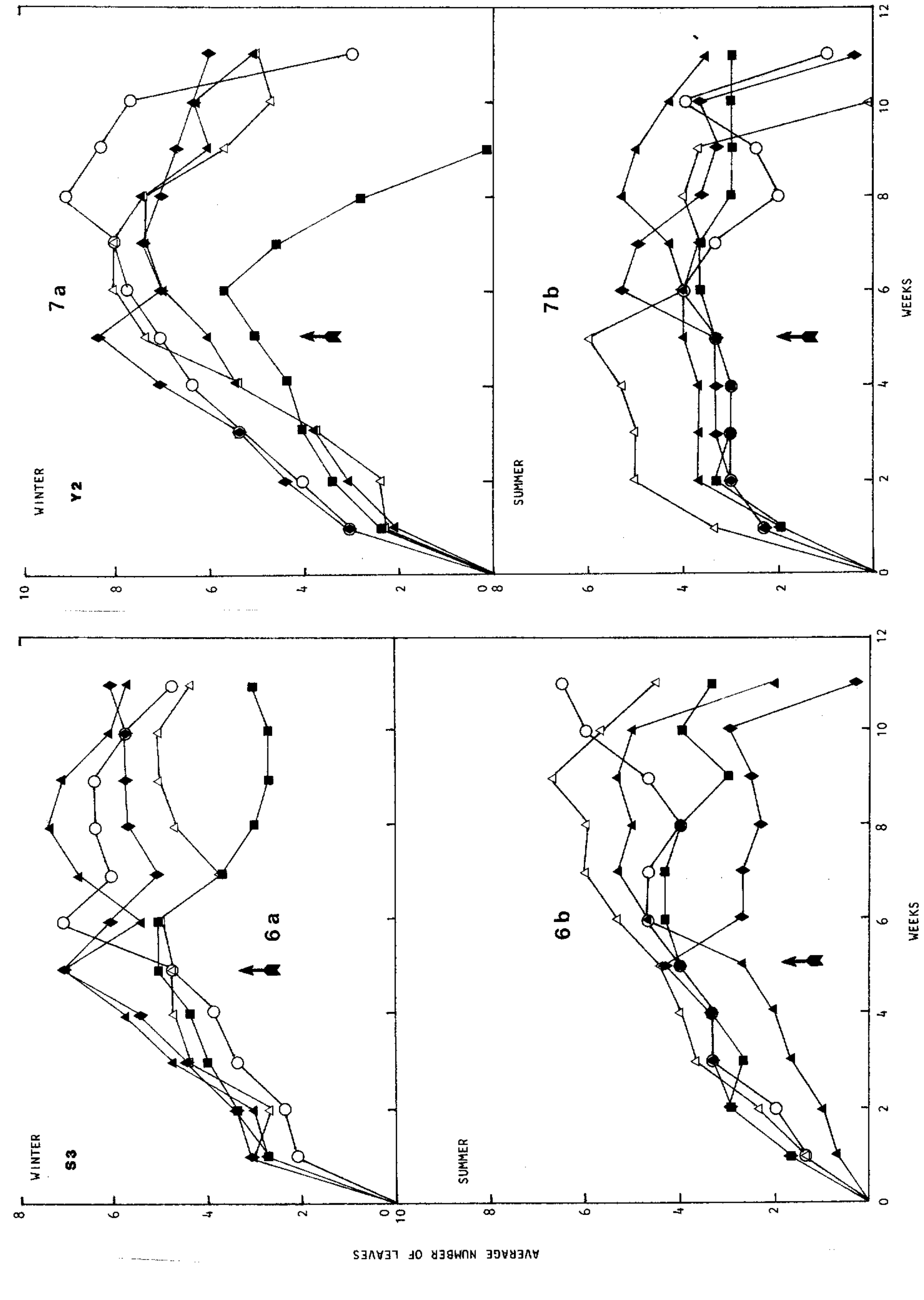
△ Leached (see text)

↑ Nutrients added


WINTER
C1
3 a
SUMMER
3 b
AVERAGE NUMBER OF LEAVES
WEEKS
18
8
6
4
2
0
10
0
12


WINTER
C7
4 a
SUMMER
4 b
AVERAGE NUMBER OF LEAVES
WEEKS
12
10
8
6
4
2
0
12


WINTER
C8
5 a
AVERAGE NUMBER OF LEAVES
0
2
4
6
8
10
12
14
16
18
SUMMER
C8
5 b


WINTER
Y2
7a
SUMMER
7b
WEEKS
WINTER
S3
6a
SUMMER
6b
WEEKS
AVERAGE NUMBER OF LEAVES

The simple and combined effects of season, and nitrogen and chloride levels on fresh and dry weights of **Cakile maritima** were determined in the second experiment. Pots with NH_3NO_4 or NH_3NO_4 plus NaCl added had higher leaf numbers and biomass of tops and roots, and the pots with NaCl added had lower leaf numbers and biomass of tops and roots, than control pots (Figures 3-7).

To determine whether season, chloride or nitrogen was critical to growth, a three way analysis of variance was carried out.[11] Only chloride had a significant (negative) effect on root fresh weight, while nitrogen had a significant (positive) effect on top fresh weight ($p < 0.05$). No interaction effects were evident.

Table 7. Percentage of variation in growth parameters attributable to the most important soil factors as calculated for soils from all sites and both seasons by step-wise multiple regression.

Dependent variable	Independent variable	% variation accounted for	direction
Top fresh wt (g)	N	39.2	+
Top dry wt (g)	N	38.6	+
Root fresh wt (g)	N	27.8	+
Total fresh wt (g)	N	40.0	+
Total deaths	Cl	17.1	+
Time to cotyledon loss (wk)	PO_4	16.8	+
Leaf number	N	22.3	+
Time to first leaf loss (wk)	water content after watering	16.8	-
Time to max. leaf no. (wk)	water content after watering	16.4	-
Time to flower (wk)	water content after watering	15.9	-
No. fruits	water content after watering	16.4	+
Final height (cm)	Cl	26.7	-
% moisture	water content after watering	8.3	-
Succulence	Cl	16.7	+

Discussion

The extent of establishment of **Cakile maritima** on Perth beaches is governed by an array of environmental variables. These include high wind velocities, wide temperature ranges, high light intensity, salt spray, winter wave overwash, periods of low water availability, and high levels of salinity. By growing plants under greenhouse conditions, some of these extremes were removed, leaving nutrient availability and salinity as the major determinants of growth. Since precautions were taken to prevent leaching in the pots it is considered that the results have a direct bearing on critical soil properties in the field.

Nutrient availability clearly limited growth of **Cakile maritima** in the experiments reported here. The amount of growth of **C. maritima** in both summer and winter samples from Cockburn Sound and Safety Bay was positively correlated with the nitrogen levels. Experimental increase in nitrogen availability resulted in greater leaf production and biomass. Reduced leafiness in the field may enable the plant to grow with minimal damage in the presence of high winds and winter storm overwash and restrict salt uptake from salt spray.[3]

Nitrogen may also affect succulence and was the major factor influencing fresh weight, but not dry weight. This effect may have been caused by increased water content per unit of dry weight as a result of incomplete metabolism of mineral nitrogen into protein.

The role of phosphorus as a critical growth factor in beach soils is not clear. Some workers have shown it to be more important for growth of agricultural crops than nitrogen[14] and it may even be necessary for nitrate reduction.[10] Others have claimed it to be as important as nitrogen[18] or to be the most critical factor.[9] Though phosphorus availability ranged from 6-15 ppm, it was not found to be strongly correlated with growth in the work described here.

It appears that the sea rocket grows in the sea drift zone with just enough nutrients to enable the plant to grow through to maturity. Experiments carried out by other workers have shown[18] that, by increasing the levels of nitrogen and phosphorus in the soil, the growth of **Cakile maritima** is enhanced considerably, but is soon replaced by other species able to make better use of the higher nutrient conditions.

All the summer soils, and eight of the fifteen winter soils, would be classed as saline (having >15 meq/l),[7] with the summer soils having on average four times the chloride concentration of the equivalent winter soils. The major effects of chloride seem to be on the physiology of the plant. It is the major factor influencing succulence[6,15] and this effect was confirmed here. The mechanism of action may be by increasing osmotic concentration of the cell vacuoles.[13]

Chloride also reduced root weight. This would in turn inhibit shoot growth as the plant requires an extensive root system to enable it to absorb as much water and nutrients as are available. Photosynthetic output per leaf will also be reduced as chloride decreases chlorophyll activity and inhibits production of cytokinins in the roots, leading to early leaf senescence. These may be the causes of chlorosis, and reduction in height and even death of plants in soils with high chloride levels in this experiment. Growth may also be reduced as chloride has been shown to reduce nitrate uptake.[5]

A major factor affecting the establishment of **Cakile maritima** seedlings was the availability of water. This is related to the ability of the plant to absorb and retain water, the ability of the soil to hold water, and the osmotic potential differences between soil and plant.[5]

The amount of water present in the soil will also affect growth, via its influence on the concentration of ions in solution. Multiple regression analysis showed that the higher the amount of water present in the soil one hour after watering, the quicker the plants matured, with no effect on major growth indices. Cyclic water stress merely served to interrupt rather than alter the normal growth pattern.

Garcia Novo claims[9] nitrogen to be the critical factor in the establishment of **Cakile maritima**, on the basis of nitrate reductase activity. The work described here, however, shows that nitrogen, chloride and water availability may all be important growth factors, depending on the index of growth under examination.

The establishment and growth of **Cakile maritima** in the vicinity of Perth, therefore, appears to depend on a number of interacting factors. Seedlings establish during winter months when conditions are favourable for growth including increased water in the soil which has a diluting effect on chloride ions, and also higher nitrogen levels. Plants flower and set seed in summer as soil conditions become less suitable for growth.

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USEFULNESS OF TOPSOIL FOR COAL MINE SPOIL REVEGETATION

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Introduction

Topsoil return to abandoned mining areas is considered a useful measure towards restoration following the extensive environmental changes caused by mining. Such a measure requires topsoil to be stripped from the surface of areas to be mined before operations commence, or to put fresh topsoil onto an abandoned area with topsoil from a new area. This can be considered as a measure to promote revegetation, assuming the topsoil holds a reservoir of seed. Following loss of vegetation regeneration of plant cover will depend upon the germination and successful growth of seeds or of other propagules already present[2]. Top soil can be a valuable source of seed of native species[3]. A number of studies have been undertaken in respect of the population of seeds buried in the surface layers of soil.

Knowledge of the numbers and types of seeds normally present in the topsoil beneath a given vegetation type may be of value in predicting the rate and direction of regeneration following disturbance[2]. The upper 10 cm of surface soil and litter beneath a coniferous forest in coastal British Colombia, has been reported to contain over 1,000 viable seeds per m^2[10]. The importance of topsoil as a seed reservoir is illustrated by Tacey and Glossop[14] in respect of the jarrah forest of Western Australia. These authors found that 93 percent of the seeds which germinated from the top 10 cm of topsoil were present within 2 cm of the soil surface. Further, germinable seed load decreased with depth in forest topsoil. Similarly, Graber and Thompson examined seeds of the beech-birch-maple forest in New Hampshire[7]. Most seed germination took place in the upper organic layer of the forest floor. Studies of the distribution patterns of seed in topsoils by Olmstead and Cutris[11] were made with litter and topsoil of conifer-hardwood stands in Maine. It was found that generally the dominants of each stand were present in their underlying seed beds. However, in each stand, seed of at least fifteen species were found for which there were no parent plants. There were also plant species within each stand which were not represented in the seed pool by propagules. It is a common experience that correlation between the sward of grasslands and the seeds in the upper soil layers beneath the sward is incomplete. Some species often take a disproportionately important place in relation to the population of viable seeds buried in the soil[4]. Barbour and Lange[2] report very low frequencies for seed of many dominant species of South Australian stands in topsoils.

The possible use of topsoil in revegetation programmes on mined areas, involving stripping and re-application, has led to the development of particular topsoil handling techniques. For rehabilitation of bauxite mined areas in Jarrahdale, Western Australia, three topsoil handling techniques were assessed: double stripping, direct whole return and stockpiling[3,14]. Double stripping involved the separate removal and direct return of the top 5 cm of topsoil over a lower stockpiled layer. This led to increased revegetation compared with direct return of the whole mixed profile (direct whole return) or return of stockpiled topsoil. These results concur with those of Clarke[5]. He reported that the value of topsoil as a seed reservoir diminished with stockpiling time and thus storage should be kept to a minimum. It has also been suggested that mixing of the whole topsoil profile in a stockpiling and direct return treatment would lead to the burial of a greater proportion of seeds at depths from which successful emergence could not occur[14]. Studies on the early stages of plant succession in Eucalypt forest in Tasmania suggest that for buried seed, seed germination and emergence vary with depth of burial[16]. Strickler and Edgerton[13] consider the effects of soil disturbance on germination. Their studies suggest that although numbers of seeds in litter and soil under mixed conifer stands in Oregon USA were sufficient to estimate successional plant growth, disturbances which affect surface configuration and soil environment would affect seed germination and establishment. The availability of suitable microsites on a soil may offer a means by which the numbers of plants establishing from seed is regulated, and by which the relative abundance or different species is determined[5].

The work reported here was undertaken to assess the usefulness of topsoil in coal mine spoil revegetation in terms of the germination of plant species from the topsoil source. Topsoil was collected from forest sites in the coal mining region of Collie (195 km south of Perth and 50 km east of Bunbury) and from another locality near Kelmscott (18 km south of Perth). The role of topsoil in possible revegetation was determined by quantifying the amount of plant material that could be germinated per unit area of topsoil.

Materials and Methods

Experiment 1 Collie Coalfield

Four topsoil samples were collected from different positions (1-4, 1 at the top) down a slope in the Collie Mineral Field 33° 26'S, 116° 19'E) located in jarrah forest, 18 km south-east of the town of Collie. The topsoil was then brought to the Field Trial Area, WAIT Bentley (32° 01'S, 115° 55'E). These samples were firstly placed into large plastic buckets. The material was then sieved to remove stones, twigs and roots from the bulk of each soil lot using a plastic colander, having a fairly large pore size of approximately 5 mm[2]. A sub-sample of approximately 10 grams was taken from each of the soil lots to assess pH, using the method of Allen et al[1]. In each case the pH was greater than 5.5.

Sets of plastic germination trays 34 x 28 x 5 cm were lined with a paper towel. Coarse sand was added to two thirds the depth (3 cm). The topsoil samples were then placed over the coarse sand to a depth of 1-1.5 cm. Area and depth of removal was not available but there was sufficient material to fill about 10 trays per topsoil sample. Fertilizer was added to 3 trays per sample to provide nitrogen, phosphororus and potassium in the quantities shown in Table 1.

Table 1 Fertilizer Addition

Element	Fertilizer	Quantities $kg\ ha^{-1}$	$g\ tray^{-1*}$
N	Agran (ammonium nitrate)	50	0.476
P	Super CSBP No. 2 (With trace elements)	92	0.876
K	Muriate of potash (KCl)	10	0.095

* based on surface area of 952 cm^2

Trays were initially watered with deionized water to field capacity every three days. However the trays dried out quickly. Each tray was then suspended over an additional tray lined with a plastic bag. Deionized water was added to the plastic bags to provide access to moisture by the topsoil material. Trays were maintained in a glasshouse for 12 weeks from July 30th 1981. Then all plant material was harvested. Fresh and dry weights were obtained for all plants from each tray.

Experiment 2 Kelmscott

Further topsoil samples were taken from jarrah forest in Churchman Block near Kelmscott (32°9'S, 116°10'E). Topsoil was collected from the top 3 cm in one metre square plots at three separate positions. These positions were characterised by the following species:-

1. **Acacia pulchella** with **Phyllanthus calycinus, Pteridium aquilinum** and **Hibbertia perfoliata.**
2. **Eucalyptus marginata** with **Chorizema ilicifolium, Leucopogon verticillatus** and **Xanthorrhoea gracilis.**
3. **Macrozamia reidlei** with **Acacia glaucoptera, Lomandra** sp. indet. and **Chorizema ilicifolium.**

Soil was prepared as in Experiment 1 and trays placed in the glasshouse on September 23rd. The watering regime utilised the double tray plastic bag system throughout. All plant material was harvested after 5 weeks. No fertilizer was used in this experiment.

Results

Acidity of topsoils

The initial pH levels of the four slope position soils from Collie ranked least to most acid were:

1 > 3 > 4 > 2

After 12 weeks the same ranking was evident with and without fertilizer (Table 2) and all soils showed a tendency to reduced acidity. The Kelmscott topsoils showed increased acidity particularly so with that from position 2. The number of trays contributing to mean result levels, which apply to all tables, are given in Table 2.

Table 2 Mean pH values for topsoils at start and finish.

		Topsoil Position Number			
1. Collie		1	2	3	4
With fertilizer (trays)		(3)	(3)	(3)	(3)
	start	6.25	5.55	5.90	5.65
	finish	6.47	5.48	6.10	5.53
	change	+0.22	-0.07	+0.20	-0.12
Without fertilizer (trays)		(7)	(6)	(7)	(9)
	start	6.25	5.55	5.90	5.65
	finish	6.54	5.72	6.17	5.78
	change	+0.29	+0.17	+0.27	+0.13
2. Kelmscott		1	2	3	
	start	6.53	5.50	6.40	
	finish	6.17	4.52	6.10	
	change	-0.36	-0.98	-0.30	
	(trays)	(6)	(6)	(6)	

Number of plants established

The total numbers of seedlings over time, per square metre, which emerged from each topsoil position are shown in Figures 1 and 2. Mean numbers per tray are given in Table 3 for the final harvest times. For the Collie topsoils a greater number of seedlings emerged from fertilized trays at positions 2 and 4, whereas the reverse applied for positions 1 and 3. Overall emergence followed the pattern 2 > 4 > 1 > 3. Monocotyledonous plants were most numerous particularly from position 2 where more plants were associated with fertilizer addition.

For the Kelmscott topsoils positions 1 and 3 produced a similar, high level of seedling emergence. Very few seedlings emerged from topsoil 2. Monocotyledons were far more abundant than dicotyledons from positions 1 and 3.

Table 3 Mean number of emerged plants per tray at harvest.

	Topsoil Position Number			
1. Collie	1	2	3	4
With fertilizer				
monocotyledons	0.7	6.3	0.7	1.7
dicotyledons	0.7	0.7	0.7	1.7
Total	1.4	7.0	1.4	3.4
Without fertilizer				
monocotyledons	1.0	4.2	1.6	1.1
dicolyledons	1.0	1.0	0.3	2.1
Total	2.0	5.2	1.9	3.2
2. Kelmscott	1	2	3	
monocotyledons	16.5	0	20.2	
dicotyledons	7.2	0.5	2.2	
Total	23.7	0.5	22.4	

Figure 1 Total number of seedlings m^{-2} emerged on topsoils with and without fertilizer, Collie topsoils.

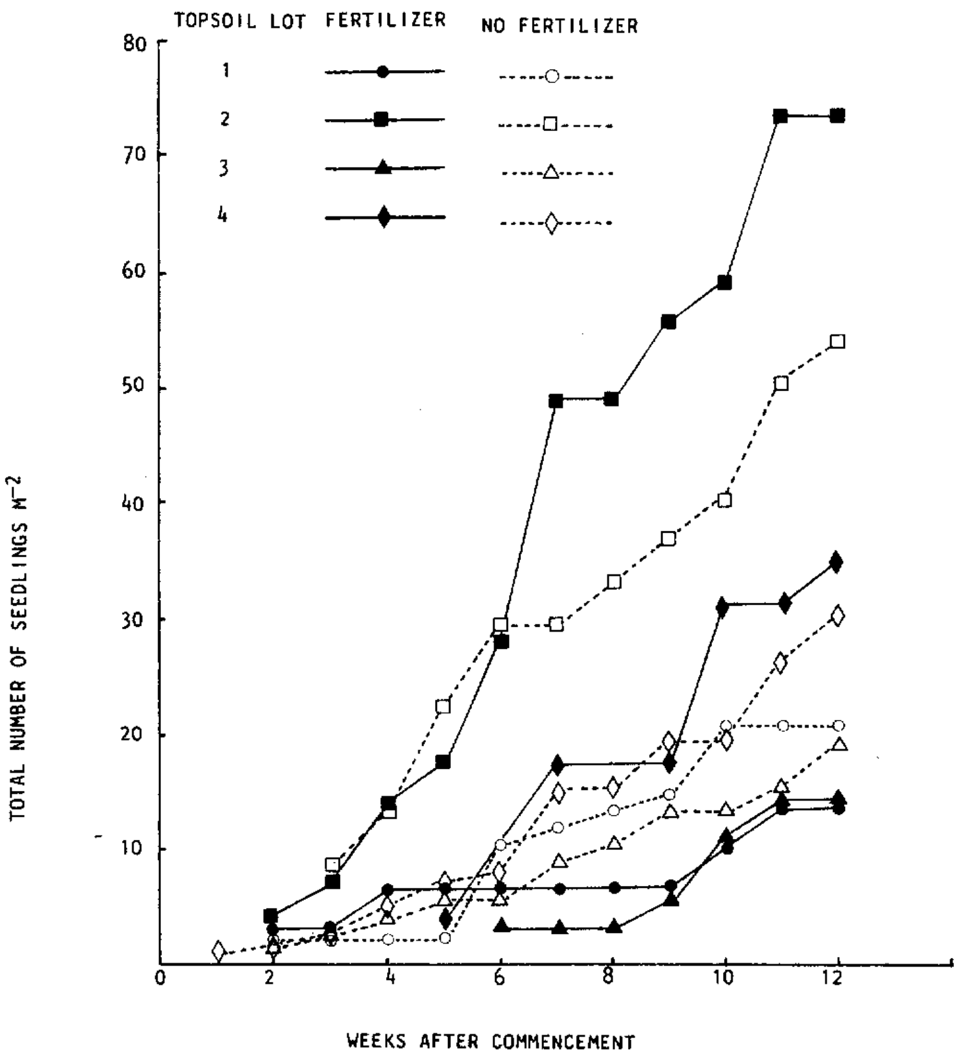

Figure 2 Total number of seedlings m^{-2} emerged on Kelmscott topsoils.

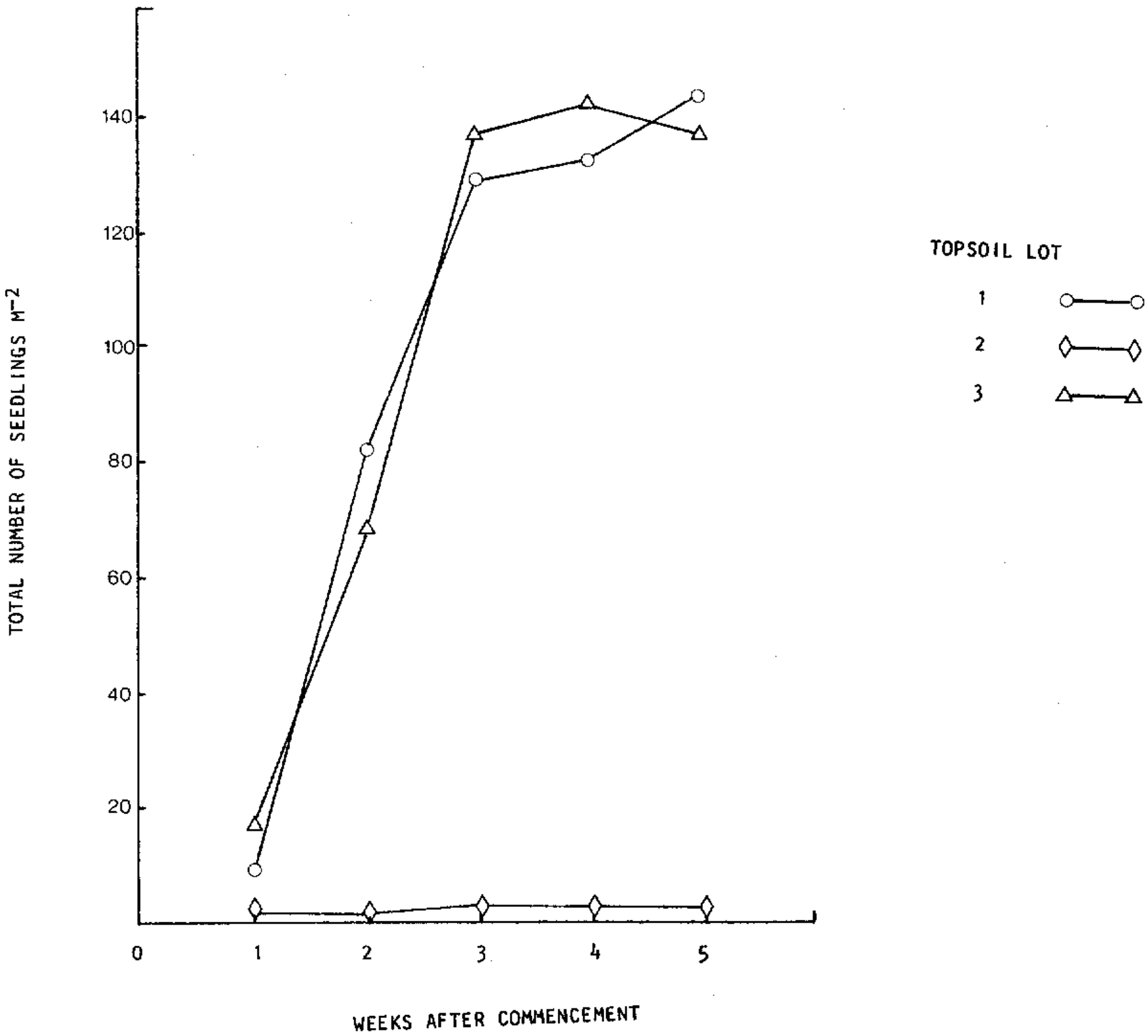

Table 4 Species numbers recovered from topsoils

	Topsoil Position Number				
1. Collie	1	2	3	4	Total species
With fertilizer	3	3	3	5	10
Without fertilizer	4	6	7	11	19
Total	4	6	8	11	20
2. Kelmscott	1	2	3	Total	
	4	2	6	7	

Number of species

Numbers of 'species' recorded are shown in Table 4. Plants were not grown on until the flowering stage so that identities are not given. A total of 20 'species' was recorded for the Collie topsoils. Of these 19 occurred in trays without fertilizer and 10 were recorded from trays with fertilizer. However the mean species density per tray was 2.92 for fertilized trays and 2.83 for those not fertilized.

One individual of **Eucalyptus calophylla** was recorded from position 4 without fertilizer, this species being one of the dominants from the area of topsoil collection. Diversity of dicotyledonous species was greater than that of monocotyledonous species.

Fewer species were recovered from the Kelmscott topsoils, and none appeared to be of the trees or shrubs characteristic of the sites. Topsoil from position 2 gave only two species of the total of seven observed from the set of three topsoils.

Biomass yield

Tables 5 and 6 summarise harvest yields for the two experiments. In Table 5 means and standard deviations are given for fresh and dry weight yields in g per tray for each topsoil position number. Harvest yields of plants grown without fertilizer showed a mean fresh/dry weight ratio of 8.4 for Collie topsoil and 8.0 for Kelmscott topsoil with little variation between positions.

Table 5 Mean and standard deviation of total plant fresh and dry weights at harvest (g).

1. Collie	Topsoil Position Number 1	2	3	4
With fertilizer				
mean fresh wt.	0.230	0.530	0.076	0.188
S.D.	0.399	0.409	0.131	1.085
mean dry wt.	0.012	0.082	0.006	0.045
S.D.	0.011	0.026	0.010	0.013
Without fertilizer				
mean fresh wt.	0.201	0.606	0.127	0.347
S.D.	0.189	0.469	0.100	0.045
mean dry wt.	0.018	0.069	0.015	0.050
S.D.	0.013	0.019	0.012	0.021
2. Kelmscott	**1**	**2**	**3**	
mean fresh wt.	0.239	0.009	0.409	
S.D.	0.077	0.010	0.083	
mean dry wt.	0.029	0.001	0.052	
S.D.	0.008	0.002	0.017	

Table 6 Total dry weight yields as kg ha^{-1} with standard deviation.

1. Collie	Topsoil Position Number 1	2	3	4
With fertilizer				
monotcotyledons	0.275	7.773	0.422	2.021
dicotyledons	0.951	0.840	0.173	2.669
Total	1.226	8.613	0.595	4.690
(standard deviation)	1.122	2.755	0.428	1.410
Without fertilizer				
monocotyledons	1.018	6.054	0.730	1.268
dicotyledons	0.918	1.229	0.876	3.984
Total	1.936	7.283	1.606	5.252
(standard deviation)	1.317	2.017	1.261	2.166
2. Kelmscott	**1**	**2**	**3**	
monocotyledons	2.253	0	4.444	
dicotyledons	0.655	0.149	0.922	
Total	2.908	0.149	5.366	
(standard deviation)	0.857	0.168	1.769	

Collie topsoil with fertilizer added showed a considerable range

Position	1	3	2	4
F/D ratio	19	13	6.5	4

with an overall mean F/D ratio of 7.1, lower than all unfertilized sets except for Collie position 4 at 6.9.

The yield ranks for Collie topsoils were

2 > 4 > 1 > 3 for all weight sets except for the fresh weight yields from fertilized trays where the rank was

2 > 1 > 4 > 3

For the Kelmscott topsoil dry weight mirrored fresh weight with 3 > 1 > 2

In Table 6 yields are given as equivalent kg ha^{-1} for each sample position with monocotyledons and dicotyledons shown separately. For the Collie topsoil overall total yield was slightly greater without fertilizer (4 kg ha^{-1}) than with (3.8 kg ha^{-1}) but the difference was not significant using analysis of variance. The percentage overall yield attributable to monocotyledons with fertilizer was 69 percent and without fertilizer 56 percent. Position 2 gave a higher total yield with fertilizer than without and Position 1 had a higher percentage of monocotyledons without fertilizer than with. Differences in total yields attributable to positions were significant with

<u>2</u> > <u>4</u> > <u>1 > 3</u>

Using the least significant difference test. These differences did not correspond with percentage yields of monocotyledons.

For the Kelmscott topsoils yields were also significantly different with

<u>3</u> > <u>1</u> > <u>2</u>

using the least significant difference test. The percentage overall yield attributable to monocotyledons was 79.5 percent. In this case differences in total yield did correspond with percentage yield of monocotyledons; position 3 having 83 percent, position 1 77 percent and position 2 zero.

Discussion

Topsoil trays with fertilizer added were slightly more acidic in reaction after the 12 week incubation period than trays which received no fertilizer. The general tendency for topsoils to become less acid was more pronounced in unfertilized trays. The Kelmscott topsoils all became more acid during the shorter, 5 week, incubation period. It is possible that in time these may also have increased in pH level. The considerable range in fresh/dry weight ratios for fertilized topsoils suggests that fertilizer may have been associated with increased water uptake in trays with topsoil from positions 1 and 3. The was not so for the sets as a whole and no acidity effect was evident with Collie topsoils on production. The most acidic topsoil from the Kelmscott set (2) was associated with inhibitory effects on both plant germination and yield. This is in agreement with the observations of Shramm[12]. This author noted that in acidic soils of pH less than 5.5 problems for seedling establishment may be associated with high levels of Fe, Mn and Zn.

Addition of fertilizer to topsoil did not increase either the number of plants or plant yield, except in the case of position 2 (Collie topsoil). Fewer plant species emerged from fertilized trays. There was a tendency for the yield of monocotyledons to be greater with fertilizer added and for the yield of dicotyledons to be less. It is possible that addition of fertilizer depresses germination of some species but this would require testing with a balanced set of replicates to eliminate the possibility that greater species numbers obtained without fertilizer may be a function of sample size. Only one species was observed which germinated in the fertilizer treatment but not in the unfertilized treatment, this was a **Melilotus**. Overall numbers were few and identifications tentative so that fertilizer effects in relation to species could not be determined.

There was evidence of species diversity increasing with time, and a suggestion that species typical of the sampled sites take longer to become established. No species from the Kelmscott sample areas had appeared in the five weeks of incubation used. Lower numbers of species from the Kelmscott topsoil is in part related to fewer trays being used. However the shorter incubation period may have resulted in fewer species' seed being exposed to the particular environmental variables for their germination. The natural variability in forest soil seed load is not known and this in itself may well explain differences between the two sets of results.

Neither biomass yield nor plant numbers were correlated with the position on the slope from where the topsoil originated. The species diversity, however, showed a strong correlation to slope position with a greater diversity being found downslope. Of some interest is the fact that the four sample positions showed differences in species numbers in a consistent order, whether unfertilized or all combined, viz:

$$4 > 3 > 2 > 1$$

Thus there was a correlation between slope and species diversity, with a higher species diversity downslope compared to upslope. This taken with the poor results for position 2 of the Kelmscott set presents strong evidence in favour of very marked variability in species richness within the soil bank. This variability in local diversity of seed may in part account for the significance of differences in total yields between sampled positions, though not in any direct statistical sense for the Collie set at least.

There was a strong indication that monocotyledonous species germinated and established earlier than dicotyledonous species. The higher proportion of dry weight in monocotyledons for the 5 week harvest set of Kelmscott topsoils and the higher percentage of monocotyledon dry weight in fertilized Collie topsoils bear out this indication. With time it would be expected that maturation of the slower growing dicotyledons would reverse the pattern. The earlier system of watering the Collie topsoils may also have leached out a certain amount of the more soluble fertilizer prior to the appearance of dicotyledonous species.

The higher rate of germination obtained with Kelmscott topsoils (Figure 2) probably reflects warmer conditions in the glasshouse from September through October than conditions prevailing earlier when incubation of the Collie topsoils commenced. Moistening of the latter at comparatively low temperatures may have inhibited germination of some monnocotyledonous seed. However as plants were not removed from the longer incubated Collie topsoil trays, the counts may have been net of some losses. Despite the higher germination rate of the Kelmscott topsoil, biomass yield (dry weight of plant material) showed a similar range for all topsoil lots. This suggests that the period of incubation may not be critical for most aspects of interest.

Conclusions

Plant production in terms of dry matter yield closely followed the pattern of numbers of plants germinated. Monocotyledons tended to give highest dry weight yields, though many of these were not representative of the communities from which the topsoil was derived, at least in the medium term scale. Nevertheless the possibility exists that biomass yield, especially in the short term, may be predicted from a count of germinants. If this were to be so then further testing could be undertaken with less effort. Should number of germinants also be correlated with cover (and we would expect biomass and cover to be related) then estimates of effective ground cover could also be made from numbers of germinants.

A comparison of germination emergence rates (Figures 1 and 2) suggests that a three to five week incubation period between early September and mid October would be most useful in determining the germinable seed load of topsoils. The results achieved give a useful guide to the availability of seed in topsoil. This needs to be more rigorously examined in relation to species identities and field performance. It is necessary to remove plants from trays and then grow them on until identification is possible.

It would also be desirable to determine the relationship between glass house productivity and field germination and establishment.

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ESTABLISHMENT OF ACACIA VICTORIAE, GERMINATION AND EARLY GROWTH

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Introduction

Acacia victoriae is widely distributed throughout arid Australia. It has been recorded as far south as latitude 36°S in South Australia, and as far north as latitude 15° in the Northern Territory. It occurs right across the continent from 114°E in Western Australia to 152°E in Queensland [7].

The preferred name for **Acacia victoriae** in New South Wales is 'Prickly Wattle' [4]. In Queensland it is known as 'Gundabluey' or 'Narran' [5] and two forms in Western Australia are known as 'Prickly Acacia' and 'Bohemia' or 'Wait-a-While' [10].

In Queensland it can be conspicuous on undulating treeless downs. It is found in **Astrebla** spp. tussock grasslands on deep grey and brown cracking clays [2]. It occurs on river flood-out country and along temperary water courses in Western New South Wales [6]. It is also found in open black box communities on heavy grey clay soils, in mulga communities on sandplains and also on sandhills and in the sandy soil of creek beds and banks [4].

In Western Australia **A. victoriae** occurs on saltland pastures, on hill slopes with crabholes, on hilly stony saline ground and in the lower parts of flood plains[10]. In the Meekatharra area of Western Australia Speck[9] recorded **A. victoriae** in two distinct communities. These were

> Community 66 **Acacia victoriae – A. tetragonophylla – Maireana pyramidata***, a haloplytic shrubland community with variable low trees, found in clumps around gilgais, occasionally with **Pittosporum phillyraeoides**.

> Cummunity 67 **Acacia victoriae – Eremophila pterocarpa**, also a halophytic shrubland community, with some **A. tetragonophylla** sparse low shrubs of **Eremophila maculata, Cassia sturtii, Scaevola spinescens** and short annual grasses **Aristida arenaria** and **Eragrostis dielsii**. This is restricted to saline alluvial plains.

The species has been noted as being of high palatability to stock[2] in Queensland but only moderately palatable in the Northern Territory[3]. It can withstant clipping[1] but although it is fairly drought tolerant it tends to shed foliage under stress [10]. It does not produce a great bulk of forage material. As it will be readily eaten by stock it may be a valuable fodder source when ground cover is unavailable [5]. This may not be a continuing source as some branches do not regrow phyllodes after grazing. It is thus comparatively unproductive [10]. The foliage is said to be of poor nutritive value. By contrast the abundant seed pods can be a useful source of protein for cattle [3].

* Formerly **Kochia pyramidata** see Wilson 1975[11]

In a run of wet seasons **Acacia victoriae** can increase. It may become a nuisance around watering places [5]. It has been classed as an 'increaser' species in lower areas, but it decreases under heavy use around crabholes and in hilly places[10]. Its ability to increase may be a useful characteristic in reclamation of eroded areas. The provision of shelter may allow the development of edible shrubs and grasses beneath it (personal communication A. Mitchell).

This report seeks to answer the following questions

1. Under what temperature regime does **A. victoriae** germinate, specifically is it a summer or winter germinating species?
2. Does the seed of **A. victoriae** require scarification to increase germination percentage?
3. Do small seedlings benefit from fertilizer treatment?
4. Is inoculation necessary to increase seedling growth rates?

Seed Germination

Table 1 summarises the results of a series of germination tests on two seed lots. The first was from Sandhill (22°45'S, 119°35'E) tested at 3.5 yr from collection, the second from Newman (23°21'S, 119°44'E) tested at 1.5 and 2.5 yr from collection. All seed tested was pretreated by pouring boiling water onto sets of 50 seed in test tubes. Each lot of 50 was assigned to a petri dish and then placed in a growth cabinet maintained at constant temperature, in darkness. Each column of the table refers to one replicate of 50 seed, except for the Newman seed aged 1.5 yr when two petri dishes were used.

