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MULGA RESEARCH CENTRE

annual report 1979

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MULGA RESEARCH CENTRE

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Contents

EFFECTS OF FIRE ON THE MULGA (*ACACIA ANEURA*) COMMUNITY.

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Introduction: Fire and the Mulga Community

Fire is a feature of the Australian environment[14,20] which is accepted and accomodated by most whose lives are touched by it.[10] Those less immediately involved seem to seldom refer to it and even our institutionalised responses to environmental problems ignore fire as an important factor in managing the environment.[4]

Fires may produce beneficial effects to plant communities where species adaptation[14] to fire is well established. In such communities the timing and severity of fire[1] influence the degree of benefit achieved. In addition to rejuvenating adapted species, the ash generated by fire enhances new growth and subsequent litter fall from scorched crowns is likely to increase nutrient availability to seedlings. [24]

In managed systems fire may directly increase herbage[1]. It may remove old fibrous and unpalatable material, thus providing young regrowth more easily reached by the grazing animal.[5] The absence of fire in managed rangelands in arid areas has been cited as a cause of increased perennial shrub stocking in North America.[18] More recently fire has been examined in New South Wales as a potential management tool to remove small shrubs from pastoral areas.[35] However in some mulga communities there are complex relations between the woody components and herbage, compounded by the varied incidence of rainfall.[30] Retention of woody perennials may be a more stabilising strategy in mulga country.[8]

Concern has been expressed over the death of mulga with such factors as senescence, drought and overgrazing linked.[23] Land use in arid country should aim at minimal disturbance to the vegetation with avoidance of erosion and overgrazing as problems of great importance.[2] Continued productive use of Australia's arid grazing lands requires management practices specially adapted to arid conditions. Such use depends on great care being taken to avoid severe disturbance.[26]

'The open nature of the mulga formation, and the presence of so much plant debris on the surface of the soil, would indicate that fires are not an occurrence of frequent periodicity in this formation and .... the highly inflammable nature of the dried Compositae would result in a rapidly moving fire unable to burn the rough and hard-barked mulga shrubs and trees'.[13]

In common with other arid areas [18] the ecosystems involved are characteristically, and usually, considered to be less affected by fire than are moister regions. There is an inescapably close correlation between the prevalence of fires and the amount of fuel. In those areas where the burning of spinifex (*Triodia* species) has been practised in the belief that fire will encourage regrowth of palatable shoots from the old tussocks[5] it was often necessary to spot-fire extensively to get a burn. Where spinifex fires immediately impinge on mulga communities then some perturbation inevitably occurs, at least at the edges.[12]

Unfavourable factors such as low temperatures, high relative humidity and moisture content[17] are not the reasons for the scarcity of fire in mulga country.
If fires did occur in mulga country they were not as extensive as in other plant formations, nor did they inflict the same damage.[13]

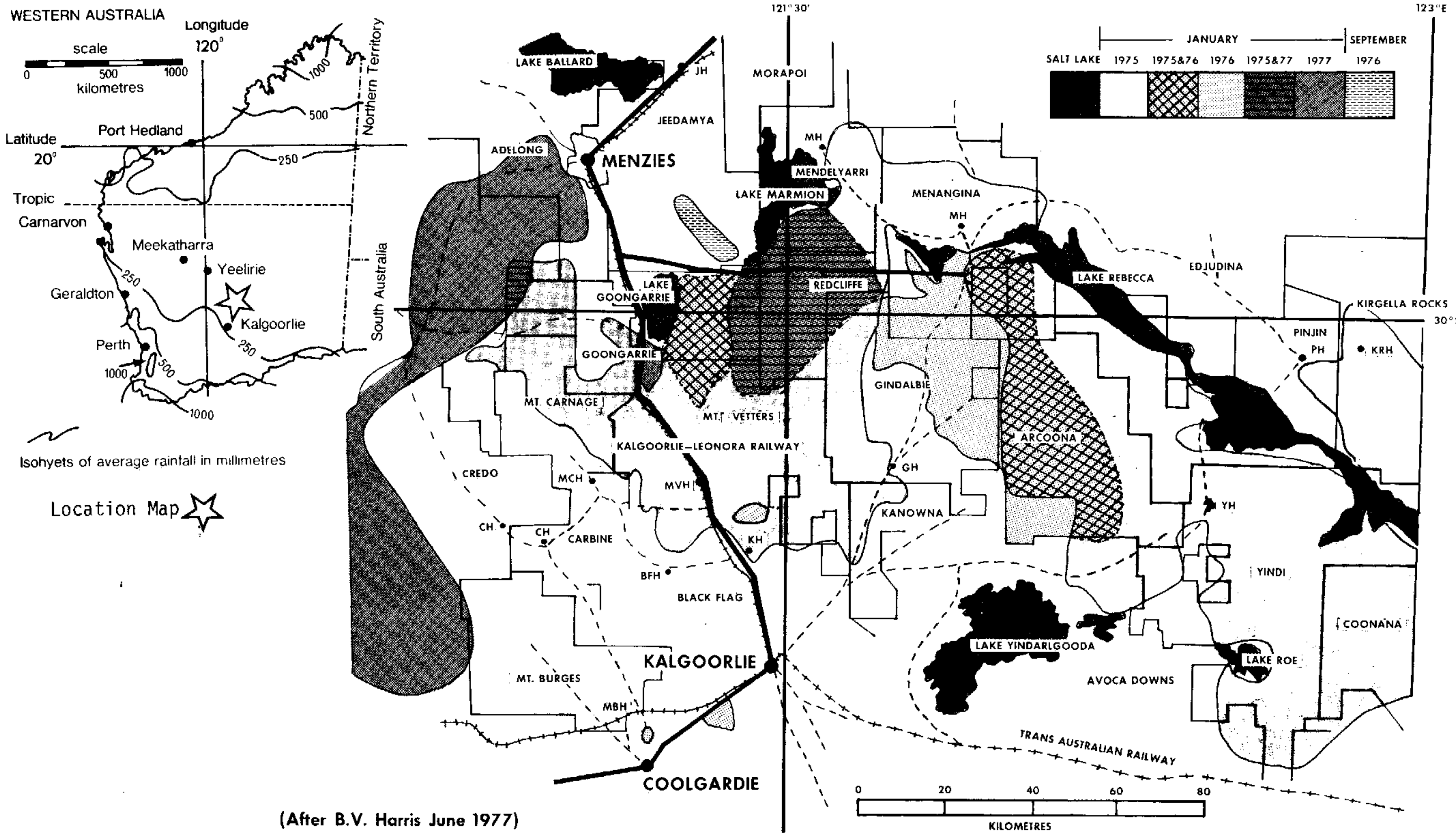
Gill[14] has reviewed [11,15,29] what is known of the 'adaptations' of *Acacia aneura* in respect of fire. He suggests its failure to regenerate over wide areas cannot be attributed to an absence of fire, as some regeneration occurs, sporadically, in many places. The main controls to regeneration have been seen to be rainfall stimuli to seed production and germination.[15,29] Hall *et al* suggest the ideal sequence of seasons which would lead to seedling germination would be a winter or summer rain to initiate flowering and seed setting, followed by a hot dry summer when the seed matures and the seed coat cracks. Torrential rains in a second summer would then initiate germination and establishment.[15]

Since *Acacia aneura* shows variation in recovery from lopping damage[11], in that new growth may occur in some places and in other areas the tree will die, Gill suggests that the region of occurrence is of importance in considering adaptation to fire regime.[14] He concludes that in some areas mulga is fire adapted. Fires occurred prior to white settlement, mulga is sensitive to fire and seed production is abundant in relatively wet years. The hard seed may be stimulated by fire to germinate. The species is long-lived (250-300 years[8]), and individuals will die from other causes than fire e.g. drought and insect attack.[14]

It is known that *Acacia* seed can persist ungerminated yet germinable in soils of the jarrah forest for some years.[32]
Acacia pulchella has been germinated by soil heating from a jarrah stand unburnt for 40 years where the plant itself has been absent for many years (S.R. Shea, personal communication). The grass *Stipa compressa* has shown the same sort of behaviour.[1]

Fire can stimulate germination by cracking the testa of far more seed than is possible during a summer drought. Hall *et al* point out that this stimulus to maximum germination may not be followed by favourable summer rain. However germination following fire did occur at Koonamore in two years when 28 new seedlings of mulga were recorded in quadrats out of a total recorded germination of 46 individuals over the period 1926-1962.[15] Nine seedlings survived and were used in later studies.[8]

The present paper reports interim results of a fire study in Western Australia's northeastern goldfields. Such a study requires long term evaluation of environmental consequences.[25] Nevertheless preliminary results give some factual biological data [27] and some information on comparative reactions of plants to fire.[31]



(After B.V. Harris June 1977)

Station details from Kalgoorlie 1: 500,000 sheet (Lands & Surveys Western Australia)

Fig. 1. Extent of Bushfires in Mulga Country north-east of Kalgoorlie, areas burnt 1975-1977. Showing station boundaries, homesteads (e.g. BFH = Black Flag Homestead) main road, railways and earthroads (dashed lines).

The 1974/75 Fire Season

In the summer of 1973-74 unusually heavy rains fell over much of the inland of Australia.[21] Lake Eyre contained water[22] and herbaceous growth everywhere became exceptionally dense. In the year from September 1973 to August 1974 Alice Springs received some 875mm compared with the normal 246mm. Many localities recorded in excess of twice the long term average rainfall.[20,21]

As the lush, continuous grass and herbage dried off, with the onset of summer, much higher fuel loads were available to support fires on a scale not experienced for at least 50 years.[20] Lightning was responsible for starting the majority of the fires.[6,21]

The first large fires occurred on the Barkly Tableland of the Northern Territory in early July, 1974, eventually covering 2.4 million ha[20,21]. By November 1974 fires were burning at the latitude of Alice Springs, and fire eventually burnt a third of the Northern Territory. Some 4 million ha of rangeland were burnt in western New South Wales, including areas where *Acacia aneura* and *Callitris columellaris* plants of < 2m height (when not completely burnt) showed poor rates of survival following crown scorch.[35]

About 12 million ha of Western Australia's pastoral country were burnt, mainly by a series of fires to the east and north-east of Kalgoorlie (Fig.1). The peak period here was from late October to December 1974 continuing into 1975. Including remote unoccupied areas of the State, it is believed that an area totalling some 29 million ha of land was burnt in bushfires in Western Australia, that is 11.5 per cent of the total State land area of 253 million ha.[20] The fires were still burning in January. In Australia as a whole 117 million ha (or 15.2 per cent of the country) were burnt.