Figure 1 illustrates the time course of cumulative germination for all the Newman seed treatments and also for the Sandhill set at 25°C. The three sets incubated at 15, 20 and 25°C for Sandhill are illustrated in Figure 2. Here the percentage of total germinants is graphed against time in contrast with Figure 1 where the percentage germinated of the total seed used is shown.

The eleven 'germination' measurements given in Table 1 are defined as follows:-

1. Final percentage germination is the total percentage of seed germinated to the time that observations ceased. This time is item 2.
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 initial treatment. The sum is then divided by the total number of germinants. Each germinated seedling is used once only. In this case only germinations up to and including 30 days from treatment are included.

$$\frac{(n_1 x t_1) + (n_2 x t_2) \ldots n_x x t_x}{\sum_x^1 n}$$

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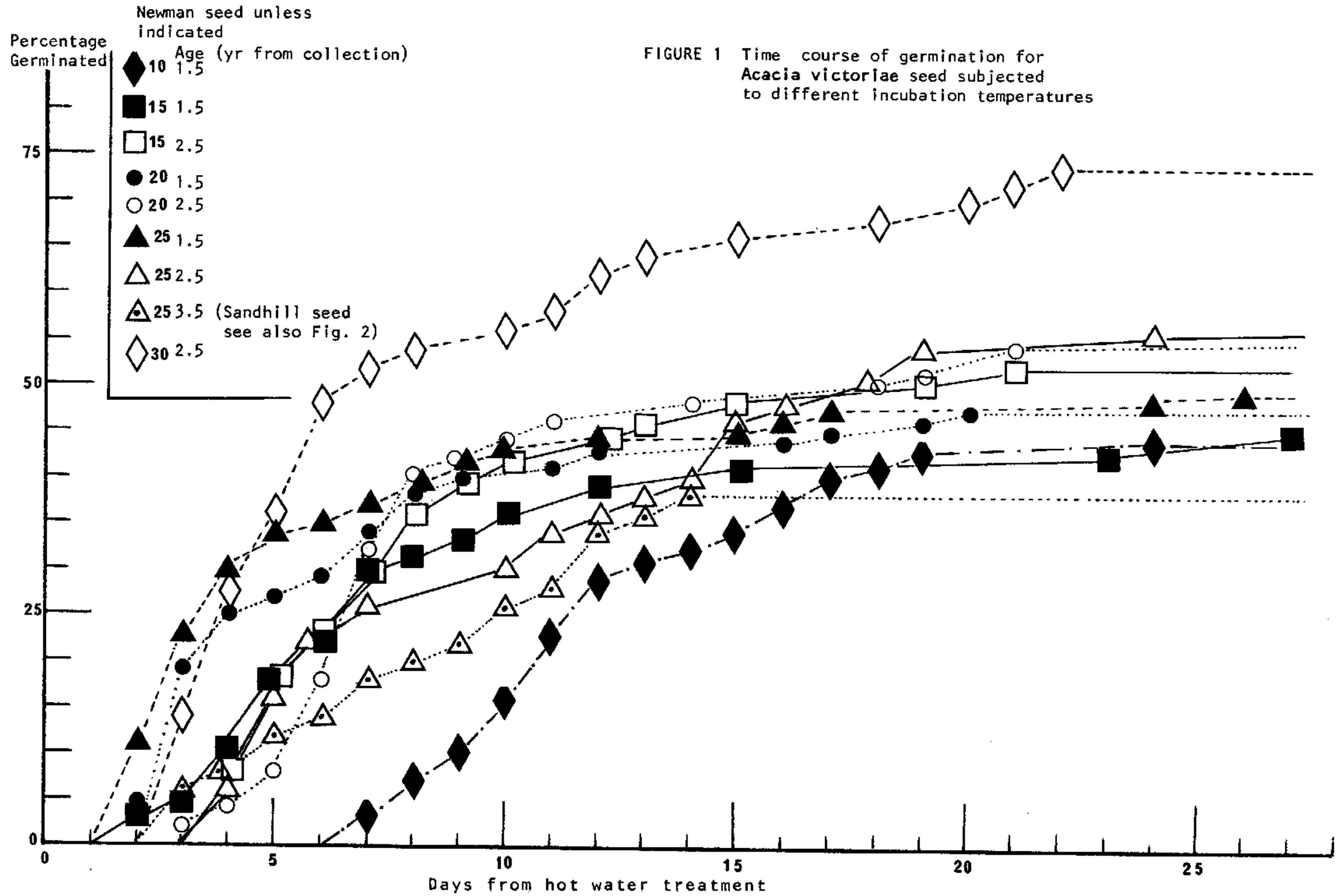

FIGURE 1 Time course of germination for **Acacia victoriae** seed subjected to different incubation temperatures

Table 1. Seed germination characteristics for *Acacia victoriae*

Germination Measurement	Seed lot 1: Sandhill (3.5 year seed)				2: Newman							
Incubation temp. (°C)	10	15	20	25	10	15	15	20	20	25	25	30
Seedage (yr)					1.5	1.5	2.5	1.5	2.5	1.5	2.5	2.5
1. Final percentage	8	34	20	38	47	47	58	47	54	49	56	76
2. Days to final germination %	18	19	15	14	64	64	41	20	21	26	24	24
3. Germination rate (30 day max.)	16.8	12.7	6.0	8.1	12.2	8.1	9.0	6.2	8.5	5.9	10.4	7.4
4. Peak value	0.4	2.1	2.7	2.8	2.4	4.3	4.5	6.3	5.0	7.7	3.7	8.0
5. M.D.G. (30 day max.)	0.4	1.8	1.3	2.7	1.8	1.7	1.8	2.4	2.6	1.9	2.3	3.2
6. G.V.	0.2	3.8	3.6	7.7	4.4	7.2	8.1	14.8	12.9	14.5	8.6	25.3
7. Energy 10/20 percentage	-	24	90	68	37	86	84	85	85	92	56	80
8. Germinative capacity 20 day percentage	8	34	20	38	43	42	51	47	53	47	54	70
9. Vigour	-	0.7	4.5	1.8	0.9	2.0	1.7	1.8	1.6	2.0	1.0	1.1
10. Germination percentage at 30 days	8	34	20	38	44	45	54	47	54	49	56	76
11. Number of days to reach 75 percent of 30 day germination	17	13.5	7.5	11	14.5	9.2	9.3	7	8.3	7	14.3	10.5

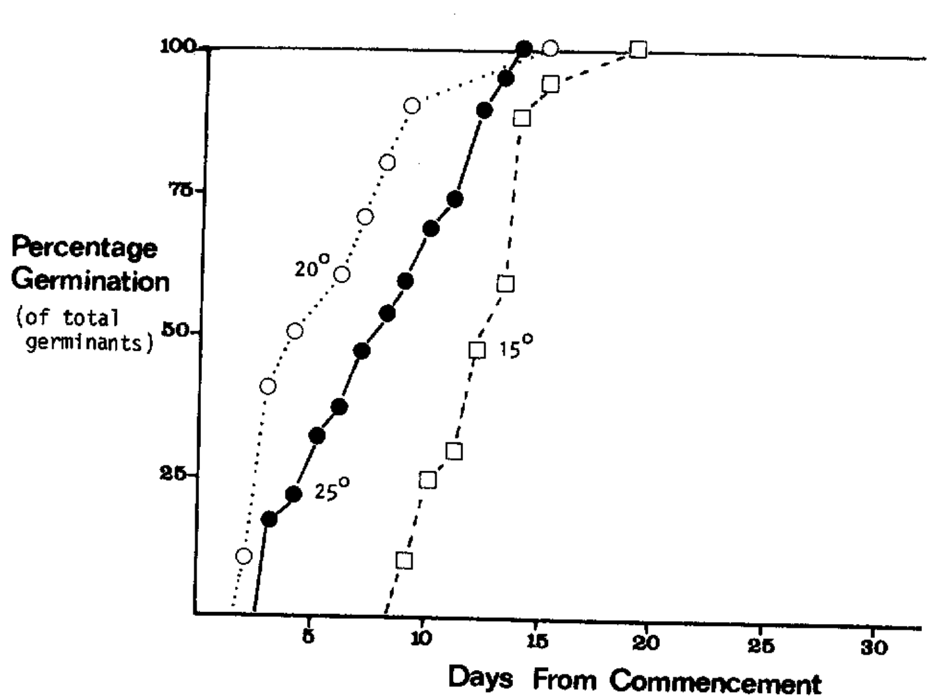

FIGURE 2 Time taken to germinate by those seeds which were viable (Sandhill seed 3.5 yr from collection).

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

5. M.D.G. is mean daily germination. It is obtained by dividing percentage germination achieved by the number of days taken for the last recorded germinant to germinate. In the present case it is taken to a maximum of 30 days, thus if 35 percent had germinated by day 27 and no more germinated prior to day 31, the value is

$$\frac{35}{27} = 1.30$$

6. G.V. is germination value. This measure combines rate of germination and viability. It is taken as the product of peak value and mean daily germination i.e.

$$G.V. = P.V. \times M.D.G.$$

7. Energy % 10/20. Here germinative energy is used as an expression giving a measure of seed 'strength'. This is obtained by taking the percentage that had germinated by 10 days divided by the percentage that had germinated by 20 days, times 100.

8. Germinative capacity is percentage germination achieved at 20 days from initial treatment.

9. Vigour. This measure combines germinative capacity and energy from 7 and 8 such that

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

It may be best considered as an objective measure of 'fitness' in terms of the viability level.

10. % germination at 30 days. This is the total percentage that had germinated by 30 days from treatment, and thus corresponds with the proportion of the seed population used to calculate items 3, 5 and, indirectly, 6.

11. 75% of 30 day germination. This is the time in days required for three quarters of the seeds which germinated by 30 days to have done so. Subtraction of this time from 30 will thus indicate the time taken for the last 25 percent of the seed in the '30 day population' to germinate.

Figure 3 illustrates a typical seed from the Newman collection. Figure 4 gives the seed weight distribution for 100 individually weighed seed from the Sandhill collection.

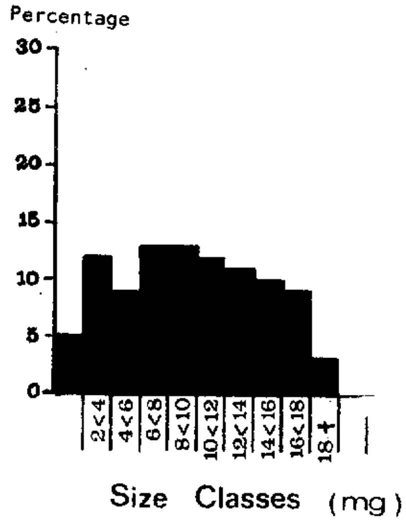

FIGURE 4 Seed weight distribution for Acacia victoriae collected at Sandhill, W.A. Data based on 100 weighed seed.

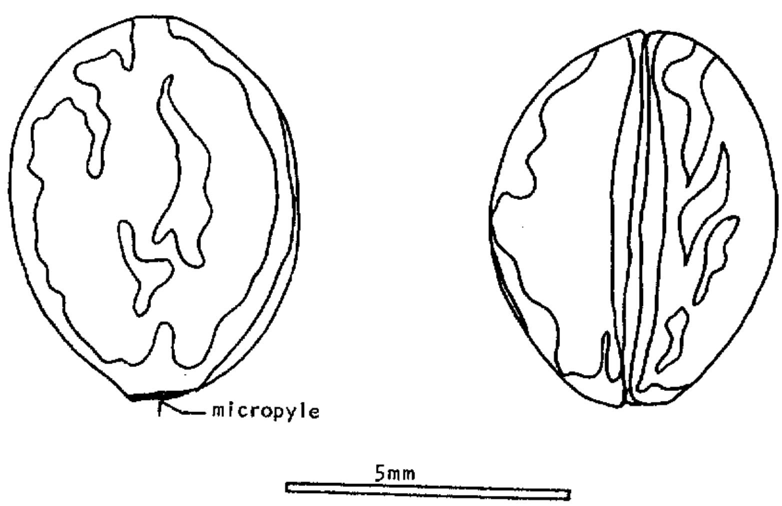

FIGURE 3 Seed of Acacia victoriae collected from Newman.

A large batch of seed ex Alice Srings (2 yr old) was provided by District Agricultural Officer, Meekatharra, for use in the fertilizer and inoculation experiment described below. This seed was subjected to several tests also. Two sets of fifty seed each were incubated at 15° and 20°C in darkness and in an alternating regime of 15°C for 12 hr darkness, 25°C for 12 hr light. These seed were pre-treated by pouring boiling water into a test tube containing the seed. When the water cooled to room temperature the seed were placed on filter paper moistened with distilled water in 9 cm petri dishes. Germination counts were taken every second day until ten days passed after the last germination.

The value of scarification versus a boiling water pre-treatment was investigated by individually treating two sets of fifty seed and placing them in petri dishes in the 20°C growth cabinet. The seed had the outer coat abraded by rubbing the seed against sandpaper. Germination counts were taken every second day and the filter papers keep moist with distilled water. Table 2 summarises germination percentages attained. Fifty seed were weighed from this batch.

Nutrients were applied at the following rates

Nitrogen: 60 kg ha-1 at 0.21 g pot of NH_4NO_3 (35% N)

Potassium: 50 kg ha-1 at 0.11 g pot of K_2SO_4 (54% K)

Phosphorus: 30 kg ha-1 at 0.40 g pot of superphosphate (9.1% P)

Molybedenum: 20 kg ha-1 at 0.06 g pot of minerals (0.04% Mo)

The molybedenum source of trace elements included the following other elements at the eqivalent rates given 50 g ha-1 B; 500 g ha-1 Cu; 500 g ha-1 Al; 350 g ha-1 Zn; 1126 g ha-1 Mn; 1651 g ha-1 Mg; 1751 g ha-1 Fe; 2.502 kg ha-1 CaO. The basal nutrients x 2 treatment consisted of N, P and K at rates twice that of the basal nutrient treatment, trace elements were at the same rate as for the basal nutrient treatment.

Germinated seed ex Alice Springs was used in the experiment. The soil in each pot was

Table 2 Germination measurements for Alice Springs seed (2 yrs)

Germination Measurement	Boiling water treatment Temperature: 15°	20°	15/25°	Scarification 20°
Final percentage	53	66	71	90
Days to final percentage	26	31	22	8
Germination rate	12.2	13.2	10.0	6.1

Fertilizer Treatments and Inoculation

Two hundred and ten round topped plastic pots, 12.5 cm d x 15 cm tall were lined with 2.5 cm of vermiculite to prevent loss of soil through the drainage holes. Soil from Meekatharra (26°36'S, 118°30'E) was added to the first rim. The pots then had fertilizer (weighed for each pot) applied to the surface. A 0.5 cm top layer of coarse sterilized sand was added to each pot, to prevent splashing of seedlings with mud when watering. The pots were then arranged in blocks of ten plants in three replicates of seven treatments.

Fertilizer treatments were as follows

1. Basal nutrients (N, P, K and trace elements)
2. Basal nutrients x 2 (2N, 2P, 2K and trace elements)
3. Basal nutrients - N (P, K and trace elements)
4. Control (no addition)
5. Basal nutrients - P (N, K and trace elements)
6. Basal nutrients - K (N, P and trace elements)
7. Basal nutrients - trace elements (N, K and P)

moistened to field capacity and seed sown burying the radicle up to the hypocotyl and leaving the seed on the surface soil. The third and successful sowing was on 1st of October, 1982. On the 26th of September, approximately three hundred seed had boiling water poured on them and the boiling water left to cool to room temperature. The seed were then placed on moistened filter papers in petri dishes and left at room temperature (c. 20°C). Seeds were sown when the radicle was 0.5 - 1.5 cm long. Watering trays were placed under each pot to prevent rapid drying of soil and loss of fertilizer by leaching. Sowing to pots was completed by 3rd October.

Inoculation

Half the plants in each treatment were inoculated on 6th October. Nodules from a Meekatharra *Acacia victoriae* specimen were stored in moist soil for several weeks, then 0.5 g of nodules were crushed with a mortar and put into suspension in 1 litre of distilled water. Five ml of the suspension was added around each of the seedlings. Inoculation thus gave a total of 14 treatment combinations. A supplementary inoculation experiment was also undertaken with more advanced seedlings ex Newman seed. A quantity of roots with nodules and soil from around the roots was also placed in two pots. A sand peat mix was placed on top of this and three four-five month old specimens of *Acacia victoriae* were transplanted to these pots.

Another two pots and six plants were used for controls. Before transfer, nodules were absent from the roots of all plants. Presence/absence of nodules was noted for all plants after a period of six weeks, while the pots were kept in a shadehouse provided with an automatic sprinkler system.

Plants from the fertilizer trial were harvested 33 days after germination. Individual plants were recorded for fresh and dry weight production.

A quantity of the Meekatharra soil was reserved for determination of bulk density, field capacity, organic matter and % nitrogen. Bulk density was determined for four samples of 100 ml of soil, these were placed in a 105°C oven for 48 hrs and dry weight recorded and bulk density calculated

$$\frac{\text{dry wt}}{\text{volume of soil}}$$

Field capacity was determined for four pots, water was added to each until water began to drip from the drainage holes and the volume added noted. Organic matter was determined for four samples of 50 g of soil (dry); the soil was placed in crucibles and placed in an electric kiln at 700°C for one hour then reweighed and organic content calculated

$$\frac{\text{initial wt} - \text{final wt} \times 100}{\text{final wt}}$$

Percentage nitrogen was determined by the Kjeldahl digestion process.

Results of Fertilizer and Inoculation Experiments

The Meekatharra soil used in the experiments was a red earth of clay loam consistency. Bulk density averaged 0.96; the organic content was 6.73 percent; percentage nitrogen 0.05; pH 6.9; conductivity 5.75 mΩ-1 cm-1. The volume of soil per pot was 740 cc which had an average field capacity of 28.7 percent.

The dramatic failure of the first two sowings of germinants was associated with difficulties in maintaining surface moisture in pots. A subsidiary trial to determine cause of early seedling death if surface drying were prevented was undertaken. Six pots of soil were leached continuously for 96 hrs. Six pots were oven dried for 48 hrs at 105°C and six pots were untreated. Observations were made over a period of two weeks from sowing for evidence of fungal attack and possible toxicity symptons. The results are given in Table 3.

Table 3 Effect of soil treatment on seedling survival in the first few weeks from sowing.

Soil Treatment	% Survival	Symptoms
Leached for 96 hrs	60	some fungal attack
Dried at 105°C for 48 hrs	25	some fungal attack and discolouration
Control	17	some fungal attack and discolouration

Survivals of the third sowing to harvest at 33 days were 18 percent for inoculated pots, and 13 percent for uninoculated pots. Losses were associated with fungal attack. Five replicates each survived for treatments 1 and 2 (basal and twice basal fertilizer) with and without inoculum. The mean harvest parameters for these 20 are given in Table 4 together with the calculated 'F' value from analysis of variance. The remaining survivors from other treatments are summarised in Table 5. Phyllode/leaf areas were not measured. It was noticable that the leaf size for control seedlings was clearly

Table 4 Mean values at 33 day harvest for treatments with 5 surviving replicates

Harvest Parameter	Treatment: 1. Basal fertilizer		Treatment: 2. basal fertilizer x 2		Analysis of Variance		Critical difference Scheffe
	a) + inoculum	b) - inoculum	a) + inoculum	b) - inoculum	F	Significance	p0.05
Mean weights (g)							
Fresh weight	0.165	0.124	0.078	0.083	4.08	*	0.089
Dry weight	0.030	0.018	0.014	0.015	5.32	**	0.014
Fresh shoot weight	0.133	0.100	0.071	0.073	3.96	*	0.062
Fresh root weight	0.031	0.024	0.007	0.010	2.87	NS	0.029
Dry shoot weight	0.023	0.014	0.012	0.013	38.92	***	0.004
Dry root weight	0.007	0.004	0.002	0.003	4.43	*	0.004
Ratios							
Fresh/Dry weight	5.4	6.8	5.8	6.2			
Dry shoot/ Root weight	3.7	3.6	7.1	5.5			
No. of replicates with nodules	3	0	0	0			

Significance levels * p 0.05; ** p 0.01; *** p 0.001

Table 5 Mean values at 33 day harvest for treatments with less than five surviving replicates (values are means where more than one survivor is indicated)

Harvest Parameter	Treatment						
	Those with inoculum					Those without inoculum	
Mean weights (g)	3 Basal-N	4 Control	5 Basal-P	6 Basal-K	7 Basal-Traces	4 Control	6 Basal-K
Fresh weight	0.195	0.115	0.060	0.070	0.16	0.08	0.15
Dry weight	0.035	0.014	0.020	0.012	0.021	0.014	0.018
Fresh shoot weight	0.155	0.080	0.050	0.050	0.115	0.06	0.09
Fresh root weight	0.040	0.035	0.010	0.018	0.045	0.022	0.06
Dry shoot weight	0.028	0.011	0.015	0.011	0.018	0.010	0.008
Dry root weight	0.007	0.004	0.005	0.002	0.003	0.004	0.004
Ratios							
Fresh/Dry weight	5.6	7.9	3.0	5.8	7.3	5.9	10.0
Dry shoot/root weight	4.0	3.1	2.0	8.0	6.7	2.6	8.3
No. of replicates	1	3	1	2	2	2	2
No. of replicates with nodules	1	2	0	1	1	0	0

smaller and narrower than for any other treatment, particularly comparing control leaves with 2 x basal and basal. Basal minus potassium also had smaller than average leaves, but were somewhat larger than for the controls.

Nodule formation

For most treatments, enough plants survived for us to see trends in the effect of fertiliser treatment on nodule formation and, to some extent, the contribution of well developed nodules to early growth of seedlings.

These trends followed the patterns given in Tables 4 and 5. No nodules were observed in uninoculated sets. All inoculated sets with survivors, except for twice basal (Table 4), and basal minus phosphorus (Table 5), had some plants with nodules. Nodules were best developed in basal minus nitrogen and basal treatment sets. Nodule formation for the established Newman Acacia victoriae exposed for six weeks to soil containing roots and nodules was significantly greater than those not treated with inoculum material (Table 6).

Table 6 Nodulation in established Newman seedlings.

Set	No. of replicates	No. with nodules	No. with curled root hairs
Inoculated	7	4	7
control	7	0	0

Discussion

a) Seed and Germination

The species is a variable one. Pedley[8] recognises two sub-species one of which A. victoriae sub-species arida, is found in the vicinity of Alice Springs.

Seed weight for the population at Fowlers Gap has been estimated at 26.5 mg [6]. For the Alice Springs seed used in the growth experiments reported above seed weight was 47 mg. This was considerably larger than the Pilbara seed sources used in germination trials (Figures 3 and 4). Mean weight of Sandhill seed was 9.62 mg, with a range of 1.27 to 20.58 mg. These latter gave 104,000 seed per kg. The expectation exists therefore that the optimal temperature regimes may vary with seed source. A consideration of Figure 1, Tables 1 and 2 suggests that variation also occurs with seed age, that viability alters with time and that collections may vary considerably in viability. Newman seed incubated at 30°C produced the highest viability value at 76 percent of the 8 different conditions tested. Viability and speed of germination increased at all incubation temperatures as between 1.5 and 2.5 yr old seed. Sandhill seed was probably less viable as a batch but also showed a tendency to faster germination at higher temperatures. The Alice Springs results suggest this batch had a higher viability perhaps associated with larger seed weight.

Boiling water treatment is useful in preparing seed for potential field esablishment but scarification is very much better. The rate of germination can be increased considerably and the highest level of viability attained.

Germination at 10°C is low and prolonged. In the immediate vicinity of Acacia victoriae stands the soil seed population in the top 5 cm may reach levels as high as 200-300 seed per square metre. These seed respond well to soaking in water at 80°C for 8 minutes but field germination following exceptionally heavy rain is very low. Established seedlings as a percentage of soil seed reserve reached 0.16 to 0.31 percent [6]. Clearly once established in an area a potential for regeneration may exist for some considerable time. If the species is to be artificially introduced perhaps not all seed sown should recieve pre-treatment in case soil moisture regimes become unfavourable.

The pot trials utilised germinants whereas field sowings would probably be made prior to radicle emergence to avoid damage. Some caution needs to be exercised therefore in dismissing **Acacia victoriae** as a fickle species too difficult to handle. If seed were to be sown and lightly raked into a moist surface similar results to those obtained from the third, relatively successful, pot trial could be anticipated. If the environmental conditions worked against fungal contamination then survivals could be much higher.

b) Fertilizer Treatments

From the pot trial it is possible to see that a fertilized treatment gives more rapid growth and therefore probably increases survival. The effect of different treatments of fertilizer on survival could not be assessed due to the death of many seedlings from fungal attack and possibly some other toxic substance in the soil that may act indiscriminately. Possibly deaths due to other than fungal infection are due to a combination of a moderately high salinity - conductivity of 5.75 m Ω^{-1} cm^{-1} and surface drying of soil. Alternatively losses were due to some other leachable substance, as the leaching treatment increased early seedling survival compared to the control. The source of fungal infection may not have been the soil itself.

Comparing the basal nutrient treatment - nitrogen, phosphate, potassium and trace elements, to the control shows more rapid growth - more leaves, greater height and greater fresh and dry weights at harvest for the former. However, there were insufficient replicates to test the statistical significance of the difference. There was no difference in root weight at harvest between the two. Leaf size was greatest for the basal nutrient treatment.

The higher fertilizer rate (twice basal) did not increase early growth rate relative to the basal level and growth was similar to control. The species may not be adapted to exploit higher fertility levels and enhanced osmotic potential of the soil solution may harm seedlings especially under drying conditions.

It was noticeable that the ratio of dry shoot to root weight was twice as large for the 2 x basal nutrient treatment compared to the basal, and the control had an even smaller ratio than the basal.

Reduced root growth is obviously undesirable as the seedlings are less likely to become established and survive low rainfall periods and thus the contribution of the plants to regeneration/protection of eroded areas would be lower.

Poor survival rates disallowed determination of the effect of the components of the basal nutrient treatment. However the low soil nitrogen status suggests that soluble nitrogen fertilizer could give a growth response in the absence of active root nodules.

c) Inoculation

Inoculation is necessary for formation of nodules. None of the seedlings not inoculated had nodules. Therefore the soil did not contain **Rhizobium** bacteria capable of forming nodules on the roots of the species. **Rhizobium** does not persist in a soil if it is subject to drying out.

Nodule formation is stimulated with increasing nitrogen in soil up to a limit, at which nodule formation is inhibited. No nodules formed on the roots of the seedlings of the 2 x basal nutrient treatment group. Nodule formation was good for the basal nutrient treatment group and the contribution of nitrogen - fixation to early growth was significant as can be seen by comparing inoculated and non-inoculated groups for the basal nutrient treatment. Inoculated plants had greater fresh and dry weights. There were significant differences in both dry shoot and root weights.

Control plants were poorly inoculated with only one or two nodules less than 0.5 mm diameter in most plants compared to several nodules up to 1.5 mm x 0.5 mm for the basal nutrient inoculated plants. This was reflected in little difference between inoculated and uninoculated control plants.

Nodules also formed on plants inoculated for the basal minus nitrogen, basal minus potassium, and basal minus trace elements. Nodule formation was very good for the single seedling that survived for the basal minus nitrogen treatment. For harvest values this plant was equal or greater than the mean of the values for the basal nutrient, inoculated plants. This suggests that if nodule formation is good, a nitrogen fertilizer is not needed but more replicates would be required to confirm this.

Nodule formation was good for the basal minus trace element inoculated plants. Trace elements may not be needed for nodule formation as harvest values were similar to the basal nutrient, inoculated plants. Again more replicates are needed to confirm this.

For the experiment with nodule formation in established specimens of **Acacia victoriae** four out of seven plants had nodules on their roots after six weeks exposed to roots and nodules from a mature specimen of **Acacia victoriae** from Meekatharra. All seven plants had curled root tips-this occurs in response to substances secreted by **Rhizobium** bacteria and is necessary before infection of the roots.

Conclusions

The available evidence suggests that **Acacia victoriae** is adapted to germination under summer conditions. Scarification of the seed coat appears to enhance germination potential. Scarification is worthwhile if a machine is available to abrade the seed coat but not otherwise as treating individual seed is too time consuming. A boiling water pre-treatment gives good germination levels even if the rate of germination is less. Establishment of plants is likely to be greatest under conditions of heavy summer rainfall. As the period of high soil moisture is difficult to predict it would be advisable not to pre-treat all seed sown into a site during a seeding exercise. This could allow more germination at a later time without a second visit.

A fertilizer treatment at the rate of the basal nutrient treatment of N, P, K and trace elements gave more rapid growth compared to the control and this in combination with inoculation gives a clear increase in growth rate and therefore is likely to increase establishment and amount of seedlings.

In groups that had good nodule formation some seedlings had no nodules - this is probably the result of the inoculation method. Inoculation of seed may be more reliable. A suspension of crushed nodules applied around the seedling can fail due to surface drying or unfavourable soil conditions, the bacteria may not survive and reach the seedling roots.

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ECOLOGICAL NOTES ON ACACIA SPECIES

1. ACACIA UROPHYLLA

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Introduction

Acacia urophylla is an understorey shrub species of the jarrah and karri forests of Western Australia. The present account describes its ecology in general terms.

Geographical distribution

Acacia urophylla has been mapped by Hnatiuk and Maslin [7] as occurring on the 1:250,000 map sheets of Perth, Pinjarra, Busselton, Collie, Augusta, Pemberton and Mt Barker. This gives it a range from about 32° to 35°S and 115°50' to 118°30'E. It is endemic to Western Australia, probably confined to the Warren and Darling botanical districts, but it may stray over into the Avon and Stirling districts. It is not found on the coastal sandplain, but occurs to the highest levels of the Darling Scarp, up to 500 m above sea-level, and close to sea level at Walpole-Nornalup National Park.

Habitat

a) Climate and Topography

The habitat enjoys a mediterranean climate, with hot, dry summers, and cool, wet winters. The range of rainfall and temperature can best be shown by the figures for Dwellingup towards the northern end, and Pemberton near the southern end of the species' range (Table 1). These climatic conditions are not necessarily directly limiting. It is not known whether the species has been grown outside its natural distribution. In nature it appears confined to forest areas, where hot fires in heavy fuels occur. These are the areas with sufficient rain to support jarrah (Eucalyptus marginata), or karri (E. diversicolor) forest. With regard to topography, the species seems to be more plentiful on the higher ridges of the scarp, on low coastal hills near Walpole and near streams within the forest areas. These areas receive the higher rainfalls and are associated with high forests and hence heavier fire fuels.

b) Soils

The species has been observed growing on soils ranging from lateritic gravel (pH between 5 and 6) to karri loams (pH from 6 to 7 or even higher). It has not been observed on sand, and when grown in a pot of sand needs small amounts of fertiliser to survive.

Communities

The species is found in the sclerophyll forests of jarrah and karri. In addition to the two key eucalyptus species, E. diversicolor and E. marginata, Acacia urophylla is also found in association with the following: **Lasiopetalum floribundum, Bossiaea aquifolium, Pteridium esculentum, Macrozamia riedlii, Leucopogon capitellatus, Phyllanthus calycinus, Clematis pubescens, Bossiaea ornata** and **Hovea chorizemifolia.**

In the northern jarrah forest it is usually found in Havel's Site Vegetation Types O, Q, S, T. A list of species of these types is given in Table 2.

Examples of the occurrence of some of these Site Vegetation Types are given in the Atlas of Natural Resources, Darling System [6]. Two of the vegetation complexes described therein are

* Dwellingup and Hester Complex in High Rainfall - Central and South - open forest of jarrah-marri. Mainly S, T some O.

* Dwellingup Complex in Medium to High Rainfall as above, S and some O.

Similar detail for karri forests is not available at present.

Response to Biotic Factors

This species tends to show seral behaviour in that it is present after hot burns. Its life span is not known but is unlikely to be greater than 10 years, probably usually 6-8 years. The frequent, cool fires of controlled forest burning may not encourage germination of

Table 1. Meteorological data extremes

Station	Location			Rainfall (mm)		Temperature °C	
	Lat.°S	Long.°S	Altitude (m)	Lowest	Highest	Lowest	Highest
Dwellingup	32.8	116.0	269	751	1976	-3	42
Pemberton	34.4	116.0	171	801	1711	-1	42

(Source: Summary of Meteorological Data in Australia - Norman Hall
Leaflet No. 114, Forest and Timber Bureau, Dept. of National Development).

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Table 2: Species found in Site Vegetation Types of the Northern Jarrah where Acacia urophylla is usually present.

Species	SITE VEGETATION TYPE O	Q	S	T
Acacia extensa	+	–	–	–
Acacia browniana	–	–	*	–
Adenanthos barbigerus	–	–	*	–
Banksia grandis	*	–	+	+
Bossiaea aquifolium	+	–	+	+
Casuarina fraserana	+	–	+	–
Chorizema ilicifolia	–	–	–	+
Clematis pubescens	–	*	–	*
Daviesia pectinata	–	–	+	–
Dillwynia cinerascens	–	+	–	–
Eucalyptus calophylla	*	+	+	*
Eucalyptus marginata	*	+	*	*
Eucalyptus patens	–	*	–	+
Hakea cyclocarpa	–	–	+	–
Hakea lissocarpa	–	*	+	+
Hibbertia lineata	–	+	–	–
Hovea chroizemifolia	+	+	*	*
Hypocalymma angustifolia	–	+	–	–
Kennedia coccinea	+	+	–	+
Lasiopetalum floribundum	–	–	*	*
Lepidosperma angustatum	*	+	+	–
Leptomeria cunninghamii	–	–	*	+
Leucopogon capitellatus	–	+	*	+
Leucopogon propinquus	+	+	+	+
Leucopogon verticillatus	–	–	+	*
Macrozamia riedlei	–	*	*	*
Patersonia rudis	–	–	+	–
Persoonia longifolia	–	–	+	–
Phyllanthus calycinus	–	*	*	+
Pteridium esculentum	–	+	–	*
Styphelia tenuiflora	–	–	+	–
Trymalium spathulatum	–	*	–	–

After Heddle 1979[5] * species should be present,
+ should be present but absence not critical,
– generally absent.

acacias. In an experimental area near Dwellingup **Acacia urophylla** plants have disappeared after two three-year cycles of cool burning. Doubtless the seeds are still present, but it is not known how long they remain viable. Cool burning for a number of decades could lead to reduction in the numbers of this species and others of relatively short life cycles.

There is some association with ants, this is dealt with below. **Acacia urophylla** is included in seed mixtures applied to establish understorey stands in former bauxite pits. A typical mix includes 80 g ha-1 of seed of this species giving 0.66 seed per square metre.[1]

Performance

a) **Gregariousness**

Acacia urophylla can occur in pure understorey stands in the karri forest. This has not been observed in jarrah forest. However, where one Acacia urophylla is observed there will usually be more found nearby.

b) **Performance in various habitats**

There is a marked difference in size of the species from north to south. This difference is partly due to different soils. On the poor, phosphate-fixing laterite gravels in the north the species attains a height of only about one metre. In the south, on red krasnozemic loams growth is much better.

The difference in performance is also related to climate. Despite similar total rainfall the higher temperatures in the north result in a shorter growing season compared with the southern areas.

Table 3 presents the heights of a set of 10 shrubs recorded in an area burnt in April 1970 at Strickland Road near Manjimup. Most rapid growth occurred in the first two to three years after the fire. If germination and

Table 3: Height Progression of Ten Acacia urophylla Plants Recorded in an Area Burnt at Strickland Road Manjimup on April 9th, 1970

Date Measured	PLANT NO. (heights in m) 1	2	3	4	5	6	7	8	9	10	Mean ht	S.D.
9th June 1971	0.46	0.37	0.58	0.67	0.58	0.43	0.46	0.76	0.52	0.79	0.56	0.14
3rd December 1971	0.79	1.01	1.04	1.40	1.22	1.31	1.19	1.58	0.79	1.49	1.18	0.27
23rd August 1972	1.37	1.62	1.52	1.89	2.04	1.55	2.32	1.68	1.25	2.13	1.74	0.35
11th March 1974	3.32	2.50	2.68	2.19	2.59	2.29	2.87	3.11	1.52	2.87	2.59	0.51
12th December 1974	3.72	2.87	3.26	2.26	2.62	2.71	3.14	3.23	1.52	2.87	2.82	0.61
15th January 1976	4.02	2.90	3.38	2.26	D	2.80	3.17	3.54	D	2.87	3.12	0.54
15th December 1976	D	D	D	D	D	D	3.54	D	D	D	3.54	-

D = plant dead at time of measurement
Data: courtesy of P. Christensen and P. Skinner, Forests Department, Manjimup.