In January 1976 bushfires were again burning in the area east and north east of Kalgoorlie. At this time a brief visit was made to the area between Menzies and Edjudina. It was reported that the fires were the most extensive in the history of European settlement (B.G. Lay, personal communication*) running through the Nullarbor Plain into the W.A. Goldfields. The owner of Menangina Station hypothesised that fire is a normal component of the mulga environment. He estimated that similar, big, bush fires occurred 200 years earlier.[33]
Further fires occurred in January, 1977.

The Study Area

Preliminary observations in the vicinity of Menangina (January 1976) indicated that fire in mulga country had given rise to a range of responses. Response appeared to be related to the local intensity of fire, the sizes of trees and their densities. Lay noted that 70-100 per cent of *Acacia aneura* died when a reasonably complete burn occurred (B.G. Lay, personal communication*). Measurements taken in conjunction with officers of the Forests Department, Kalgoorlie, confirmed this generalisation, and suggested that *Acacia aneura* , *Acacia hemiteles* and *Codonocarpus cotinifolius* regenerated best in or near ash beds following the fire of the 1974-75 summer. Subsequent fires resulted in an apparent range of 'fire times' being available for study within a reasonable distance of Menangina Homestead. With the cooperation of S.J. Tonkin, holder of the Menangina pastoral lease, the Menangina property was selected for a study of the effects of fire on regeneration and growth of *Acacia aneura* and its associates.

Rainfall

Seasonal year rainfall[9] for Menangina is illustrated in Fig. 2 for the period 1929-1978. Mean annual rainfall on this basis has been 235mm over the period 1927-1978. Seasonal year rainfall has been less than the mean more often than it has been greater. The period 1969-72 was the longest dry period recorded. By late 1970 the worst conditions, in terms of drought, were reported for 44 years (since records began) with trees and spinifex dying off. At the end of calendar year 1971 stock was down to 50 per cent of normal and at the end of 1972 to 25 per cent. There were 23 rainy days in 1969, 27 in 1970, 26 in 1971 and 25 in 1972. By the end of 1972 the vegetation on the property was reported as being in very poor condition. January 1973 was wet with 60mm of rain recorded (43mm on January 23rd). However it was not until March 28th that the drought really broke. From then until September 21st a total of 302mm was recorded on 40 rainy days, with a total of 55 rainy days for the calendar year. The winter season for 1973 was particularly wet with 202mm (Table 1). The calendar year total for 1973 was 397mm. The summer of 1973-74 continued to be wet and there were 57 rainy days in 1974. The drought had finally gone and the two years 1973 and 1974 were the wettest two consecutive years recorded for the property.
Towards the end of calendar year 1974 the rain cleared. November had 26mm on 4 days, in December only two falls were recorded: 11.8 on December 8th and 6.6mm on December 13th. In December the bushfires had reached Menangina, spreading in from the south east. Another seasonal effect was that mice were reported to be in plague proportions on the property by this time. Less than 4mm of rain fell on January 30th 1975, giving a very poor total rainfall to date for the 1974-75 summer. The fires continued burning in January and it was not until February 20th 1975 that rain commenced again.

Then in the 7 day period February 20-26 a total of 279mm fell, effectively finishing any residual bushfires and initiating another stand of luxuriant grass growth. This fall of rain represented the largest amount ever recorded in one month, it boosted the summer rainfall total to 335mm, and the 1975 seasonal year total to 571mm, the second highest recorded (Fig.2). The winter of 1975 was not as wet as in the previous two years though spring rainfall was well up-no rain fell in September but in a total of 10 rainy days October produced 75.6 mm making it the wettest October on record, and further stimulating herbage growth. The summer of 1975-76 produced little rain and another dry cycle commenced, with the two seasonal years of 1976 and 1977 being well below the average rainfall. Fires in January 1976 burnt through portions of country already burnt between December 1974 and January 1975 as well as burning land areas not burnt in the first big fires

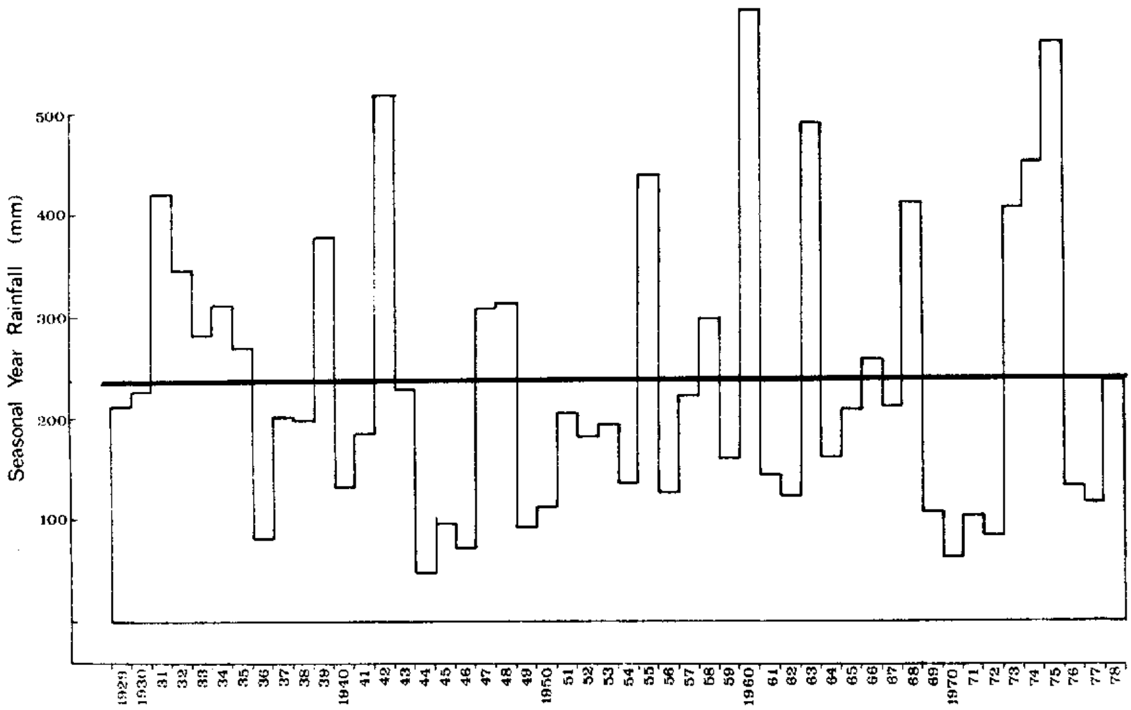


Fig. 2 Seasonal Year Rainfall, Menangina 1929 - 1978. Line represents mean of 235mm.

Table 1 Rainfall by Seasons at Menangina 1970-1979 (mm) (to April 30th 1979).

YEAR	SUMMER	AUTUMN	WINTER	SPRING	TOTAL
1970	23	10.2	31.8	16	81
1971	54	0	54	4.3	112.3
1972	37.8	0	47.5	0	85.3
1973	100	43	201.9	58.4	404
1974	193.7	45.6	139.8	71.4	450.5
1975	334.8	74.4	86.5	75.6	571.3
1976	50.7	0	15.4	69	135.1
1977	10.4	0	79.1	30	119.5
1978	101.9	6	101	28	236.9
1979	162	8			

Seasons as tabulated by Davies[9] viz Summer : November 1st of preceeding year to March 31st of calender year; Autumn : April; Winter : May 1st to August 31st; Spring : September 1st to October 31st.

of that summer. Areas to the west of the first big fires were burnt out in January 1977. Oak paddock at Jeedamya was burnt in September, 1976.

Fire Records

Fire boundaries shown on Fig.1 are based on mapped compilations undertaken by the Bush Fires Board and the Forests Department. The boundaries shown on Fig. 3, which gives the study area in more detail are partly based on those of Fig. 1 and partly on Menangina Station records (I.Duncan, personal communication). In both cases it will be observed that fires often burntout at the edges of salt lakes. The saltbush and bluebush succulent steppe vegetation [3] formed effective barriers to the spread of fire.

The fire boundaries are generalisations. Parts of the area between plots 30 and 21 on Tonkin Highway (Fig. 3) were burnt in January 1975, including plots 28 and 31. Plots 29 and 30 were burnt in September 1976 or January 1977. Stands of *Eucalyptus oleosa* intermingle with mulga in the vicinity of plots 14-21. These do not appear to have burnt at all during the period under review.

The Sample Plots

Several study plots of 20x25m were established at Jeedamya in July 1977, plots 29-36. These are not reported in the present account. A thorough inspection of Menangina Station was undertaken in January 1978 and a set of 27 permanent sample plots of 20x25m was established using the following criteria:

- **Acacia aneura* presence, at least prior to fire.
- *Definite evidence of substantial fire damage within the general area concerned.
- *Reliable evidence of the time that fire occurred.
- *Location easily mappable and site likely to be found again easily in future.
- *Access guaranteed in most weather conditions.
- *Subjective visual estimate that the site was reasonably representative of the surrounding landscape.
- *Representative sample of fire-time strata available for study.

In addition to plots 1-27 forming the set, summarised in Table 2, observations are also included from study plot 28, where regular measurements commenced in April 1977. This latter is not a fixed area sample plot but includes a number of individual plants in a wide area.
Plots 1-27 were assessed in January 1978, July 1978 and July 1979. A summary of these assessments follows.
All residual woody shrubs and trees were plotted and measured for height, crown width and, if of tree habit, for stem diameter at 1.3m on the bole.
All regenerating *Acacia* and *Codonocarpus cotinifolius*, *Duboisia hopwoodii*, and representatives of other species, were similarly measured at each visit. Ashbeds, dead standing trees and fallen wood were also plotted at the time of plot establishment.

Areas sampled by fire sets (Table 2) are as follows.

A 0.4ha, B 0.1ha, C 0.45ha and D 0.4ha.

Table 2 Summary of Plots and Fire History

Set	History and Plot Numbers
A	Burnt summer of 1974/75 (January1975?) Plots 9,10,12,13,22,23,24,25 Measured at 36,42,54 months after fire
B	Burnt summer of 1974/75 (January 1975?) and summer of 1975/76 (January 1976?) Plots 3 and 11 Measured at (24)36, (30)42, (42)48 months after fire.
C	Burnt summer of 1975/76 (January 1976?) Plots 1,2,4,5,6,7,8,26,27 Measured at 24,30,42 months after fire.
D	Burnt January 1977 Plots 14,15,16,17,18,19,20,21

Individual Plot Details

SET A *Burnt summer of 1974/75*

Plot 9
2 km SE of corner fence east of Princess Bore. Three large dead *Acacia aneura* (6.5m) and two *Casuarina cristata* (7.4m). There are undamaged stands of taller *Eucalyptus* ? *oleosa* in the vicinity.
At January 1978 51 *A. aneura* seedlings present, none over 0.5m tall.
Other regenerating perennials: *Acacia hemiteles* *A. tetragonophylla*, *Cassia nemophila*, *Casuarina cristata*, *Codonocarpus cotinifolius*, *Eremophila* ? *longifolia*, *Eucalyptus* sp., *Grevillea* sp., *Leichardtia australis*, *Scaevola spinescens*, *Solanum lasiophyllum*, *Solanum* sp.
Of these *C. nemophila* was the most abundant.

Plot 10
Near Plot 9
Several large dead mulga cf Plot 9, but also a number of burnt stems of shorter stature (3.2m) - total 16 dead.
This plot contained a large number of mulga seedlings in Jan. 1978 : at least 126, and 244 by July 1979. *Scaevola spinescens* was particularly abundant. Other regenerating perennials: *Acacia acuminata*, *A. hemiteles*, *A. murrayana*, *A. tetragonophylla*, *Cassia nemophila*, *C. pleurocarpa*, *Dodonaea filifolia*, *Dodonaea* sp., *Eremophila* sp., *Exocarpos aphyllus*, *Grevillea* sp., *Leichardtia australis*, *Solanum lasiophyllum*, *S. orbiculatum* and Malvaceae (indet.)

Plot 12
5.7km NE of Menangina Homestead, north of track. This area was very bare in January 1978. Most of the *Acacia aneura* (approx 17 trees) had been burnt through at the base, collapsed and continued to burn. Three dead standing mulga remained (4.4m). Fire probably hotter than at Plots 9,10. At January 1978 4 *A. aneura* seedlings present, none over 0.21cm tall, recruitment continued in the following 18 months to give a total of 7 by July 1979.
Regenerating perennials scarce: *Acacia murrayana* (1) *A. ramulosa*(1) *Rhagodia* sp,(1), *Solanum lasiophyllum* (4) and Malvaceae indet. However a number of daisies had germinated following June rain and grasses after February rain.

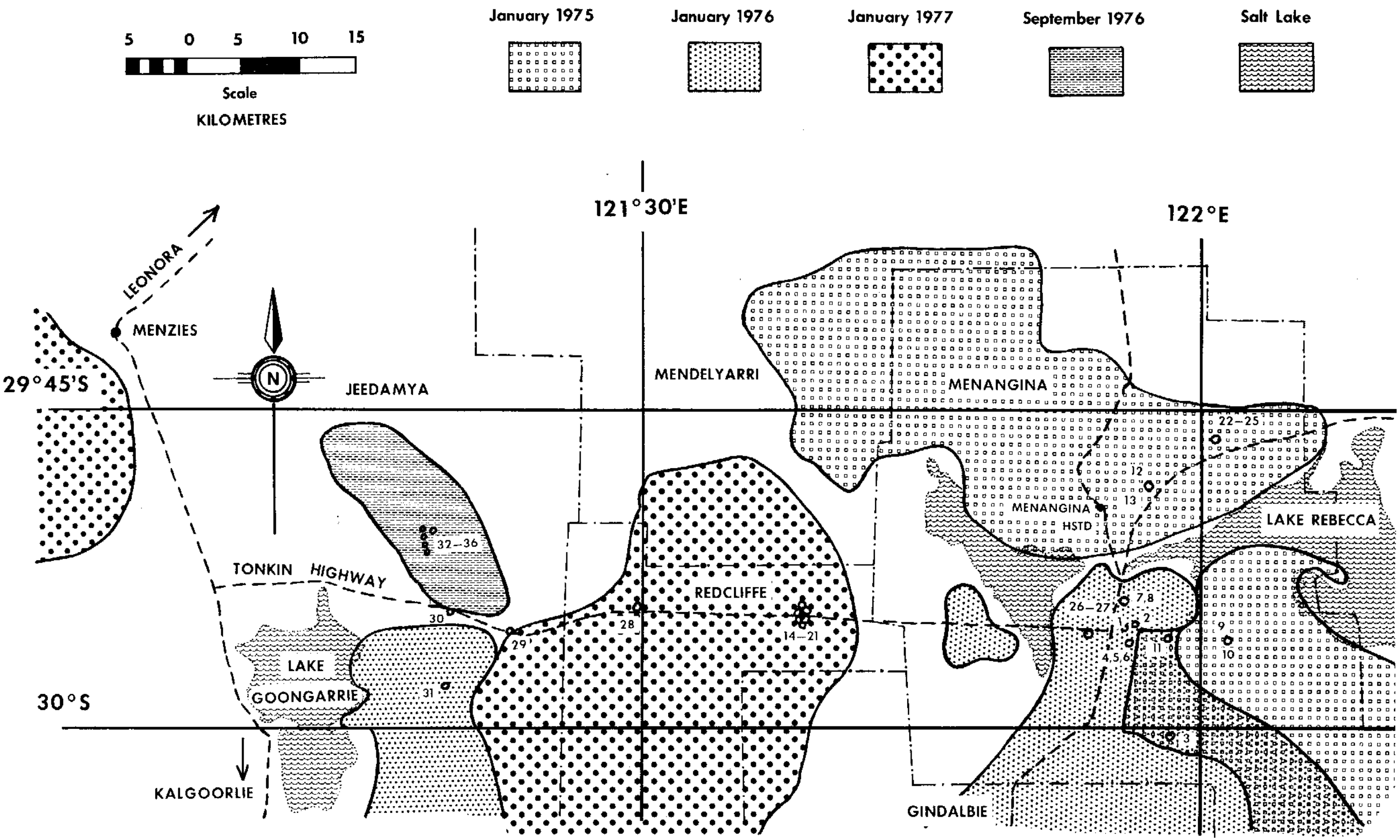


Fig. 3 Fire History of the Study Area showing plot locations and station boundaries.
(Fire Boundaries after Harris and S.J. Tonkin).

Plot 13
Near Plot 12, south of track.
Six standing dead *Acacia aneura* (5.3m) and another 5 ashed on the ground. One large *Brachychiton gregorii* survived the fire. There were more seedlings than in Plot 12 and greater coninuing recruitment. The plot was characterised by vigorous regeneration, from seed, of several *Duboisia hopwoodii* reaching 1.1m by January 1978 and 1.7m by July 1979. A solitary desert poplar also grew vigorously from 4.0m to 6.75m in the same period. A number of *Acacia linophylla* seedlings were present in this plot. Many of these showed signs of grazing.
In addition to those described the following perennials are also regenerating : *Acacia hemiteles*, *A. ligulata*, *A. tetragonophylla*, *Cassia nemophila*, *Cassia* sp., *Grevillea* sp., *Leichardtia australis*, *Sida* sp, *Solanum lasiophyllum*.

Plot 22
3 km NE of Norman Well, West of fence.
Open country, fire probably less severe, A large *Brachychiton gregorii* (6m) survived the fire and three large *Acacia aneura* (6.4m) were also burnt. Of these two died, and one survived to July 1979 with approx 10 per cent of its crown alive.
At January 1978 only one *Acacia* seedling was present (*A. ramulosa*) but three *Acacia aneura* germinated subsequently and reached 8cm height by July 1978. One *Duboisia hopwoodii* occurred. Two distinctive clumps of *Melaleuca* sp occurred in this plot, both were destroyed by the fire but sprouts grew out from the root mounds, growing up to 1m in height by July 1979. The only other perennials recorded regenerating in this plot were *Leichardtia australis* and *Solanum lasiophyllum*.

Plot 23
75m West of Plot 22
More ash here than in Plot 22, two standing burnt *Acacia aneura*, one (8.5m) surviving to July 1979 with 20 per cent of its crown alive. 10 vigorous *Duboisia hopwoodii* four of which reached 2m or more in height by July 1979. There were 10 very small *Acacia aneura* seedlings in January 1978, plus a large number of *A. ramulosa*, *A. linophylla*. All showed signs of grazing over the period of measurement. Other regenerating perennial species in this plot were *Acacia* sp., *Dodonaea* sp, *Scaevola spinescens*, *Sida* sp and *Solanum lasiophyllum*.

Plot 24
3 km NE of Norman Well, East of fence.
Eight dead *Acacia aneura* (4.6m). 31 seedlings were observed in January 1978 often sheltered by fallen branches and grass clumps, average height 7.8cm. Also present a number of regenerating *Acacia linophylla*, *A. ramulosa* and *Cassia nemophila*, many of these three growing from old root stocks. Many of these plants showed signs of grazing by July 1978.
Other regenerating perennials included *Cassia artemisiodes* *Dodonaea* sp, *Duboisia hopwoodii*, *Scaevola spinescens*, *Solanum lasiophyllum* and Malvaceae indet.

Plot 25
90m East of Plot 24.
Three dead standing *Acacia aneura*. Excellent regeneration of its seedlings, with 52 measured in January 1978.
Other species regenerating *Acacia hemiteles* (1), *A. linophylla* (4) *A. ramulosa*/*A. acuminata* (9), *A. murrayana* (9), *A. tetragonophylla* (9), *Codonocarpus cotinifolius* (1), *Dianella revoluta* (1) *Duboisia hopwoodii* (10), *Cassia nemophila* (1).

SET B *Burnt summers of 1974/75 and 1975/76*

Plot 3
South of Pardon Me
Further to the south of this plot is a broad expanse of *Eucalyptus salmonophloia* woodland. Prior to the fires there were 11 mulga trees in the plot of varying sizes. While the fires left a considerable amount of ash, no seedlings of *Acacia aneura* have been recorded. The plot has been characterised by a dense cover of *Halgania cyanea* (a Boraginaceae, low shrub). Regeneration of perennials to date includes *Acacia* sp, *A. murrayana*, *A. tetragonophylla*, *Brachychiton gregorii* (1) *Codonocarpus cotinifolius* (1) and *Leichardtia australis* (1).
In addition a number of daisies were noted in July 1979.

Plot 11
This is 1.15km West of Princess Mill and south of fence.
Some five dead standing *Acacia aneura* here (5.6m) with 35 mulga seedlings in January 1978. Good regrowth of a mixture of *Acacia* species is proceeding.
Perennials regenerating include *Acacia hemiteles*, *A. ligulata*, *A. ramulosa*, *A. tetragonophylla*, *Cassia nemophila*, *Codonocarpus cotinifolius*, *Scaevola spinescens*, *Solanum lasiophyllum*.

SET C *Burnt summer of 1975/76*

Plot 1
1 km East of end of Tonkin Highway towards Princess.
There were 11 standing dead *Acacia aneura* (5.7m) and 3 *A. ramulosa* (3.4m) in this plot. Seventeen mulga seedlings were recorded in January 1978 with some subsequent recruitment. Other regenerating perennials include *Acacia ramulosa*, *Cassia nemophila*, *Scaevola spinescens*, *Solanum lasiophyllum*, *Exocarpus aphyllus* and *Hakea* sp.