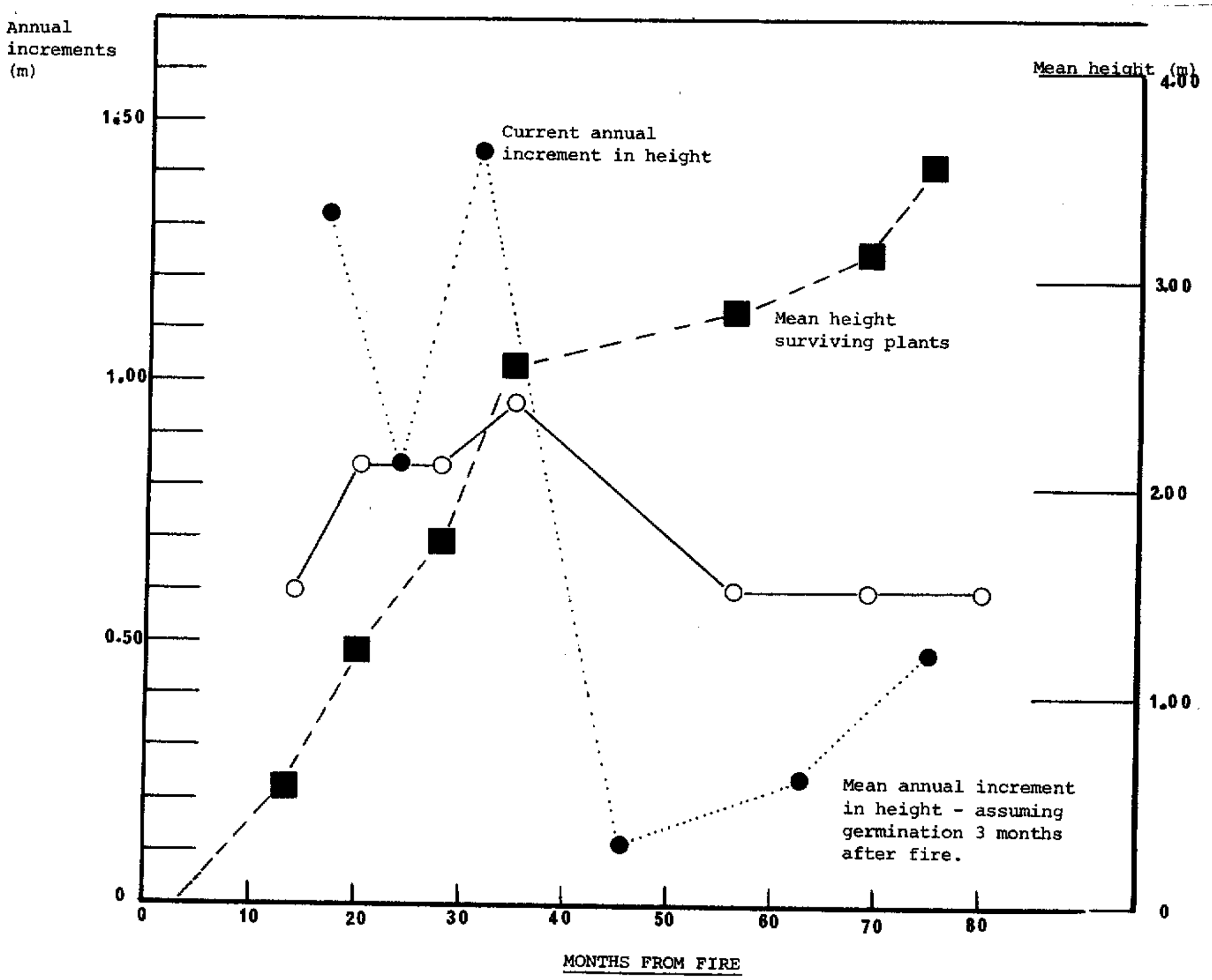

FIGURE 1 Acacia urophylla mean and current annual height growth for 6-7 years following germination (see Table 3 for raw data).

establishment are assumed to require three months then the mean and current height increments of this set of plants are as shown in Figure 1. By the third spring season from establishment mean growth declined to about 60 cm per annum. The majority of plants had died 6-7 years after the fire.

The tallest specimen noted (D.W.) is one of 4.5m at Pine Creek, Manjimup in 1976.

c) **Effect of extreme conditions**

From the climatic data (Table 1) it may be noted that the species can tolerate temperatures from frost to over 40°C. Although it occurs in high rainfall areas this may be connected with fire fuel requirements for germination rather than survival. The species has several xeromorphic features such as sclerotic phyllodes and an extensive root system, and can probably well survive seasonal drought.

It has been observed to show some regrowth from rootstock after fire (Figure 2).

Successful regeneration in bauxite-mined areas has been recorded.[4]

Adaptive Features

a) **Morphology**

The species is xeromorphic, with leathery phyllodes. It grows to a height of at least 4.5 m with a stem diameter of 3 cm. It has a deep and extensive root system - at least at the nothern end of its range where a small plant 0.4 m high was found to have roots to at least 1.5 m deep and reaching out horizontally for 2 m.

Mature phyllodes are somewhat ovate to broadly ovate lanceolate 3-7 cm long and 2-3 cm broad below the middle. Phyllodes are distinguished by the 2-4 nerved arrangement (Figure 2, F,G) and a marginal gland. Flowers are borne in globular heads and are pale yellow to white in colour. The seed pod is 12-15 cm long, narrow with thickened dilated sutures. Seeds are oval-oblong longitudinal the last 2 or 3 folds of the funcile thickened into a small aril under the seed.

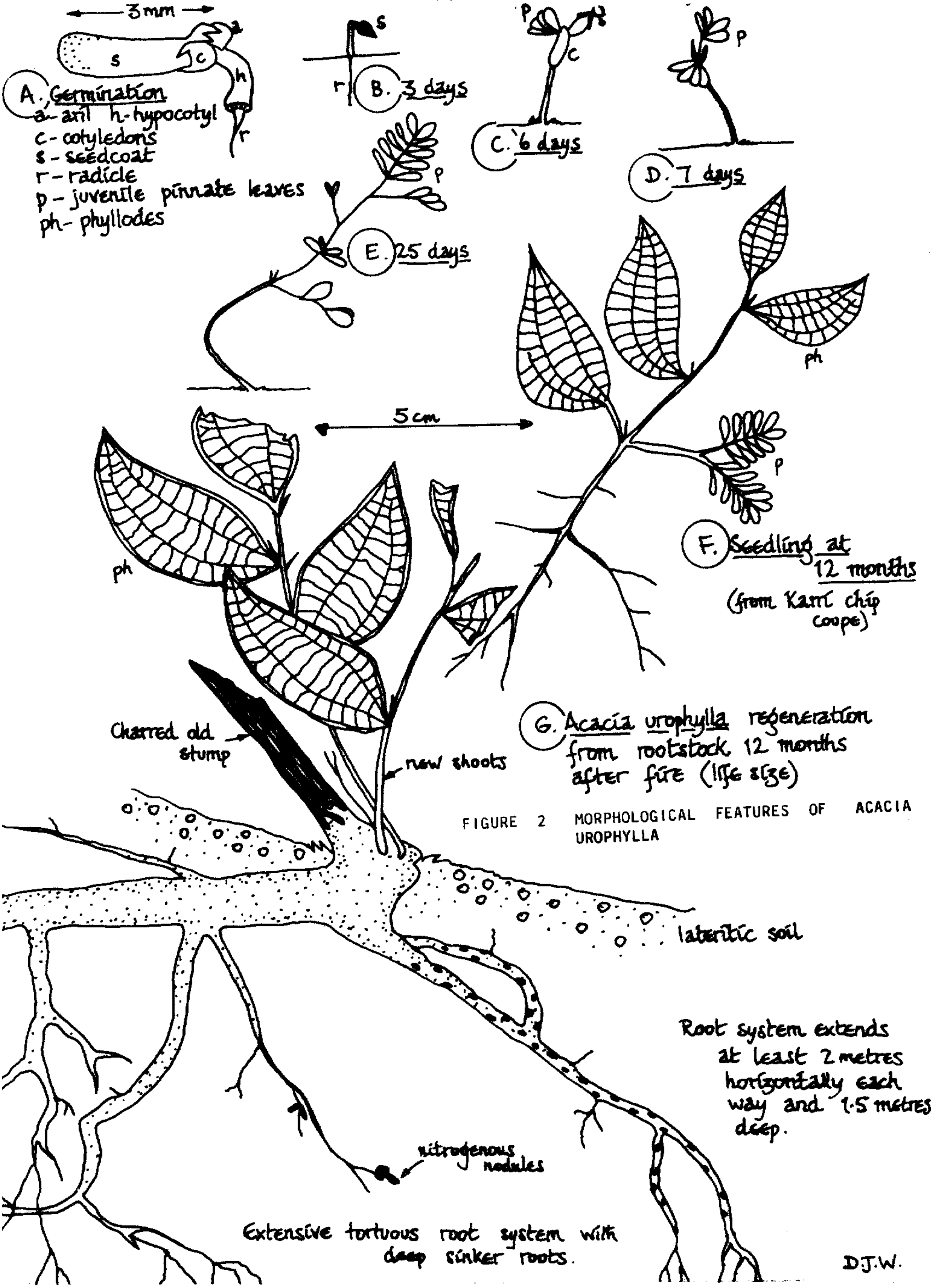

FIGURE 2 MORPHOLOGICAL FEATURES OF ACACIA UROPHYLLA

b) Mycorrhiza

The status of fungal associations with the roots is unknown. However root nodules inhabited by the bacterium **Rhizobium** sp. are present. These nodules are oval capsules roughly 1 mm wide by 1.5 to 2 mm long. They are not very plentiful on specimens examined, and seemed to be absent on a seven-year old senescent specimen in the karri forest.

A total of 21 nodules were recorded from one plant 1 m tall. The nitrogen fixation rate for one-year old seedlings in karri forest has been estimated at approximately 2.3 kg ha^{-1} yr^{-1} (pers. comm. N. Malajczuk).

c) **Perennation**

Growth is probably at its lowest in mid-winter and late summer, in the first case associated wih low temperature and in the latter with reduced soil moisture. The presence of epicormic buds is confirmed by the ability to sprout (Figure 2g).

d) **Nutrition**

Table 4 gives the elemental composition of the species.

Table 4: **Acacia urophylla** Elemental Composition

Element	Phyllode	Stem
Percentage		
Nitrogen	1.90	0.47
Phosphorus	0.061	0.011
Potassium	0.79	0.49
Sulphur	0.25	0.04
Calcium	1.77	0.44
Magnesium	0.27	0.09
Sodium	0.06	0.07
Chlorine	0.85	0.63
Parts per million		
Manganese	86	18
Copper	5	3
Zinc	6	1

(Data from N. Malajczuk)

Phenology

Acacia urophylla commences flowering comparatively early compared with other wattles, with first flowers produced in June. Flowering continues through the winter and specimens may be found with flowers as late as October. The fruits are ripe by late November to January, with maximum seedfall usually in December.

Life History

a) **Floral biology**

The compound globular flowers are borne on axillary peduncles 4 to 10 per axil, and are about 3 mm in diameter. There are 6-8 ovaries per nodule. The superior ovaries are entire with about 20 stamens. There is a small unobtrusive perianth of distinct calyx and corolla.

Pollination is probably effected by insect vectors.

b) **Hybrids**

Hybrids are not known.

c) **Seed production and dispersal**

The quantity of seed produced probably varies strongly with age and size of plant, and with rainfall. At Manjimup seed trays (0.5 m square) placed under three stands of **A. urophylla** for several years, with three trays to each stand gave the results shown in Table 5.

Table 5: Seedfall per hectare **Acacia urophylla**

Year	Plot 1	Plot 2	Plot 3	Rain-fall (mm)
1971				1130
1972	10,225,492	119,261,530	21,204,442	781
1973	7,215,320	16,556	98,840	1118
1974	4,612,600	101,311,000	22,898,000	1061
1975	19,274,580	2,298,123	7,413	874
1976	13,838,160	1,655,637	nil	947

Data: courtesy of P. Christensen, P. Skinner and P. Kimber, Forests Department, Manjimup.

Mean annual seedfall 3-5 years from fire has been estimated as 2-4630 seeds per square metre[2]

Dispersal from the plant is effected by seed ejection from explosive twisting of the dehiscent pod valves in hot weather. It is probable that ants of the genus **Rhytidoponera** may carry seeds to their nests, obtaining purchase on the otherwise smooth seed by gripping the aril (pers. comm. J.D. Majer).

d) **Viability of seeds, germination**

It is probable that seed remains viable in the soil surface and in ants nests for considerable time periods.

A germination experiment was undertaken to test the effect of heat treatment and differing temprature and light regimes. A batch of seed was mixed thoroughly. Ten replicates were weighed and the weight of sound seed was estimated at 6.6 g per thousand, in close agreement with the 6.67 g (150 seed per g) given by Bartle et al[1].

Table 6: Germination Measurement Values for Acacia urophylla Seed Subjected to 8 Different Conditions

Germination Measurement	Regime	SEEDS BOILED 1	2	3	4	Mean	SEEDS NOT BOILED 1	2	3	4	Mean
Final %		21	51	47	30	37.3	28	36	32	32	32.0
Days to 1		32	46	46	46	46	32	39	32	20	39
Germination rate		17.5	21.8	25.0	17.2	21.3	15.1	17.5	15.6	13.0	15.4
Peak value		0.9	2.1	1.2	1.4	1.3	1.6	1.5	1.5	2.1	1.6
M.D.G.		0.7	1.1	1.0	0.7	0.8	0.9	0.9	1.0	1.6	0.8
G.V.		0.6	2.3	1.3	0.9	1.1	1.4	1.4	1.5	3.3	3.3
Energy % 12/24 days		29	39	19	11	26	15	22	16	44	25
Germinative capacity % 24 days		17	36	26	27	26	26	32	31	32	30
Vigour		1.7	1.1	0.7	0.4	1.0	0.6	0.7	0.5	1.4	0.8

Regimes: 1 - Growth cabinet at 25°C for 12 hr in light, followed by 12 hr darkness at 15°C.
2 - Growth cabinet at 13°C in darkness
3 - In laboratory at ~ 20°C with ambient light
4 - Growth cabinet at 20°C in darkness.

Eight sets of one hundred sound seeds were counted out. Each set was subjected to different treatment as listed here:

Treatment A

Boiling water poured over the seeds and left to cool. Seeds washed then kept moist on filter paper in a petri dish in an incubator or in the laboratory.

1. Incubator set at 12 hours light at 25°C then 12 hours darkness at 15°C. The light was provided by a 'Grolux' approximating natural sunlight.

2. Incubator in darkness set at constant temperature of 13°C.

3. Petri dish left in the laboratory at 20°C with ambient light.

4. Incubator in darkness set at constant temperature of 20°C.

Treatment B

Seed soaked in de-ionized water at room temperature (20°C) for 24 hours. One set of 100 seed each was then subjected to the four regimes as in 1, 2, 3, 4 above respectively.

A summary of germination measurement values is given in Table 6 following the method outlined by Fox[3] The difference between mean germination of the boiling water treatments (37.3 per cent) and soaking (32 per cent) was not significant (90 per cent confidence intervals, 4 per cent). However germination under the alternating conditions of regime 1 was poorest with both boiling water and soaking. Pooling of the two sets for each of the temperature regimes gives the following:

	1	2	3	4
Total	49/200	87/200	79/200	62/200
Confidence intervals per 100	25 ± 5	44 ± 6	40 ± 6	31 ± 5

thus implying 1 4 3 2

that germination in the dark at 13°C was significantly greater than the alternating regime and at 20°C in darkness, and that the set exposed to laboratory conditions was significantly better than the alternating regime.

The time course of germination is illustrated in Figure 3. Despite the limitations of this experiment it is probable that germination would occur in nature in the cooler months, when soil moisture is likely to be high. Of particular interest perhaps is the delay in radicle emergence following initial preparation, giving a period of 8-12 days prior to germination

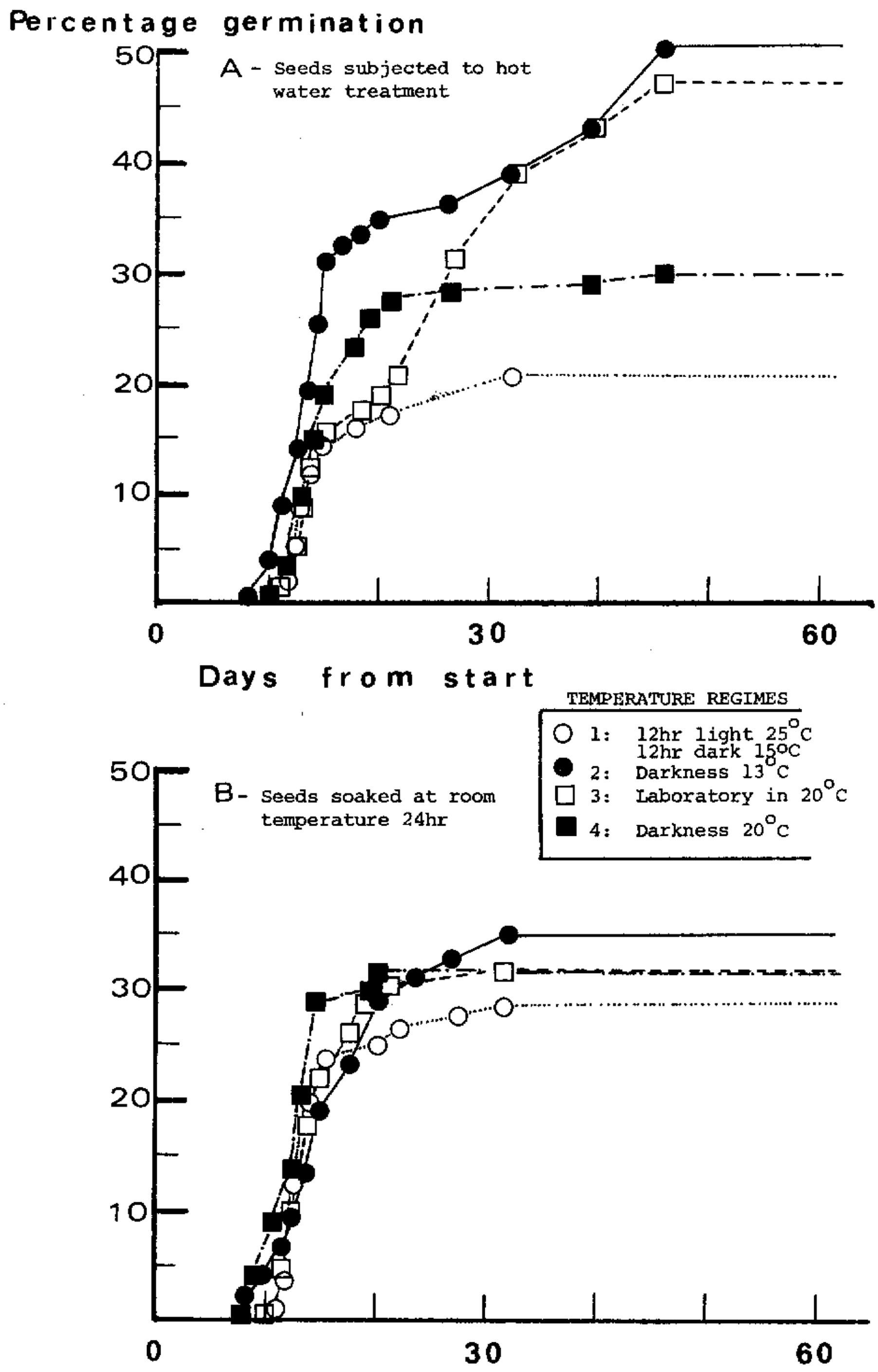

FIGURE 3 Cumulative germination percentages for <u>Acacia urophylla</u>

commencing. The two most successful regimes (2 and 3) differed in rates of germination with most rapid early germination shown at 13°C.

The mean viability at 34.6 per cent is low for Acacia seed, suggesting that selection of the best germination regime has eluded us so far.

e) **Seedling morphology**

Following emergence the cotyledons are shed early. The first leaves are pinnate true leaves with 2–5 pairs of leaflets. Flattened phyllodes develop later with phyllodinous bipinnate leaves persisting up to a year from germination (Figure 2).

Other Biotic Factors

a) **Animal feeders**

Some grazing of phyllodes of year-old seedlings was observed in the karri forest, with kangaroo and emu droppings nearby. In the northern jarrah forest invertebrate grazing has been noted - probably grasshoppers or moth larvae. Ants of the genera **Iridomyrmex**, **Camponotus** and **Diceratoclinea** (pers. comm. J.D. Majer) are common on the phyllodes at certain times of the year. They may be obtaining food from the glands which function as extra-floral nectaries. Ants may also consume the aril of the seed.

b) **Plant parasites**

None noted.

c) **Diseases**

A "witch's broom" disease has been observed in senescent stands in the karri forest, possibly caused by a virus. Whether this is a cause or a result of senescence is not clear.

History

The species was named and described by Bentham in 1841 (Bot. Reg. 1841 Misc. 24 and in Hooker, Lond. Journ. i 329).

Acknowledgements

The authors wish to thank P.E. Christensen, P.C. Kimber, J.D. Majer and N. Malajczuk for valuable assistance.

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OBSERVATIONS ON THE EARLY GROWTH OF TRACHYANDRA DIVARICATA

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Introduction

Trachyandra divaricata is an introduced lily of South African origin. It has become well established on coastal dunes of the south west of Western Australia. Its most commonly observed habitat is the first stable dune where it is often a dominant member of the community.

It is believed to have been established on Western Australian dunes from at least 1936 (P.G. Wilson, personal communication). Seeds of the species are thought to have been imported from South Africa in sand used as ballast in trading vessels[1]. Levyns refer to the species as **Anthericum divaricatum**. The genus has been renamed several times according to Obermeyer[2] but Willis[3] equates the two genera.

Trachyandra divaricata has been a most successful alien species. Some stands of large well grown plants may cover and choke out other vegetation. It is comparatively long lived and can form large tussocks. It occurs to the water-line in sheltered locations on Rottnest Island and also occurs on limestone at Woodman Point (G.G. Smith, personal communication).

We have observed it well inland at Yalgorup National Park where it is strongly associated with near surface limestone. It occurs well up stream on the banks of the Swan River and is particularly common on the Como foreshore. The species must have an efficient adaptation to salt tolerance and a strong root system to persist in the thin sands overlying limestone. Obermeyer[2] notes that **Trachyandra divaricata** has a large woody and irregular rhizome. It may draw upon reserves from this in times of water stress during unfavourable conditions.

The plant develops a mass of ribbon-like shiny dark green leaves giving it the tussock like appearance referred to above. After a years growth a central erect and rigid inflorescence is produced. This has branches perpendicular to the axis. Old inflorescence stalks become detatched from the tussocks and blow about. Abundant seed are produced and the plant regenerates freely from seed.

The present report includes a comment on germination characteristics and an analysis of growth of potted plants subjected to different dilutions of sea water.

Germination of Trachyandra divaricata

Seed collected at Woodman Point (32°9'S, 115° 44'E) in November 1981 was counted out into replicates of 50. Six replicates each were placed on moistened filter paper in petri dishes and incubated at four different temperatures in darkness. Germination was unsuccessful at the higher temperature used, 25°C. Under this regime only one germinant was recorded from 300 seed. This germination took place 19 days after the start of incubation.

Germination was rapid at 10 and 15°C with first germination recorded after 3 days incubation. The time course of cumalative germination is illustrated in Figure 1 and germination measurements are summarised in Table 1. Seed viability was 88 per cent, the mean germination attained at the best temperature regime, 10°C. Under this regime 50 per cent of viable seed had germinated by 8 days from the start and 75 per cent by 12 days. At 15°C these percentiles had germinated by 9 and 14 days respectively. At 20°C germination was much slower with first germinants recorded at 6 days and 50 per cent of viable seed germinating by 21 days : this treatment included one replicate where seed dried out. If this is ignored then mean final germination is improved from 49 per cent to 58 per cent, with 50 per cent of viable seed germinating by day 16.

The indication is that in nature germination will occur at low temperatures when seed are stimulated by winter rains.

Growth of seedlings is illustrated in Figure 2. Early growth is quite rapid with up to 10 cm first leaf height achieved within 5 weeks of germination. Each mature plant produces large numbers of seed. Mean seed size is of the order of 2 mm diameter (Figure 2).

Table 1 Germination characteristics of **Trachyandra divaricata**

Germination measurement	Temperture of incubation (°C) 10	15	20
a) Final germination percentage to maximum of 30 days	88	77	49
b) Time taken (days)	21	30	28
c) Germination rate (numbers x days/ total germinated)	9.3	9.0	14.4
d) Mean daily germination (a/b)	4.2	2.6	1.8

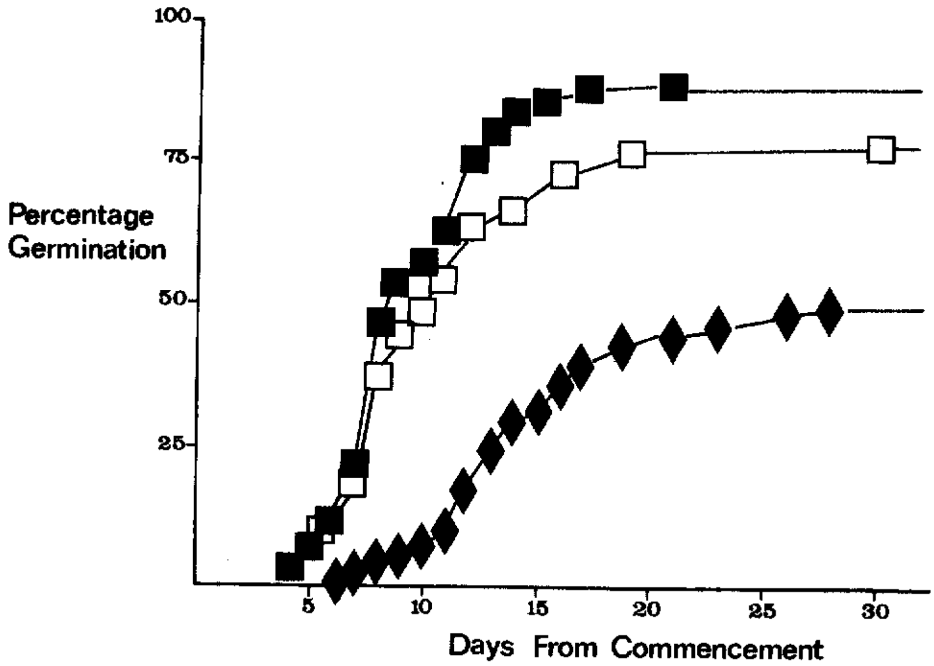

FIGURE 1 Germination of Trachyandra divaricata Mean values of 6 replicates of 50 seed each where closed squares incubated at 10°C; open squares incubated at 15°C and closed diamonds incubated at 20°C.

Plant Growth in Relation to Salinity and Fertility

Methods Used

Trachyandra divaricata seedlings germinated from March 1982 in the trial referred to above were raised in jiffy pots. In August a set of plants were potted on into 12.5 cm d black plastic pots with a mixture of three parts fine sand to one part peat moss. The plants were acclimatised for a week in the glasshouse prior to treatment.

Fresh seawater collected from Port Beach was diluted with deionised water. Five salinity levels were used : 0 (deionised water control), 5 per cent sea water (mM NaCl 29); 15 per cent sea water (88); 30 per cent seawater (175); and 60 per cent sea water (mM NaCl 350). Three fertility levels were superimposed on the salinity tretments giving a split plot design. These were 0, 10 kg ha-1 and 50 kg ha-1 of 90 day 'Osmacote°. This fertilizer has the following percentage composition NH4 N 8.2, NO3 N 5.8 (total N 14 per cent); water soluble P 4.8, citrate soluble P 1.3 (total P 6.1); potassium 11.6 and sulphur 4.5 per cent. Seven plants were grown in each fertility level giving twenty-one per salinity level and 105 plants overall.

Following initial treatment pots were brought to field capacity twice weekly by watering with 50-100 ml of the appropriate solution. The amount applied depended on the relative dryness of the soils. Two harvests of three plants from each treatment combination were taken at 38 and 66 days from initial treatment.

Results

Harvest values are summarised in Table 2. The mean values of 10 plants harvested at the start of the experiment were as follows:

Fresh weight	0.068 g
Dry weight	0.008 g
Fresh/Dry wt ratio	8.86

The control and lowest level of sea water treatments showed greatest increases in weight over the experimental period. The fresh/dry weight ratio declined rapidly at 30 and 60 per cent of sea water, whereas the 15 per cent treatment was able to maintain a relatively high fresh weight.

Analysis of variance for the first harvest showed no significant difference due to salinity or fertility level for fresh weights. At the second harvest there were significant differences due to both salinity and fertility levels (Table 3). The higher fertility level had significantly greater growth than the other two levels. Control and 5 per cent sea water had significantly greater fresh weights than the other three salinity levels. The interaction of fertility and sea water was also significant. This was shown in a relatively large increase in growth in the plants with 50 kg ha-1 'Osmacote' in control and 5 per cent sea water.

Table 2 Harvest Values **Trachyandra divaricata** mean values per plant for each treatment.

Salinity level (% sea water)	0			5			15			30			60		
Fertility level (kg ha-1 osmacote)	0	10	50	0	10	50	0	10	50	0	10	50	0	10	50
HARVEST ONE (38 days)															
Fresh wt (g)	0.101	0.152	0.139	0.077	0.070	0.087	0.183	0.055	0.088	0.100	0.070	0.079	0.075	0.029	0.060
Dry wt (g)	0.016	0.023	0.022	0.016	0.013	0.014	0.032	0.012	0.016	0.022	0.018	0.015	0.027	0.008	0.027
Top/Root ratio	0.34	1.12	0.69	0.48	1.08	0.82	0.43	0.74	0.43	0.34	0.61	0.16	0.27	1.04	0.41
Fresh/Dry wt ratio	6.3	6.7	6.4	4.8	5.5	6.3	5.7	4.8	5.5	4.6	3.9	5.3	2.7	3.6	2.2
HARVEST TWO (66 days)															
Fresh wt (g)	0.102	0.339	1.122	0.257	0.237	0.427	0.046	0.128	0.082	0.018	0.060	0.020	0.023	0.038	0.036
Dry wt (g)	0.020	0.041	0.089	0.034	0.031	0.053	0.009	0.025	0.018	0.007	0.019	0.010	0.012	0.017	0.012
Top/Root ratio	0.25	0.37	0.71	0.48	0.38	0.42	0.85	0.29	0.47	0.46	0.57	0.59	0.48	0.40	0.47
Fresh/Dry wt ratio	5.1	8.3	12.6	7.6	7.6	8.1	5.3	5.2	4.7	2.7	3.2	1.9	1.9	2.3	2.9

Table 3 Analysis of Variance of Fresh Weights At Harvest 2

Source	DF	Sums Squares	Mean Square	F	Significance
Fertilizer	2	0.49	0.25	12.38	***
Salinity	4	1.65	0.41	20.56	***
Interaction	8	1.30	0.16	8.08	***
Error	30	0.60	0.02		
Total	44	4.04			

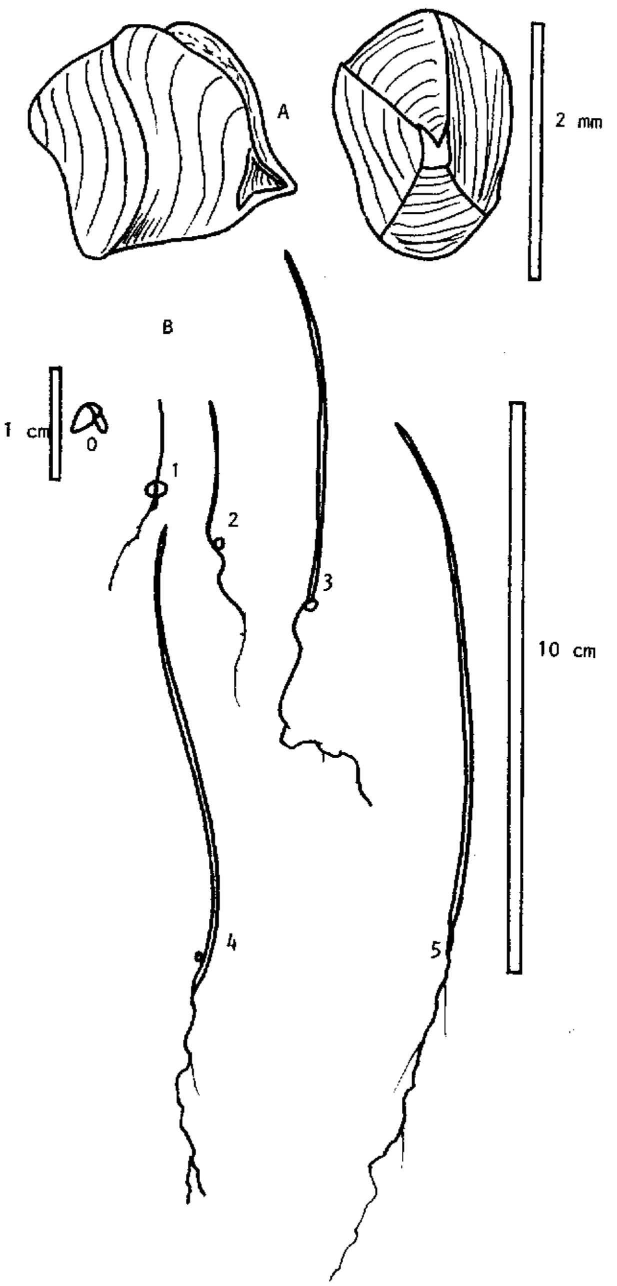

FIGURE 2 Germination and early growth of **Trachyandra divaricata** A-seed; 0-germinated seed; 1-5, seedling at one, two, three, four and five weeks from germination.

Discussion

Transplant shock was probably partly responsible for the decline in fresh/dry weight ratio through all treatments to the first harvest. However the plants subjected to the higher levels of sea water showed little or no increase in weight.

Observed salinity tolerance may have been affected by the possibility that the plants were stressed when the experiment was begun. A salinity of 15 per cent sea water (90 mM NaCl) inhibited growth of **T. divaricata** seedlings with no fertilizer and with 50 kg ha-1 'Osmacote'. Five per cent sea water seemed to have little effect but those with no fertilizer added grew better than plants with deionized water. In the 15 per cent set addition of 50 kg ha-1 fertilizer decreased both fresh weight and the fresh weight/dry weight (FW/DW) ratio. This may have been due to an additional salinity effect as total salts in fertilized pots would be higher. The addition of 10 kg ha-1 fertilizer increased fresh weight and FW/DW ratio. Additions of fertilizer to the 30 per cent and 60 per cent sea water sets had no effect probably because plants were highly stressed by the salts from the sea water. The salinity tolerance of **Trachyandra divaricata** is probably above 15 per cent sea water (90 mM NaCl) but because of the presumed extra stress of transplant shock in this experiment it appeared to be lower, at between 5 and 15 per cent, possibly around 10 per cent.

Addition of 'Osmacote' to control plants dramatically increased their growth. Addition of 50 kg ha-1 equivalent 'Osmacote' gave a greater growth increase than addition of 10 kg ha-1.

In the 5 per cent sea water level the addition of 10 kg ha-1 equivalent fertilizer slightly increased growth. Whereas the 50 kg ha-1 treatment greatly increased growth .

Addition of 10 kg ha-1 'Osmacote' increased growth in the 15 per cent sea water group but the higher level of fertilizer had no effect. Fertilizer added to the 30 and 60 per cent sea water sets had a minor positive effect on growth.

Consideration of the 15 per cent sea water set suggests that addition of the higher level of fertilizer has the opposite effect from that exhibited in the control set. That is fertilizer decreases fresh weight and FW/DW ratios below those for a lower level of applied fertilizer. This result may be due to an increase in total salinity levels within the pot above tolerance levels, not offset by the beneficial effects of fertilizer addition. Addition of fertilizer can thus have a beneficial effect if water is freely available (Sets 1 and 2), or a deleterious effect if the plants are already stressed (Sets 3,4 and 5).

Summary

Trachyandra divaricata germinates freely with moisture available at 10-15°C, coincident with winter rains leaching out surface salt accumulations from dune soil. The salinity tolerance of Trachyandra divaricata is suggested as being about 10 per cent of that of sea water. The species shows a dramatic growth response to fertilizer in the absence of sea water.

Acknowledgements

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ACACIA ANEURA AT LEINSTER DOWNS: PERIMETER VEGETATION AND THE ROLE OF GRAZING

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Introduction

The property known as Leinster Downs Station is leased by Agnew Mining Co. Pty. Ltd. This company is a joint venture formed to manage the Agnew Nickel Project. The joint venturers are Western Selcast Pty. Ltd. (60 per cent) and Mount Isa Mines Ltd (40 per cent). The Agnew Nickel deposit was discovered in 1971 and the joint venture was formed in August 1974.

The new town of Leinster is located 660 km north east of Perth and 330 km north of Kalgoorlie (Figure 1). Important regional settlements include Leonora which is located 130 km to the south, Wiluna 130 km to the north, Sandstone 130 km to the west, and Laverton 190 km to the

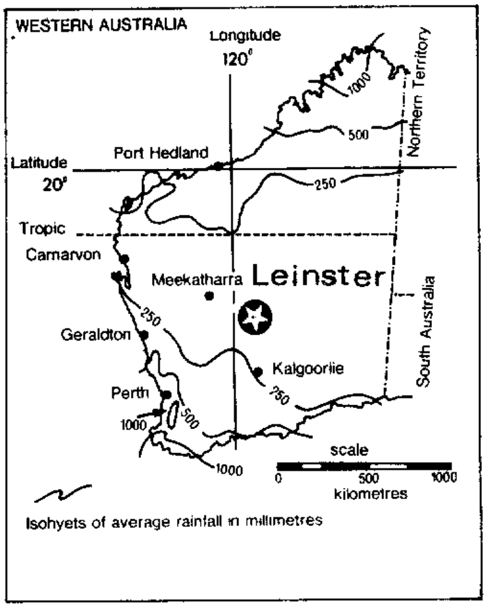

FIGURE 1 Western Australia showing location of the new town of Leinster.

Table 1. Mean rainfall by seasons over the period of observations (a) and for Pinnacles (28°12'S; 120°26'E) by seasonal years 1975–1982 (b).

Period	Season: Summer	Autumn	Winter	Spring	[1]Seasonal Year
(a) All data					
1896–1977 (81 years)	104.6	20.6	77.3	12.7	215.2
1896–1981 (85 years)	93.4	19.2	75.7	11.2	199.5
1896–1925 (30 years)	89.6	24.3	81.9	12.0	207.8
1926–1973 (48 years)	106.5	17.9	74.0	10.2	208.6
(b) Pinnacles					
1975	493	54	81	84	712
1976	45	7	8	50	110
1977	3	1	102	13	119
1978	168	0	88	38	294
1979	74	22	49	12	157
1980	84	21	288	6	399
1981	66	0*	76	2*	144*
1982	81	4	95	76*	

Notes: Rainfall for Lawlers 1896–1925, and Pinnacles 1926–1982

* interpolation from records taken at Leinster when no records available for Pinnacles

1 seasonal year as follows: Summer November 1st–March 31st; Autumn April; Winter May 1st–August 31st; Spring September 1st–October 31st.

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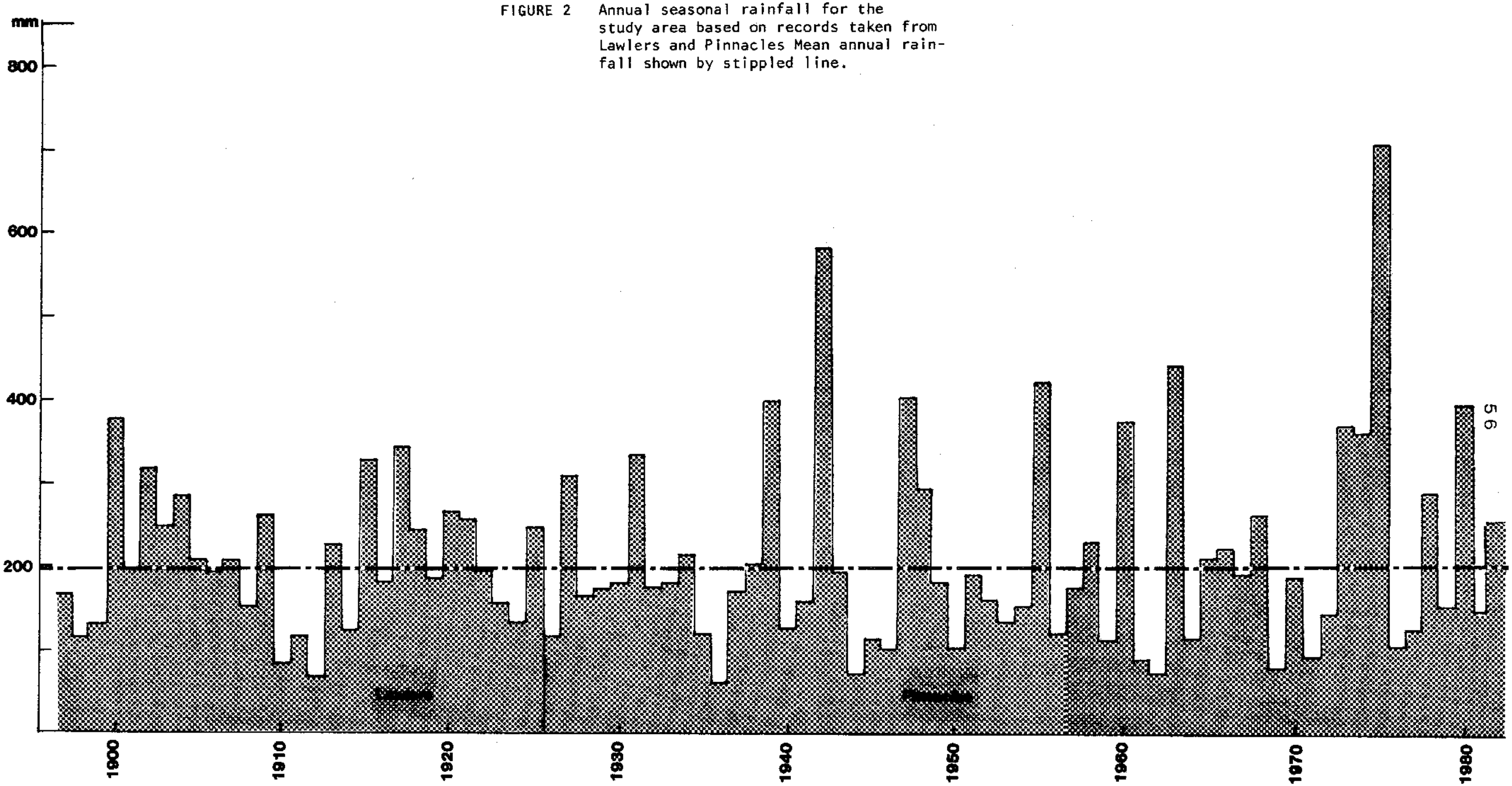


FIGURE 2 Annual seasonal rainfall for the study area based on records taken from Lawlers and Pinnacles Mean annual rainfall shown by stippled line.

south-east. The minesite is at 27°50'S latitude, 120°30'E longitude. The Leinster Downs Homestead is 10 km west of the mine, the old townsite of Agnew is 28 km to the southwest, and that of Lawlers is 10 km south of Agnew. The homestead 'Pinnacles' is a further 14 km south-west of Lawlers.

Under the terms of the lease purchase the previous lessees retained grazing rights to the end of 1977. Agnew Mining Co. then obtained exemption from stocking for five years to enable the pasture to re-establish . Leinster Downs is a 146,000 ha property. It was taken up about 1914 and ran about 6,000 sheep continuously until 1977.

A study was commenced in January 1978 to examine the status of the vegetation inside the station in contrast with that of the immediately adjoining, stocked, country. A set of 31 plots was established. Of these 16 were inside Leinster Downs and 15 in the adjoining properties of Wildara (Plot 22), Weebo (Plots 5, 6, 12, 13, 15 and 16) Yandal (Plots 9 and 10), Yakabindie (Plots 25, 28, 35 and 36) and Depot Springs (Plots 30 and 32). These have been reassessed several times. Several reports on other aspects relating to the ecological status of *Acacia aneura* have been prepared in recent years[7,8].

Climate

The climate of the region is arid with a mean annual precipitation of approximately 200 mm[2]. The weather pattern is variable and influenced by both northern, summer, tropical cyclonic disturbances and predominantly winter westerly systems. The former give heavy, short-duration downpours of rain whereas the latter bring steady drizzle, often persisting for several days. Both the seasonal distribution[6](Table 1) and total rainfall (Figure 2) are extremely unreliable. However the bulk of rain on average falls in the first six months of the year (Figure 3). September/October is the driest period on average though dry periods have occurred throughout the year. Droughts of some years duration have been common. The erratic nature of rainfall is emphasised by that shown since 1969. A run of four years of below average rainfall was followed by three exceptionally heavy years 1973–1975 (Figure 2). Since then rainfall has been generally low. Using records for Lawlers (1896–1925) and Pinnacles (1926–1981) we note that mean annual rainfall 1896–1977 was 215 mm, but that for 1896–1981 was 200 mm.

The annual potential evaporation is calculated at 2400 mm at Wiluna[3]. This may be a considerable underestimate.

FIGURE 3 Mean monthly rainfall at Lawlers and Pinnacles.

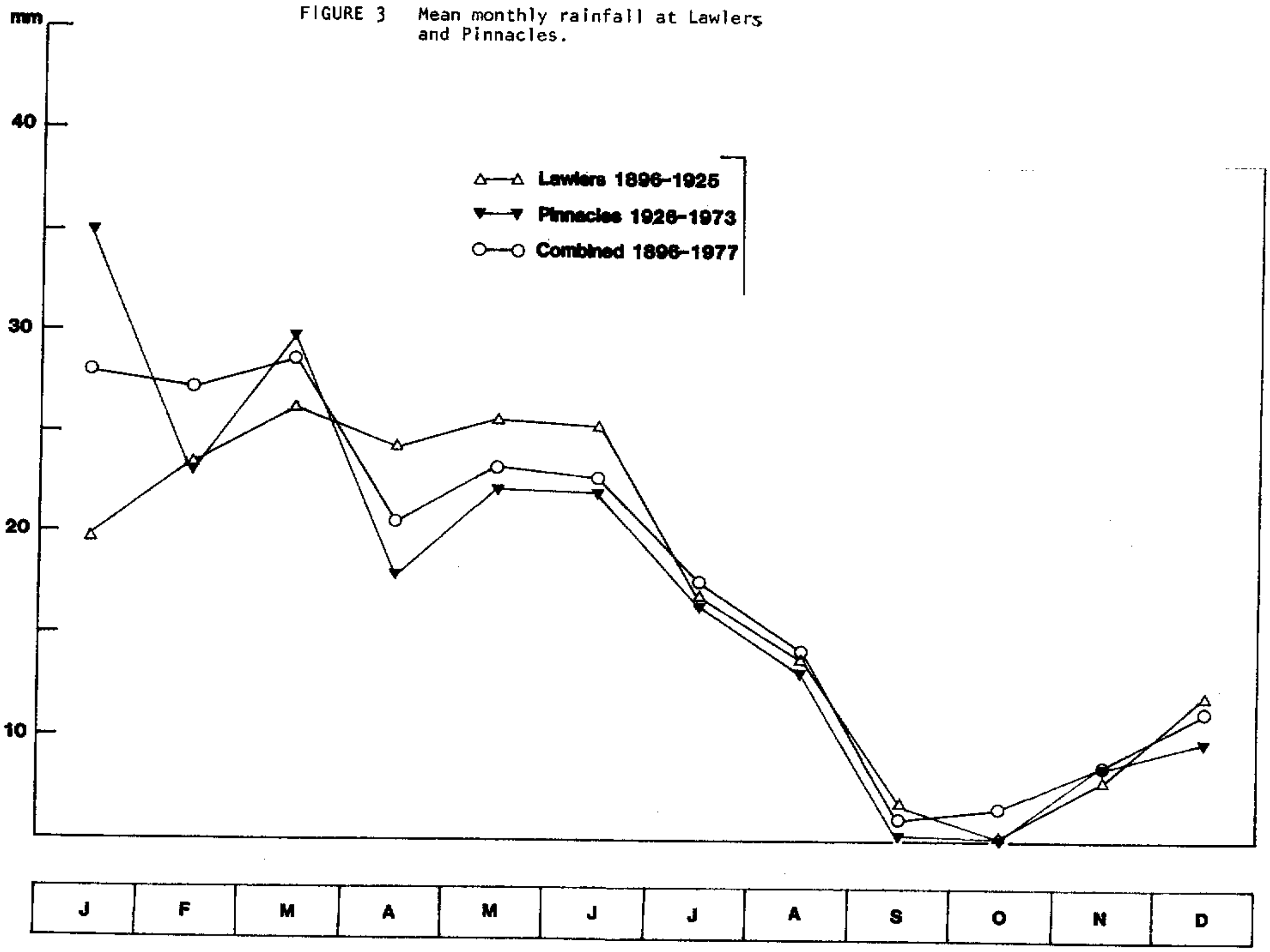
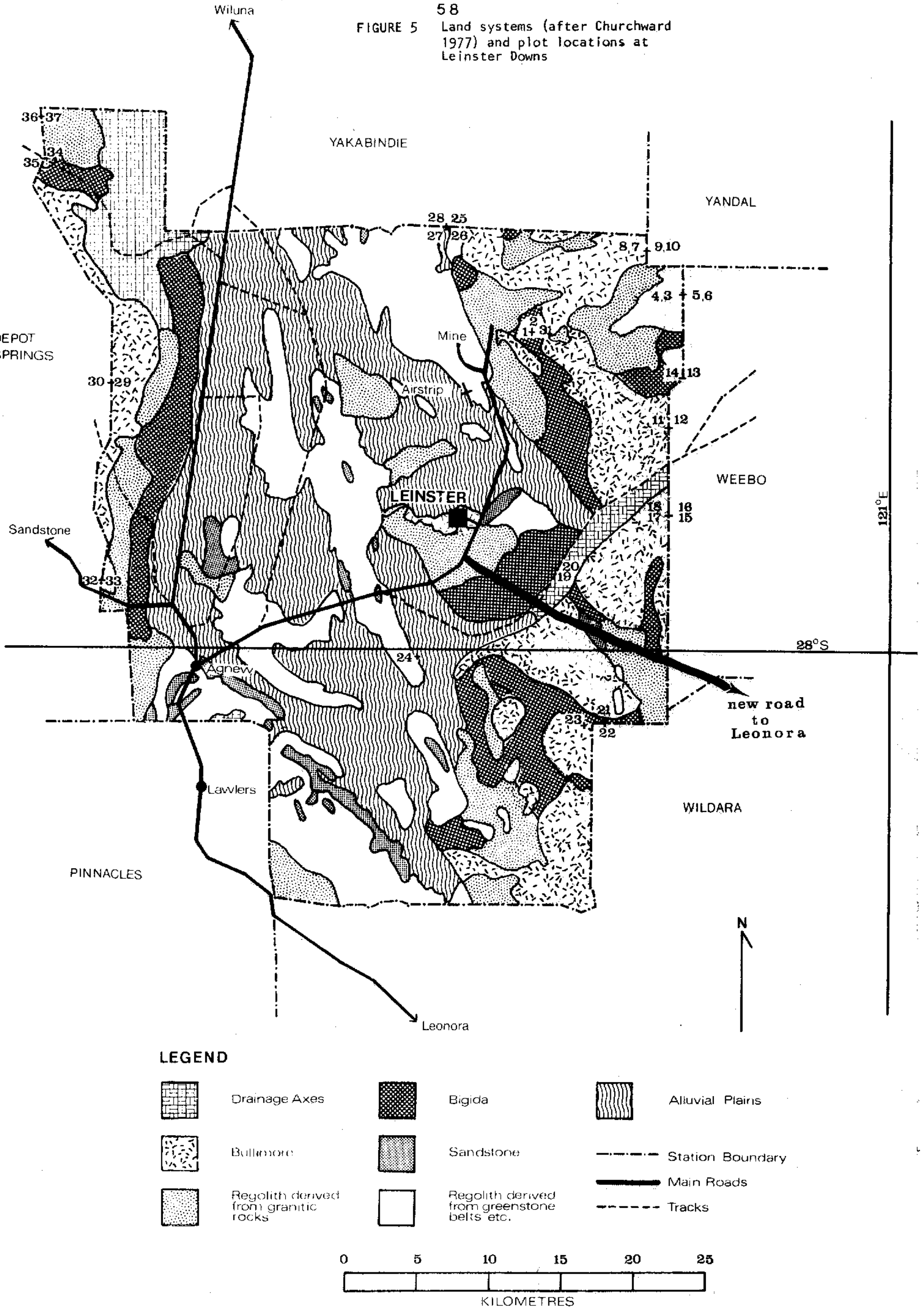


FIGURE 5 Land systems (after Churchward 1977) and plot locations at Leinster Downs



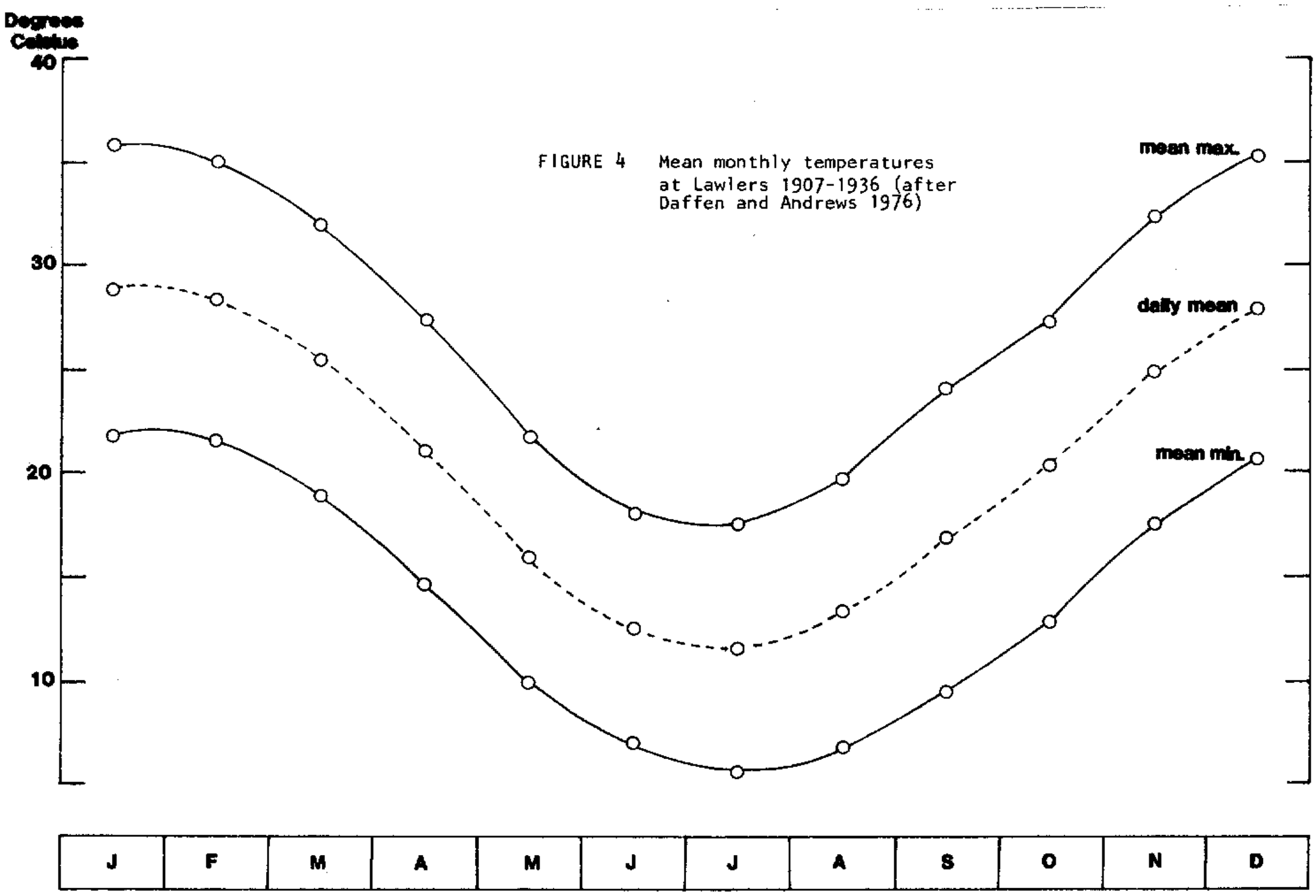


FIGURE 4 Mean monthly temperatures at Lawlers 1907-1936 (after Daffen and Andrews 1976)

Relative humidity at Wiluna, 130 km north of Leinster, is 50 percent from May to October. This drops to 35 percent between November and April. The strong prevailing winds in summer and early autumn are mainly from the east with a windspeed greater than 5 m sec^{-1}. For the remainder of the year lighter winds of variable orientation prevail[5].

Temperatures are lowest in July and highest in January (Figure 4). The diurnal range is slightly greater in summer than winter.

Geology and Soils

The study area lies within the Yilgarn Block, an Archean shield dominated by granitic rocks with narrow north-westerly trending greenstone belts. The thickness of the regolith varies from a few metres on parts of the pediments to as much as 50 m on the alluvial plains [4,5].

Soils are weakly aggregated earths with red hues dominant (2.5 YR to 5 YR)[1]. The soils are usually acid to neutral with a pH range of 5.5 to 6.5. The sample plots fell on two main landform units (Figure 5) which have been described by Churchward[4]. Both types are derived from granitic rocks and are classified as regolith of depositional landforms as follows:

1. Bullimore This mapping unit is the main sand plain of the area which typically extends down the gentle back slopes of breakaways to the trunk valleys. Hard pan occurs within 2 m of the surface on the lower slopes, but is uncommon beneath the sandy materials of the upper slopes. The soils are generally deep, red-brown earthy sands grading into deep, red-brown sandy earths downslope. Termitaria are common comprising a sandy clay loam material. Bullimore is mainly found to the eastern side of the station.

2. Bigida This landform unit (L.F.U.) comprises alluvial lobes and plains which are crossed by broad drainage floors. Soils vary from gritty red sandy loams upslope to gritty red clay loams and sandy light clays further down the system. In general there is little increase in clay with depth. The shallow hardpan (50 - 100 cm depth) is continuous for the whole unit and ranges from 10 to 20 m thick. The most extensive development is west of the old Agnew/Wiluna road and north east, east and south east of Leinster.

Other land forms summarised on Figure 5 are: 'Drainage axes' Miranda L.F.U. consisting of saline clays associated with the salt lake, Lake Miranda in the north west; Gardine L.F.U. deep sandy red earths in the east.

'Regolith derived from granitic rocks' Marloo, Nuendah and Falconer L.F.U.'s shallow clayey or earthy red sands associated with breakaways and Leinster L.F.U. of granite and silcrete outcrops with red clayey sands and red earths.

'Sandstone' L.F.U. gravelly red clay sands and red clayey sands as long gentle slopes.

'Regolith derived from greenstone belts etc'. Keith L.F.U. shallow medium to fine textured red earths of breakaways and Montague L.F.U. of low stoney hills with shallow medium and fine textured red earths.

'Alluvial Plains' occupy much of the central part of the station and consist of lower (Youno L.F.U.) and upper (Juliet L.F.U.) tributary alluvial plains with shallow, medium or fine textured red earths.

Vegetation

The area falls in the Eremaean Botanical Province [9]. The Environmental Assessment undertaken in 1973 recognized three general vegetation associations related to land forms[5] viz:

* Spinifex - marble gum on sand plains
* mulga - wattle scrub on red earth plains
* cypress - hop bush of breakaways.

Vegetation communities of the general region have been described in more detail by Speck [13]. A complete list of species recorded at Leinster Downs by Mulga Research Centre is given in Appendix 1. At this stage we note that spinifex grasslands (**Triodia basedowii** plus **Plectrachne melvillei**) are typical of lands of the Bullimore mapping unit with occasional mallee (**Eucalyptus kingsmillii**) and mulga (**Acacia aneura**). Churchward [4] notes that mulga woodlands are probably the most extensive community of the general area. These are particularly well developed on the alluvial tracts associated with erosional landforms. There is a tendency for mulga to grow as slightly arcuate bands aligned approximately along the contour. Groves are neither as well expressed or as frequent a feature as in the mulga communities further north-west described by Speck. The mulga woodlands tend to have a well-developed shrub layer with species of **Eremophila**, **Cassia** and **Dodonaea** while associated grass species include **Danthonia** and **Eragrostis** species. Daisies and forbs (especially **Ptilotus** species) are abundant after heavy winter rain. These woodlands are generally associated with Churchward's Bigida mapping unit.

Other communities of the area include halophytic shrub communities of saline drainage areas, particularly species of **Maireana**, communities with **Melaleuca uncinata**. Also present are communities dominated by the river red gum **Eucalyptus camaldulensis** which line the major drainage channels .

Overgrazing was considered to have led to a general degradation of the flora at the time of purchase by the joint venture company[5].

Field Measurements

Permanent rectangular sample plots 20 x 25 m were established using the following criteria:

* presence of **Acacia aneura** or other **Acacia** species

* location approximately equidistant between watering points to eliminate piosphere effects[12]

* access guaranteed in most weather conditions

* subjective visual estimate that the site was reasonably representative of the surrounding landscape.

Plots 3-18, 29 and 30 were assessed in January 1978, July 1978, July 1979, July 1980 and July 1982; Plots 19, 20, 25-28, 32-37 at the same dates except July 1978; Plots 21-23 in January 1978, July 1979, July 1982; and Plot 24 in January 1978 and July 1982. All trees and shrubs mainly including **Acacia aneura**, **A. linophylla** other **Acacia** species and **Eucalyptus** spp. were plotted, tagged and measured for height, crown width and, if of tree habit, for stem diameter at 1.3 m up the bole.

In addition soil depth was measured through the centre of the plots at 5 locations 5 m apart at plots 3-18, 29-30, 34-37; and at 3 locations 5 m apart at plots 19-33. At each plot soil texture was assessed and soil colour was recorded using the Munsell Soil Colour Chart [1].

Individual Plot Details

Plots are considered in sets viz those on Bullimore, Bigida, Bullimore/Bigida, and Sandstone landform units respectively. When dead trees are mentioned these are **Acacia aneura** unless otherwise named and the cause of death is unknown (old age, drought) unless fire is mentioned. A fire is documented for Plots 13 and 14 as having occurred in 1953, other mentions of fire are possibilities only.

GROUP A - BULLIMORE

Plot 3 - Not Grazed

This plot is located at 2 km south of Nanadie Mill and 50 m from the fence.

Soil is orange-brown (2.5 YR 5/8), sandy, with an average depth of 77 (65 - 80+) cm. There is some evidence of an old fire previous to 1978.

There are 6 **Acacia aneura** ranging in height from less than 1 metre to higher than 5 metres, 3 young **A. linophylla**, and 2 dead trees. Clumps of **Triodia basedowii** occur in the north-west corner of the plot. In July 1980 the annuals **Calotis hispidula**, **Erodium crinitum** and **Eragrostis eriopoda** were present. In July 1982 there was some grazing of the mulga, possibly by goats.

Plot 4 - Not Grazed

Located 50 metres west of Plot 3.

Soil is red-brown (2.5YR 5/6), sandy with an average depth of 51 (34 - 78) cm. There is evidence of fire damage previous to 1978.

This plot had one **Acacia aneura** (8.5m) the crown of which was dead in 1982. 1 young **A. linophylla**, with four dead trees. Other species include 1 **Rhagodia eremaea**, 1 **Solanum lasiophyllum**, and in July 1982 a lot of **Calotis hispidula**. **Triodia basedowii** occurs nearby, but not in the plot.

Plot 5 - Grazed

Situated 1 km north of fence towards Nanadie Mill, 50 m east of the fence.

Soil is an orange-brown (2.5 YR 5/8) sandy loam with an average depth of 62 (37 - 80)cm. There is evidence of on old fire previous to 1978.

There are 3 **Acacia aneura** ranging in height from 2.0 to 5.2 metres, initially 2 young **A. linophylla** one of which died between 1980 and 1982, and 1 dead tree. Other species include 1 **Eremophila leucophylla**, 1 **Scaevola spinescens**, 1 **Rhagodia eremaea**, 1 **Solanum lasiophyllum**, and a couple of small **Triodia basedowii** clumps. In July 1980 the annuals **Helichrysum davenportii**, **Calotis hispidula**, and a **Ptilotus** sp. were present.

Plot 6 - Grazed

Located 50 m east of Plot 5.

Soil is an orange-brown (2.5 YR 4/8) sandy loam with an average depth of 71(61 - 80+)cm. There is evidence of an old fire previous to 1978.

There are 8 **Acacia aneura** only one of which is less than 3.0 m high, 2 **A. craspedocarpa** approximately 2 m tall, and 6 dead trees. Other species include 4 **Eremophila leucophylla**, 1 **Rhagodia eremaea**, and 1 **Solanum lasiophyllum**. In July 1980 the daisies **Helipterum splendidum** and **Helichrysum davenportii** were present, and in July 1982 the annuals **Velleia rosea**, **Ptilotus** sp. and a lot of **Eragrostis eriopoda**.

Plot 7 - Not Grazed

Situated 2.5 km from Nanadie Mill near the boundary with Yandal Station, 50 m west of the fence.

Soils vary from a deep orange-brown (2.5 YR 5/8) silty loam with surface quartz to an orange-brown (2.5 YR 4/8) sand with an average depth of 77 (62 - 80+)cm.

There are 16 **Acacia aneura** the majority being 2-4 m high 2 young **A. linophylla**, and 4 dead trees. Other species include 6 **Eremophila leucophylla**, 1 **E. foliosissima**, and a number of **Triodia basedowii** clumps in the north-east of the plot. In July 1980 the daisies **Helichrysum davenportii** and **Helipterum humboldtianum**, were common and in July 1982 the grass **Eragrostis eriopoda** was present.

Plot 8 - Not Grazed

Located 50 m west of Plot 7.

Soil is a deep (80+ cm) red-brown (2.5 YR 5/6) sand.

There are 15 **Acacia aneura** mostly 3-4 m high and the only seedling is dying, 1 **A. linophylla**, and 1 dead tree. **Eremophila** species are common with 11 **E. leucophylla** and 4 **E. foliosissima**. A small patch of **Triodia basedowii** occurs in the north-west corner of the plot.

Plot 9 - Grazed

Situated 2.5 km from Nanadie Mill near the boundary with Yandal Station, 50 m east of the fence.

Soils are generally deep with an average of 76 (61 - 80+)cm and vary from an orange-brown (2.5 YR 5/8) cracking clay loam to a brown (2.5 YR 4/4) sand. The area appears to have been burnt some time before 1978.

There are 11 young **Acacia aneura** all less than 1.2 m high, with one 4.4 m tall, 1 **A. linophylla** (1.1 m) and 10 dead trees. Other species include 9 **Eremophila leucophylla**, 4 **E. foliosissima**, and numerous scattered clumps of **Triodia basedowii**. In July 1980 **Helipterum humboldtianum** and in July 1982 **Eragrosis eriopoda** were common.

Plot 10 - Grazed

Located 50 m east of Plot 9.

Soils vary from an orange-brown (2.5 YR 5/8) silty loam to a red-brown (2.5 YR 5/6) sandy loam, with an average depth of 70 (56 - 80)cm.
There are 17 **Acacia aneura** all less than 1.5 m tall, except for 2 mature trees higher than 4 m; 1 **A. linophylla** (1.8 m), and 14 dead trees. Other perrennials include 15 **Eremophila leucophylla** and 10 **E. foliosissima** and a few scattered **Triodia basedowii** clumps. In July 1980 **Erodium crinitum** was present, and in July 1982 **Eragrostis eriopoda** was common.

Plot 11 - Not Grazed

Situated 3 km north of Alans Bore, along the boundary with Weebo Station, and 50 m west of the fence.

Soil is a red-brown (2.5 YR 5/6) coarse grained, sandy loam which is mostly deep, averaging 71 (35 - 80+)cm. The shallow core is possibly due to termite activity. There is evidence of a fire some time before 1978.

Acacia aneura is absent from this plot. Triodia basedowii covers the plot with 1 Acacia aff. coolgardiensis (2.2 m) and 1 Acacia sp. nov. (1.4 m) being present.

Plot 12 - Grazed

Located near Plot 11, but 50 m east of the fence.

Soil is a deep (80+cm) red-brown (2.5 YR 4/6) sandy loam with coarse grains on the surface.

Acacia aneura is absent from this plot, but it is covered by Triodia basedowii. There is 1 Acacia longispinea, 3 young Acacia sp. nov., 3 old Eucalyptus kingsmillii, and 1 dead tree. The low bush Melaleuca leiocarpa grows in this general area.

Plot 13 - Grazed

Situated 1 km south of Kennys Mill, at a bend in the boundary fence with Weebo Station, and 50 m east of the fence.
Soils vary from a deep (80+cm) brown (5 YR 5/8) clay loam to a red-brown (2.5 YR 5/8) silty clay loam with an average depth of 65 (56 - 72)cm. There is one termite mound. Area burnt in 1953.

There are 23 Acacia aneura ten of which are less than 1.0 m tall and only 1 greater than 4.0 m tall; 5 A. linophylla (1.5 - 2.1 m tall), and 20 dead trees. Eremophila is abundant with 29 E gilesii and 1 E. latrobei. Other species include 1 Canthium lineare, 1 Rhagodia eremaea, 5 Dodonaea sp. a couple of Triodia basedowii clumps, and some Leichardtia australis. In July 1980 there was a lot of Erodium crinitum and Eragrostis eriopoda, but no daisies.

Plot 14 - Not Grazed

Located near Plot 13, but 50 m west of the fence.

Soils are generally deep with an average of 71 (63 - 80+)cm, varying from a red-brown (2.8 YR 4/8) silty clay loam to a brown (5 YR 5/8) clay loam with small quartz particles on the surface. Area burnt in 1953.

There are 4 Acacia aneura less than 1 metre tall and 4 A. aneura over 4 m tall, 6 A. linophylla less than 2 m tall, and 8 dead trees. Other species include 26 Eremophila foliosissima and 1 E. gilesii. In July 1980 Erodium crinitum and Eragrostis eriopoda were common with a few Helipterum splendidum.

Plot 15 - Grazed

Situated 3 km south along the eastern boundary from the point where the Alans Mill fence meets the fire break, and 50 m east of the fence.

Soil is a deep (80+ cm) red-brown (2.5 YR 5/6) sand.

There are 10 young Acacia aneura (1 m high) with an average of 1 recruit per year, 2 A. aneura 1 - 1.5 m high and 3 A. aneura taller than 5.5 m. Other species include 7 A. aff. coolgardiensis, 1 Eremophila leucophylla and an abundance of Triodia basedowii.

A dead Eucalyptus gongylocarpa occurs just outside the plot. In July 1979 only 1 A. aneura seedling was seen growing out of 5 observed in February. In July 1980 the daisy Helichrysum davenportii was present.

Plot 16 - Grazed

Located on the north side and adjacent to Plot 15.

Soil is a deep (80+cm) red-brown (2.5 YR 4/6) sand.

There are 19 Acacia aneura less than 2 m high and 5 A. aneura 3-6 m tall, 4 young A. aff. coolgardiensis, 2 dead trees and 2 stumps. A Eucalyptus gongylocarpa (4.5 m) grows in the north-east corner of the plot. Numerous clumps of Triodia basedowii are scattered over the plot.

Plot 17 - Not Grazed

Located near Plot 15, but 50 m west of the boundary fence.

Soil is a deep (80+cm) red-brown (2.5 YR 5/6) sand.

There are 8 Acacia aneura ranging in height from 0.8 m to 6.5 m. In July 1980 there were 7 young A. aff. coolgardiensis, but two had died by July 1982. A big dead Eucalyptus gongylocarpa occurs near the plot centre. Numerous Triodia basedowi clumps are scattered over the plot. In July 1980, a few daisies were growing here.

Plot 18 - Not Grazed

Located on the north side and adjacent to Plot 17.

Soil is a deep (80+cm) orange-brown (2.5 YR 5/8) sand.
There are 4 A. aneura less than 1 m high and 5 A. aneura taller than 5 m, 1 A. linophylla, and 2 dead trees. Numerous Triodia basedowii clumps are scattered over the plot. In July 1982 a few Helipterum humboldtianum daisies were present.

Plot 25 - Grazed

Situated 1.8 km west of the calcrete road and 50 m north-east of the point PX, on the northern side of the boundary fence with Yakabindie Station.

Soil is dark brown in colour (5 YR 4/8) with an average depth of 65 (47 - 73)cm.

There are 10 Acacia aneura less than 2.1 m tall and 4 A. aneura greater than 3.6 m high, 1 A. linophylla seedling, and 22 dead trees. Other species include 8 Eremophila serrulata, 2 E. fraseri, 1 E. latrobei, 2 Solanum sp., 1 Rhagodia eremaea, 4 Leichardtia australis, 2 Ptilotus sp. There is a lot of Hakea suberea in this general area. In July 1980 there were a few daisies, and in July 1982 a lot of daisies around the trees and in the south-west of the plot.

Plot 26 - Not Grazed

Located near Plot 25 and 50 m south-east of point PX on the south side of the fence.

Soil is dark brown in colour (5 YR 4/8) with an average depth of 69 (68 - 71)cm. In this plot some big heaps of washed litter have been observed after heavy rain. A drainage creek system lies just to the south. Three termite mounds occur in the plot.

There are 11 Acacia aneura ranging in height from 0.3 m to 5.5 m, and about 20 dead trees. Other species include 4 Eremophila serrulata, 1 E. fraseri, 1 E. leucophylla, 1 Leichardtia australis, some Solanum sp. and Ptilotus sp. In July 1982 there were a lot of daisies, Erodium crinitum, and Velleia hispida. Similar to Plot 25 Hakea suberea is common in the area. Also present are Indigofera georgei, and in the general vicinity of Plots 25-28 Wurmbea deserticola, Helipterum splendidum, and Brachycome ciliocarpa have been recorded.

Plot 27 - Not Grazed

Located near Plots 25 and 26, 50 m south-east of point PX.

Soil is a deep sandy loam (80+cm) and is dark brown (5 YR 4/8) in colour. There are 3 termite mounds within the plot area.

There are 3 Acacia aneura seedlings and 7 A. aneura higher than 5 metres, 1 A. linophylla seedling, and 8 dead trees. Other species include 4 Eremophila foliosissima and 4 Dodonaea sp. In July 1982 there was some Erodium crinitum, however the plot was fairly barren and the gate was open into Plot 28 suggesting that some grazing may have occurred.

Table 2.

Acacia aneura distribution by height classes in plots on Bullimore L.F.U. at 1978 and 1982 grazed and ungrazed

Plot No.		1978						1982					
		Height classes (m)											
Grazed		1	1<2	2<3	3<4	4<5	5+	1	1<2	2<3	3<4	4<5	5+
5		0	0	1	0	2	0	0	0	1	0	1	1
6		0	1	1	1	2	3	0	1	0	2	2	3
9		10	0	0	0	1	0	10	1	0	0	1	0
10		16	1	0	0	1	1	16	1	0	0	1	1
12		0	0	0	0	0	0	0	0	0	0	0	0
13		9	3	4	6	0	1	10	4	3	5	1	0
15		6	1	1	0	0	3	10	1	1	0	0	3
16		8	12	1	0	3	1	7	12	1	0	2	2
25		2	7	1	2	0	2	1	8	1	2	0	2
28		0	2	1	0	2	1	0	3	1	0	3	0
	Mean	5.09	3.18	1.00	0.91	1.09	1.09	5.36	3.64	0.82	0.91	1.00	1.09
	Cumulative	12.36	7.27	4.09	3.09	2.18	1.09	12.82	7.46	3.82	3.00	2.09	1.09
Ungrazed													
3		1	2	0	1	1	1	1	0	2	1	0	2
4		0	0	0	0	0	1	0	0	0	0	0	1
7		2	2	6	6	0	0	2	2	8	4	0	0
8		1	0	1	11	1	1	1	0	1	11	1	1
11		0	0	0	0	0	0	0	0	0	0	0	0
14		4	0	0	0	4	0	4	0	0	1	3	0
17		3	0	2	1	2	1	2	0	1	2	2	1
18		2	0	0	0	0	4	4	0	0	0	0	4
26		5	3	0	1	1	1	5	2	1	1	1	1
27		3	0	0	0	0	7	3	0	0	0	1	6
33		11	4	0	0	0	2	11	5	0	0	0	2
	Mean	2.91	1.09	0.82	1.82	0.82	1.64	3.00	0.82	1.18	1.82	0.73	1.64
	Cumulative	9.10	6.19	5.10	4.28	2.46	1.64	9.19	6.19	5.37	4.19	2.37	1.64

Plot 28 – Grazed

Located near Plots 25-27, 50 m north-west of point PX.

Soil is a deep sandy loam (80+cm) dark brown (5 YR 4/8) in colour. There is one termite mound in the plot.

There are 7 **Acacia aneura** (1.1 – 4.8 m tall), 5 **A. linophylla**, and 4 dead trees. Other species include 10 **Eremophila spectabilis**, (another one died betwen 1979 and 1980) 1 **E. leucophylla**, and a **Sida calyxhymenia** which was grazed in 1982.

Table 2 summarises stocking of **Acacia aneura** in 1 m height classes for 1978 and 1982 assessments of the Bullimore plots. In addition plots 32 and 33 are included. These show more affinity with Bullimore than Bigida but details are given below, treating them as a separate group Bullimore/Bigida.

GROUP B – BIGIDA

Plot 19 – Not Grazed

Both this and the next plot lie inside the Station proper and are not part of the perimeter set. The plot is 2.4 km south of East Brilliant mill west of the track and a north-south fence and north of an east-west fence.

Soil is a dark brown (5 YR 4/8) sandy clay loam with an average depth of 78 (74-80) cm.

The area has been heavily cut over in the past for fence posts or mine props. There are 17 old mulga stumps in the plot area. Nine **Acacia aneura** (0.3-5.2 m) occur in the plot, with two young **Acacia linophylla**.