Plot 2
1km East of Plot 1.
This plot contained a stand of 31 *Acacia aneura* (4.5m) whose crowns were scorched. Little ash was produced and the 31 trees retained scorched phyllodes for some time although only one tree was alive in January 1978 (3.2m height, 40% live crown). Only one *A. aneura* seedling was noted in January 1978 at 12cm height; this had died by July 1978 and no subsequent recruitment has been observed. In this case the fire was sufficient to kill existing trees but perhaps not hot enough to induce fresh germination.

There are patches of *Solanum lasiophyllum* near ash beds and several regenerating *Cassia nemophila*.

Plot 4
SW of Plot 2
Here the main species is *Acacia ramulosa*. Specimens of 2-3m in height were fire damaged but recovered. There are also individuals of other species which survived viz *A. aneura* (6.9m, 50% crown) *A. acuminata* (2.5m, recovered) *A. tetragonophylla* (2.5m, recovered) *Santalum spicatum* (2.5m recovered).
Only one seedling of *Acacia aneura* has been recorded. Other regenerating perennials include *Dodonaea filifolia*, *Eremophila* sp., *Leichardtia australis* and *Scaevola spinescens*.

Plot 5
Adjoins Plot 4 to the North.
This area was more severely burnt with a lot of ash from burnt out wood. Three standing *Acacia aneura* remain, one dead (6.7m) and two partially alive (7.5m, above fire damage, senile from old age?; and 6.6m, 20% crown alive).
37 seedlings of *A. aneura* were recorded in January 1978, with 15 greater than 0.5m in height.
Other regenerating perennials included *Acacia hemiteles*, *A. ramulosa*, *A. tetragonophylla*, *Canthium lineare*, *Cassia nemophila*, *Dodonaea filifolia*, *Eremophila* sp., *Eucalyptus* sp.

Plot 6
28m NW of Plot 5.
This plot encompasses a dense grove of mulga trees killed by the fire, some 50 trees (4.3-5.8m height) of which three only have remained partially alive (4.4m, 70% crown; 5.7m 75% crown, and 4.9m 95% crown).
Some 150 mulga seedlings were recorded in January 1978, it seems that where there are no seedlings and a lot of dead trees then the fire burnt the tree crowns but not the grass (or the grass had subsequently regrown) and the dense grass cover inhibited seedling germination or establishment.
Three specimens of *Codonocarpus cotinifolius* were also found within the plot. These have not grown as well as this species elsewhere in more open conditions.

Plot 7
1.5km South of Menangina/Edjudina road junction, and east of the road.
In this area fire was very intense, all trees were burnt to black stumps or ash, with no standing individuals left for height measurements. At least seven *Acacia aneura* trees occurred here before the fire.
Cassia pleurocarpa was a noticeable pioneer at this site. Seven plants grew from an average height of 37cm in January 1978 to 73cm in July 1978 and to 151cm in July 1979.
One *Acacia aneura* seedling was recorded in January 1978 and another in July. Other regenerating species here are *Acacia murrayana* and *A. ramulosa*.

Plot 8
This is 100m East of Plot 7.
Some 10 dead *Acacia aneura* (3.5m) occur on this plot. *Acacia aneura* seedlings have been added to the stand continuously from 1 in January 1978, 2 in July 1978 and 6 in July 1979.
As for Plot 7 *Cassia pleurocarpa* was particularly prevalent (25 stems).
Other regenerating perennials include *Acacia murrayana*, *Acacia ramulosa*, *Eucalyptus* sp, *Sida* sp, *Solanum lasiophyllum*. Herbs include *Brunonia australis*, *Helichrysum apiculatum* and *Wurmbea tenella*.

Plot 26 and 27
1.9km West along Tonkin Highway, south of road. This area contained more *Casnarina cristata* than the other plots, probably being closest in original composition to Plot 9. In Plot 26 there was one (7.8m) and one large *Acacia aneura* : the former was still alive in July 1979 with 30% crown, while the latter was dead in January 1978. In Plot 27 three large *Casuarina* trees had similarly deteriorated by July 1979, and while still alive then had much bark missing, fungal presence and active termite workings. Several patches of ash testify to the local severity of fire but a number of shrubs 1-2m in height were only partially scorched and have recovered from the fire by crown regeneration. These include *Acacia acuminata*, *A. hemiteles*, *A. ramulosa*, *Alyxia buxifolia*, *Exocarpus aphyllus*, *Acacia tetragonophylla*, *Cassia nemophila*, *C. artemisiodes*, and *Scaevola spinescens*.
Seedling regeneration has been scarce, with only one *Acacia aneura* recorded from Plot 26.

SET D Burnt summer of 1976/77

Plots 14-21 form a set of spaced samples, four each side of the road, 25km West along Tonkin Highway.
This locality represents an area severely burnt lying between stands of *Eucalyptus* which appeared not to have suffered much in the way of crown damage due to the fire.

Plot 14
Seven dead *Acacia aneura* trees (6.9m) and a lot of ash in this plot at establishment. Continuing recruitment of *A. aneura* seedlings from 2 in January 1978, to 5 in July 1978 and 10 in July 1979.
Seedling and root regeneration of *Acacia hemiteles* particularly abundant. One plant of *Duboisia hopwoodii* grew from 7cm in January 1978 to 0.8m in July 1979.
Also regenerating well are *Cassia nemophila*, *Leichardtia australis* and *Solanum lasiophyllum*.

Plot 15
Here one dead *Acacia aneura* (5.4m) and one dead *Casuarina cristata*. No seedling regeneration of *A. aneura* observed, but very large numbers of seedling *Acacia hemiteles* are present.
Other regenerating species include *Cassia nemophila*, *Codonocarpus cotinifolius*, *Eremophila* sp, *Leichardtia australis* and *Scaevola spinescens*.

Plot 16
Three large mulga occurred here before the fire (5m) but all woody vegetation completely burnt off. *Acacia hemiteles* seems to have been present as shrubs to 0.5m high - many seedlings of this species present at January 1978. By July 1979 one *Acacia aneura* seedling was present and 3 *Codonocarpus cotinifolius* had germinated and reached an average height of 22cm.
Other perennials present : *Cassia nemophila, Leichardtia australis* and *Solanum lasiophyllum*.

Plot 17
Very similar to Plot 16, but one large *Acacia aneura* (7m) still surviving with 50% crown. Only one seedling recorded, new in July 1979. One surviving bush (0.6m) of *Acacia hemiteles*, with a few seedlings present on the plot.
Other perennials present *Cassia nemophila, Leichardtia australis, Scaevola spinescens* and *Solanum lasiophyllum*.

Plot 18
Entire plot area bare in January 1978 apart from 2 small *Acacia hemiteles*, one of which did not survive until July 1978.
Casuarina cristata was present before the fire. The eastern end of the plot is badly eroded with gullies eating back though a number of daisies were present in July 1979 including *Cephalipterum drummondii* and *Pterigeron cylindriceps*. At that time shooting from old roots of *Acacia hemiteles* had occurred, one *Cassia nemophila* was evident, a number of *Leichardtia australis* had germinated and several *Solanum lasiophyllum* were growing well.

Plot 19
Five dead *Acacia aneura* trees (5.8m). At January 1978 there were three seedlings each 3cm high, these had grown to 26cm by July 1979 with no further recruitment.
By July 1979 there were several *Acacia hemiteles, Cassia nemophila, Duboisia hopwoodii, Leichardtia australis, Sida* sp., and *Solanum lasiophyllum*.

Plot 20
This area had one large dead *Acacia aneura* (5.4m), no seedlings were present in January 1978 but one appeared by July 1978.
Seedling regeneration of *Acacia hemiteles* is plentiful, as is *Cassia nemophila, Leichardtia australis* and *Solanum lasiophyllum*. One specimen of *Acacia acuminata* and one of *Acacia tetragonophylla* were recorded at July 1979.

Plot 21
Two dead *Acacia aneura* (4.4m) and only one seedling recorded.
Several *Acacia hemiteles* growing from rootstocks, as also *Cassia nemophila*. Several *Scaevola spinescens* present and a number of *Leichardtia australis* and *Solanum lasiophyllum*.

Note: other plots shown on the plan do not form a part of these four sets. However data from Plot 28 is included in the present account.

Regeneration Stocking of *Acacia aneura*

The preceeding plot summaries suggest that mulga regeneration has occurred in all fire sets. A summary of all measured *Acacia aneura* seedlings by height classes is given in Table 3 for each fire set at each measurement period. As the plots were not observed at the time of fire and timing of fire is based on indirect evidence some caution must be exercised in precision of results. Similarly rainfall over such a wide area cannot be adequately dealt with by reference to one recording location. The total sample plot area of 1.45 ha is representative of some 700km^2 sampled, a sample of the order of 0.002 per cent.

There is a trend of increasing mean height of seedlings with time from fire across all sets and including areas with additional germination during the period studied. A comparison of sets B and C (Fig. 4) suggests that seedlings in these two probably both commenced growth after the summer 1974-75 fire. It has been noted above that no successful germination has occurred in plot 3 of set B and that this sample is wholly due to seedlings in plot 11.

In due course it will be possible to give more precise height age correlations as natural thinning progresses and by concentrating measurements on the first recorded individuals only.
In passing we may note that Crisp[8] has shown a size/age correlation for young mulga.
He took 47 years of size measurements for 3

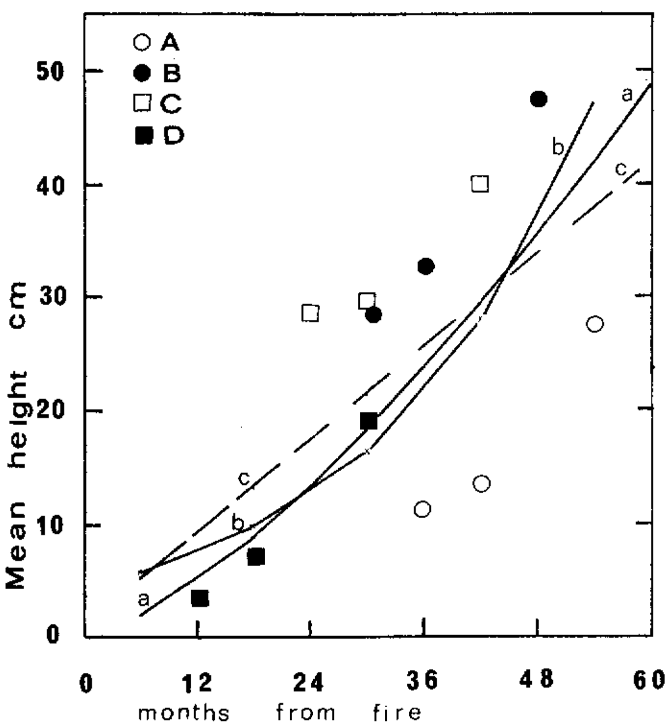


Fig. 4 Mean height of *Acacia aneura* seedlings and time in months after the occurrence of fire.
The data is derived from Table 3, regressions as follows (MH mean height; Mo months):

a $MH = 0.153\ Mo^{1.407}$ $r = 0.770$ **
b $MH = 4.454e^{0.044Mo}$ $r = 0.682$ *
c $MH = 1.074 + 0.680\ Mo$ $r = 0.621$ *
A.B.C.D. refer to Fire Sets

Table 3 Total *Acacia aneura* seedlings recorded in size classes, by months after fire.

Fire Set	Months after fire	Numbers of *Acacia aneura* seedlings by height classes (cm)											
		1 < 10	2 10-14	3 15-19	4 20-24	5 25-29	6 30-34	7 35-39	8 40-44	9 45-49	10 50+	Total	Means
A *	36	85	51	29	22	11	12	5	2	-	3	220	11.5
	42	68	46	19	35	18	8	8	10	2	4	218	13.8
	54	30	37	46	29	15	17	12	10	8	34	238	27.1
B	24/36	-	3	4	6	6	7	5	2	2	-	35	28.5
	30/42	-	1	1	5	8	5	6	6	2	2	36	32.5
	42/54	-	2	-	1	2	4	4	5	3	17	38	47.5
C	24	29	30	22	27	17	20	10	17	8	25	205	27.3
	30	21	37	23	23	14	18	22	11	11	32	212	29.3
	42	14	19	16	21	16	16	12	12	17	71	214	39.6
D	12	6	-	-	-	-	-	-	-	-	-	6	3.3
	18	10	-	-	-	-	-	-	-	-	-	10	7.1
	30	2	5	5	3	2	2	-	-	-	-	19	18.8

* In plot 10 of Set A an additional 61 unmeasured seedlings present in 1978 and 179 present in July 1979. These have not been included here as they do not contribute to the mean heights given.

mulga that grew after fire and summed height (H) and canopy diameter (CD) to obtain an index of size (I) : H + CD = I
The relationship between age (A) and I was linear and highly significant.

Age = 2.81 + 0.048 I

similarly

Stem girth = -1.3 + .040 I

and, by algebra,

Age = 4.39 + 1.20 stem girth

In the present case a power curve fits the data presented better than a linear regression (Fig. 4). In these analyses the data of set B have been assigned a time from fire midway between the two events i.e. 30 months for the first entry of Table 1. If set B is excluded from the power curve calculation the equation becomes:

$$\text{Mean Height} = 0.208\ \text{Months}^{1.282}$$
$$r = .754^{*(1)}$$

a less significant result.

There is an obvious trend of increasing numbers of seedlings with increased time from fire. This is examined in subsequent graphs where numbers of seedlings present in set A have been adjusted (see Table 1) and all sets have been standardised to numbers of seedlings per hectare. Taking all seedlings the very low numbers recorded from set D produce an S shaped curve. However if seedlings of 30cm height and larger (individuals which are well established and likely to persist), are considered then a pronounced linear trend is observed (Fig. 5). Excluding the first two observations of set D the linear regression is:

$$\text{N}^{\text{os}}\ \text{seedlings}{>}30\text{cm ha}^{-1} = 9.806 + 4.384\ \text{Months}$$
$$r = 0.410$$

(1) * p 0.05, ** p 0.01, *** p 0.001

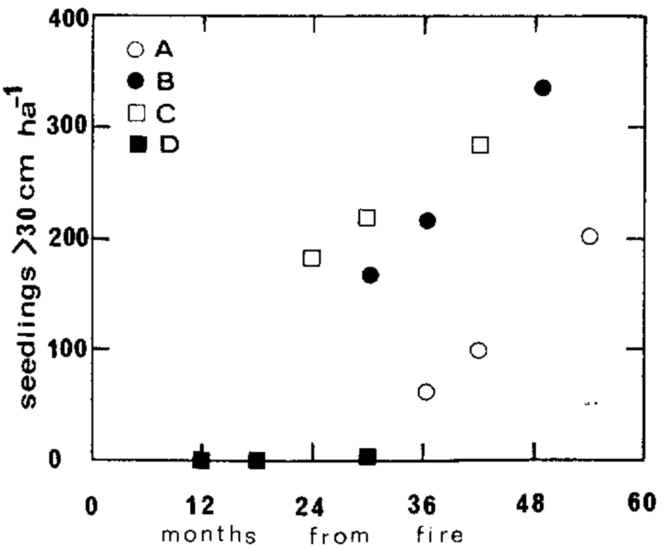


Fig. 5 Number of seedlings exceeding 30cm in height per hectare and time after the occurrence of fire (Data from Tables 3 and 4) *Acacia aneura* only.

In relation to crowding we may assume that as heights increase numbers per ha will fall. As these regenerating stands age then the mean height may become dependant on numbers of stems per hectare. A set of regressions is shown in Fig. 7 for numbers of stems exceeding different height intervals per ha. These are all inclusive so that as one moves across the figure all previous data contribute to each regression, with the relation between the smallest class considered being least significant. All four regressions illustrated are significant at p 0.05 or better. Shorter minimum height regressions are not significant and are not illustrated.

This value of r is not significant at the 10 per cent level.

If we consider the stocking of seedlings per ha and its relation with mean height there is a much closer relationship, though it cannot be said that stocking numbers depend on height (Fig. 6). For the example of seedlings of 30cm and taller the regression is :

Nos seedlings > 30cm ha^{-1} = 8.343 Mean Height -57.272 r= 0.925 ***

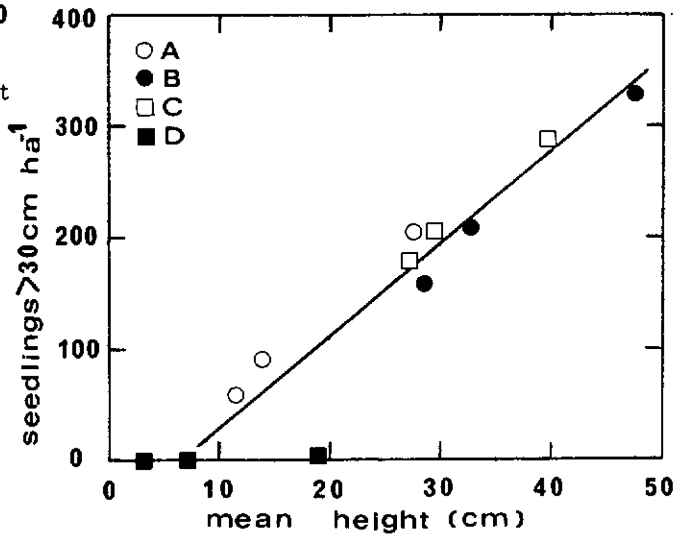


Fig. 6 Number of seedlings exceeding 30 cm in height per hectare and mean height of all recorded *Acacia aneura* seedlings (Data from Tables 3 and 4).

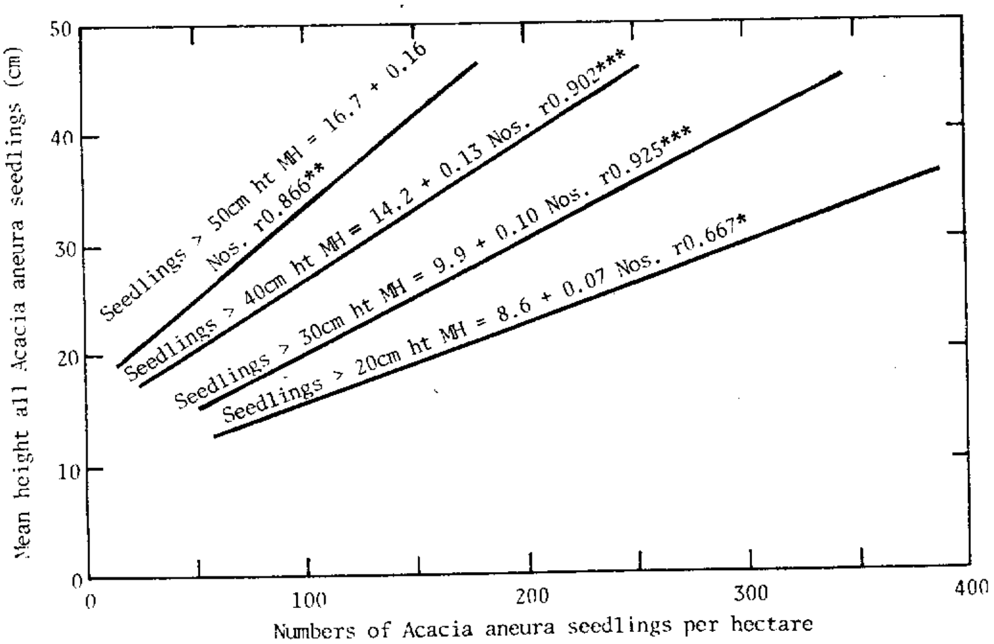


Fig. 7 Calculated regressions for mean height of all *Acacia aneura* seedlings exceeding the heights indicated and number of *Acacia aneura* seedlings per ha (Data from Tables 3 and 4).

Variation in Stocking

Thus far stocking has been illustrated on the broadscale. The individual plot summarises show that there is considerable variation per unit area between plots of a set. For example of the 291 seedlings present at July 1978 (Table 4) of set A (including unmeasured individuals in plot 10) plots 12, 13 and 22 contribute 17 seedlings (6 per cent) while plot 10 contributes 126 (43 per cent). The imbalance is even more pronounced in set C with 6 plots 2, 4, 7, 8, 26, 27 contributing 6 seedlings (3 per cent) and plot 6 contributing 151 seedlings (71 per cent) to the total of 212.

Division of the 20 x 25m plots into 20 subplots of 5 x 5 m allows spatial variation in stocking to be examined more closely. Table 4 summarises stocking, at July 1978, for subplots by both presence/absence of *Acacia aneura* seedlings and proportion of the subplot containing ash from the fire. It will be recall-

Table 4 Menangina Fire Plots : numbers of subplots with 0, 1, >1 seedlings of *Acacia aneura* July 1978, by ash cover levels.