A mistletoe is growing on one of the medium height **A. aneura**. Other species include six **Eremophila foliosissima**, one **Rhagodia eremaea**, one **Leichardtia australis**, and one **Sida** sp. In July 1982, **Eragrostis eriopoda** was common.

Plot 20 – Not Grazed

Located north and adjacent to Plot 19

Soil is a dark brown (5 YR 4/8) sandy clay loam or hard red earth with an average depth of 52 (50-53)cm.

This area has been heavily cut (10 stumps) and grazed in the past. There are nine **Acacia aneura** less than 1 m tall and three **A. aneura** taller than 2.3 m, four young **A. linophylla**, and thirteen **Eremophila foliosissima**. In July 1980, **Erodium crinitum** and a few daisies were growing in the plot.

Plot 21 – Not Grazed

Location 1 km east of Weebo mill in the south-east, and 30 m north of the boundary fence with Wildara Station.

Soil is dark brown (5 YR 4/8) slightly stoney with clay skins on the surface and an average depth of 36 (35-39)cm. There is one termite mound in the plot.

There are eleven **Acacia aneura** (0.2-3.7 m tall), three **A. tetragonophylla**, and eight dead trees. There appears to be some grazing by goats of the Acacias. Other species include twelve **Eremophila latrobei**, two **E. leucophylla** and two **Dodonaea** sp. In July 1982, a **Ptilotus** sp. was frequent.

Plot 22 – Grazed

Located near Plot 21 but 30 m south of fence and in Wildara.

Soil is a dark brown (5 YR 4/8) sandy loam with an average depth of 38 (34-42)cm. There are nine termite mounds present in the plot.

There are ten **Acacia aneura** of which seven are over 3.0 m tall, three **A. craspedocarpa**, and nineteen dead trees. Other species include about nine **Eremophila latrobei**, one **E. leucophylla**, five **Dodonaea** sp., one **Dianella revoluta**, one **Rhagodia eremaea**, and a few **Ptilotus** sp. **Eremophila fraseri** and **E. maculata** are growing in the vicinity. Some rust is present in three of the mulgas.

Plot 23 – Not Grazed

This plot is 0.7 km west of Weebo mill.

Soil is deep (80+cm), brown (5 YR 5/6) loamy sand. The area appears liable to flooding and on several occasions the soil in this area has been rather moist. Some large branches have been cut from the mulga and there is much dead wood present, with four dead trees. There are seventeen **Acacia aneura** taller than 3.9 m, and four **A. linophylla**, the smallest of which is dying. Other species include eleven **Eremophila? foliosissima**, a **Solanum** sp. and **Leichardtia australis**, and **Helichrysum cassinianum**. The grass **Eriachne helmsii** is frequent . In July 1982, there was a very green herbaceous layer with the annuals **Eragrostis eriopoda**, **Velleia rosea** and some diaisies being pesent including **Helichrysum cassinianum**.

Plot 29 – Not Grazed

This plot is west of Division Well, 2 km north along the western boundary of Leinster Downs, and 50 m east of the fence.

This is a brown (5 YR 5/8) sandy loam with an average depth of 70 (30-80+)cm.

There are thirty-three **Acacia aneura** less than 2.2 m tall and four **A. aneura** taller than 4.5 metres, one **Eucalyptus kingsmillii** (5.4 m), nineteen **Eremophila leucophylla**, and five dead trees.

Numerous **Triodia basedowii** clumps are scattered over the plot. In July 1980 some **Helipterum humboldtianum** were present. In 1982 two groups of mulga seedlings which were alive in February had died by July.

Plot 30 – Grazed

Located near Plot 29 but 50 m west of the fence.

Soil is generally a brown (5 YR 5/6) sand, with an average depth of 66 (28-80+)cm. The shallow recording was taken where termites were active, the soil there being a sandy loam.

Table 3.

Acacia aneura distribution by height classes in plots on Bigida L.F.U. at 1978 and 1982 grazed and ungrazed

Plot No.	1978						1982					
	Height classes (m)											
	1	1<2	2<3	3<4	4<5	5+	1	1<2	2<3	3<4	4<5	5+
Grazed												
22	2	0	1	5	2	0	2	0	1	6	1	0
30	2	1	1	3	10	0	2	1	1	5	7	1
35	0	3	8	0	0	0	0	3	8	0	0	0
Mean	1.33	1.33	3.33	2.67	4.00	0	1.33	1.33	3.33	3.67	2.67	0.33
Cumulative	12.66	11.33	10.00	6.67	4.00	0	12.66	11.33	10.00	6.67	3.00	0.33
Ungrazed												
19	4	0	3	1	0	1	4	0	3	1	0	1
20	8	1	1	1	1	0	9	0	2	0	0	1
21	3	3	4	1	0	0	3	4	3	1	0	0
23	0	0	0	11	11	5	0	0	0	11	11	5
29	11	18	0	0	2	2	12	18	3	0	1	3
34	4	0	0	0	0	2	5	0	0	0	0	2
Mean	5.00	3.67	1.33	0.67	2.33	1.67	5.50	3.67	1.83	0.50	2.00	2.00
Cumulative	12.67	7.67	6.00	4.67	4.00	1.67	15.50	10.00	6.33	4.50	4.00	2.00

Wood has been cut in the vicinity of this plot (6 stumps). There are seventeen **Acacia aneura** of which thirteen are over 3 m tall, one **Eucalyptus kingsmillii** (5.9 m), twenty-nine **Eremophila leucophylla**, and one **Cassia nemophila**. **Triodia basedowii** clumps are scattered over the plot. In July 1982 a few **Helichrysum davenportii** and **Helipterum humboldtianum** were present.

Plot 34 - Not Grazed

Location 1 km south of Paddy's Mill and 50 m east of the fence.

The soil varies from an orange-brown (2.5 YR 4/8) sand to a light orange-brown (2.5 YR 6/6) sandy loam, and has an average depth of 71 (55-80) cm. Some surface calcrete is present in this plot.

There are five **Acacia aneura** less than 1 m tall and two **A. aneura** over 5 m tall, one **Eucalyptus trivalvis** (5.0 m) which is infested with meat ants, seven **A. linophylla** and three dead trees.

Other species include twelve **Eremophila leucophylla**, two **Cassia nemophila**, and a number of **Triodia basedowii** clumps. In July 1980 a lot of **Helichrysum davenportii** were growing in the shelter of shrubs and **Triodia** clumps.

Plot 35 - Grazed

Located near Plot 34, but 50 m west of the fence.

The soil varies from a light orange-brown (2.5 YR 6/8) sandy loam with a coarse sandy surface to a brown (5 YR 5/8) silty loam; the average depth is 54 (44-64)cm.

There are eleven **Acacia aneura** (2-4 m), four **A. linophylla** (2-3 m), fourteen **Eremophila leucophylla**, and eight dead trees. A few clumps of **Triodia basedowii** occur mainly along the northern edge of the plot. In July 1980 a few daisies were present.

Table 3 summarises stocking of **Acacia aneura** in 1 m height classes for 1978 and 1982 assessments of the Bigida plots. Three other plots in Bigida (1, 2, 31) in the central part of the station are not described here. These represent very dense mulga in flood-prone low-lying country. However, they are included in Figures 7, 8 and 10.

GROUP C - BULLIMORE-BIGIDA

As noted above the two plots in this group are more akin to the Bullimore group than to the Bigida (Table 2).

Plot 32 - Grazed

This plot is to the west of the station, north of Sandstone Road, 0.8 km up the boundary and 50 m west of the fence.

Soil is a deep red-brown (2.5 YR 5/6) sand, more than 80 cm depth.

There are sixteen **Acacia aneura** of which fourteen are less than 2 m tall, one **A. aneura aff. coolgardiensis** and one each of **A. acuminata**, and **Eucalyptus kingsmillii** (5.3 m), with four dead trees. Other species include about twenty-two **Eremophila leucophylla**, one each of **Acacia kempeana**, **Solanum lasiophyllum** **Hibiscus pinonianus**, and a **Dodonaea** sp. with an

Table 4. Acacia aneura distribution by height classes in plots on miscellaneous L.F.U. at 1978 and 1982

	Plot No.	1978						1982					
		Height classes (m)											
		1	1<2	2<3	3<4	4<5	5+	1	1<2	2<3	3<4	4<5	5+
Sandstone													
Grazed	36	0	0	0	1	2	0	0	0	0	1	0	0
Ungrazed	37	0	4	1	3	2	0	0	4	1	1	2	2
Stoney Ungrazed	24	2	1	0	0	1	0	2	1	0	0	0	1

abundance of **Triodia basedowii**. In July 1980, a number of annuals were growing including **Erodium crinitum**, **Pimelea microcephala**, **Calotis hispidula**, **Helipterum humboldtianum**, **H. maryonii** and **Helichrysum davenportii**. In July 1978, cattle were observed grazing in the plot.

Plot 33 - Not Grazed

Located near Plot 32, but east of the fence.

Soil is a deep (80+cm) dark brown (2.5 YR 4/8) sand.

There are sixteen **Acacia aneura** less than 2 m tall and two **A. aneura** taller than 6 m, three **Eucalypus kingsmillii**, and six dead trees. Other species include five **Eremophila leucophylla**, one each of **Solanum** sp., and **Hibiscus pinonianus**, and numerous clumps of **Triodia basedowii**.

GROUP D - SANDSTONE

Plot 36 - Grazed

This plot is located 1 km north of Paddy's Mill 50 m to the west of the fence.

Soil is a brown (5 YR 5/8) silty clay loam with some coarse quartz sand and some white stones on the surface; average depth is 29 (24-40)cm.

There are three **Acacia aneura** (3.3-4.7 tall), three **A. tetragonophylla** (1.7-2.4 m tall) and eight dead trees. Other species include one each of **Eremophila leucophylla** and **E. latrobei**. In July 1979 the daisies **Brachycome ciliocarpa** and **Cephalipterum drummondii** were present. In July 1982 these latter two annuals were again present, as well as **Actinobole condensatum**, **Angianthus burkittii**, **Calotis hispidula**, **Chthonocephalus pseudevax**, **Helipterum maryonii**, **H. splendidum**, **Isoetopsis graminifolia**, **Podolepis lessonii**, and **Ptilotus austrolasius**.

Plot 37 - Not Grazed

Located near Plot 36 but 50 m east of the fence.

Soil is red-brown (2.5 YR 5/6) to orange-brown (2.5 YR 6/6) in colour. Texture is a hard silty loam with coarse fragments on the surface; average depth is 23 (19-32) cm. An old sheep track runs north to south-west through the plot.

There are six **Acacia aneura** (1.1-5.1 m), three **A. tetragonophylla** (1.9-3.5 m), and one **Eremophila leucophylla** present. In July 1980 the same annuals as those growing in Plot 36 were present here.

Table 4 summarises the stocking at 1978 and 1982 of the **Acacia aneura** in these two plots.

MISCELLANEOUS

Plot 24 - Not Grazed

This plot is 3.8 km north of Four Corners mill, towards the west centre of Leinster Downs station. The area is mapped as Juliet L.S. on upper alluvial plains, with extensive hardpan under shallow red earths. In the plot the soil is a brown (2.5 YR 4/8) stony sandy loam with an average depth of 16 (12-23)cm. The surface is littered with small gibber stones.

Eremophila fraseri characterises this area. There are nine bushes less than 1.5 m tall. Three **Acacia aneura** at less than 1.6 m and one at 4.8 m tall are present. In July 1982 some daisies were present around the base of several of the **E. fraseri**. the stand is summarised in Table 4.

Growth of Acacia aneura

Height assessment at successive measurements suggests little overall change during the period January 1978 to July 1982. The accuracy of measurement declines with height of the subject tree so that less credence can be attached to relative changes in the taller individuals. The gross data on stocking by height classes (Figure 6) suggests that increase in height of smaller Acacia aneura was most apparent in plots on Bullimore land form unit. In the ungrazed Bigida plots A. aneura less than one metre tall increased whereas the proportion over 5 m decreased. The latter is clearly an artefact, and tends to negate the value of the observation that larger (5 m plus) trees in grazed Bigida plots increased. Likewise little credence can be attached to an apparent increase in height for both ungrazed and grazed Sandstone land form unit plots.

It may be postulated that soil depth is an important variable in relation to growth potential. Consequently an analysis of growth in height in relation to mean plot soil depth was undertaken (Figure 7). Rather more ungrazed plots than grazed plots showed an apparent decline in height. In this analysis only trees present at successive recording events are included in the data sets. The higher stocking of smaller plants in ungrazed Bigida plots compared with grazed plots suggests that absence of grazing may have allowed more smaller individuals to have developed (Figure 6). In Figure 8 mean percentage height change is related to the 'sum of heights' change, this being another indicator of overall stocking capacity. There is a clear trend for higher positive height change to be associated with changes in the sum of heights. Bullimore plots occur across the range of values detected whereas Bigida plots sort into more discrete

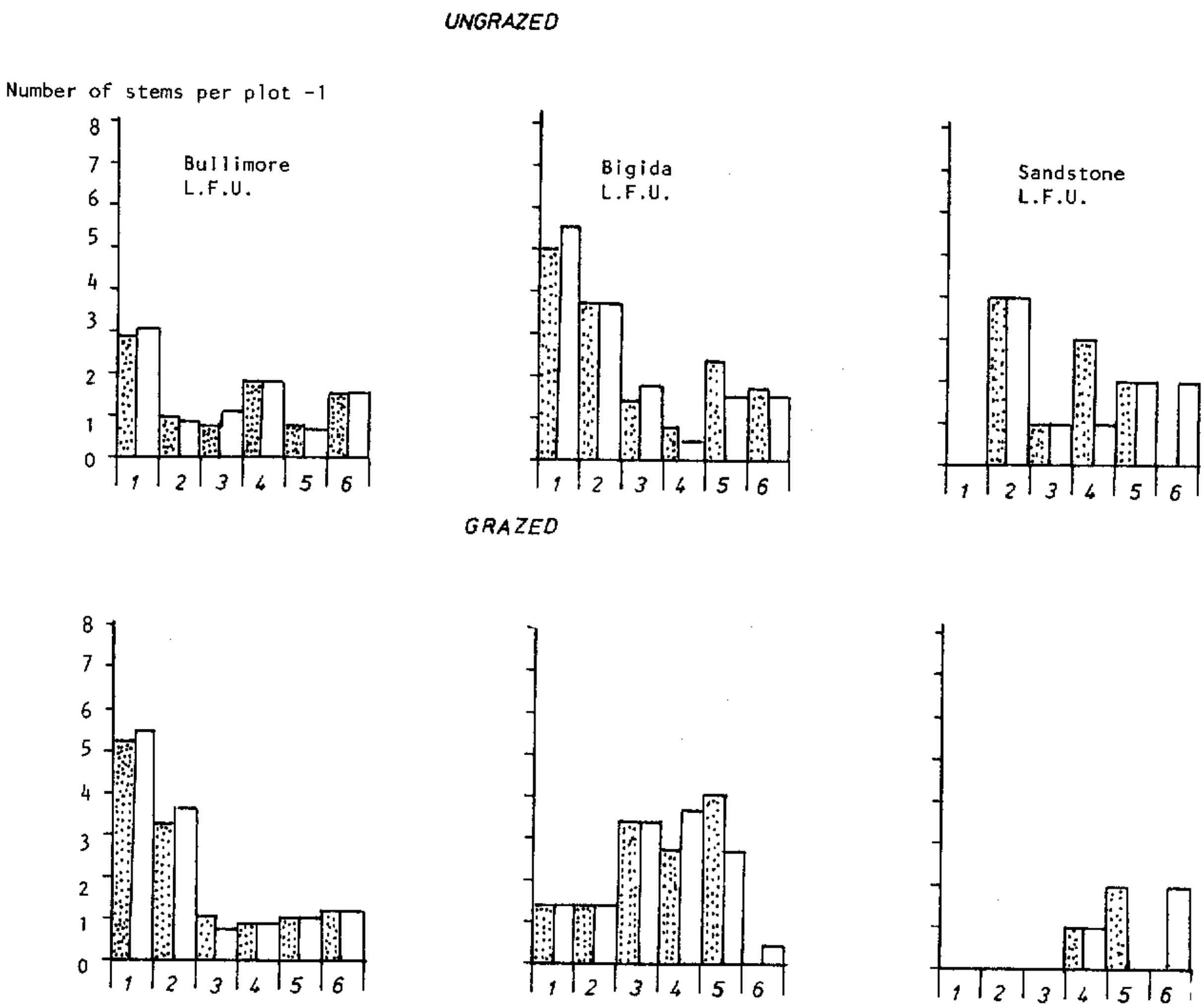


Figure 6 Size Class Distribution
Average numbers of Acacia aneura per plot
ungrazed and grazed (Size classes as in Tables 2-4)
1978 1982

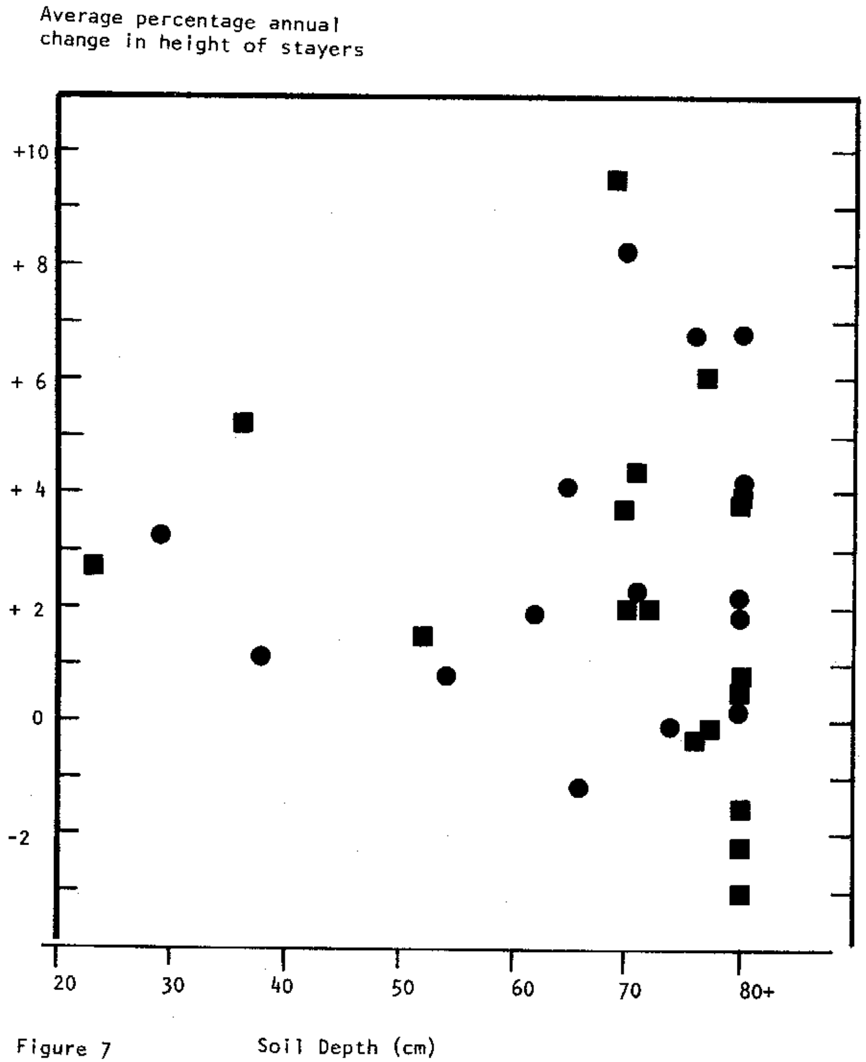


Figure 7

Change in height in relation to soil depth. Closed circles represent grazed plots, closed squares represent ungrazed plots.

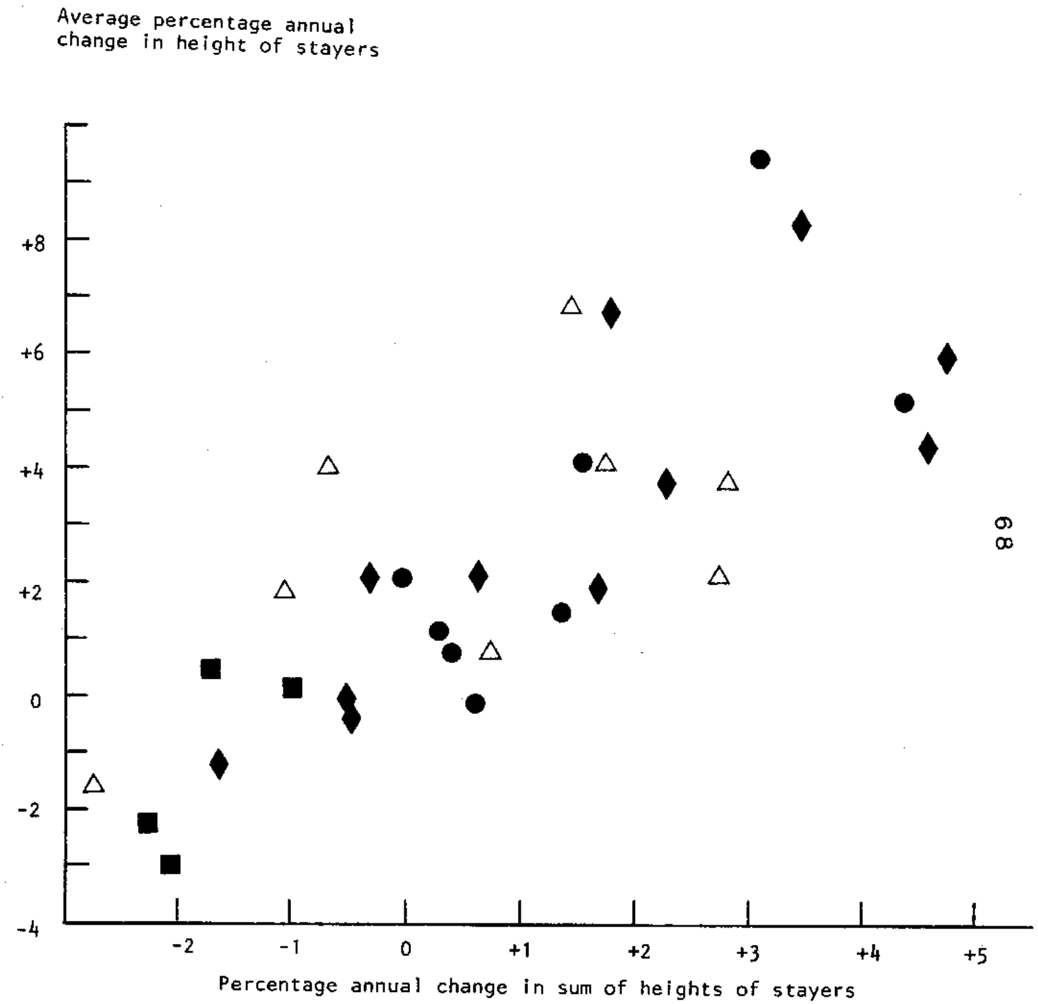


Figure 8 Change in height mean per tree versus sum of heights Plots in Bigida : closed circles <80cm soil depth, closed squares >80cm depth; Bullimore : open triangles >80cm soil depth, closed diamonds <80cm depth.

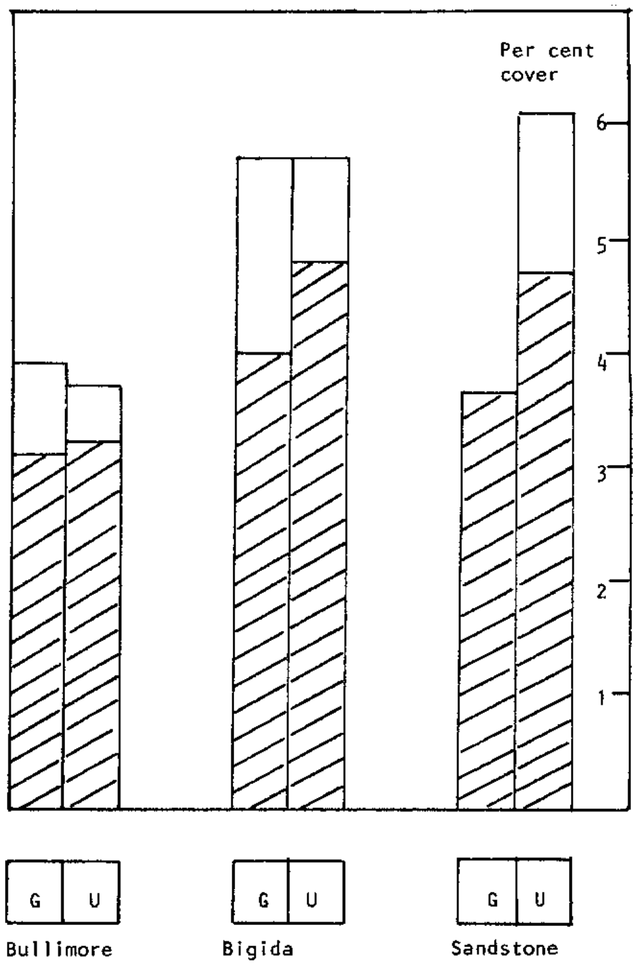


Figure 9 Average canopy cover (%) of all trees per plot

1978 1982

groups related to soil depth. The four Bigida plots on deep soil exhibited inferior growth to those on shallower soil. These were associated with fairly active water courses and suffered periodical flooding over the study period.

Projective canopy cover of all tree species (expressed as percentage of ground covered) apparently increased in all groups except for the grazed Sandstone land form unit plot. In both Bullimore and Bigida sets there was an apparently greater increase in cover for grazed plots compared with ungrazed plots. The Bigidia plots tended to have greater cover than the Bullimore plos (Figure 9).

Ordination

Presence or absence of eighteen attributes (of soil and vegetation: species and structure) were assigned to each of the 37 plots. Centred Principal Components Analysis[14] gave a separation of Bullimore and Bigida plots on second and third axes (Figure 10). Plots along Axis 2 were aligned with three attributes

1. Churchward Land Type
2. Presence or absence of **Triodia basedowii** (spinifex)
3. Presence or absence of bowgada **Acacia linophylla** and **A. ramulosa.**

Plots were separated on Axis 3 by

1. Soil colour orange-brown, or red-brown
2. Soil texture sand or clay loam
3. Presence or absence of small **Acacia aneura.**

It is possible to generalise from the principal components analysis that the Bullimore plots are characterised by the presence of spinifex and bowgada, have few mulga less than 1 m tall, and typically have orange-brown sandy soil. In contrast, Bigida rarely has spinifex or bowgada, commonly has mulga <1 m tall and a red-brown clay/loam soil.

Conclusions

The study of **Acacia aneura** communities at Leinster Downs shows that a clear distinction can be drawn between the two major land types of Churchward[4]. Bullimore is characterised by an orange-brown sandy soil, with less dense **Acacia aneura** and fewer recruits. The mulga usually occurs in association with bowgada (**A. linophylla**) and some spinifex (**Triodia basedowii**). In comparison, Bigida is characterised by red-brown clay/loams with more **A. aneura** and with individuals less than 1 metre tall being common. The occurrence of bowgada and spinifex is less frequent.

The methods employed in this study were unable to show any significant difference in grazed or ungrazed plots. Contrary to expectations, an increase in foliage cover was apparent in the grazed plos compared to the ungrazed ones. However to obtain a more realistic comparison of the differential response of plots to grazing, a more detailed study of species which are most palatable to herbivores would be desirable.[10]

Height changes require a longer period of study for trends to become apparent. The vegetation described accounts for the status of the communities after some 65 years of sheep grazing followed by a very short period of de-stocking. Overall growth of woody perennials has been minimal. No dramatic improvement has been observed in ungrazed plots inside Leinster Downs Station.

It is recommended that deferral of grazing be sought for a further five year period to allow vegetation recuperation.

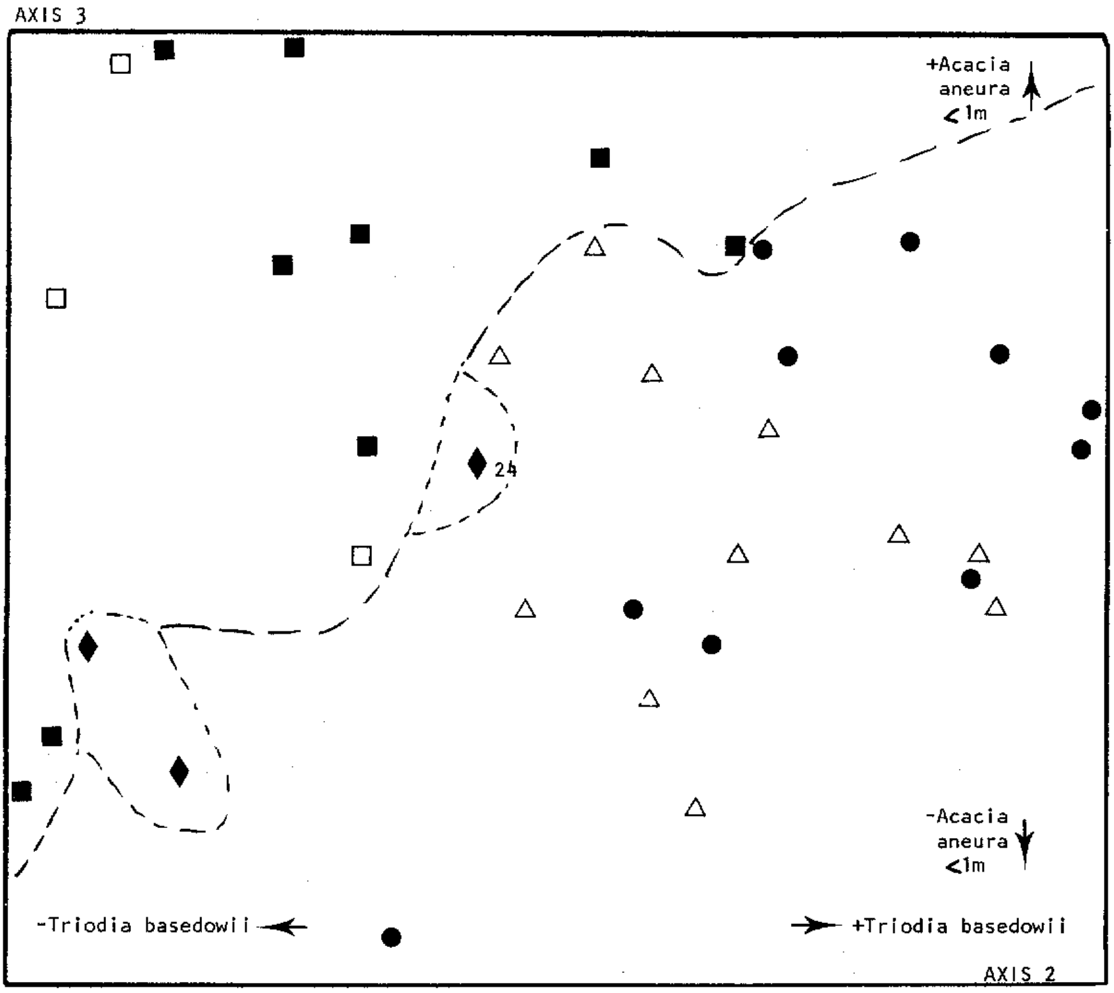


Figure 10 Principal Coordinate Analysis Leinster Downs plots
Bigida L.F.U. squares : open grazed, closed ungrazed; Bullimore L.F.U. Circles ungrazed, triangles grazed; Miscellaneous : diamonds

Acknowledgements

This study was made possible by financial support from the Agnew Mining Co. Ltd., Western Mining Co. and the W.A. Forests Department. Initial support was also received from the Utah Foundation. The following individuals have participated in measurements in the field: Mark Hood, Mark Lehmann, Donald Griffiths, Greg Smith, Kevin Walker, Philip Holliday, David Kaljuste, Lois Rasmussen, Lyn Darlington, Tim Maddocks, John Spice and Phil Unsworth. We thank Arthur Daffen for initial encouragement and Leo Bonney, Chris Cooke and many other staff of Agnew Mining Co. for assistance.

The W.A. Herbarium staff have been most co-operative in identifying plant specimens. M.I.H. Brooker elucidated the eucalypts of the area for us.

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Appendix 1

Preliminary Plant Species List for Leinster Downs

As far as possible names agree with Jessup[11]

FAMILY — Species name — Common name — Collection Number

PTERIDOPHYTA Ferns and fern allies

Marsilea drummondii A. Braun Drummond's Nardoo 3227

GYMNOSPERMAE Conifers

Callitris columellaris F. Muell. White Cypress 4472

JUNCAGINACEAE

Triglochin calcitrapum Hook. Spurred arrow grass 3238

POACEAE Grasses

Aristida contorta F. Muell. Wind Grass 3574
Eragrostis dielsii Pilger Mulka Grass 3235
Eragrostis eriopoda Benth. Naked woollybutt 3252
Eragrostis leptocarpa Benth. Drooping lovegrass 3226
Eragrostis setifolia Nees Narrow-leaf neverfail *
Eragrostis xerophila Domin. Knotty-butt neverfail *
Eriachne benthamii (Domin) Hartley Swamp wanderrie 1982
Eriachne helmsii Hartley Woollybutt wanderrie 3564
Iseilema membranaceum (Lindl.) Domin. Small Flinders grass 3260
Monochather paradoxa Steud. Mulga oats *
Plectrachne melvillei C.E. Hubbard (soft) spinifex *
Themeda australia (R.Br.) Stapf. Kangaroo grass 1981
Triodia basedowii E. Pritzel. Hard spinifex 1952
Tripogon loliiformis (F.Muell.) C.E. Hubbard Five minute grass 3255

CYPERACEAE

Fimbristylis aff. **schultzii** Boeck 3253

JUNCACEAE

Juncus? kraussii Hochst. Sea rush 1981

LILIACEAE

Dianella revoluta R.Br. Spreading flax lily *
Wurmbea? deserticola T.D. Macfarlane 4465
Wurmbea dioica (R.Br.) F. Muell. Early Nancy 4441

PROTEACEAE

Grevillea sp. 3344
Grevillea obliquistigma C.A. Gardn. 1255
Grevillea sarissa S. Moore 1988
Grevillea stenobotrya F. Muell. 1980
Hakea rhombales F. Muell. 4476
Hakea suberea S. Moore 4448

SANTALACEAE

Santalum acuminatum (R.Br.) A.DC. Quandong*
Santalum lanceolatum R.Br. Plumbush 4480
Santalum spicatum (R.Br.) A.DC. Sandalwood 3553

LORANTHACEAE Mistletoes

Amyema miquelii (Lehm. ex. Miq.) Tiegh. 4446
Lysiana casuarinae (Miq.) Tiegh. 1976
Lysiana murrayi (F.Muell. & Tate) Tiegh. 4414

POLYGONACEAE

Emex australis Steinh. Doublegee *
Rumex vesicarius L. Rosy dock *

CHENOPODIACEAE

Dysphania Sp. indet 3237
Enchylaena tomentosa R. Br. Ruby saltbush 3218
Maireana carnosa (Moq.) P.G. Wilson 3251
Maireana georgei (Diels) P.G. Wilson Satiny bluebush 3219
Maireana planifolia (F. Muell.) P.G. Wilson 3601
Maireana triptera (Benth.) P.G. Wilson Three winged bluebush 1959
Rhagodia eremaea Wilson mans. 3219B
Rhagodia preissii Moq. 4435

AMARANTHACEAE

Ptilotus astrolasius F. Muell. 3370
Ptilotus chamaecladus Diels 3392
Ptilotus exaltatus Nees Pink mulla mulla 1243
Ptilotus helichrysoides (F. Muell.) F. Muell 4473
Ptilotus sp.indet. 3600

PHYTOLACCACEAE

Codonocarpus cotinifolius (Desf.) F. Muell Desert poplar *

PORTULACACEAE

Calandrinia cf. brevipedata F. Muell 3395
Calandrinia eremaea Ewart Small purslane 3557

CARYOPHYLLACEAE

Polycarpon tetraphyllum (L.) L. Four leaf all seed 3388

CRUCIFERAE

Cuphonotus sp indet 3398
Menkea australis Lehm. 3366
Stenopetalum anfractum Shaw 3569
Stenopetalum sphaerocarpum F. Muell. 3346

MIMOSACEAE

Acacia acuminata Benth. Jam 1953
Acacia aneura F. Muell. ex Benth. 1187
Acacia craspedocarpa F. Muell. 4468
Acacia aff. coolgardiensis Maiden 3276
Acacia kempeana/stowardii (indet) 1249
Acacia kempeana F. Muell. Witchetty bush 1951
Acacia ligulata A. Cunn. ex. Benth. Dune wattle 1251
Acacia linophylla W.V. Fitzg. Bowgada 1979
Acacia longispinea A. Morrison 1195
Acacia oswaldii F. Muell. Miljee 3273
Acacia murrayana F. Muell. ex Benth. Murray°s wattle 3278
Acacia quadrimarginea F. Muell. 1199
Acacia ramulosa W.V. Fitzg. Bowgada 1193
Acacia aff. ramulosa 1246
Acacia tetragonophylla F. Muell. Kurara *
Acacia sp.nov. 4456

CAESALPINIACEAE

Cassia artemisioides Gaud ex DC. Silver cassia 1206
Cassia nemophila A. Cunn. ex Vogel. Punty bush 1984
Petalostylis cassioides (F. Muell.) Symon 1257

FABACEAE

Glycine canescens F.J. Hermann Silky glycine 3259
Indigofera georgei Pritzel 1203
Kennedia prorepens (F. Muell.) F. Muell. Desert runner 1258
Swainsonia rostellata A.T. Lee 3258
Swainsonia stipularis F. Muell. Orange pea 1986

GERANIACEAE

Erodium crinitum Carolin Blue crowfoot 3373

ZYGOPHYLLACEAE

Zygophyllum sp. indet 3250

EUPHORBIACEAE

Poranthera microphylla Brongn. *

SAPINDACEAE

Dodonaea microzyga F. Muell. 4404A
Dodonaea viscosa Jacq. 4471

RHAMNACEAE

Trymalium aff. myrtillus S. Moore 3576

MALVACEAE

Abutilon sp. indet 3269A
Hibiscus pinonianus Gaud. 1254B
Sida calyxhymenia J. Gay 1967

STERCULIACEAE

Brachychiton gregorii F. Muell. Desert kurrajong *
Keraudrenia integrifolia Steud Common firebush 3592

THYMELEACEAE

Pimelea microcephala R.Br. Shrubby rice-flower 3356

MYRTACEAE

Baeckea cryptandroides F. Muell. 3577
Eucalyptus camaldulensis Dehnh. River red gum 1985
Eucalyptus clelandii (Maiden) Maiden Clelands blackbutt 4477
Eucalyptus gonglyocarpa Blakely Marble gum 1954
Eucalyptus kingsmillii Maiden & Blakely Kingsmills' mallee 1248
Eucalyptus leptopoda Benth. Tammin mallee 1260
Eucalyptus loxophleba Benth. York gum 1262
Eucalyptus lucasii Blakely 3272
Eucalyptus oldfieldii F. Muell. Oldfield's mallee 1250
Eucalyptus oleosa F. Muell. ex Miq. Giant mallee 4478
Eucalyptus striaticalyx W.V. Fitzg. Cue York Gum *
Eucalyptus trivalvis Blakely 1978
Melaleuca leiocarpa F. Muell. 1186
Melaleuca uncinata R.Br. ex Ait Broombush 1256

HALORAGACEAE

Haloragis odontocarpa F. Muell. 3599

OLEACEAE

Jasminum lineare R.Br. Desert jasmine *

ASCLEPIADACEAE

Leichardtia australis R.B. Coggler *

DICRASTYLIDACEAE

Spartothamnella teucriiflora (F. Muell.) Moldenke 3596

SOLANACEAE

Solanum lasiophyllum Dun. Flannel bush 4450

MYOPORACEAE

Eremophila foliosissima Kraenzlin 1182
Eremophila fraseri F. Muell. Turpentine bush 4469
Eremophila georgii Diels 1972
Eremophila gilesii F. Muell. Green turkey -bush 1183

Eremophila glabra (R.Br.) Osten. 4487
Eremophila granitica S. Moore 1974
Eremophila homoplastica S. Moore 4499
Eremophila latrobei F. Muell. Crimson turkey-bush 1965
Eremophila leucophylla Benth. 1966
Eremophila longifolia (R.Br.) F. Muell. 4470A
Eremophila maculata (Ker.) F. Muell. Spotted fuchsia 4487
Eremophila oldfieldii F. Muell. 4505
Eremophila serrulata (A. Cunn. ex DC) Druce Green fuchsia-bush 1197
Eremophila spectabilis C.A. Gardn. 1950
Eremophila sp. indet 3219A

RUBIACEAE

Canthium latifolium F. Muell. ex Benth. Native currant 4479
Canthium lineare E. Pritzel 3231

GOODENIACEAE

Goodenia pinnatifida Schlechtd. 4484
Scaevola spinescens R.Br. Spiny fan-flower 3390
Velleia rosea S. Moore 4462
Velleia sp. indet 4463A

ASTERACEAE

Actinobole condensatum (A.Gray) Short 3380
Actinobole uliginosum (A.Gray) Eichler 3228
Anglanthus burkittii (Benth.) J.M. Black 3371
Brachycome cheilocarpa F. Muell. 3236
Brachycome ciliocarpa W.V. Fitzg. Showy daisy 1961
Calotis hispidula (F.Muell.) F. Muell. Bogan flea 1963
Calotis multicaulis (Turcz.) Druce 4463
Cephalipterum drummondii A. Gray 1962
Chthonocephalus pseudevax Steetz Croundheads 3385
Gnaphalium sp. indet 3243
Helichrysum cassinianum Gaudich 4451
Helichrysum davenportii F. Muell. 3345
Helipterum adpressum W.V. Fitzg. 3293
Helipterum humboldtianum (Gaud.) DC. 3264
Helipterum maryonii S.Moore 3361
Helipterum splendidum Hemsley 1957
Isoetopsis graminifolia Turcz. Grass cushions 3382
Podolepis canescens A. Cunn. ex DC. 4495D
Podolepis capellaris (Steetz) Diels 3393

Podolepis lessonii (Cass.) Benth. 3375
Sonchus asper (L.) Hill Prickly sowthistle 1971
Waitzia acuminata Steetz. Orange immortelle 3588

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* Species observed, not collected, see Daffen and Andrews.