Fire Set	Ash cover (%)	Number of seedlings per sub-plot: 0	1	>1	Total sub-plots	% of sub-plots	% stocked	Total seed-lings	Mean No. of seedlings per sub-plot	per stocked sub-plot
		Number of sub-plots								
A	0	49	9	20	78	49	37	165	2.12	5.7
	< 10	24	13	9	46	29	48	52	1.13	2.4
	10-19.9	9	5	12	26	16	65	64	2.46	3.8
	20+	5	2	3	10	6	50	10	1.0	2.0
	Totals (means)	87	29	44	160	100	(45.6)	291	(1.82)	(3.99)
B	0	9	1	2	12	30	25	5	0.4	1.7
	< 10	11	2	0	13	32.5	15.4	2	0.15	1.0
	10-19.9	7	0	1	8	20	12.5	3	0.38	3.0
	20+	2	1	4	7	17.5	71.4	26	3.71	5.2
	Totals (means)	29	4	7	40	100	(27.5)	36	(0.90)	(3.27)
C	0	70	15	15	100	56	30	137	1.37	4.6
	< 10	32	7	6	45	25	29	46	1.02	3.5
	10-19.9	16	1	1	18	10	11	4	0.22	2.0
	20+	13	1	3	17	9	24	25	1.47	6.3
	Totals (means)	131	24	25	180	100	(27.2)	212	(1.18)	(4.33)
D	0	38	4	0	42	26	9.5	4	0.095	1
	< 10	44	3	0	47	29	6.4	3	0.064	1
	10-19.9	30	2	0	32	20	6.3	2	0.063	1
	20+	38	1	0	39	24	2.6	1	0.026	1
	Totals (means)	150	10	0	160	00	(6.3)	10	(.063)	(1)
All sets	0	166	29	37	232	43	28	311	1.34	4.7
	< 10	111	25	15	151	28	26.5	103	0.68	2.6
	10-19.9	62	8	14	84	16	26.2	73	0.87	3.3
	20+	58	5	10	73	14	20.5	62	0.85	4.1
	Total (means)	397	67	76	540	101	(26.5)	549	(1.02)	(3.84)

ed that earlier observations suggested some correlation of regeneration with quantity of ash (page 3). Taking all subplots:

308 had some ash, 232 had none; 77 of the former and 66 of the latter had *Acacia aneura* seedlings. Chi-square analysis shows these proportions as not significant. Only in set A is the number of subplots with ash and containing seedlings sufficiently greater than the number of subplots without ash yet with seedlings for Chi-square to reach significance at p 0.05. In set C more subplots without ash had seedlings than did those subplots with ash. Even in this set however subplots with a lot of ash held a high density of seedlings on average (Table 4).

Once old trees have died the fallen timber may remain on the ground for years.[30] It was not possible to always distinquish between old wood as a source of ash and standing trees consumed by fire. However it was possible to be fairly precise about numbers of standing trees before the fire. It is instructive to compare the July 1978 stocking by subplots with the level of stocking of large mulga achieved prior to the fire. The following summarises each plot set:-

A. 78 subplots with no ash, of these 27 subplots had one or more mulga trees prior to the fire, 19 subplots contained one or more seedlings in July 1978.
   Of the 82 subplots with ash, 22 had one or more live mulga before, versus 44 with one or more seedlings in July 1978.
   The average ash content of subplots with seedlings was 7.4 per cent, and of those without seedlings 4.6 per cent.

B. 12 subplots with no ash, of these 5 subplots had one mulga tree prior to the fire, 3 subplots contained one or more seedlings in July 1978.
   Of the 28 subplots with ash, 8 had one or more mulga before, versus 8 with seedlings in July 1978.
   The average ash content of subplots with seedlings was 13.9 per cent and of those without 7.1 per cent.

C. 100 subplots with no ash, of these 28 held trees prior to the fire, whereas 30 contained one or more seedlings in July 1978.
   Of the 80 subplots with ash, 28 held mulga before versus 19 in July 1978.
   The average ash content of subplots with seedlings was 4.5 per cent and of those without 6.2 per cent.

D. 42 subplots with no ash, of these 6 subplots had a mulga tree before the fire, whereas 4 subplots were stocked with one seedling each by July 1978.
   Of the 118 plots with ash, 14 had a mulga before versus 6 in July 1978. (There has been additional stocking since)
   The average ash content of subplots with seedlings was 6.2 per cent and of those without 11.7 per cent.

Interestingly set B, burnt twice, had more ash present than did the other sets, though set D had a higher percentage of subplots with some ash in them.

The mean number of seedlings per subplot (Table 4) needs to be multiplied by 400 to give number per ha. The last column of Table 4 emphasises the gregarious nature of *Acacia aneura* at the seedling stage. We must confirm the statement of Everist[11] that seedlings are more plentiful near ash than elsewhere in the paddock. However there are reservations to this in that -

1. too intensive a fire may destroy seeds.
2. insufficient fire may not remove grass competition.

Evidence for these qualifications comes from plot 3 where 60 per cent of subplots had ash (see also page 7) and a comparison of lower percentages of subplots with no ash for sets B and D (Table 4), in respect of the first. In the second case no regeneration in plot 2 (page 7) and patchiness in plot 6 (page 8) support the assertion.

Plot 29

Plot 29 has previously been referred to as 'Macs Mulga'.[12] This is not part of the set previously discussed. It is included as more observations have been taken here. Layout of the area studied is shown in Fig. 8. All standing mulga have been assessed for fire damage. The area was burnt in December'74 or January 1975, contra Fig. 3, and in July 1979 26 of the 60 mulga trees still held some live foliage in their crowns. It will be apparent that mulga seedlings measured are predominantly in groups, and not many of them are near the standing burnt trees. A complete survey of all seedlings in the area of about 0.2 ha has not been undertaken but the densest groups are those included in assessments.

Average heights are shown in Table 5. Here it will be seen that the early comparative advantage of seedlings with longer phyllodes[12] has been maintained through the measurement period. Five seedlings with narrow phyllodes (almost terete) have not been measured consistently but these have outgrown the broad phyllode plants. There are not many individuals with very narrow phyllodes in the general area. Their growth of 18.6 cm in 12 months may be compared with the increase of 11cm shown by the fastest growing 10 per cent of the broad phyllode seedlings. Reasons for differential growth are not readily apparent yet may have important consequences for stands in the area. While measurement data for the Menangina set have not been subjected to phyllode analysis, it should be noted that records have been kept of phyllode type, and that, on the whole, there are many more seedlings of broad phyllode characteristics in the set.

Movement through height size classes (as in Table 1) for 50 *Acacia aneura* seedlings at plot 28 is shown in Fig. 9. Seedlings with long phyllodes are shown stippled, the others are short, but all 50 are of the broad phyllode category[12]. Despite the same 'average' growth (Table 5) those with long phyllodes have passed through height classes more rapidly.

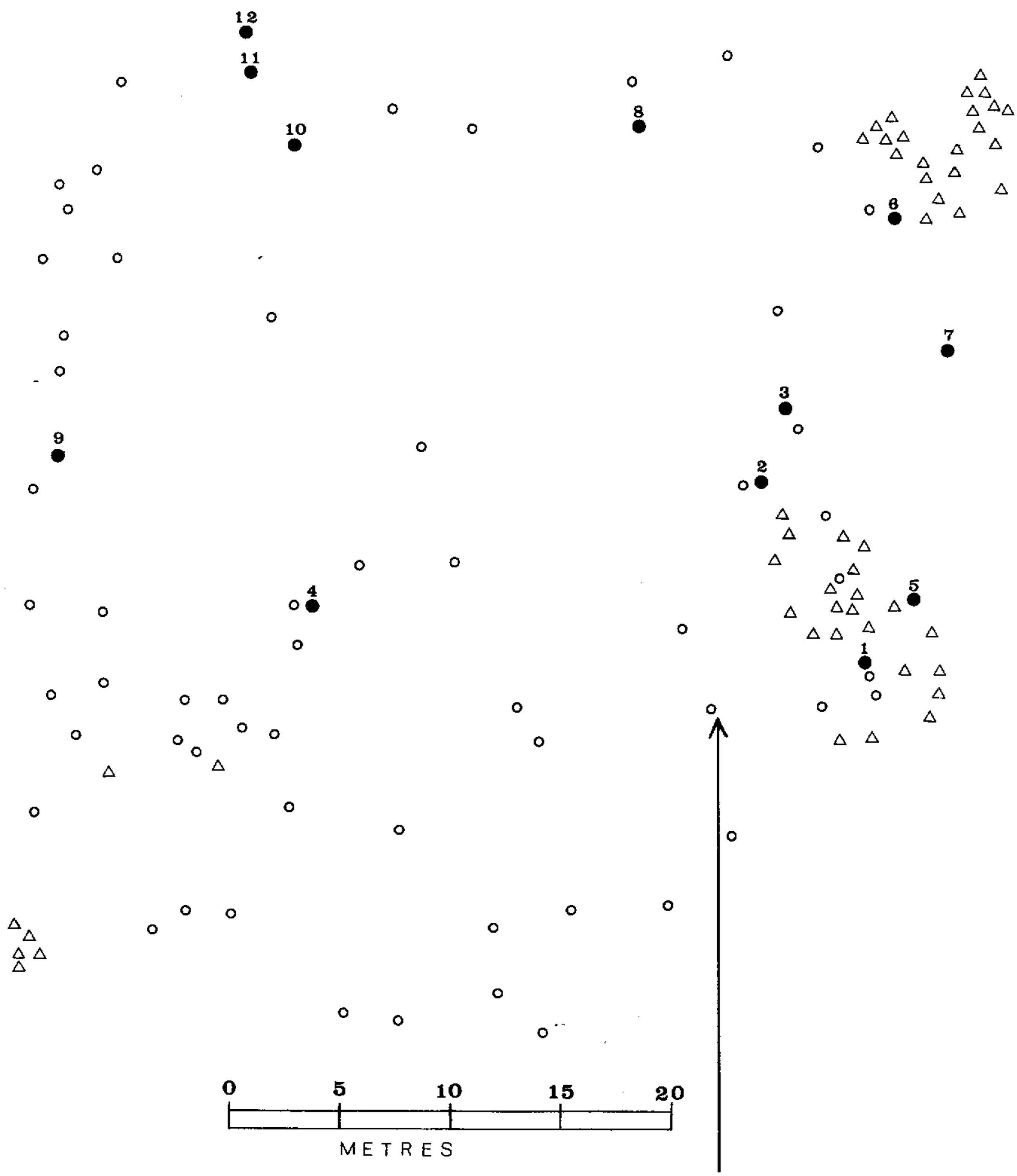


Fig. 8 Distribution of desert poplar, measured mulga seedlings and standing mulga trees killed by fire in Plot No. 28.
● 1, 2 Desert poplar trees
○ Dead mulga
△ measured mulga seedlings

Table 5 Summary of Height Measurements Plot 28.