THE INFLUENCE OF FLUOROACETATE PRODUCING PLANTS UPON SEED SELECTION BY SEED HARVESTING ANTS

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Introduction

Sodium monofluoroacetate (compound 1080) is a highly toxic substance which is used for the eradication of mammalian vermin[2,3,7]. Once absorbed into the body, the toxic manifestations of fluoroacetate (monofluoroacetate) arise from its in vivo transformation into fluorocitrate[11,19]. Fluorocitrate then inhibits the mitochondrial tricarboxylic acid enzyme aconitate hydratase (E.C.4.2.1.3.) with resultant accumulation of citrate[19,20]. In addition, recent studies suggest that fluorocitrate may also inhibit citrate transportation into and out of mitochondria[11]. The consequences of fluoroacetate toxicity are similar in a wide range of organisms and result in a dysfunction of the tricarboxylic acid cycle leading to energy deprivation and death.

Fluoroacetate occurs naturally in several plant genera[14], in particular, in thirty-three species of **Gastrolobium** and **Oxylobium**. Indigenous mammalian herbivores inhabiting areas where such vegetation occurs have a higher tolerance to fluoroacetate than animal populations which have not had evolutionary exposure to fluoroacetate-bearing vegetation[16,24]. The range of these fluoroacetate-tolerant species correlates with the distribution of fluoroacetate-bearing vegetation .

Sodium fluoroacetate can act as a systemic insecticide and it was patented as a moth-proofing agent in the 1930's[22]. Sodium fluoroacetate is known to have good insecticidal action against mustard beetles[6] and aphids[5]. Very little is known, however, about the fluoroacetate susceptibility of invertebrate fauna from areas whose vegetation includes fluoroacetate-bearing plants.

It has been established that many Australian ants are seed harvesters. Harvester and decorator ants may remove large quantities of seed from forests and agricultural pastures for food or for nest building materials[12,15,25].

As fluoroacetate is toxic to invertebrates and because seed harvesting ants co-exist with fluoroacetate-bearing vegetation in some areas of Western Australia, it becomes interesting to speculate on how these invertebrates avoid fluoroacetate intoxication. Investigations were therefore conducted to assess whether the presence of fluoroacetate in the seed of toxic species of **Gastrolobium** influenced the seed selection by harvesting ants in an area where such vegetation occurs.

Methods

The study was conducted during March 1983, in the Dryandra State Forest near Narrogin (32°56'S, 117°11'E) which is approximately 160 km south-east of Perth. The climate is warm mediterranean with an average yearly rainfall of 508 mm.

The vegetation is a typical **Eucalyptus wandoo** open woodland with the understorey dominated by **Gastrolobium microcarpum**, locally present to levels of 80 per cent cover. **Acacia pulchella**, **Astroloma epacridis**, **G. oxyloboides** var. **angustifolia**, and **Lomandra leucocephala** were occasionally present.

All ants mentioned in this study have been sorted to species level. Species names were given where possible. When these were unavailable, they were either coded with Western Australian Institute of Technology (J.D.M.) code numbers or, if voucher specimens are deposited there, with Australian National Insect Collection (ANIC) codes.

Description of Seed

Ants were provided with seed from three leguminous species. These were **G. microcarpum** (Papilionaceae) (mean mass from 10 seeds, 5.4 mg), **Bossiaea eriocarpa** (Papilionaceae) (mean mass, 1.5 mg) and **Acacia pulchella** (Mimosaceae) (mean mass, 6.9 mg). **G. microcarpum** elaborates fluoroacetate (400-600 mg kg^{-1})[1] whereas the others do not. The seed of these species offered ants a choice between toxic and non-toxic seed and a range in seed mass. Seed was previously collected from Dryandra in December, 1982 and all three genera produce seed with elaiosomes[4].

Seed Taking

To determine which ants were seed takers and also their relative capacity to remove seed, twenty seed depots (20 x 15 cm Masonite boards) were placed out in a 5 x 4 grid spaced 5 m apart. In the early morning twenty seeds of each species were placed on each depot and at 2h intervals, for a 24 h period, a count of the number of seeds removed per depot was made. Seed removed from depots was not replenished. The soil temperature (depth 1-2 cm) was also recorded at 2 h intervals. Any ants removing and/or feeding on seed were collected and the time of day recorded.

Determination of the Fate of Harvested Seed

To assess whether the toxic seeds of **G. microcarpum** were removed but later rejected by ants, a seed depot with twenty marked **G. microcarpum** seeds was placed at the nest entrance of a known seed taking ant species (located outside the main study plot). Over a 48 h period, brief inspections of seed removal were made. After approximately 72 h, a 15 x 15 x 25 cm soil core was taken around each nest and the seed content analysed. Seeds were separated from the nests using a combination of sieving and hand sorting. The nest midden was treated separately from the below-ground nest.

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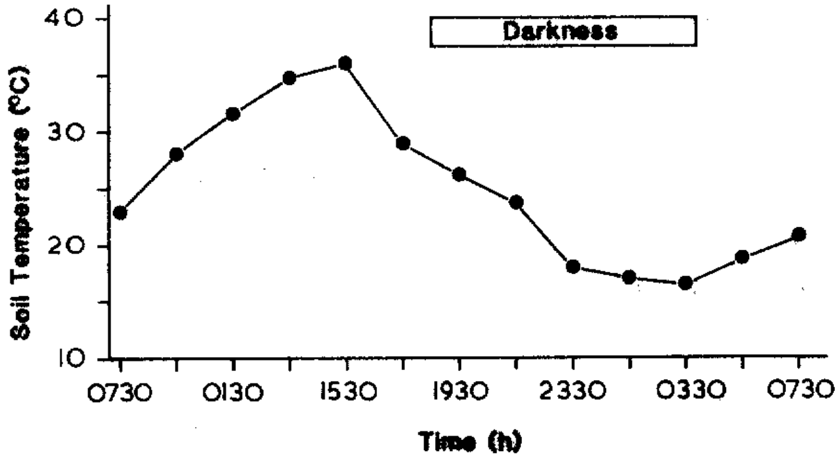


FIGURE 1 Soil Temperature (0°C) for top 1-2 cm of Soil during Seed Taking Trial.

Results

The range in soil temperature during the 24 h seed taking trial is presented in Figure 1.

Fourteen species of ants from nine genera were found in the study plot; six of these species were active seed harvesters (Table 1). Other species may have been present but were insufficiently common or conspicuous to observe. The periods when ants were active is shown in Figure 2. With the exception of **Melophorus** sp. J.D.M. 117 and **Camponotus** sp. J.D.M. 549, which were diurnal, the foraging behaviour of most ant species was mainly nocturnal with foraging extending into the cooler morning and evening (Figures 1 and 2). **Melophorus** sp. J.D.M. 117 was only active during the period when soil temperature was at a maximum (Figures 1 and 2).

Table 1. Ant species recorded during seed taking experiment

Species	Collection frequency
Brachyponera lutea	1
Camponotus sp. J.D.M. 182	1
Camponotus sp. J.D.M. 183	5*
Camponotus sp. J.D.M. 549	2*
Iridomyrmex sp. J.D.M. 200	2
Iridomyrmex sp. J.D.M. nov.	1
Melophorus sp. J.D.M. 117	3*
Meranoplus sp. 2 (ANIC)	1
Meranoplus sp. J.D.M. 400	4*
Monomorium sp. 1 (ANIC)	3*
Rhytidoponera sp. J.D.M. 121	2*
Stigmacros sp. J.D.M. 113	1
Stigmacros sp. J.D.M. 375	1
Tapinoma sp. J.D.M. 134	1

* Known seed harvester

Seed Taking

Thirty-six point five percent, 33 percent and 63.5 percent of the **G. microcarpum**, **A. pulchella** and **B. eriocarpa** seed respectively, were harvested by seed-taking ants (Figure 3). This represents 44.3 per cent of the total seed offered. Most of this seed was taken during the early morning when soil temperatures were moderate (Figures 1 and 3a).

The rate of seed removal for all three seed species was significantly different with respect to each other ($p < 0.05$, Table 2). The order of magnitude of seed removal was; **B. eriocarpa** > **G. microcarpum** > **A. pulchella**. Rank of seed mass, **A. pulchella** > **G. microcarpum** > **B. eriocarpa**, was inversely correlated with the quantity of seed taken.

Fate of Harvested Seed

No marked **G. microcarpum** seeds were recovered from the extracted ant nests. However, two of the four **Melophorus** sp. J.D.M. 117 nests

Table 2. Analysis of Variance and Critical Differences for Seed Removed Over 24 h period.

Species	Difference between means (Scheffe test p 0.05, CD 2.00)	
	A.p.	**B.e.**
G. microcarpum		
A. pulchella	2.03*	
B. eriocarpa	−10.59*	−12.63*

Analysis of Variance F = 3.17, F p 0.05 3.68

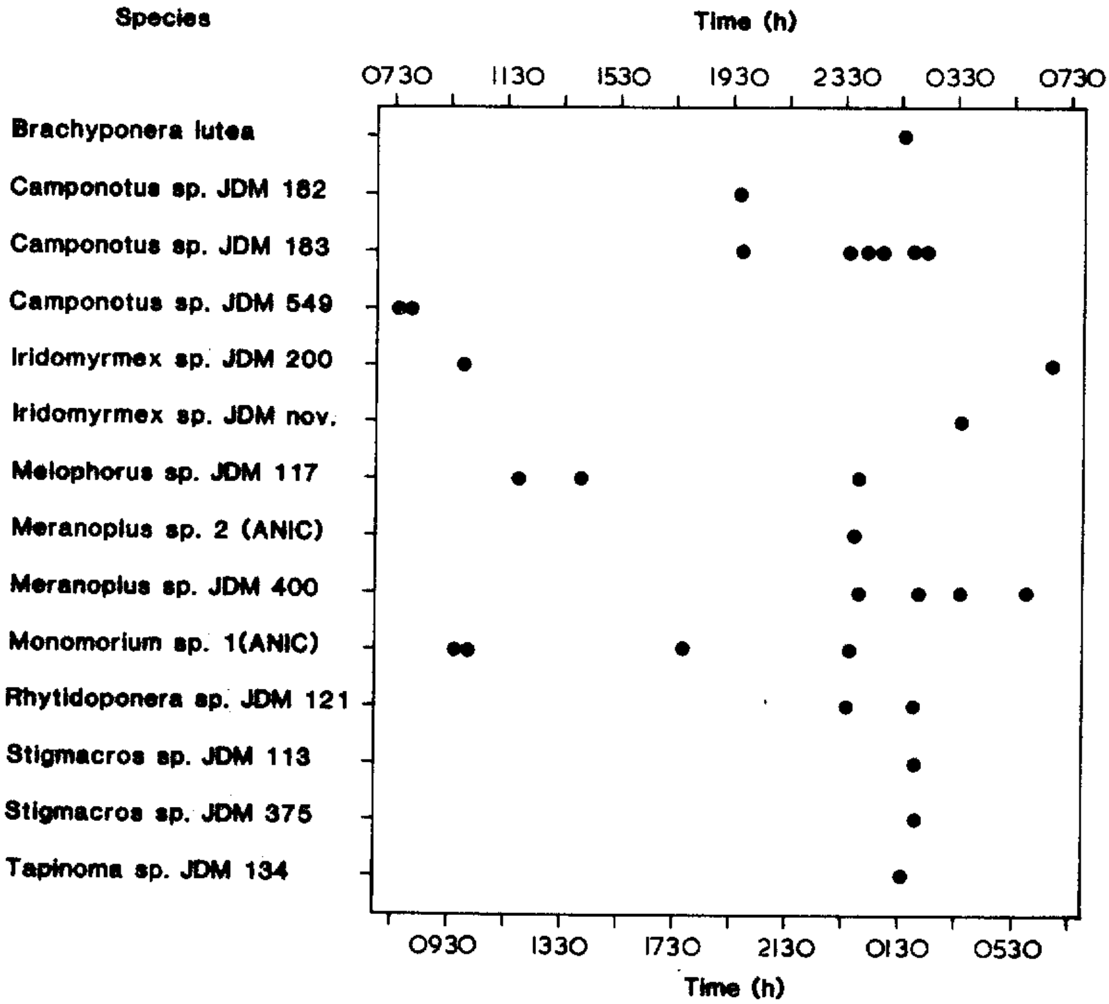


FIGURE 2 Times When the Various Ant Species were Foraging.

examined were found to contain small numbers of G. microcarpum seed (Table 3). Most of these seeds lacked the elaiosome.[4] No seeds of any plant species were recovered from the nest middens.

Table 3. Seeds recovered from inside nests

Nest species	Number of Seed Recovered		
	+ Elaiosome	- Elaiosome	Total
Melophorus sp. J.D.M. 117	2	5	7
Melophorus sp. J.D.M. 117	-	12	12
Melophorus sp. J.D.M. 117	-	-	-
Melophorus sp. J.D.M. 117	-	-	-
Camponotus sp. J.D.M. 182	-	-	-

Discussion

The number of ant species recorded for Dryandra indicates the existence of a populous and relatively species-rich ant community [13]. **Camponotus** sp. J.D.M. 183, **Melophorus** sp. J.D.M. 117, **Meranoplus** sp. J.D.M. 400, **Monomorium** sp. 1 (ANIC) and **Rhytidoponera** sp. J.D.M. 121 were active seed harvesters. However, due to insufficient observations and because the abundance of seed taking ants in the Narrogin/Katanning area declines during late summer/early autumn [25] it was not feasible to rank seed taking ants.

The level of seed removal over the 24 h period (44 percent) was of similar magnitude to that recorded in Australian pastures and grasslands (61 percent after 3d[21], 35 percent after 24 h[8], 20-30 percent after 24 h[25]) and in Western Australian forests (48-66 percent after 24 h[12]). These figures may well be inflated due to seed being placed in concentrated patches. Naturally spread seed would produce a more dispersed distribution of seeds which would probably be gathered less efficiently by ants.

The influence of soil temperature upon ant foraging activity is well documented[8,17,23]. At Dryandra for example, **Melophorus** sp. J.D.M. 117

was only active when soil temperatures were above 30°C while some species of **Camponotus** which were mainly nocturnal, were only active when temperatures were below 25°C (see Figures 1 and 2).

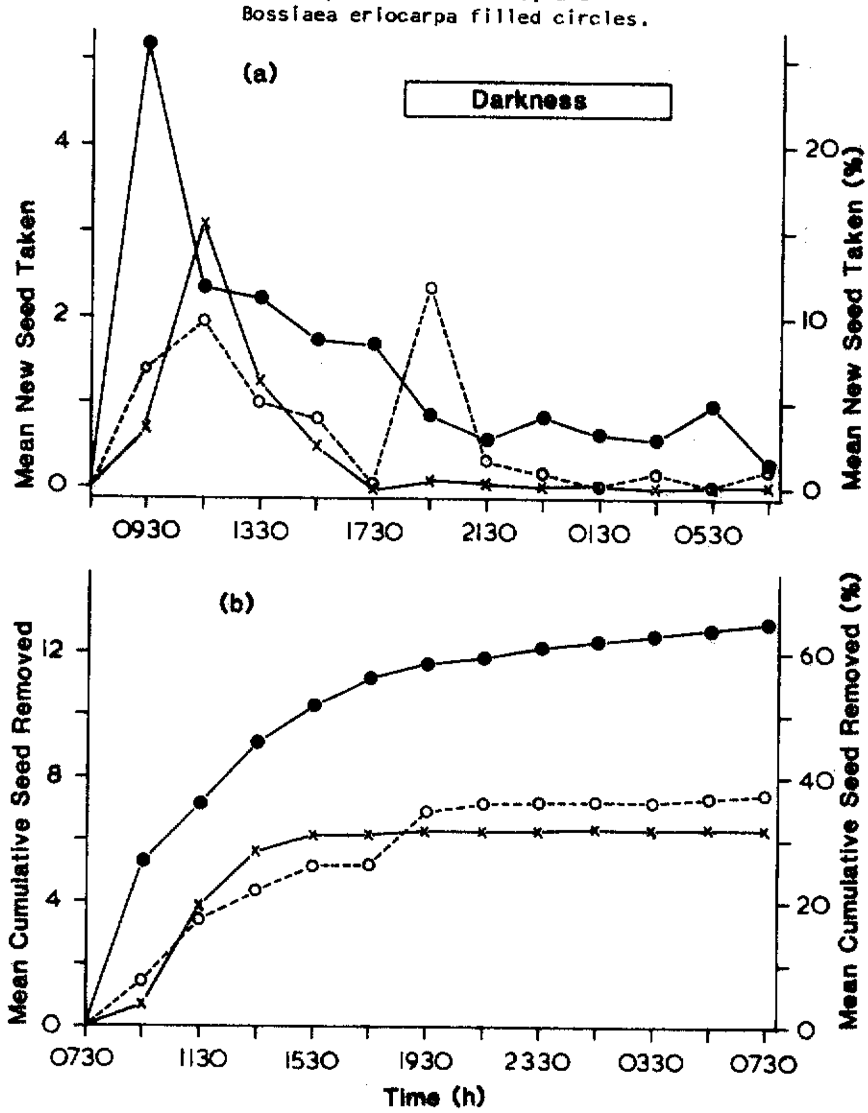
The differences in the rate of seed removal of the three seed species are best explained by seed size selection rather than by the absence or presence of fluoroacetate in the seed. **B. eriocarpa**, the lightest seed, was preferentially harvested. **Monomorium** sp. 1 (ANIC), which is a relatively small ant, appeared to lack the physical ability to remove the larger seed, but was frequently observed removing **B. eriocarpa**. **Monomorium** sp. 1 (ANIC) was also one of the more densely populated species. In Australian grasslands, the relatively small and lighter seeds (such as ryegrass, **Lolium rigidum** seed) have also been shown to be preferentially removed by seed taking ants[15,23]. The lack of selection for, or against, fluoroacetate-bearing seed is further exemplified by the very low Scheffe value when comparing the theft rates of the two larger seed species, **G. microcarpum** and **A. pulchella** (see Table 2).

It is interesting to note that the **G. microcarpum** seed retrieved from the extracted ant nests mainly had elaiosomes removed (see Table 3). While some ants are known to feed exclusively on elaiosomes[4,13] no definitive conclusions on the fate of the elaiosomes on seed extracted from ant nests at Dryandra can be made. These elaiosomes may have been removed by the soil sieving process. The sieving may have also removed the white paint used to mark the **G. microcarpum** seed. This may account for the failure to retrieve marked **G. microcarpum** seed from the extracted ant nests.

Whether fluoroacetate is evenly distributed through the seed and elaiosome, and the effect of weathering upon the fluoroacetate content of

FIGURE 3 Seed Taken During the Trial

(a) Mean new seed taken per depot
(b) Cumulative seed taken
Gastrolobium microcarpum open circles,
Acacia pulchella crosses, and
Bossiaea eriocarpa filled circles.



these components, is not known at present. Fluoroacetate may be less concentrated in the elaiosome or it may be leached more quickly from the fleshy elaiosome than the fluoroacetate of the seed. This could be one of the factors influencing the selection of seed by harvesting ants in areas where toxic plants occur. However, it is more likely that, as with the indigenous mammalian herbivores from the south-west of Western Australia, the invertebrate fauna from areas whose vegetation includes fluoroacetate-bearing plants are less susceptible to fluoroacetate.

G. microcarpum was by far the most dominant plant species in the understorey at Dryandra and as **G. microcarpum** seed is a nutritious and readily obtainable food source, it is unlikely that the ants would ignore **G. microcarpum** seed. This implies interaction between the toxic plants and the ants. In order to regularly consume fluoroacetate-bearing seed, the ants would need to have evolved mechanisms for circumventing the toxic manifestations of fluoroacetate. Such mechanisms have been suggested by recent studies on the fluoroacetate sensitivity of Bag Moth larvae (Family: Noctuidae) from Dryandra. Caterpillars of the bag moth have been shown to tolerate 100-200 mg 1080 kg-1 body weight (Twigg, unpublished data) which suggests the invertebrate fauna in areas containing fluoroacetate-bearing vegetation may be less susceptible to fluoroacetate.

The fluoroacetate susceptibility or tolerance of indigenous invertebrate fauna from areas in Western Australia, where toxic species of **Gastrolobium** and **Oxylobium** are present, is currently being investigated. Studies are also being conducted on the concentration and distribution of fluoroacetate within the seed and elaiosome of toxic species of **Gastrolobium**. It is hoped that these investigations may provide answers to the questions posed during the current study.

Summary

Little is known about the influence of fluoroacetate-bearing seed upon the selection of seed by harvesting ants. The response of ants to seed containing fluoroacetate, which were placed out in artificial depots in an **Eucalyptus wandoo** open woodland, suggested that the presence of this substance had very little influence upon the seed selection of harvesting ants. Of the total seed offered, 44.3 percent was removed in 24 h. The principal ant species observed taking seed were **Camponotus** sp. J.D.M. 183, **Melophorus** sp. J.D.M. 117, **Meranoplus** sp. J.D.M. 400, **Monomorium** sp. 1 (ANIC) and **Rhytidoponera** sp. J.D.M. 121. Small numbers of **Gastrolobium microcarpum** (fluoroacetate producing) seed were recovered from two of five extracted ant nests.

Acknowledgements

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FURTHER NOTES ON EUCALYPTUS SPECIES OF THE PILBARA REGION, HAMERSLEY PLATEAU

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Introduction

In a previous paper germination characteristics of seven **Eucalyptus** species from the Pilbara Region were presented[1]. The present paper gives information on the response to fire of the same species plus a brief note on **Eucalyptus microtheca**. Reference collections are given in the previous paper for the seven species, that for E. **microtheca** is 4144. The plants examined were in stands within a study area of about 25 km radius of 118°40'E and 23°05'S. Supplementary observations in the Packsaddle (118°45'E, 23° S) and Munjina (118°50'E, 22°30'S) areas are included.

Eucalyptus dichromophloia (Bloodwood)

This species has two coloured flakey bark which endows it with fire resistance. The crown is also capable of regeneration. It is a frequent tree along drainage lines of little or spasmodic flow with **E. patellaris, Acacia aneura, A. pruinocarpa** and also higher up the banks of major channels where **E. camaldulensis** occurs. It is not confined to valley sites and is also found on slopes dominated by **Triodia** grasslands with **E. setosa**. It reaches greatest size (over 20 m tall) in flood plains of mulga lined valley systems. Seedling regeneration is occasionally seen after fire. Fruiting is spasmodic and seed production is far from regular. Fruit numbers taken from three trees used to estimate seed load are reported in Table 1. Seeds per fruit from Tree Two are given in Table 2.

Table 1. Fruit and Seed Load Estimate Eucalyptus dichromophloia

Tree number	1	2	3
Crown Diameter N-S (m)	19.6	4.7	2.65
E-W (m)	15.8	4.8	3.2
Height (m)	c.20	7.21	4.65
Stem diameter (cm)	41.3	9.1	7.85
No. of fruit collected	2149	640	354
Percentage of fruit load	15	50	100
Size of fruit (mm)	15	13	15
Seeds per fruit (mean of 10)	7	7.1	3.2
Size of seed (mm)	8.4	8.1	7.5
Weight of seed + frass (g)	13.1	10.97	6.26
Estimated whole tree wt (g)	87.33	21.94	6.26

Mean dimensions are 17.8 mm for fruit and 8.1 mm for seed.

The seed is comparatively large and winged.

Table 2. Seed Dimensions per Fruit Tree 2 E. dichromophloia

Fruit	Size (mm)	No. Seed	Seed Size (mm)
1	18	7	9.00
2	17	7	8.75
3	18	5	7.00
4	19	8	8.25
5	17	3	8.00
6	18	10	8.00
7	19	6	7.50
8	18	12	8.00
9	16	4	8.50
10	18	9	7.75

The average seed weight is 8.54 mg with 117 seed per g. Germination tests in seed trays gave a yield of 88 per g or 75 per cent germination from fresh seed. Germination tests at different temperatures on perhaps rather stale seed, taken from old fruit and stored for three months gave the values presented in Table 3.

Table 3. Germination Values for Eucalyptus dichromophloia

Measurement	Temperature (°C) 10	15	20	25
Percentage germinated	12	18	25	19
Germination capacity (28)	10	18	25	19
Time to completion	31	28	20	20
Germination rate	23	18	9	7
Mean daily germination	0.4	0.7	1.3	1.0

Viability of these seed was low, with 17 and 20 per cent recorded from two tests. Lower temperatures depressed and prolonged the rate of germination.

Eucalyptus gamophylla (Twin-leaved Gum)

This mallee is widely distributed and is particularly common on mid slope locations with Triodia pungens. Associated trees and shrubs include Acacia aneura, A. pruinocarpa, A. victoriae, Eucalyptus leucophloia and E. oleosa.

The largest specimen measured was 7.85 m tall with a crown of 5.15 m and three stems with diameters of 9.0, 12.6 and 9.8 cm.

Burnt clumps regrow from the lignotuber base and seedlings are scarce. Fruits are whitish grey with a surface indumentum and are borne in large clusters. Measurements of 10 fruits are given here in mm: 13, 12, 16, 15, 14, 14, 14, 13, 14, 11 that is mean 13.6 mm SD 1.4.

From these an average of 6 seeds were obtained, mean length of 5.5 mm. Three complete clumps were sampled for fruit and the seed load is shown in Table 4.

Table 4. Fruit and Seed Load Estimate Eucalyptus gamophylla

Tree number	1	2	3
Crown Diameter N-S (m)	1.8	6.3	6.7
E-W (m)	1.9	9.1	9.1
Height (m)	2.52	5.27	4.27
Stem diameter (cm)	3.55	6.7+5.5	5.3
No. of fruit collected	757	2879	2133
Percentage of fruit load	100	20	25
Size of fruit (mm)	15	12.6	14.4
Seeds per fruit (mean of 10)	3.8	6	8
Size of seed (mm)	4	6.6	3.25
Weight of seed + frass (g)	14.93	31.45	31.56
Estimated whole tree wt (g)	14.93	157.25	126.24

(note tree 2 fruit from 2 stems, another 2 stems of 8.7, 7.7 cm d; tree 3 another 3 stems 5.5, 5.3, 4.2 cm d.)

The seed is comparatively small, average weight 2.36 mg with 424 per g. A total of 206 germinants from 1 g of seed were recorded with seed tray testing representing a germination percentage of 48.6 percent. This is not dissimilar to the average viability of 44 per cent in germination tests at four different temperatures (Table 5) where seed were counted out into petri dishes.

Table 5. Germination Values for Eucalyptus gamophylla

Measurement	Temperature (°C) 10	15	20	25
Percentage germinated	36	40	50	50
Germination capacity (28)	36	40	50	50
Time to completion	20	16	12	8
Germination rate	12	9	7	5
Mean daily germination	1.8	2.5	4.2	6.3

Lower temperatures prolonged and depressed the rate of germination and there was an increase in the rate of germination through the range of temperatures used.

The measurements given in Table 6 were taken in an area burnt 22 months earlier.

Table 6. Regrowth of Eucalyptus gamophylla

Status	No.	Height (m)	Crown (m)	No. of stems
Root regrowth	1	2.36	2.45	17
	2	2.10	2.90	21
	3	2.42	1.95	14
	4	2.05	1.77	13
	5	1.41	1.40	5
	6	2.30	2.40	16
	$\bar{X}$	2.11	2.15	14.3
	SD	0.37	0.54	5.4
Seedlings	1	1.05	0.68	-
	2	0.98	0.65	-
	3	0.68	0.69	-
	4	1.05	1.62	-
	5	1.12	0.82	-
	6	1.13	0.54	-
	7	0.31	0.20	-
	$\bar{X}$	0.90	0.74	-
	SD	0.30	0.43	-

Seedling survival in an area of regenerating mallee clumps is likely to be low over time and the initial growth suggests that few seedlings will be recruited into stands.

Eucalyptus kingsmillii

Eucalyptus kingsmillii is predominantly a higher altitude species mainly occurring at the top of hills or ridges. This species is also a mallee with a number of stems spreading out from a root base. It regrows from the root base when damaged by fire. The measurements given in Table 7 were taken on a hill top.

Table 7. Fruit and Seed Load Estimate Eucalyptus kingsmillii

Tree number	1	2	3
Crown Diameter N-S (m)	3.63	7.5	4.7
E-W (m)	3.92	8.5	4.9
Height (m)	2.0	4.4	3.44
No. of fruit collected	406	646	1113
Percentage of fruit load	100	50	100
Size of fruit (mm)	17.1x24.9	16.9x23.7	15.8x26
Seeds per fruit (mean of 10)	3	12	6
Size of seed (mm)	2.5	2.1	2.8
Weight of seed + frass (g)	3.5	69.68	65.12
Estimated whole tree wt (g)	3.5	139.36	65.12

These plants were all mallees with a number of stems:

Tree 1 - 2.2, 2, 2.1, 1.9, 2.3, 1.8 cm stem diameters

Tree 2 - 4.1, 4.2, 7.2, 2.3, 3.9, 4.3, 5.2, 4.2, 4.0, 5.1, 4.1, 2.3, 5.0, 5.3 and 5.1 cm

Tree 3 - 4.2, 2.1, 4.1, 2.75, 3.6, 2.15, 2.8 and 2.55 cm.

Fruit of Trees 1 and 3 were badly affected by seed eating grubs.

On hill tops it is associated with **Triodia wiseana**, **Eucalyptus leucophloia**, **Acacia maitlandii** and **A. cowleana**. It is also found at lower elevations where it is, however, much less common. The small angular seed weighs about 1.29 mg, with 775 per g. In seed tray testing 124 germinants were obtained from 1 g representing a percentage germination of 16. Viability under laboratory conditions appears to be much higher as Table 8 suggests.

Table 8. Germination Values for Eucalyptus kingsmillii

Measurement	Temperature (°C) 10	15	20	25
Percentage germinated	92	100	100	94
Germination capacity (28)	72	100	100	94
Time to completion	45	26	16	25
Germination rate	21	10	8	11
Mean daily germination	2.2	3.9	6.3	3.8

These values suggest that **E. kingsmillii** may have a lower optimum temperature for germination than other eucalypts.

Eucalyptus leucophloia (Snappy Gum)

This is a widespread species inhabiting all but the driest and steepest areas in the region. It is prevalent around dry creek beds but is also common at the top of ridges and small hills. The tree has a distinctive white bark with black where old branch stubs occur. The crown is able to regrow after fire producing juvenile leaves but the stem, if burnt back, may not regrow from the base. However, some epicormic growth has been observed. Seedlings are noticeable in burnt areas after rain. **E. leucophloia** is found with a wide range of species amongst which its commonest associates are probably **Triodia wiseana** and **Acacia pruinocarpa**. The mistletoe **Amyema miquelii** is often found in the crown of **E. leucophloia**. Trees are stout though not very tall, with well developed boles in relation to the height.

The fruits are small and often abundant. Seed counts were made of sets of 4-5 fruits (Table 9).

Table 9. Seed count for E. leucophloia

No. Capsules Used	No. Seeds	Average capsule Length (mm)	Average number Seeds/Capsule
5	17	4.0	3.4
5	17	4.5	3.4
4	16	4.5	3.5
5	19	4.0	3.8
5	30	5.0	6.0

Seed weight is lowest of those eucalypts examined in detail, at 1.24 mg. There are 806 seeds per g and 338 germinants were obtained from 1 g in seed tray testing. This represents a germination percentage of 42 per cent. Under controlled temperature conditions in the laboratory germination was much higher (Table 10).

Table 10. Germination Values for Eucalyptus leucophloia

Measurement	Temperature (°C) 10	15	20	25
Percentage germinated	94	96	100	100
Germination capacity (28)	16	12	10	10
Time to completion	16	12	10	10
Germination rate	13	8	6	5
Mean daily germination	5.9	8.0	10.0	10.0

There is a consistent falling off in speed of germination with successively lower temperatures. At higher temperatures over 50 per cent of seed germinated within 5 days of moistening. Three trees were assessed for regenerative capacity as follows (Table 11).

Table 11. Fruit and Seed Load Estimate *Eucalyptus leucophloia*

Tree number	1	2	3
Crown Diameter N-S (m)	6.9	3.55	4.75
E-W (m)	4.8	2.45	3.9
Height (m)	7.1	4.67	5.02
Stem diameter (cm)	24.7	8.4	9.2+9.5+4.1
No. of fruit collected	2893	440	376
Percentage of fruit load	15	15	20
Size of fruit (mm)	3	3	3
Seeds per fruit (mean of 10)	2	2	2
Size of seed (mm)	0.4	0.4	0.4
Weight of seed + frass (g)	1.52	1.60	1.68
Estimated whole tree wt (g)	10.13	10.67	8.40

A seedling of 0.60 m height was recorded in an area burnt 22 months earlier.

Eucalyptus microtheca (Coolibah)

This species is restricted to flood plains and banks where it grows in association with **A. aneura, A. citrinoviridis** and **Eucalyptus camaldulensis**. It is difficult to distinguish from the latter as both have white bark.

Small trees are uncommon. Sites where coolibah occurs are not susceptible to fire under natural conditions. However, strong epicormic growth on floodfallen individuals suggests that it could possibly regrow after fire. Seedlings are uncommon except after flooding.

The measurements given in Table 12 were taken of four trees on a river bank.

Table 12. Size and spacing **E. microtheca**

Tree	Height (m)	Crown (m)	Stem diameter (cm)	Distance to next tree (m)
1	12.86	7.4	37.60	24.9
2	14.06	6.3	27.10	40.6
3	15.46	7.1	29.95	18.9
4	13.26	9.0	28.65	

Eucalyptus oleosa v.oleosa (Giant Mallee)

This mallee species is locally common in a variety of habitats e.g. stoney hillsides, lower valley slopes and rocky creeks. It is distinguished by brown, shining, thin bark. Common associates include **Eucalyptus gamophylla, Triodia pungens, A. aneura, A. pruinocarpa.**

This species is adapted to fire and will regrow from root stocks. Seedlings are decidedly uncommon yet most trees always carry fruit. Presumably seed dispersal is also associated with the heat of a fire, though fruits do not persist on the stems beyond the 4th year. The estimates of seed load per 'tree' were made on three plants (Table 13).

Table 13. Fruit and Seed Load Estimate **Eucalyptus oleosa**

Tree number	1	2	3
Crown Diameter N-S (m)	5.1	3.8	6.8
E-W (m)	5.7	3.2	6.3
Height (m)	4.57	2.64	4.87
Stem diameter (cm)	4.8+6.6*	4.7+4.5*	4.4+6.0*
No. of fruit collected	1682	207	354
Percentage of fruit load	30	40	18
Size of fruit (mm)	5.9	5.8	5.8
Seeds per fruit (mean of 10)	8	8	10
Size of seed (mm)	1.25	1.3	1.2
Weight of seed + frass (g)	9.65	9.33	13.64
Estimated whole tree wt (g)	32.17	23.33	75.78

* These are mallees, fruit taken from the stems given above. In addition other stems for Tree 1 were 4.5, 5.1, 6.4, 6.5 cm d; Tree 2 - 4.3, 6.2, 5.8 cm d; Tree 3 - 4.3, 3.5, 2.6, 3.9, 3.8, 4.3, 3.7, 3.3, 3.2 cm d.

The seed is small (1.3 mg) and rounded. At 769 per g 420 germinants were obtained in seed tray germination representing 55 per cent. In laboratory conditions germination is much higher with a marked diminution in the rate of germination with decreased temperature.

Table 14. Germination Values for **Eucalyptus oleosa** (means of 4 sample sets)

Measurement	Temperature (°C) 10	15	20	25
Percentage germinated	98	97	100	100
Germination capacity (28)	94	97	100	100
Time to completion	36	19	18	22
Germination rate	15	10	8	6
Mean daily germination	2.7	5.1	5.6	4.5

Eucalyptus patellaris (Weeping Box)

This eucalypt tends to be a creek oriented species and occurs mainly around dry creek beds and their flood plains. In some localities it is found in association with Eucalyptus dichromophloia. It is a tall spreading tree from 6-12 m in height. Three trees of a range of sizes were sampled for fruit load (Table 15).

Average seed weight is 2.13 mg with 469 per g. In seed tray testing 214 germinants were obtained from 1 g giving a percentage of 46. Two separate tests are combined in Table 16, seed from the two lots gave 58 and 76 per cent germination under laboratory conditions.

Table 15. Fruit and Seed Load Estimate Eucalyptus patellaris

Tree number	1	2	3
Crown Diameter N-S (m)	2.4	2.9	8.35
E-W (m)	2.2	2.2	9.4
Height (m)	3.41	5.06	8.40
Stem diameter (cm)	5.2	8.3	14.2
No. of fruit collected	159	2517	567
Percentage of fruit load	100	100	12.5
Size of fruit (mm)	6.6	7.5	7
Seeds per fruit (mean of 10)	7	5	4
Size of seed (mm)	1.5	1.4	1.5
Weight of seed + frass (g)	2.41	17.5	3.94
Estimated whole tree wt (g)	2.41	17.5	31.54

Table 17. Dimensions of Eucalyptus patellaris at various stages of growth after fire

Site	Height (m)	Crown (m)	Number of Stems	Average Stem Diameter (cm)	Distance to next E. patellaris (m)
Unburnt for at least 5 years	4.92	6.8	11	6.5	24.3
	6.0	4.4	2	9.8	30.5
	5.0	3.3	9	5.7	21.5
	5.92	4.7	3	12.7	9.8
	3.54	1.95	3	2.5	5.1
	3.42	4.5	8	6.2	-
$\bar{X}$	4.80	4.28	6.0	7.2	NA
SD	1.12	1.61	3.8	3.5	
Burnt 25 months earlier growth from rootstock	1.72	1.50	2	1.3	19.5
	2.24	1.73	15	1.4	13.2
	2.85	3.00	4	2.8	14.0
	2.35	3.70	4	2.1	4.9
	2.85	1.20	5	2.5	8.7
	2.58	2.00	8	2.7	-
$\bar{X}$	2.43	2.19	6.3	2.1	NA
SD	0.43	0.96	4.7	0.7	
Burnt 24 months earlier growth from rootstock	2.60	2.80	2	NA	NA
	3.20	3.20	10	-	
	3.20	2.90	5	-	
	2.10	2.90	5	-	
	2.55	2.80	10	-	
$\bar{X}$	2.73	2.92	6.4		
SD	0.47	0.16	3.5		
Seedlings after 24 months	0.78	0.38	NA		
	0.50	0.13	-		
	0.81	0.24	-		
	0.73	0.31	-		
	0.79	0.33	-		
	0.52	0.20	-		
	0.44	0.15	-		
	0.98	0.48	-		
$\bar{X}$	0.69	0.28			
SD	0.19	0.12			

Table 16. Germination values for *Eucalyptus patellaris*

Measurement	Temperature (°C) 10	15	20	25
Percentage germinated	64	69	73	63
Germination capacity (28)	56	69	73	63
Time to completion	48	26	20	16
Germination rate	18	12	8	7
Mean daily germination	1.3	2.7	3.7	3.9

E. patellaris appears to be relatively insensitive to temperature in respect of germination response, compared with many other eucalypts.

A number of measurements have been taken from different regrowth stands. These are summarised in Table 17.

The main response to fire is a complete burning back of the pre-existing tree, leaving stumps and partially burnt boles. Regrowth is then vigorous from ground level with taller trees probably able to resprout in the crown. At the time of the measurements given the regrowth from root stock was already showing dominance by one outstanding stem. This suggests that a mallee form would not result and that the 'single stem' form would resume. However it must be noted that a number of large **E. patellaris** clumps occur in floodplain sites, with abundant **Triodia pungens**, which appear to have a common underground root system. It is possible that these have resulted from past burning.

Eucalyptus setosa (Rough-leaved blood wood)

This is a medium sized well branched often crooked tree. The largest tree measured was 7.5 m tall, crown 7 m and stem 33 cm diam. The bark is rough with thick scaley plates, rendering the tree somewhat fire resistant. It occurs in a variety of habitats from valley edges through lower slopes and plains extending into fairly steep hilly country. However, it is usually absent on the higher hills and steeper slopes. The tree is often as tall as its crown is broad, as the measurements from a low ridge show in Table 18.

Table 18. **E. setosa** dimensions

Height (m)	Crown (m)	Stem diameter (cm)
4.20	4.10	6 (2 stems)
3.10	3.90	8
3.80	4.00	14
4.30	6.00	11 (5 stems)

Response to fire varies. Very few small trees are seen suggesting that in **Triodia pungens**, **Triodia basedowii** grasslands it may be fire sensitive as a small tree. The larger trees appear to scorch and regrow from burnt crowns. One or two cases of regrowth from rootstock have been observed. Seedlings are also uncommon.

Table 19 summarises estimates of fruit and seed load on five different individuals.

Table 19. Fruit and Seed Load Estimate *Eucalyptus setosa*

Tree number	1	2	3	4	5
Crown Diameter N-S (m)	4.1	2.23	3.8	3.35	6.9
E-W (m)	3.9	3.1	2.6	3.3	7.5
Height (m)	3.27	2.6	3.5	2.34	7.13
Stem diameter (cm)	1.7+9.2	5.2+5.4	14.6	8.6+6.2	16.2
No. of fruit collected	1572	772	1321	1642	4385
Percentage of fruit load	100	100	100	100	100
Size of fruit (mm)	12	12	13	13	12.1
Seeds per fruit (mean of 10)	3.7	4.0	4.0	4.0	3.6
Size of seed (mm)	7	7	7.1	7.1	7.0
Weight of seed + frass (g)	9.34	6.78	9.84	11.91	39.08
Estimated whole tree wt(g)	9.34	6.78	9.84	11.91	39.08

The seed is winged and takes up considerable space in the fruit. Seeds per fruit on these trees were rather less than for another collection (Table 20).

Table 20. Seed count for E. setosa (one tree)

Capsule length (mm)	No. Seeds	Average seed length (including wing)(mm)
16	7	7.7
14	7	6.7
14	9	5.1
15	9	6.6
15	7	6.4
14	10	6.5
15	5	7.6
15	4	7.8
13	4	6.5

Average seed weight is 6.13 mg with 163 per g. In seed tray testing 1 g gave 154 germinants or 95 per cent germination. This level was also attained with temperature experiments under laboratory conditions (Table 21).

Table 21. Germination values for Eucalyptus setosa

Measurement	Temperature (°C) 10	15	20	25
Percentage germinated	90	96	96	90
Germination capacity (28)	90	96	96	90
Time to completion	17	14	14	4
Germination rate	12	7	4	4
Mean daily germination	5.3	6.9	6.9	22.5

Germination was particularly rapid at 25°C with all germinants recorded within 4 days of moistening the seed. The results suggest that 20–25° contains the optimum range for this species.

Acknowledgements

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Reference

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RECOLONIZATION BY INVERTEBRATES IN REHABILITATED MINERAL SAND MINES AT CAPEL, SOUTH-WEST WESTERN AUSTRALIA

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Summary

This paper describes an investigation of invertebrates, and particularly ants, colonizing sand-mined areas at Capel, Western Australia. This is in a relatively moist area, so the data provide an interesting comparison with similar studies already performed in sand mines at Eneabba where rainfall is lower and in the bauxite mines in moist areas south of Perth.

Six sand mines and 2 woodland controls were investigated. The mines represented areas rehabilitated 3 - 15 years previously. With one exception these mines were rehabilitated to pasture with grazing introduced to some plots.

Rehabilitation was found to encourage a grassland invertebrate community of characteristic ant species composition, low ant species richness and low species evenness. One ant species was extremely abundant. In keeping with other grassland areas, the levels of certain Collembola (springtails) Coleoptera (beetles), Dermaptera (earwigs), Acarina (mites) and Araneae (spiders) were also high in the mined areas.

The build-up of ant species richness was only partly linked to time since rehabilitation and the return rates were lower than those in the Eneabba sand mines and in the bauxite mines where rehabilitation to native vegetation is, in part, practiced. Comparison of the results of this study with those from the bauxite and Eneabba sand mines illustrates the importance of rehabilitation strategy to the type of invertebrate fauna which colonizes the area.

Introduction

Mineral sand mining is currently being performed in the vicinity of Capel, in the south-west of Western Australia, by three mining companies.

The heavy mineral deposits are situated 5-6 km inland and represent material laid down on beaches during the late Pleistocene [10]. The growing season of this, now inland, area lasts from early-May to mid-October and the annual rainfall is 873 mm. Mean monthly maxima and minima range from 16.8 - 27.6°C and 8.2 - 15.1°C respectively.

The area which is being mined comprises part of the Forests Department Ludlow pine plantation, some cleared arable land and the remainder is woodland of **Banksia** spp., Jarrah (**Eucalyptus marginata**), marri (**Eucalyptus calophylla**) and peppermint (**Agonis flexuosa**). Some **Melaleuca** sp./sedge swamps are also being mined.

Prior to mining the vegetation is cleared and burnt and, in recent times, the topsoil is stripped and stored. The deposit is then mined by the open-cut method and the minerals separated by a wet gravity process [10]. The silica sand tailings are then pumped to mined out areas for back filling. The finer clay slimes are either mixed with the tailings or spread over the surface of the tailings and then ploughed in.

Following the return of residue to the mines a lime (at the A.M.C.L. mine only) and fertilizer treatment is added and appropriate cover crop is applied. This may be cereal rye (**Secale cereale**), Wimmera rye (**Lolium rigidum**), Veldt grass (**Ehrharta calycina**), Tama rye (**Lolium perenne**), oats (**Avena sativa**), sub-clover (**Trifolium subterraneum**), lupin (**Lupinus** spp.) or serradella (**Ornithopus compressus**). Sheep or cattle may be introduced at a later stage as they are believed to accelerate development of the soil. In addition to the pasture rehabilitation option some other areas are being rehabilitated as tuart (**Eucalyptus gomphocephala**) plantations or as artificial wetlands.

The benefit of the early return of invertebrates to mined lands has already been discussed elsewhere[2,3,7]. Studies on invertebrate, and particularly ant, return have already been performed in Western Australian bauxite mines at Jarrahdale/Del Park[3,5] and sand mines at Eneabba.[7] Most of the mines in these areas have been rehabilitated to native vegetation.

Comparison of the Eneabba (mean annual rainfall 550 mm) with the Jarrahdale/Del Park (mean annual rainfall 1155-1287 mm) data revealed that the return of ant species approached linearity over the first 3 - 5 years with 6 and 10 species respectively being established after 3 years at Eneabba and Jarrahdale/Del Park. Majer et al.[7] attributed these differences to the characteristic rainfall, temperature and growing season at these sites. Since the ant fauna provides an effective bio-indicator of other invertebrates and, to some extent, the botanical and physical environment, it was argued that ecosystem recovery was proceeding in a slower, climate-mediated manner at Eneabba than in the bauxite mined areas. Alternatively these results could be explained in terms of difference in soil types.

In view of these 2 possible explanations it was considered that a study of ant colonization in the sand mines further south in Western Australia, where the climate is closer to that of the bauxite mines, might answer the question about what factors influence ant return.

An additional aim of this investigation was to assess the rate of invertebrate return in mined areas at Capel and relate this to site factors and rehabilitation methods with a view to elucidating factors which maximize invertebrate return.

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Methods

The work was performed in areas mined by Associated Minerals Consolidated Ltd. (A.M.C.L.) and Westralian Sands Ltd (W.S.L.). Wherever possible the measurements were performed in an identical manner to that performed at Eneabba.

Study Sites

Six rehabilitated plots and 2 woodland controls were selected. Their characteristics are briefly summarized below:

Control 1 - This was a remnant area of flooded gum (**Eculayptus rudis**) and marri woodland situated adjacent to a river in the A.M.C.L. mine. The area had probably been grazed at some time as the impoverished native flora was partly replaced by non-native grasses. The area was adjoined on all sides by mines and bulldozers were seen driving through the woodland.

Control 2 - Another remnant area of woodland adjoining the W.S.L. mine. Part of the area was currently grazed by cattle and extensive areas of non-native grasses were present.

Mine 1 - Situated in A.M.C.L. mine and rehabilitated in 1967. Topsoil was returned to the surface and grasses were seeded. Grazing commenced 2 years later.

Mine 2 - Situated in W.S.L. mine and rehabilitated in 1972. Topsoil was returned to the surface and grasses were seeded. Grazing commenced 2 years later.

Mine 3 - Situated in A.M.C.L. mine, filled with tailings and then covered to a depth of 30 cm with slimes in 1976. The area was seeded with grasses and planted with trees. Grazing was introduced in 1981.

Mine 4 - An A.M.C.L. mine treated identically to Mine 3 except that slimes were not spread over the surface.

Mine 5 - A W.S.L. mine which was filled with tailings in 1977 and revegetated with sown grass and planted trees.

Mine 6 - This A.M.C.L. mine was filled with tailings and then covered in slimes to a depth of 2 m in 1978. In 1980 the area was revegetated by planting tuart in a grid pattern. At the time of sampling the trees were about 3 m tall and this was the only mine plot in which trees were conspicuous; all other mine plots were predominantly grassy.

Site Measurements

A 100 m transect was established through a representative area of each mine and control plot. Wire flags were placed at 5 m intervals along each transect. This provided the location for all subsequent measurements which were performed during February 1982.

Soil bulk density was measured by taking 10 soil cores (6 cm diameter, 8 cm deep), drying the soil to constant weight, weighing and then dividing the soil mass in g by soil core volume in cm3. The data were also used to calculate percentage soil moisture.

At each of the 10 intercepts, recordings were made of soil pene-trability using a Proctor penetrometer. The plunger was pressed into the soil to a depth of 5 cm.

Ten 1x1m square quadrats were placed out at 10 m intervals along the quadrat and a visual estimate of both percentage live vegetation cover and dead grass cover made. An assessment was also made of plant species richness in the plots by counting the number of plant species which could be found in a 30 minute period.

Invertebrate Sampling

Two complementary sampling methods were utilized to survey the ants.

(a) Twenty pitfall traps, consisting of 18 mm internal diameter Pyrex test tubes containing 5 ml of alcohol/ glycerol (70/30 v/v), were installed along each plot transect. Traps were operated for 7 days from 9th February 1982. Further details of the design and performance characteristics of this type of trap are given in Greenslade and Greenslade[1] and Majer[2].

(b) Hand collections were performed in each plot for 1 man-hour during daytime and 0.5 man-hours at night. Collections were made between 8th and 20th February 1982.

The collections from (b) were used to augment those obtained by pitfall trapping.

Invertebrates were sorted and counted to the order or family level. The ants were sorted and, where possible, identified to species level. Many species are not yet named. In such cases, they are either coded with Western Australian Institute of Technology (J.D.M.) code numbers or, if voucher specimens are deposited there, with Australian National Insect Collection (ANIC) codes. A full collection of voucher specimens, labelled "Capel Collection", is housed at the School of Biology, Western Australian Institute of Technology.

Data Treatment

The transect means for all physical and vegetation recordings were calculated. A mean of the 2 control plot values was also calculated in order to provide a reference point against which to compare the mine plot measurements.

A checklist of ants for each plot was obtained by combining the collection data obtained from the 2 sampling methods. The total number of species obtained from each plot is referred to as ant species richness. The pitfall trap samples afforded some quantitative information on the abundance of individual species, although the catch was biased by the relative activity of species[9]. However, they were considered to provide an approximate representation of ant community compostition, and accordingly the Shannon and Weaver[8] diversity index (H1) was calculated using the pitfall trap ant data. This was obtained using the formula.

$$H^1 \text{ (decits)} = (N \log N - \sum_i ni \log ni)/N$$

where N = total number of individuals and ni the importance value of the ith species. The ant diversity index was also used to calculate the ant evenness index (J1). This is the equitability of the apportionment values among each species in each plot, and was obtained by the formula

$$J^1 = H^1 (decits)/\log S$$

where S is the total number of species in the pitfall traps.

The total number of invertebrates in each taxon for the 20 pit- fall traps was also obtained.

Results

Table 1 shows the means and, where appropriate, standard deviations of the plot physical and vegetation factors.

The most noticeable feature of the mine plots was the lack of trend with time for most physical and vegetation factors.

The youngest two mine plots (mine 6 and 5) exhibited the highest soil bulk density factors. This may have reflected the compacted nature of the recently returned sand or, at least in mine 6, that the surface slimes had a higher bulk density than the larger particle sized sand. The bulk density values of the older mine plots (>6 years old) ranged from 1.1 - 1.3 g cm-3 and differed little from those of the control plots (Table 1).

Soil penetrability and moisture values varied greatly between the mine plots although, in most cases, they fell within, or close to the range of, the control plots. The one exception was mine 6 which had higher soil moisture values and lower penetrability values than any other plot (Table 1). This was probably caused by the surface layer of soft, water-holding slimes. Soil bulk density was negatively correlated with soil moisture ($r = -0.82$, $p < 0.05$)

Once again, no clear time trend existed with any of the 3 measured vegetation factors (Table 1). Dead grass cover was similar to that of the control plots in 3 of the mine plots. The lower values in mines 1 and 2 were probably due to grazing and, in mine 6 with the fact that trees were established here rather than grasses.

The amount of live plant cover was low in all plots and differed little from the control plots (Table 1). The low value in mine 6 did not include the tree strata which covered approximately 25 per cent of the area. Tree cover values were not included in the control plot measurements either.

Plant species richness values were lower in all mine plots than control plots. The elevated values in mine plots 6 and 5 may have been associated with the absence of grazing (Table 1).

Table 2 shows the total ants of each species collected in the 20 pitfall traps. The hand collections added no additional species to the pitfall trap list.

Eighteen species of ant were encountered in this study. Of these, 12 were found in the mines, 15

TABLE 1 Mean and standard deviation (in brackets) values for plot physical and vegetation factors.

	MINE 6 (3yr)	MINE 5 (5yr)	MINE 3 (6yr)	MINE 4 (6yr)	MINE 2 (10yr)	MINE 1 (15yr)	CONTROL 1	CONTROL 2	CONTROL X̄
Time since rehabilitation (years)	3	5	6	6	10	15	-	-	-
Soil bulk density (g cm-3)	1.6 (0.1)	1.5 (0.1)	1.3 (0.1)	1.1 (0.2)	1.3 (0.1)	1.2 (0.1)	1.2 (0.2)	1.4 (0.1)	1.3
Soil penetrability (KPa)	251 (65)	484 (232)	582 (263)	672 (150)	530 (150)	623 (189)	>900 (-)	558 (171)	>729
Soil moisture (%)	7.5 (2.2)	0.7 (0.3)	1.1 (0.7)	5.1 (3.1)	2.7 (2.1)	0.9 (0.6)	4.2 (3.2)	0.3 (0.2)	2.3
Dead grass cover (%)	13 (18)	48 (9)	69 (23)	75 (9)	26 (13)	24 (18)	87 (18)	72 (22)	79.5
Live plant cover (%)	1 (1)	6 (4)	4 (4)	1 (2)	5 (3)	8 (5)	3 (3)	4 (4)	3.5
Plant species richness	7	6	3	4	4	3	15	13	14

TABLE 2 Total ants collected by 20 pitfall traps from each study area. The calculated ant community parameters are also shown.

SPECIES	MINE 6 (3yr)	MINE 5 (5yr)	MINE 3 (6yr)	MINE 4 (6yr)	MINE 2 (10yr)	MINE 1 (15yr)	CONTROL 1	CONTROL 2
PONERINAE								
Brachyponera lutea								4
Rhytidoponera inornata	1						1	
R. violacea						187	140	120
MYRMICINAE								
Cardiocondyla nuda		5	1	4	3		20	
Monomorium sp. 1 (ANIC)							92	
Monomorium sp. 2 (ANIC)			1					
Pheidole latigena		2	33	23	15	21	91	54
Tetramorium sp. JDM nov.					1			
T. sp. 9 (ANIC)							4	5
Meranoplus sp. 12 (ANIC)								4
FORMICINAE								
Camponotus sp. JDM 199								29
C. sp. JDM 110							10	
Melophorus sp. 1 (ANIC)	3	147	3		117	186	64	56
M. sp. JDM 117		2	21				14	18
DOLICHODERINAE								
Iridomyrmex purpureus	2	58	2		35		172	
I. sp. JDM 9	2057	72	26	65	107	187	797	2422
I. nitidus			1					
I. sp. JDM 85 (*agilis* gp.)	435	85	14		13	35	11	
Ant species richness (S)	5	7	9	3	7	5	12	9
Ant species diversity (H^1)	0.21	0.62	0.71	0.31	0.58	0.59	0.65	0.22
Ant species evenness (J^1)	0.30	0.73	0.75	0.65	0.68	0.84	0.60	0.23

in the controls, six (Brachyponera lutea, Monomorium sp. 1 ANIC, Tetramorium sp. 9 (ANIC), Meranoplus. sp. 12 ANIC, Camponotus sp. JDM 199 and Camponotus sp. JDM 110), were confined to the control plots and three (Monomorium sp. 2 ANIC, Tetramorium sp. JDM nov. and Iridomyrmex nitidus) to the mine plots (Tables 2 and 3).

The ant species richness, diversity and evenness values for each plot are shown in Table 2. Control plot ant species richness was uncharacteristically low for natural ecosystems in Western Australia[4] and this probably reflects the highly disturbed nature of both these sites. Ant species richness was generally lower in the mine plots than the control plots although there was a slight increase with time up to 6 years. Thereafter there was no trend, or even perhaps a slight decline. This coincided with the introduction of grazing.

Neither ant species diversity nor evenness values showed a time trend or consistent difference between mine and control plots. The major reason for variations in these measures was the abundance of one ant species: Iridomyrmex sp. JDM 9. The abundance of this ant was negatively correlated with ant species diversity and evenness ($r = -0.78$, $p < 0.05$, $r = -0.95$, $p < 0.05$ respectively).

In Table 3 ant species are arranged by the year in which they were first found in mine plots. This is an attempt to place the ants in an order of colonizing ability. The Table indicates a fairly rapid initial colonization by species followed by progressively less species as time increases.

Table 4 shows the total number of invertebrates collected in 20 pitfall traps in each plot. The pitfall trap data indicates that ants were the most prominent fauna, followed by Collembola (springtails), Coleoptera (beetles), Dermaptera (earwigs), Acarina (mites) and Araneae (spiders). A number of other taxa were also present in the mined areas in lower abundance. Consideration of these rankings should be tempered by the knowledge that pitfall traps sample fauna in proportion to their abundance, activity level and attractance to preservative Nevertheless, high numbers of the taxa mentioned above are characteristic of native ecosystems which have been colonized by exotic grass species [2,6]. There was little consistent difference, at the level these animals were scored, between mine and control plot. This may reflect the fact that the control plots were also heavily dominated by exotic grasses.

TABLE 3 Sequence of ant colonization in mined areas of increasing age.

Present after 3 years

Rhytidoponera inornata
Melophorus sp. 1 (ANIC)
Iridomyrmex purpureus
I. sp. JDM 9
I. sp. JDM 85 (agilis gp.)

Present after 5 years

Cardiocondyla nuda
Pheidole latigena
Melophorus sp. JDM 117

Present after 6 years

Monomorium sp. 2 (ANIC)
Iridomyrmex nitidus

Present after 10 years

Tetramorium sp. JDM nov.

Present after 15 years

Rhytidoponera violacea

Only present in control plots
6 species.

Discussion

The data on invertebrate colonization obtained by this study is chracterized more by the lack of trends than by clear-cut rehabilitation method/invertebrate return correlations. This probably reflects the varying substrates and agricultural treatments carried out in each area.

Comparison of mined area invertebrate levels with those of controls is also made difficult by the fact that the control plots were themselves highly degraded areas. While tree cover and understorey species richness were higher in the controls than the mines, the measurements of soil bulk density, soil penetrability, soil moisture, dead grass cover and live plant cover of mine and control plots were generally similar. This may explain why the variety of taxa present in the mines was similar to that of the control plots (Table 4).

The invertebrate fauna of the mine and control plots was highly characteristic of ecosystems dominated by grasses[2,6]. The Collembola and Acarina are mostly pasture species, obtaining nutrition from the abundant grasses and the Dermaptera are predators which are invariably common in Western Australian tall-grassland communities. The massive ant counts obtained in this study were largely caused by one species: Iridomyrmex sp. JDM 9. This is an omnivorous species which derives much of its nutrition from Homoptera-produced saps. It is probable that this species was directly benefitting from the abundant Homoptera which were associated with the grasses in the area. Such Homoptera would not have been sampled by the pitfall traps (Table 4).

This study has shown that the ant fauna of the mined areas had not attained the higher of the two control plot values. This partly results from the lack of variation in the habitat provided by pasture-type rehabilitation. The number of ant species per mine is plotted against time since rehabilitation in Figure 1. A curve has been fitted to the youngest 3 plots

TABLE 4 Summary of invertebrate fauna orders collected by pitfall traps from each study area. Numbers represent total individuals obtained from 20 traps.

CLASS	ORDER		MINE 6 (3 yr)	MINE 5 (5 yr)	MINE 3 (6 yr)	MINE 4 (6 yr)	MINE 2 (10 yr)	MINE 1 (15 yr)	CONTROL 1	CONTROL 2
Arachnida	Acarina		181		23	6		2		8
	Araneae		6	9	13	24		136	33	6
Crustacea	Isopoda					441				
Insecta	Collembola		14	20	490	68	149	3392	361	113
	Orthoptera:	Gryllidae	33			5			6	
		Acrididae		1	1	1				
	Blattodea			1			1	1	1	
	Dermaptera		42	15	16	61	10	25	131	
	Isoptera							1		
	Thysanura									3
	Mantodea				1					
	Homoptera		2			1		3		
	Heteroptera		3	1			4		4	
	Lepidoptera			21			2	3		
	Diptera			4	7	1	1	3	4	5
	Diptera Larvae				3					
	Hymenoptera:	Formicidae	2498	372	102	92	291	616	1418	2711
	:	Others	4	3	3	5	4	3		8
	Coleoptera :	Curculionidae	1		1		31	8	1	
	:	Carabidae	1	3		8	28		7	4
	:	Others	8	70	11	12	121	38	1	18
	:	Larvae			1		6	1	3	
	Total taxa in plot		12	12	13	13	12	14	12	9

with highest richness values in order to give an idea of the potential for ant return. Also shown on this graph are the fitted lines for the Eneabba sand mines (0-3 years) and Jarrahdale/Del Park bauxite mines (0-5 years). The Capel line indicates that lower ant species richness values are likely to be attained per unit time than at either of the other 2 sites. This is probably attributable to the fact that pasture has a more limiting effect on ant species return than does native vegetation. The current study has therefore yielded no useful information for deciding whether climate or substrate caused the differences in ant return at Eneabba and Jarrahdale/Del Park. What has become clear from this study, however, is that rehabilitation strategy has a marked influence on the type of invertebrate fauna which colonizes a mined area.

The lower ant species richness in the 10 year, 15 year and 1 of the 6 year old mine plots (Figure 1) may well be associated with cattle grazing in these areas. In a survey of ants in pasture and forest at Dwellingup, Western Australia, Majer[2] found that ant species richness was reduced in pastures and that this was probably associated with trampling by cows as well as by habitat simplification. The heavy loss of pitfall traps by trampling in the present study supports this suggestion.

To conclude then, rehabilitation at Capel is producing an invertebrate fauna characteristic of agricultural land. It differs from that of the native vegetation in terms of its ant species composition, its low ant species richness and evenness and by the abundance of many grassland associated invertebrates.

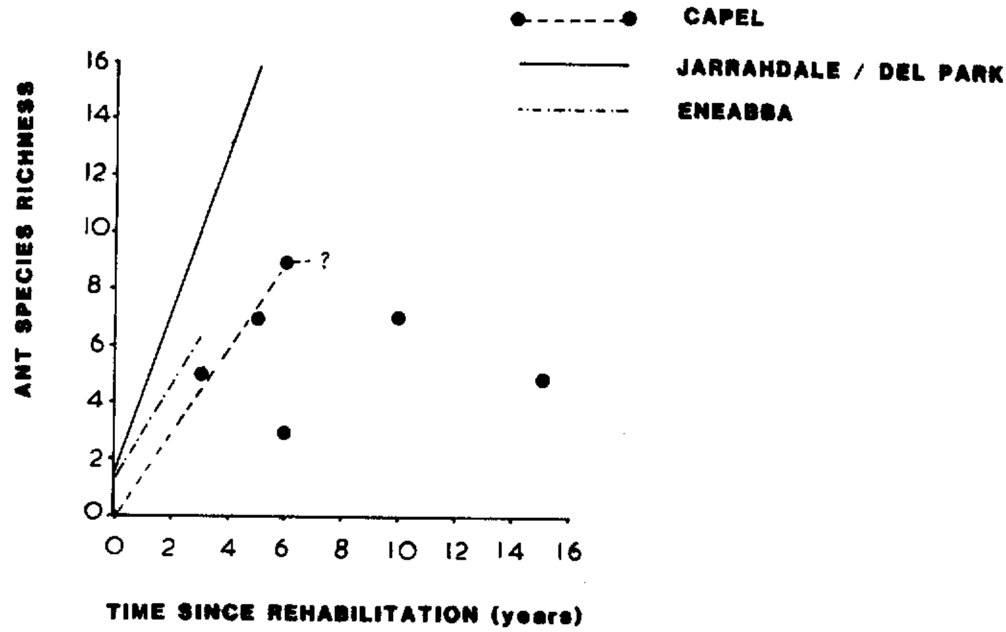

FIGURE 1 Relationship between number of ant species (richness) per rehabilitated plot and time since rehabilitation in the Capel sand mines. The fitted curve attempts to show the upper limits of ant return. The regression lines for the Eneabba sand mines (0-3 years) and Jarrahdale/Del Park bauxite mines (0-5 years) are shown for comparison.

Acknowledgements

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VEGETATION AND REACTION TO FIRE IN COASTAL HEATH AT SORRENTO, WESTERN AUSTRALIA

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Introduction

The Sorrento Recreation Reserve is located 27 km north of the mouth of the Swan River and 3 km north of Sorrento (Figure 1). A fence runs around the reserve perimeter. The Reserve is bounded by Flinders Avenue, West Coast Highway, Waterford and Angove Drive, Hillarys (31°50'S, 115°45'E). It occupies an area of 28 ha and was established in July 1952 for the purpose of recreation. The development of the reserve has been in the hands of the National Fitness council of Western Australia, the Youth, Community Recreation and National Fitness Council and currently the Department of Youth, Sport and Recreation. The area was classified as an 'A' Class Reserve in 1970. The development of facilities has included watering of grassed areas and the formation of tracks and firebreaks. In contrast the land to the north adjacent to the reserve is in a more or less natural state. It is currently zoned Special Development A and owned by the Whitford Beach Pty. Ltd.

A set of semi-permanent strip plots was laid out in May 1980 to contrast the effects of watering grassed areas on adjacent natural vegetation with controls away from the direct influences of watering. Concern had been expressed by the Department of Youth, Sport and Recreation that excessive growth of the bush could create a fire hazard. In March 1981, a wild fire swept through the coastal dune heath to the north and adjacent to the Sorrento recreation camp reserve.

It was a particularly hot fire and razed the vegetation completely. This was the first fire after a partially controlled burn of the area by the Shire of Wanneroo in February 1973.

The reserve area was not burnt, except for a localised area in the north-west corner and at one or two points along the northern fence. Between October 1981 and October 1982 students from the School of Biology at WAIT have visited the burnt area to monitor and assess the regeneration pattern of the vegetation. The aim of this study is to document the regeneration pattern and to use this towards assisting in the development of management plans for the reserve.

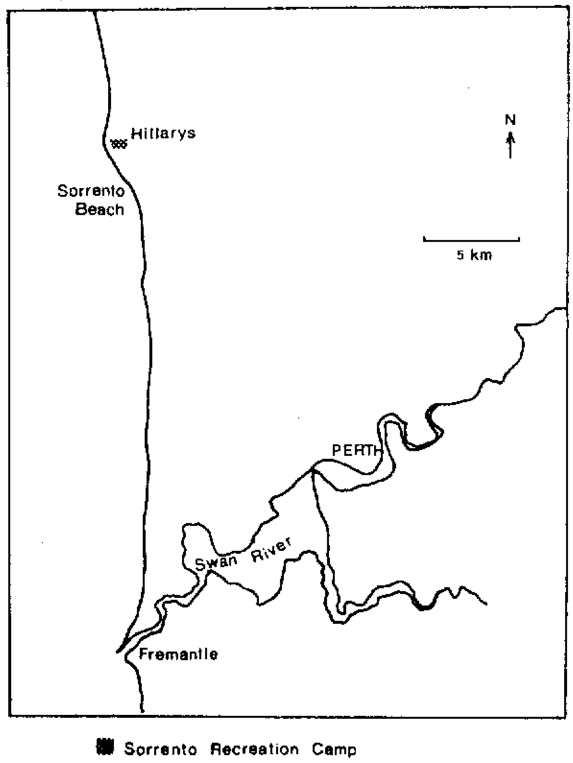

Figure 1 Location map showing study area at Hillarys in relation to the Swan River.

General Description

Climate

The Perth area experiences a warm mediterranean climate with rain occurring in the cooler winter months - summers are hot and dry. The dry period extends from mid-October to the end of March. Temperature and rainfall measurements for the period January 1981 to December 1982 are shown in Figure 2. The mean annual rainfall recorded at Perth is 883 mm. The total rainfall at Wanneroo in 1981 was 773 mm and in 1982 was 790 mm.

The coastal region is subject to almost daily onshore winds (sea breezes) and during the winter months very strong winds from the west and south west. The variable onshore winds are significant in the development of "blowouts" in unstable sand dunes.

Physiography

The Sorrento area forms part of the Quindalup Dune System[8]. The Quindalup is the youngest dune formation in the coastal belt and is formed from both fixed and mobile sand dunes which trend north-south.

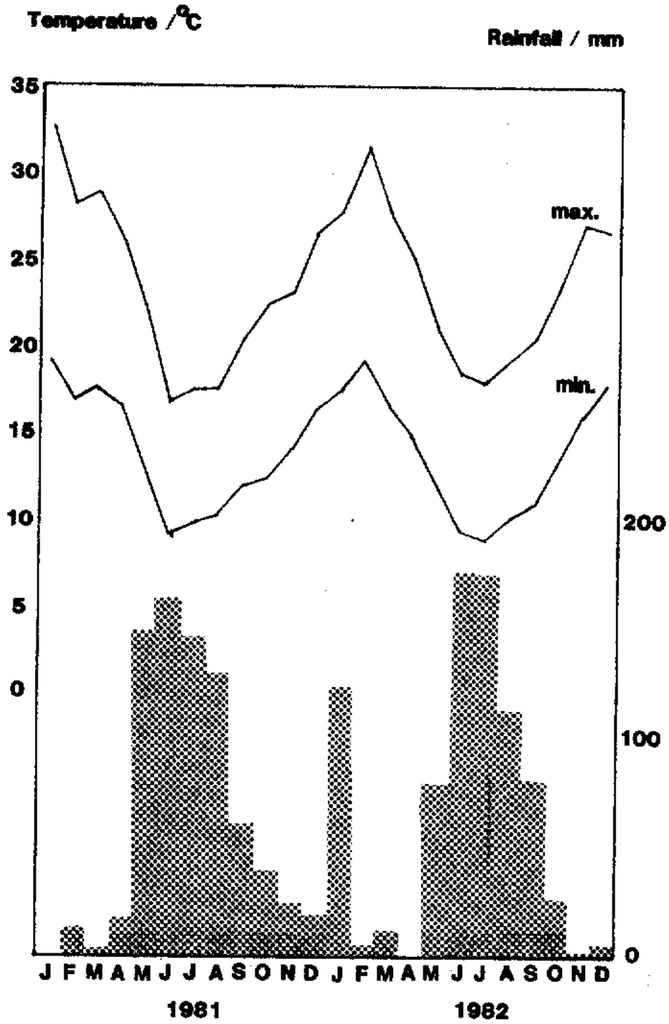

Figure 2 Meteorological data for the period January 1981-December 1982. Rainfall at Wanneroo, temperatures at Perth. (Source: Bureau of Meteorology Perth).

A diagrammatic representation of the coastal dune system is shown in Figure 3. The Sorrento reserve lies to the landward side of the highway in the region labelled 'stable dunes'.

Geology

The reserve lies within the Perth Basin. The Basin was formed towards the end of the Cretaceous when the continent was uplifted from the sea [2].

During the Pleistocene the sea level varied repeatedly, and in one of the interglacial stillstands of the sea level the sea threw up an enormous mass of calcareous beach sand some 10 km wide. The former sand dunes have become lithified to form "coastal limestone". On the seaward margin this is overlain by weakly consolidated or still mobile dunes deposited during the current sea level stillstand over the past 5 000 years[2].

Soils

In the Quindalup Dune System the chief soils are calcareous sands in the dunes with varied sand, loam, and clay soils in the swales [8]. Nearest the shore there is uniform carbonate throughout the profile while in the eastern part in lower horizons there is a concentration of carbonate and the beginning of cementation.

Vegetation of the Area

The vegetation communities in the region lie withing the Drummond Botanical District of Beard in which nine vegetation systems can be recognised.[2] Beards' Guilderton System is the vegetation of the Recent calcareous sands of the Quindalup Dune System from Fremantle northwards to Green Head.