Date	Months from fire	*Acacia aneura* (a) short, broad phylls	(b) long, broad phylls	(c) narrow phylls	(d) med-narrow phylls	(e) a+b+d	(f) fastest growing 10% (e)	*Acacia hemiteles*	*Acacia ramulosa*	*Codonocarpus cotinifolius*
	number	33	16	5	1	50	5	16	1	12
		Average heights (cm)								
20.4.1977	27	24.9	36.2	-	30	28.6	39.8	47.2	-	305
18.10.1977	33	(27.1)*	(40.1)	-	33	31.4	43.8	48.9	-	312
16.1.1978	36	26.7	35.5	-	32	29.6	46.0	50.1	68	346
8.7.1978	42	26.9	36.7	81.2	30	30.1	47.2	51.0	68	412
17.10.1978	45	28.5	36.9	-	31	31.2	49.8	54.3	-	429
18.4.1979	51	(30.1)	40.8	-	31	33.5	57.8	55.8	-	446
4.7.1979	54	29.9	42.1	99.8	30	33.8	58.2	56.5	67	(438)
18.10.1979	57	30.7	42.5	-	30	34.5	59.7	57.3	-	463

* Brackets indicate the measurements concerned are likely to have been overestimated.

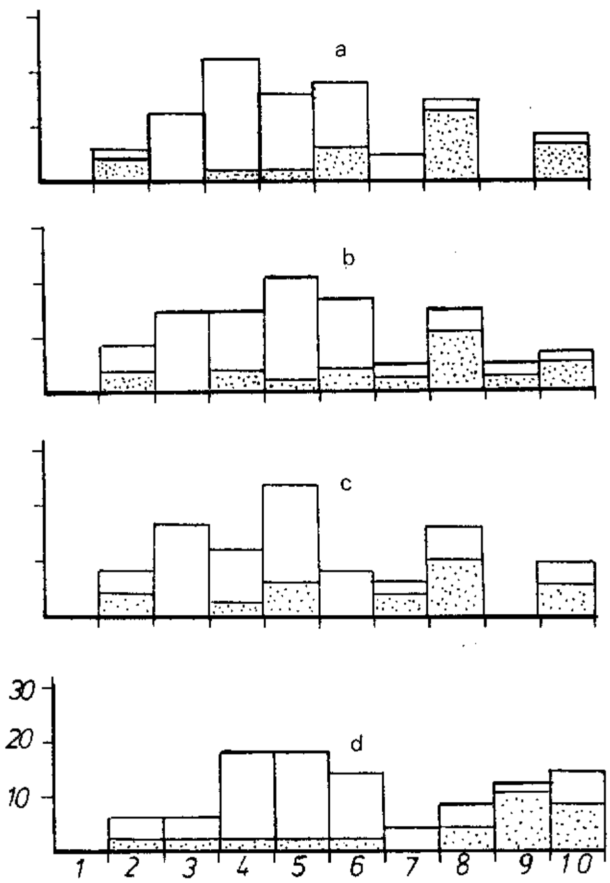


Fig. 9 Progression through size classes of 50 measured *Acacia aneura* seedlings 20.4.77 to 4.7.79 (Plot 28) stippled part of the bars represent seedlings with long broad phyllodes. All histograms are percentages in the same size classes as in Table 3.
a 27 months; b 36 months; c 42 months; d 54 months; from fire

Other Species

It has been noted[35] that *Cassia eremophila* may throw out regrowth from burnt plants. This is confirmed by events in plots 29-36[12]. In these, individuals badly burnt sent out new shoots, in most cases from root material. Most did not persist and were unable to form the basis of a rejuvenated plant. Seedling survival of this species has been patchy.

Another species of general interest in the general region about Menangina is *Acacia hemiteles* (referred to as *Acacia graffiana* earlier.[12]) It is present in 15 of the 27 Menangina plots. A small stand (Fig. 8) has been measured in plot 29 (Table 5). It can regenerate from fire scorch and from root stocks. In many areas it is difficult to determine whether seedlings are present or whether one is observing root regeneration. The vigour of the 16 plants measured in plot 29 may be due to rootstock regeneration or to the fact that they line the edge of a strong ashbed. Passage through height classes of these individuals is shown in Table 6.

Table 6 *Acacia hemiteles* in Plot 29

Months from fire	Numbers in Height Classes (cm) 30-34	35-39	40-44	45-49	50+
27	4	-	2	2	8
36	1	2	2	2	9
42	-	3	2	1	10
54	-	-	2	2	12

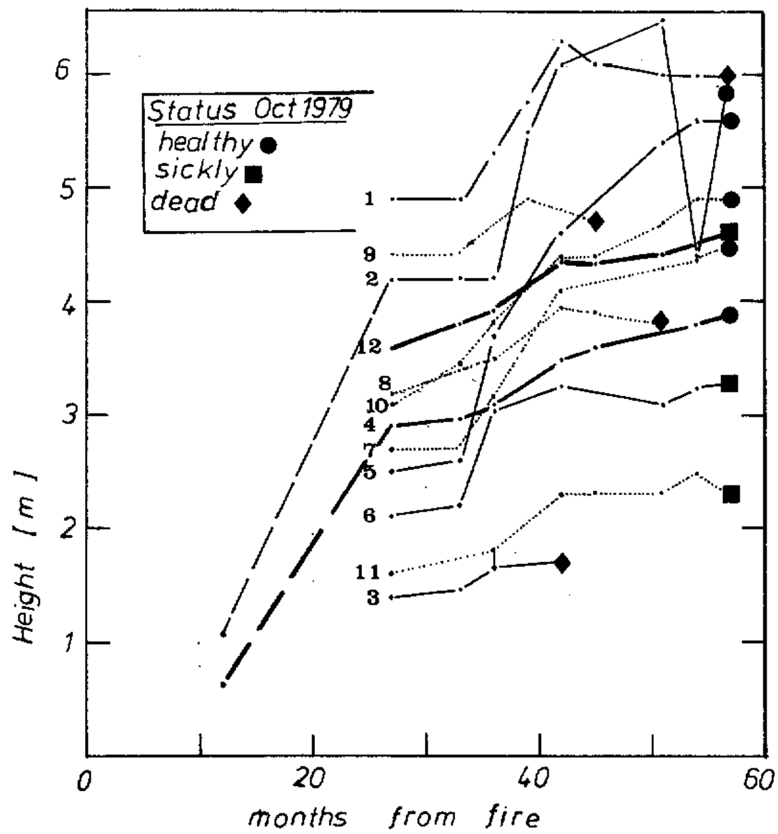


Fig. 10 Recorded heights of desert poplar trees in Plot No. 28, with status as at October, 1979.

Condonocarpus cotinifolius, the desert poplar, is a fast growing species after fire. It behaves as a nomad and can outgrow all the permanent constituents of the mulga woodlands.[12]

Heights attained by individuals (Fig. 8) at plot 29 are shown in Fig. 10. Two of the twelve trees had died within 4 years of the fire (not four years of germination!)another one died at 51 months. By October 1979 only 5 remained in an apparently healthy condition. The irregular growth of number 2 is explained by the fact that its leader bent over almost horizontal and branches resumed upward growth. It could not support its fruit crop in 1978/79. By late 1979 lateral branches had restored its height to 6m.

Tree 5 dramatically demonstrates the phenomenal growth rate attainable by *Codonocarpus* (Fig. 10). This individual was 2.5m tall at 27 months after the fire. It grew to 5.6m in the ensuing 30 month period, i.e. at a rate of 1.24m per annum, almost twice the mean rate of growth of 0.63m per annum.

Seven trees flowered in their second year and carried fruit by October 1977.

Fig. 11 shows individual *Codonocarpus cotinifolius* trees from the set of Menangina plots. Numbers refer to plots and the vertical bars represent standard deviations of the mean values for trees of Plot 29. The growth of poplar in plots 3 and 11 suggests that they commenced growing at the same time as those of plots 13 and 25 in set A i.e. that the January 1975 fire was responsible for initiating their growth. This is borne out by a comparison with the plot 29 data.

It may be postulated that if desert poplar does not attain 3.5m in height by 5 years it will not survive. However the very fast growing individuals also show signs of early demise. Thus if it exceeds 4.3m after 2 years it will not survive.

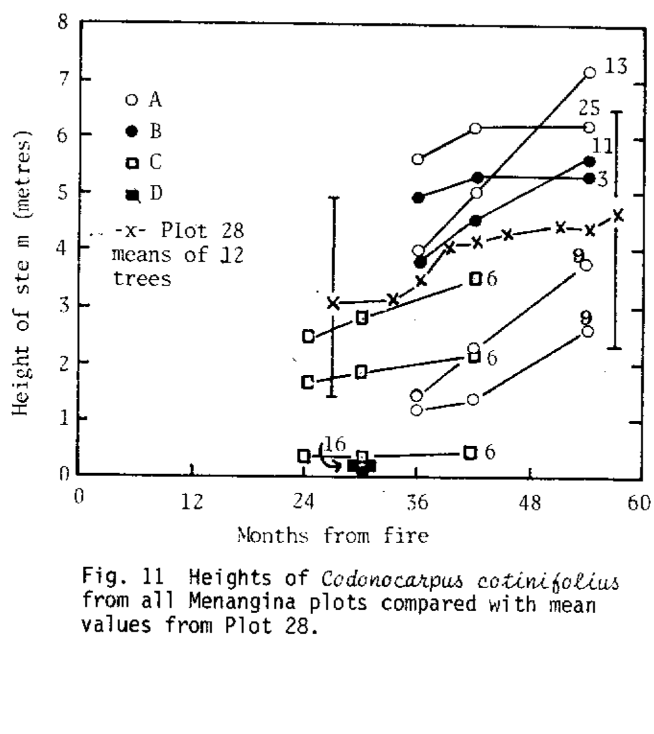


Fig. 11 Heights of *Codonocarpus cotinifolius* from all Menangina plots compared with mean values from Plot 28.

Table 7 attempts to summarise the patterns of regeneration for species thus far observed in Menangina regeneration plots.

Table 7 Regeneration Patterns of some Menangina Species

Species	Behaviour* A	B	C	D	E	F
Acacia acuminata		+	+			
A. aneura				+		
A. hemiteles	+		+			
A. ligulata		+	+			
A. linophylla		+		+		
A. murrayana					+	
A. ramulosa	+		+			
A. tetragonophylla			+	+		
Alyxia buxifolia			+			
Brachychiton gregorii		+	+			
Canthium lineare		+				
Cassia artemisiodes					+	
C. nemophila	+		+			
C. pleurocarpa					+	
Casuarina cristata				+		
Codonocarpus cotinifolius					+	
Dianella revoluta	+					
Dodonaea filifolia					+	
Duboisia hopwoodii					+	
Eucalyptus oleosa		+				
Exocarpos aphyllus		+	+			
Grevillea sp.	+					
Halgania cyanea					+	
Leichardtia australis		+		+	+	
Melaleuca sp.	+					
Rhagodia sp.			+			
Santalum acuminatum		+		+		
Scaevola spinescens	+		+			
Solanum lasiophyllum				+		
S. orbiculatum					+	
S. plicatile					+	
Wurmbea tenella						+
Asteraceae					+	+
Malvaceae					+	

* A. Will sprout from root stocks, B. Partially sprouting from rootstocks, but also seedling regeneration, C. Crown can regenerate, D. Non-sprouting and fire sensitive, obligatory seedling regeneration, E. Opportunist species, from seed, in burnt areas, F. Ephemerals, may become abundant after fire.