The coastal dunes have also been defined as the Quindalup Complex by Heddle et al [7]. The following authors have also described the vegetation: Sauer [12], Seddon [13], after Speck [15], Smith [14] and Beard [2].

The vegetation is graded from the first colonizers above high water mark through sand binders to the stable dunes where more mature, diverse communities are found. Two ephemeral species, *Cakile maritima* and *Arctotheca populifolia* colonize the beach between high-

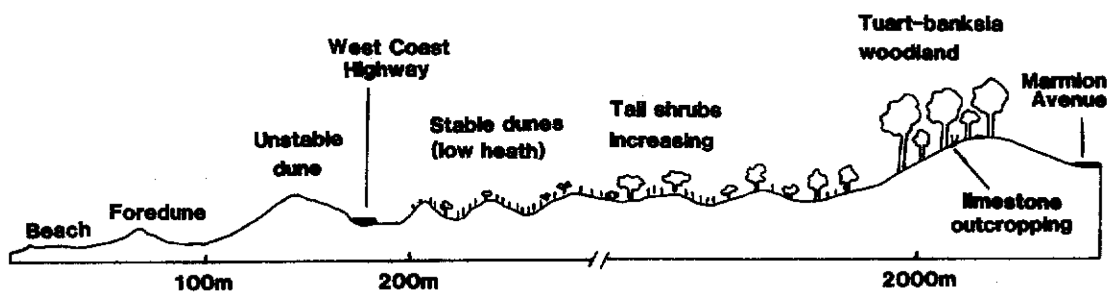

Figure 3 Diagrammatic representation of coastal dune systems eastwards from the beach at Sorrento.

water mark and the incipient foredune. The perennial grasses **Spinifex hirsutus** and **S. longifolius** and the introduced **Ammophila arenaria**, which grow rapidly after light sand burial, bind the incipient foredunes. Sheltered hollows and lower slopes are favoured by **Scirpus nodosus**, **Calocephalus brownii**, **Angianthus cunninghamii**, **Pelargonium capitatum** and **Spinifex longifolius**.

Towards the foredune crests the plant cover becomes closer and consists of **Tetragonia decumbens**, and the larger shrubs **Olearia axillaris**, **Myoporum adscendens**, **Acacia cyclops**, **Scaevola crassifolia** and large clumps of **Lepidosperma gladiatum**. These plants which remain low when exposed to salt-spray and wind become taller and more luxuriant on the sheltered lee slopes.

The characteristic dominants of the windward slopes of the stable dunes are **Olearia axillaris**, **Melaleuca acerosa**, and **Acacia lasiocarpa**. The low vegetation (about 1.25 m tall) is maintained by salt-pruning.

On the sheltered slopes of the dunes taller thickets develope mainly dominated by **Acacia** spp. in particular **Acacia rostellifera**. The creepers, **Clematis microphylla** and **Hardenbergia comptoniana** are common components. The climax is probably **Callitris preissii** although there are now only a few isolated remnants.[2]

The plant formations which comprise the study area are categorised by Beard as:

1. Heath - a closed layer of low shrubs under 1 m. An **Acacia lasiocarpa** - **Melaleuca acerosa** association on coastal Recent dunes.

2. Thicket - Closed shrubland over 1 m tall, with a community of wattle thicket (**Acacia rostellifera**).

A list of species recorded in the study area is given in Appendix 1.

Methods Used to Study the Vegetation

1. Unburnt Sites

A set of 16 semi-permanent strip plots were established within the Sorrento Recreation Area in May, 1980. Relative frequency, relative density, and relative abundance of species in 1 x 15 m plots were calculated. Seven of these plots were in "undisturbed" areas, and 9 plots were chosen such that the effect of lawn watering on the boundary vegetation could be assessed.

In September, 1982 a further twenty five 1 x 1 m quadrats were established along the Northern boundary fence in areas still in a state of natural vegetation (i.e. no lawn or artificially watered areas were included). Regions of swales, crest and slope were represented; their locations are given in Figure 4. A marker peg was placed in the south-east corner of each quadrat.

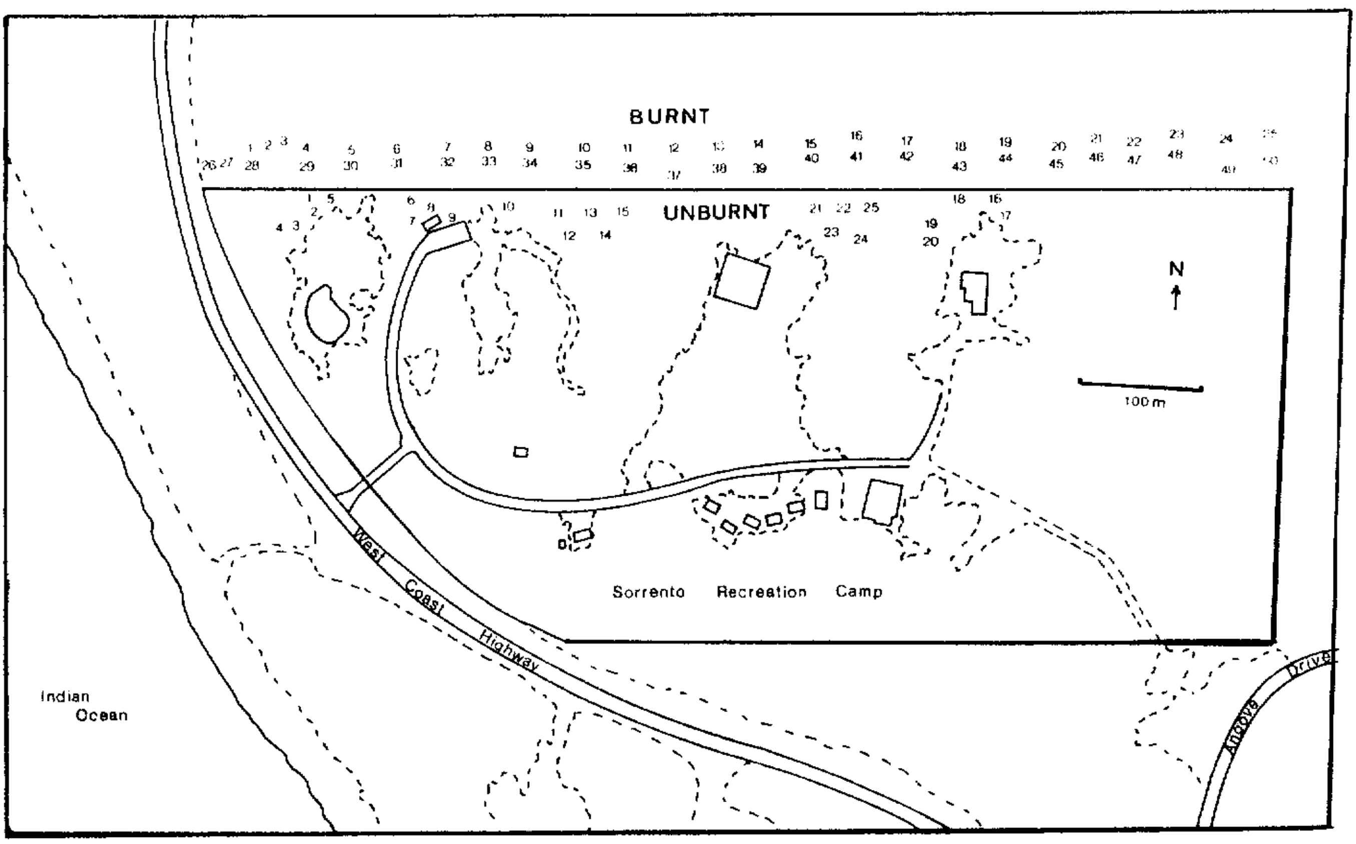

Figure 4 The study site at Sorrento showing location of 1 x 1 m quadrats inside the Sorrento Recreation Reserve and adjacent to the north.

2. Burnt Area

At 4 months after the fire (July 1981) an assessment of the extent of fire damage was made. Observations were made regarding species regrowth.

At 7 months after the fire (October 1981) a set of fifty 1 x 1 m quadrats was established. These lay outside and parallel to the northern boundary fence of the Sorrento Recreation Reserve.

These quadrats were placed in two half kilometre strips. Twenty five pegs were placed in a fairly regular pattern north of the fence in a line moving from west to east. Another 25 were placed in a zig-zag fashion between 10 and 15 metres from the fence (Figure 4). Regions of swales, crest and slope were represented, and each quadrat was positioned so that the marker peg was in the north-east corner. All plants were listed by species and measured for the number of individuals (n for >30) and percentage projected foliage cover.

A 14 months after the fire, in May 1982, a less intensive study was carried out on the inter-dunal swales, dune crests and slopes. It involved the estimation of the minimum area required to adequately sample the species present in the floral community. The information relevent to this report consists of an indication of the species which were regenerating at that time and their relative importance.

At 17 months after the fire the 50 x 1 m^2 quadrats established in October 1981 were resampled (September 1982). The species present, plant height, number of stems in each plot and the percentage projected foliage cover for each species were determined. From the density, dominance and frequency measurements, the importance value of each species was calculated.

Soil moisture was estimated by samples taken from the 50 x 1 m plots in the burnt area on 18 October 1982, and from plots 1 - 25 in the unburnt area on 20 October 1982. Both were warm days and the soil was taken between 10.00 a.m. and 2.00 p.m., at 5 to 10 cm depth. Samples were placed in airtight tins and weighed. Samples were dried at 105°C for 48 hours, then the percentage soil moisture for each sample calculated.

Results

First Winter Regrowth

Despite the bare appearance of the area in March, by July 1981 a considerable number of plants showed regeneration. Species with some basal growth included **Acacia saligna, A. rostellifera, Templetonia retusa, Diplolaena dampieri** - these all being woody shrubs. The herbaceous plants showing recovery included **Lepidosperma gladiatum, Acanthocarpus preissii**, and sedge species. The vines **Clematis microphylla** and **Hardenbergia comptoniana** had both grown from root stocks. New seedlings of the latter species together with **Anagallis arvensis** and **Pelargonium capitatum** were noted as well as possible regrowth of the latter.

First Spring Regrowth

By Spring 1981 many herbaceous annuals had colonized the burnt region (see Appendix 1). The species with the highest importance value was the low spreading parakeelya (**Calandrinia** cf. **liniflora**) and the four-leaved allseed (**Polycarpon tetraphyllum**) (Table 1). A number of monocotyledons were common, including the introduced wild oats (**Avena fatua**), veldt grass (**Ehrharta longiflora**) and **Lolium temulentum**, and the native coarse club rush (**Scirpus antarcticus**).

Examination of regenerated plant material from rootstock revealed that about 30 percent of the study area, especially the milder western facing dune slopes, was dominated by dense stands of **Acacia rostellifera** with individuals of **A. saligna** occurring within the dense thickets. Some seedling regeneration of these species was evident in close proximity to the dead remains of the dense **Acacia** thickets.

A feature of the regeneration pattern was that particular species were growing in localized areas of about 10 m^2. This was particularly common with the herbaceous species e.g. **Clematis microphylla, Acanthocarpus preissii, Loxocarya flexuosa**, and **Lepidosperma gladiatum**.

Table 1 Ranked importance values for most frequent species recorded in the burnt area north of Sorrento Camp, October 1981.

SPECIES	IMPORTANCE VALUE
Calandrinia cf liniflora	34.6
Polycarpon tetraphyllum	27.5
Crassula sp.	26.7
Scirpus antarcticus	20.4
Acacia rostellifera	11.9
* Avena fatua	11.2
* Lolium temulentum	11.0
Xanthosia sp.	9.5
Tetragonia decumbens	9.1
Scaevola crassifolia	8.6
* Bromus diandrus	7.9
* Anagallis arvensis	7.4
Clematis microphylla	7.2
Schoenus grandiflorus	6.8
Santalum acuminatum	6.7
Trachymene sp.	6.5
* Romulea longifolia	6.3
Acanthocarpus preissii	5.6

* Species not native to Western Australia

Regeneration in intensely burnt areas was very low. The average number of species per square metre was less than 5, suggesting that much rootstock and seed material stored below the soil surface was destroyed by the intense heat.

Autumn Regrowth

A set of new sites was selected for sampling by transects which characterised the location by topography as dune slopes, crests or interdunal swales, in May 1982. Importance values of species present calculated for the slopes and swales only and species presence or absence are given for the crests in Table 2.

a) Dune Slopes

The slopes generally face east and west and vary between three and ten degrees in elevation. The seaward facing (western) slopes were most intensively surveyed compared to the leeward (eastern) slopes. The assessed western slopes were dominated by **Scaevola crassifolia** and characterised by relative absence of **Melaleuca acerosa**. **Lepidosperma gladiatum** was relatively evenly distributed across the slope and had a higher relative frequency than **Scaevola crassifolia**. The vines **Hardenbergia comptoniana** and **Clematis microphylla** were commonly growing in localised patches, the former species was also present on the sheltered leeward slopes.

b) Dune Crests

The more exposed, unstable, dune crests are generally aligned in a north-south direction and vary from one to five metres in width.

The plants found growing on the crests were very small with large areas of bare sand occurring between individuals. The dominant species was **Opercularia vaginata**. Stunted **Melaleuca acerosa** were growing on the crest with taller individuals being present on both windward and leeward slopes. Similarly, **Conostylis candicans** grew taller on the lee slope than on the dune crest. Regeneration on the crests was proceeding slowly, but the area was at risk due to damage by wind erosion.

c) Interdunal Swales

The swales which occur in a low part of the dune profile are relatively protected from the wind, and soils retain a higher moisture content.

Wild oats (**Avena fatua**) was the most important species, occurring at all sample sites. The most dominant species however was **Lepidosperma gladiatum**, followed by **Santalum acuminatum** and **Pelargonium capitatum**.

Second Spring Regrowth

Spring saw a re-introduction of grass species which were noticeably absent in Autumn. **Bromus diandrus** was especially common, as well as veldt grass, horsetail grass and wild oats. Other monocotyledons which dominated a number of plots include: **Acanthocarpus preissii**, **Loxocarya flexuosa** and **Conostylis candicans**, and more rarely **Scirpus antarcticus** and **Lomandra** sp. On the dune crests **Leptomeria cunninghamii**, **Anthocercis littorea**, **Calandrinia brevipedata**, **Trachymene** sp., and **Stylidium** sp. were prevalent. **Crassula colorata** often dominated the eastern slopes, with **Pelargonium capitatum**, **Clematis microphylla**, and **Calandrinia** cf. **liniflora** occurring less commonly. On the more exposed western slopes common species were **Euphorbia terracina** and **Leptomeria cunninghamii**, but these were often only in localised patches (Table 3). Generally, however the plots were dominated by **Acacia rostellifera** especially in the interdunal swales.

Effect of Burning on Plant Species

A total of 39 species were recorded from the unburnt plots. This is by no means the total population of the area, but the sampling comparisons have some general validity. By contrast 61 species were recorded in burnt plots in the spring of 1981. The number declined to 54 species by spring 1982 (Appendix 1).

Table 2 Importance values of selected woody species less than 1 m and herbaceous species recorded in the burnt area north of Sorrento Camp. May 1982.

SPECIES	IMPORTANCE VALUES		Presence + Absence −
Site type:	Slope	Swale (presence +)	Crest
Scaevola crassifolia	56		+
Lepidosperma gladiatum	45	43	+
Pelargonium capitatum	32	10	+
***Festuca** sp.	21	17	+
Opercularia vaginata	20		+
Clematis microphylla	17	26	+
Hardenbergia comptoniana	14	12	−
Acanthocarpus preissii	14		+
Acacia lasiocarpa	13		+
Hemiandra pungens	13		+
* **Avena fatua**	11	63	−
Leucopogon sp.	8		−
Melaleuca acerosa	8	+	+
Rhagodia baccata	6	12	−
Lepidosperma angustatum	6	+	+
Anthocercis littorea	6		+
Santalum acuminatum	3	24	+
* **Romulea longifolia**	−	23	−
Trachyandra divaricata	−	+	−
Carex preissii	−		+
Olearia axillaris	−	+	+

* Species not native to Western Australia

Comparison of the number of plots in which a species was present (Table 3) and the species importance value (Table 4) shows that **Acacia rostellifera** and **Bromus diandrus** are the dominant and most important species in both burnt and unburnt areas. Differences were apparent in the different physiographic units sampled, but there were generally more species recorded from burnt plots (Table 3, bottom line).

Alien species accounted for about the same importance in both unburnt plots (29.3 per cent) and burnt plots (27.5 per cent). However some 15 aliens were present in burnt plots compared with 9 species in unburnt plots. Aliens present in burnt sites and not listed in Table 4 were as follows **Lagurus ovatus** (i.v. 3.0), **Euphorbia peplus** (2.5), **Cerastium glomeratum** (2.6), **Solanum nigrum** (1.9), **Trachyandra divaricata** (1.0), **Brassica tournefortei** (0.7), and **Sonchus oleraceus** (i.v. 0.4).

In the swale regions, **Acacia rostellifera** was the most common species in both areas, with the average percentage cover greatest in the unburnt area (70 per cent compared with 45.6 per cent). In this region of the burnt area, the presence of **Clematis microphylla** and **Bromus diandrus** also appeared important. The average soil moisture

Table 3 — Representation of species in plots spring 1982 - Sorrento study area

Species with more than 10 per cent cover in any one plot are included
Plots are grouped according to dune topographical position : W - western slope; E - eastern slope; C - crest; S - swale

Species arranged by families	Number of plots in which the species was present									
	UNBURNT SITES				Total (%)	BURNT SITES				Total (%)
	W	E	C	S		W	E	C	S	
POACEAE										
Avena fatua	-	-	-	1	4	-	1	1	-	4
Bromus diandrus	-	1	1	1	12	2	5	2	4	26
Erharta longiflora	-	-	-	-	-	2	-	-	1	6
Lagurus ovatus	-	-	-	-	-	-	1	-	1	4
Poa australis	-	-	-	-	-	-	1	2	2	10
Poa poiformis	-	-	2	-	4	-	1	-	-	2
sp. indet	-	-	-	-	-	1	-	-	1	4
CYPERACEAE										
Lepidosperma gladiatum	1	2	1	-	16	-	-	-	-	-
Scirpus antarcticus	-	-	-	1	4	-	1	-	1	4
RESTIONACEAE										
Loxocarya flexuosa	-	-	1	1	8	-	2	1	-	6
LILIACEAE										
Acanthocarpus preissii	1	1	1	-	12	1	2	-	1	8
Trachyandra divaricata	-	-	-	-	-	1	-	1	-	4
Lomandra sp	1	-	-	-	4	1	1	2	1	10
AMARYLLIDACEAE										
Conostylis candicans	-	-	-	-	-	1	1	-	1	6
SANTALACEAE										
Leptomeria cunninghamii	-	-	-	-	-	2	1	3	1	14
CHENOPODIACEAE										
Rhagodia baccata	-	1	1	-	8	1	-	-	-	2
AIZOACEAE										
Carpobrotus virescens	-	1	-	-	4	-	-	-	-	-
PORTULACACEAE										
Calandrinia brevipedata	-	-	-	-	-	-	-	1	2	6
C. aff. liniflora	-	-	-	-	-	2	1	-	1	8
RANUNCULACEAE										
Clematis microphylla	1	1	1	-	12	-	1	1	3	10
BRASSICACEAE										
Brassica tournefortei	-	-	-	-	-	1	-	-	-	2
Heliophila pusilla	-	-	1	-	4	-	-	-	-	-
CRASSULACEAE										
Crassula colorata	-	-	-	-	-	-	4	-	1	10
GERANIACEAE										
Erodium cicutarium	-	-	-	-	-	-	-	-	1	2
Pelargonium capitatum	2	3	-	-	24	1	1	-	1	6
LEGUMINOSAE										
Acacia cochlearis	-	-	-	-	-	1	-	-	-	2
A. lasiocarpa	1	1	1	-	12	-	-	-	-	-
A. rostellifera	2	3	-	4	36	6	2	3	8	38
A. saligna	-	-	-	-	-	-	2	-	-	4
A. truncata	1	-	-	-	4	-	-	-	-	-
Hardenbergia comptoniana	-	-	1	-	4	-	-	-	-	-
Templetonia retusa	-	1	1	-	8	-	-	-	-	-
RUTACEAE										
Eriostemon spicatus	-	-	-	-	-	-	-	-	1	2
EUPHORBIACEAE										
Euphorbia terracina	-	-	-	-	-	1	-	-	-	2
Phyllanthus calycinus	1	-	-	-	4	-	-	-	-	-
RHAMNACEAE										
Spyridium globulosum	-	-	-	1	4	-	-	1	-	2
DILLENIACEAE										
Hibbertia glaberrima	-	-	1	-	4	-	-	-	-	-
MYRTACEAE										
Eucalyptus sp	1	-	-	-	4	-	-	-	-	-
Melaleuca acerosa	2	1	4	1	32	-	2	-	1	6
APIACEAE										
Trachymene sp	-	-	-	-	-	-	-	1	-	2

Cont.....

Cont/2

Species arranged by families	Number of plots in which the species was present									
	UNBURNT SITES				Total	BURNT SITES				Total
	W	E	C	S	%	W	E	C	S	%
EPACRIDACEAE										
Leucopogon parviflorus	-	-	1	-	4	-	-	-	-	-
LAMIACEAE										
Hemiandra pungens	1	-	-	-	4	-	-	-	-	-
SOLANACEAE										
Anthocercis littorea	-	-	-	-	-	1	2	1	-	8
RUBIACEAE										
Opercularia vaginata	-	2	1	1	16	1	-	2	-	6
GOODENIACEAE										
Scaevola crassifolia	-	-	-	-	-	2	1	-	-	6
STYLIDIACEAE										
Stylidium sp	-	-	-	1	4	-	-	1	-	2
Total number of species	12	12	15	9	27	18	20	15	19	34

Table 4. Species importance values (I.V.) and mean height, Spring 1982: 17 months after fire. Species ranked in descending order of importance values for 1mx1m quadrats in unburnt and burnt sites.

UNBURNT AREA Species	I.V.	Mean Ht.	BURNT AREA Species	I.V.	Mean Ht.
Acacia rostellifera	28.9	175	Acacia rostellifera	32.8	93.6
*Bromus diandrus	25.4	33.2	*Bromus diandrus	23.7	33.4
Melaleuca acerosa	21.3	60.0	Trachymene sp.	19.9	5.5
Opercularia vaginata	21.3	33.6	Crassula colorata	19.4	10.2
Lomandra sp.	16.2	27.3	Scirpus antarcticus	18.8	7.1
*Avena fatua	14.1	28.4	Leptomeria cunninghamii	12.2	80.5
*Pelargonium capitatum	13.1	48.4	Loxocarya flexuosa	12.0	10.8
Poa poiformis	13.0	38.1	Opercularia vaginata	11.8	30.0
Acanthocarpus preissii	12.4	51.9	*Erharta longiflora	10.9	27.2
*Erodium cicutarium	11.4	8.3	*Romulea longifolia	9.9	20.0
Loxocarya flexuosa	10.5	20.0	Poa australis	8.4	27.5
Trachymene sp.	10.1	8.1	Lomandra sp.	7.5	38.1
*Lagurus ovatus	9.1	20.2	Scaevola crassifolia	7.1	33.1
Conostylis candicans	8.9	32.8	Acanthocarpus preissii	6.5	42.5
Lepidosperma gladiatum	8.1	73.2	*Pelargonium capitatum	6.6	30.9
Acacia lasiocarpa	7.8	50.9	Calandrinia cf liniflora	6.4	7.0
*Sonchus oleraceus	6.7	10.8	*Erodium cicutarium	5.7	4.6
Pelargonium littorale	6.2	7.5	Anthocercis littorea	5.5	61.2
Hemiandra pungens	6.0	44.8	*Poaceae indet.	5.4	17.2
Carpobrotus virescens	5.2	16.3	Conostylis candicans	5.1	39.9
Templetonia retusa	4.8	52.0	Poa poiformis	4.3	26.3
Scirpus antarcticus	4.2	5.7	*Avena fatua	4.2	37.6
Clematis microphylla	4.1	48.0	Eriostemon spicatus	4.1	22.7
Rhagodia baccata	3.8	64.3	Clematis microphylla	4.0	53.0
*Solanum nigrum	3.4	13.5	*Euphorbia terracina	3.9	61.3
*Heliophylla pusilla	2.4	32.0	Tetragonia decumbens	3.8	7.7
Leucopogon parviflorus	2.3	42.5	Melaleuca acerosa	3.4	49.8
Plus another 12 species			Plus another 27 species		

content was greater in the burnt area than the unburnt area for the swale regions (Table 5). It can be seen (Table 3) that the presence of **A. rostellifera** was also important in the crest regions of the burnt area. An average cover of 42.5 per cent was recorded while that in the unburnt area had a mere 8 per cent. **Leptomeria cunninghamii** had the greatest average percentage cover on crests in the burnt area, but this species did not appear at any of the plots in the unburnt area. Instead, **Melaleuca acerosa** and **Bromus diandrus** were most important in the unburnt area. Again the average soil moisture percentage was greater in the burnt area.

On the protected eastern slopes **A. rostellifera** had an average percentage cover of 73.3 per cent for the unburnt area compared with 45 per cent in the burnt area. **Pelargonium capitatum** featured prominantly in the unburnt area though not in the burnt area, as did **Acanthocarpus preissii**.

On the western slopes, **A. rostellifera** occurred most often in both areas, but average percentage

Table 5. Soil moistured levels at October 1982

Site Type	Unburnt Plots		Burnt Plots		't' test*
	No of samples	Mean % Soil Moisture (S.D.)	No of samples	Mean % Soil Moisture (S.D.)	
Western slope	6	2.96(1.98)	13	2.59(1.11)	NS
Eastern slope	8	2.50(1.47)	12	2.73(1.52)	NS
Crest of Dune	7	1.80(0.93)	10	4.35(2.33)	*
Swale	4	2.42(2.06)	13	4.60(1.57)	NS

* 't' test of difference between means for significance at p. 0.05.

cover was greater in the burnt area. **Ehrharta longiflora** was present with an average percentage cover of 11 in the burnt area and was located on the slopes closest to the ocean and along the firebreak which runs parallel to the northern boundary fence of the Recreation Area.

E. longiflora was not recorded at any plot of the unburnt area. Average soil moisture percentage did not differ greatly between plots on western slopes in the two areas.

From the breakdown it is very clear that the presence of A. rostellifera is important in all regions, except perhaps the crests in the unburnt area.

Bromus diandrus was most important in swales and eastern slope regions of the burnt area and most important in the crest regions of the unburnt regions. **Melaleuca acerosa** was most important in the crest regions and was well represented in the other regions of the unburnt area, but was generally absent in the burnt area. **Opercularia vaginata** was also well represented across all regions of the unburnt area and the crest regions of the burnt area.

The average soil moisture is higher in the burnt than the unburnt areas, except for the western slopes of the burnt area (Table 5). This can be explained by loss of water through transpiration by plants in the unburnt area, and a greater exposure to wind having a dessicating effect on the western slopes in the burnt area.

Discussion

The Mediterranean climate is typified by a long dry summer with periods of dessicating winds. These create conditions favourable for large, destructive bush fires. Seasonal daily and immediate weather changes affect the flammability potential of living and dead fuel in the bush.[9]

Total fire size is primarily controlled by the length of time severe wind conditions exist and the age of the fuel. As the vegetation ages the probability of large fires occurring increases.[10] Gardner noted[4] that the effect of fire in shrub heath is the total destruction of the aerial parts of the woody plants. However only a small percentage of the total suite of species present is killed. Consequently rapid recovery of the bush can take place.[1] The first appearance of the burnt area at Sorrento was one of total destruction from which it seemed impossible that recovery could occur. Nevertheless two growing seasons after the fire has seen the bush well on the way to recovery.

Gill[5] notes that many species possess adaptations which assist regeneration after fire. Many species have buds often just below the soil surface which sprout if the foliage is killed. Lignotubers with many such buds are found in some Myrtaceae, Proteaceae, Dilleniaceae and Leguminosae. Younger mature plants may possess higher vitality than aged plants and thus have a greater chance of survival.[5] Reproduction may be enhanced by burning providing a flowering response, by release of seed held in woody fruits (e.g. some **Melaleuca** species) or through fire stimulated germination.[5] Fire may enhance seed germination by cracking the hard seed coats of **Acacia** and other legumes or by providing a direct heat stimulus to germination.[11] The suckering habit of some **Acacia** species allows faster regeneration than **Melaleuca** species regenerating from seed. At Sorrento this is exemplified by dense regrowth of **Acacia rostellifera** at a much faster rate than **Melaleuca acerosa**.

Changes in the physical structure of the soil, increasing its suitability as a seed bed, or the availability of nutrients such as phosphate, may improve conditions fo seedling survival.[11]

Others[3] believe that loss of nutrients through sublimation and particulate loss in smoke of burnt vegetation, which is low in nutrients, can cause relatively larger proportions of nutrients to be removed. After an initial rapid uptake of nutrients following the disturbance, the community requirement may largely be met by recycling.[6]

Fire cleans the ground leaving an open site for invasion. There may be destruction of phytochemicals and other effects which allow the ingress of a range of post-fire species and grasses to appear.[10] At Sorrento we note the occurrence of the fire weed **Anthocercis littorea**, early abundance of **Calandrinia** cf **liniflora**, and heavy growth of introduced grass species particularly adjacent to West Coast Highway and at the edges of firebreaks. The total number of species surpassed pre-fire levels by the end of the first year after the fire. The pre-fire species suite is augmented by others which will probably disappear in time through competition as the slower growing larger shrubs of the community reassert dominance.[11]

If reserves are to be preserved as naturally functioning ecosystems it is important to determine the natural fire frequency of a particular vegetation community so that site degradation does not occur.[16] In plant communities characterised by species regenerating from underground root stocks, such as the coastal heath and thicker community studied here, the firing frequency to ensure the maximum level of species survival is likely to be that approximating the time at which shoot biomass reaches a plateau.[6] For Sorrento this may be 7-10 years, perhaps longer, between fires. Hot infrequent fires by stimulating germination and seedling survival will act to increase plant populations and eventually the soil seed populations. Frequent, cool fires may tend to eliminate species by causing mortality in the population without being hot enough to stimulate seed germination for replacement. In time this may lead to decline in the populations of some species and local extinctions.[11] In the case of short intervals between fires such heath scrub elements as those of the Myrtaceae, Proteaceae, and Epacridaceae may be eliminated or their occurrence reduced.

The Sorrento Recreation Reserve is heavily used by the public. Consequently a complete burn over the whole area is not feasible, despite the general desirability of this in terms of long term plant health and vegetation maintenance. At this stage it is suggested that hot fires should be used in discrete patches one at a time each summer until all the natural areas have been covered.

It is recommended that the first area to be treated is the **Acacia rostellifera** thicket in the north-east corner of the Reserve. Here the **Acacia** has developed a great deal of fuel in swale sites and in some places is becoming moribund. By contrast our preliminary observations suggest that crests take longer than swales to build up vegetative material and perhaps therefore fires should be induced at longer intervals on the crests.

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APPENDIX 1 SORRENTO SPECIES LIST

Arranged in systematic order, all plants collected from the area, with presence in burnt areas after fire shown.

* = species not native to W.A.

MONOCOTYLEDONAE

	Present after fire (Months) 4	7	14	17
POACEAE				
Agropyron scabrum (Labill.) Beauv.				
* Anthoxanthum odoratum L.		x		
* Avena fatua L. Wild oats		x	x	x
* Bromus diandrus Roth.				x
Danthonia sp. indet.				
* Ehrharta longiflora Sm. Veldt grass		x	x	x
Festuca sp. indet.		x	x	
* Lagurus ovatus L. Harestail Grass		x	x	x
* Lolium temulentum L.		x		
Poa poiformis (Labill.) Druce				x
Stipa variabilis Hughes Variable Speargrass		x		
Sp. indet			x	x
CYPERACEAE				
Carex preissii Nees			x	
Lepidosperma angustatum R.Br.		x	x	
Lepidosperma gladiatum Labill. Coast sword-sedge	x	x	x	x
Schoenus grandiflorus (Nees) F.Muell. Large-flowered bog-rush		x	x	
Scirpus antarcticus L. Coarse club-rush		x		x
Scirpus nodosus Rottb. Knotted club-rush				
RESTIONACEAE				
Loxocarya flexuosa (R.Br.) Benth.		x		x
LILIACEAE				
Acanthocarpus preissii Lehm.	x	x	x	x
* Trachyandra divaricata (Jacq.) Kunth. Cape dune-lily		x	x	x
Liliaceae sp.				x
Lomandra sp.		x	x	x
AMARYLLIDACEAE				
Conostylis aculeata R.Br.				
Conostylis candicans Endl. Grey Cottonhead		x	x	x
IRIDACEAE				
* Romulea rosea (L.) Eckl. Guildford grass		x	x	x
ORCHIDACEAE				
Caladenia flava R.Br. Cowslip orchid				
Sp. indet.				

DICOTYLEDONEAE

	Present after fire (Months) 4	7	14	17
SANTALACEAE				
Leptomeria cunninghamii Miq.				x
Santalum acuminatum (R.Br.) DC. Quandong		x	x	
CHENOPODIACEAE				
Rhagodia baccata (Labill.) Moq. Sea berry-saltbush		x	x	x
Salsola kali L. Rolypoly				
AIZOACEAE				
Carpobrotus virescens (Haw.) Schwantes Coastal Pig Face		x		x
Tetragonia decumbens Miller - Sea Spinach		x	x	x
PORTULACACEAE				
Calandrinia brevipedata F. Muell.				x
Calandrinia cf. liniflora Parakeelya		x		x
CARYOPHYLLACEAE				
* Cerastium glomeratum Thuill. Mouse-ear Chickweed		x		x
* Polycarpon tetraphyllum (L.) L. Four leaved allseed		x		
RANUNCULACEAE				
Clematis microphylla DC. Small-leaved Clematis	x	x	x	x

	Present after fire (Months) 4	7	14	17
BRASSICACEAE				
* **Brassica tournefortii** Gouan. Wildturnip		x		x
* **Cakile maritima** Scop. Sea Rocket				
* **Heliophila pusilla** L.				
* **Raphanus sativus** L. Wild radish		x	x	
CRASSULACEAE				
Crassula colorata (Nees) Ostenf. Stonecarp		x		x
Crassula sp.		x		
GERANIACEAE				
* **Erodium cicutarium** (L.) L'Herit. Common crowfoot				x
* **Pelargonium capitatum** (L.) L'Herit.	x	x	x	x
Pelargonium littorale Huegel Coast Storksbill		x		x
LEGUMINOSAE				
Subfamily – MIMOSOIDEAE				
Acacia cochlearis (Labill.) H.L. Wendl. Rigid wattle		x		x
Acacia cyclops A. Cunn. ex G. Don.				
Acacia lasiocarpa Benth.		x	x	x
Acacia rostellifera Benth.	x	x		x
Acacia saligna (Labill.) H.L. Wendl. Orange wattle	x	x		x
Acacia truncata (N.L.Burman) Hort. ex Hoffmans			x	
Subfamily – PAPILIONOIDEAE (FABACEAE)				
Bossiaea eriocarpa Benth.				
Gompholobium tomentosum Labill.				x
Hardenbergia comptoniana (Andr.) Benth. Native wisteria	x	x	x	x
Kennedia prostrata R.Br. Scarlet runner		x		
* **Melilotus indica** (L.) All. Common melilot		x		
Oxylobium reticulatum Meissn.			x	
Templetonia retusa (Vent.) R.Br. Cockies' tongues	x	x	x	

	Present after fire (Months) 4	7	14	17
RUTACEAE				
Diploaena dampieri Desf.	x			
Eriostemon spicatus A.Rich. Pepper and Salt		x		x
EUPHORBIACEAE				
* **Euphorbia peplus** L. Petty spurge		x	x	x
* **Euphorbia terracina** L. False caper, Geraldton carnation weed.		x		x
Phyllanthus calycinus Labill. False Boronia		x		x
Poranthera microphylla Brongn. Small Poranthera				
SAPINDACEAE				
Diplopeltis heugelii Endl.				
RHAMNACEAE				
Spyridium globulosum(Labill.) Benth.		x	x	x
Trymalium ledifolium Fenzl.				
DILLENIACEAE				
Hibbertia glaberrima F.Muell.			x	x
MYRTACEAE				
Melaleuca acerosa Schauer		x	x	x
APIACEAE				
Trachymene pilosa Sm. Native parsnip		x		
Trachymene sp.		x		x
Xanthosia sp.		x		
EPACRIDACEAE				
Leucopogon parviflorus (Andr.) Lindl. Coast beard-heath		x	x	x
Leucopogon sp.2.			x	
PRIMULACEAE				
* **Anagallis arvensis** L. Scarlet Pimpernel	x	x		
Anagallis pumila Sw. Blue Pimpernel		x		

	Present after fire (Months) 4	7	14	17
LAMIACEAE				
Hemiandra pungens R.Br. Snakebush		x	x	x
SOLANACEAE				
Anthocercis littorea Labill.			x	x
* **Solanum nigrum** L. Deady nightshade		x		x
Solanum symonii Eichler				
SCROPHULARIACEAE				
* **Dischisma arenarium** E. Meyer				
OROBANCHACEAE				
Orobanche australiana F.Muell. Australian broom-rape		x		
MYOPORACEAE				
Myoporum adscendens R.Br. Boobialla			x	
RUBIACEAE				
Opercularia vaginata Labill.		x	x	x
LOBELIACEAE				
Lobelia tenuior R.Br. Slender lobelia		x		
GOODENIACEAE				
Scaevola crassifolia Labill. Thick-leaved fanflower		x	x	x
STYLIDIACEAE				
Stylidium sp.				x
ASTERACEAE				
Actites megalocarpa (J.D. Hooker) N.S. Lander				
Anglanthus cunninghamii (DC.) Benth.				
Athrixia pulverulenta (Lindl.) Druce Bristle Daisy		x		
* **Dittrichia graveolens** (L.) W. Greuter Stinkwort		x	x	
Olearia axillaris (DC.) F.Muell. Coast Daisybush		x	x	x
Senecio lautus Forst. f. ex Willd. Coastal Groundsel			x	x
* **Sonchus oleraceus** L.			x	x
Waitzia acuminata Steetz		x	x	

(Names after J.W. Green 1981 Census of the Vascular Plants of Western Australia. W.A. Herbarium)