Discussion

Some workers would classify the fires as a slight disturbance to the ecosystem, in terms of classical succession,[7] as mulga was not wiped out. That is the seed in the soil survived and regeneration was not dependant on colonisation from without. Seed of the desert poplar on the other hand may well have come into the burnt areas after fire - the seed is borne in a winged envelope and presumably possesses some degree of vagility.

The eventual fate of scorched mulga remains to be seen. Can scorched trees eventually produce fruit?

As mulga seed can clearly persist in soil and germinate after fire when adequate moisture becomes available the vegetation types containing mulga are likely to remain comparatively stable over time. It may well be that browsing by feral goats[16] or sheep, or rabbits elsewhere[15,28], or soil compaction by hoofed animals generally, are factors more likely to generate instability within the ecosystems. There is an undoubted interactive effect of grazing on regeneration occurring after fire[19]. The majority of species referred to here have shown some evidence, at least in respect of new, succulent foliage, of grazing *Leichardtia australis* (Asclepiadaceae) the 'coggler' is perhaps an obvious exception, this plant has white sap and may not be eaten.

Fire may differentially favour different phyllode types within *Acacia aneura* . It has varied effects on spinifex[5] and in areas where frequency is low fire may favour *Eucalyptus* species especially where these adjoin mulga. In the long term our main concern is with stability. Degradation has been defined as occurring when 'ecosystem components do not recover to the expected degree during the normal fire frequency period'[34] This period is obscure but must be rather long.[33] Certainly the signs of fire are likely to persist for a very long time.[18] Susceptibility to fire may be wholly independant of the dominance or density of *Acacia aneura* at a particular location. That is no matter how dense the mulga trees become over the course of time, when exceptionally abundant rainfall occurs, that stimulates a dense growth of ground level herbage, then the mulga are vulnerable to death by fire. That small plants are susceptible to death by fire suggests that frequent fire would eliminate mulga quite quickly.[35]

After the 1974/1975 fires it is now recognised that although fire hazard is usually negligible, it may become serious at rare intervals when a season of very much above average rainfall produces a prolific growth of grasses and herbs.[20]

Whether or not fire is a normal, cyclical, component of the ecological environment of mulga woodland remains somewhat open to question. Studies of the nature reported herein require a much longer time span to deal with the question of long term stability. It has been suggested[7] that in order to determine the degree of stability of the species composition of a community one requires:

1. An area large enough to encompass the range of site diversity, or that perturbations occur at intervals no longer than an early succession species will persist, including the period during which the seeds lie dormant.

2. An observation period at least as long as the longest generation time of any of the species, and long enough for such that the range of perturbations would have had a chance to occur.

We may be able to continue these studies into the future.

Conclusions

In contrast to the forests of the south-west of Western Australia many plant species of the mulga zone are killed by fire. Fire was not considered to be a feature of much consequence in this zone until 1974. Experience since the fires which began following herbage growth after heavy rain suggest that *Acacia aneura* seems to be adapted to occasional fire sufficient to crack hard seeds. Low intensity fires may kill the plants but fail to stimulate the hard seed to germinate. Germination appears to be stimulated by wet conditions. It is possible that vegetative plants of mulga could be absent from an area due to fire, or other causes, yet the species could persist as seeds in the soil.

The desert poplar shows phenomenal growth after fire and is a useful indicator species for fire.

Acknowledgements

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WESTERN AUSTRALIAN NATIVE PLANTS USED BY ABORIGINALS AS MEDICINAL TREATMENTS

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Introduction

In 1977, Mrs. Ellen J. Reid completed a library research project in the Graduate Diploma in Pharmacy course on the title topic. During 1978, Dr. J.E.D. Fox collected specimens of plants mentioned in the report whilst on Mulga Research Centre expeditions. In 1979, some of these specimens have been used at displays presented at a Native Plant Symposium held at the University of Western Australia in August, and for Open Day at W.A.I.T. in September.

The Display

This explained that -

" 'bogeys' are a common Aboriginal medicinal treatment, made by bruising fresh plant material, macerating it in water (possibly with heat), and consuming or washing with the extract. Many bogeys are used for respiratory and rheumatic disorders "

Five specimens were displayed, with the following notes:

1. *Codonocarpus cotinifolius*

   'Cundilyong' 'Mustard Tree' 'Kandurangu'

   'Firebush'

   Bark bogey (with other plants) used for rheumatism, and cancer. Leaves chewed as narcotic-analgesic.

2. *Euphorbia drummondii*

   'Piwi' 'Matspurge' 'Caustic Creeper'

   Herb bogey or latex used as general healer for snakebite, dysentery, venereal disease, etc.

3. *Pittosporum phillyraeoides*

   'Buning' 'Butterbush' 'Yaliti'

   'Cheesewood'

   Bogey of branches used for general sickness, colds, sores. Leaves in compress are lactation inducer.

4. *Scaevola spinescens*

   'Maroon' 'Currant Bush'

   Bogey of woody stems used for alimentary ulcers and cancer treatment.

5. *Leichhardtia australis*

   'Kukula' 'Austral Doubah' 'Wira'

   Ground seeds used as oral contraceptive.

Reference

E.J. Reid and T.J. Betts, 1979. Records of Western Australian Plants Used by Aboriginals as Medicinal Agents. *Planta Medica* 36, 164-173.

STABILITY IN MULGA STANDS IN TIMES OF DROUGHT

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Introduction

Acacia shrublands occupy 24 per cent of the land surface of Australia. The proportion in Western Australia is 37 per cent.[15] The term 'mulga' describes *Acacia* shrublands and woodlands where *Acacia aneura* F. Muell. *ex* Benth. is the main species. In this account 'mulga' is used to describe *A. aneura* and 'mulga zone' the area of its occurrence (Fig. 1).

The data to be presented form part of a study with the aim of comparing sheep grazing and its cessation by means of paired plots. In particular the investigation seeks to determine whether the removal of sheep has any measurable effects on stocking of mulga. In this context 'stability' refers to numbers, sizes and growth rates of mulga, and its associates, over time at differing sites. Persistence of individuals, their changes in size and death/recruitment are the parameters by which stability is to be assessed.

The study commenced in mid-1977 and is expected to run for a number of years.

Stability

Mulga is frequently the largest and most abundant tall perennial species on much of the land area in which it occurs. Occupying land around the arid heart of Australia, it encounters great diurnal and seasonal temperature ranges.[16] The major portion of the mulga zone has a mean annual rainfall of 250mm (Fig. 1). The mulga zone is a vegetation type of great interest due to its extent. *A. aneura* tends to perform a stabilising role in the landscape. Mulga trees once established do not grow in height and retain essentially the same branching pattern and crown shape. Seedlings of mulga are often scarce and, of a large number of sites examined in 1977 at only 4 could a set of seedlings sufficient to study growth rates be tagged.[12] These observations were on a property still under pastoral lease and conformed with the view of Allen[1] that in the absence of stock regeneration of mulga could be more rapid.

Despite the appearance of stability, provision of watering points and the addition of sheep are perturbations of the pre-settlement ecosystem. At least locally both may contribute to species change *e.g.* due to the piosphere effect.[3] Patches of dead mulga are common throughout the

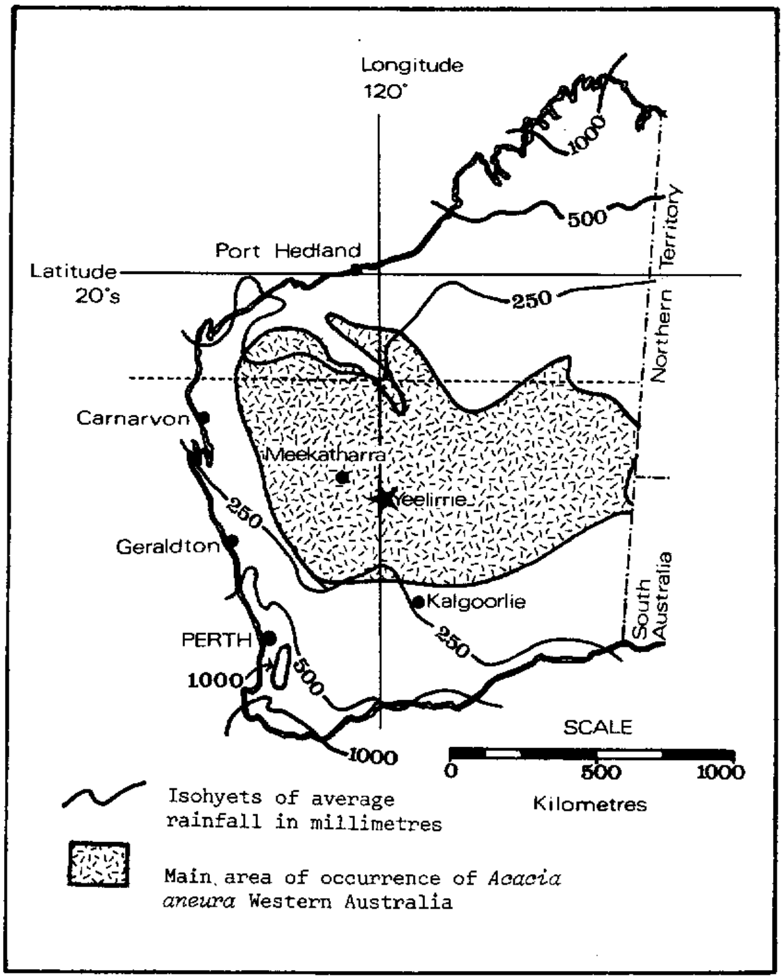

Fig. 1 Western Australia showing area of occurrence of *Acacia aneura* and average annual rainfall. (After Beard 1974, Nix and Austin 1973)

mulga zone and are frequently attributed to pastoral activity.

'Day after day he saw millions of dead trees. His companion told him .... in good years seed would germinate and produce young saplings. The sheep and cattle munched the plants before they ever had a chance. Man is creating a creeping desert. The whole heart of Australia is being eaten out'[11]

This observation dealt with the route between Adelaide and Alice Springs, but the generalised view is common place and is not new:

'Away and away by a long winding track across the plains, through those stretches of country where mulga was standing, stiff and shining as metal, so long it had been dead and bleaching in the sun'
(Prichard 1929, writing of the area south-west of Port Hedland[19]*).*

More precise statements separate trees and seedlings *e.g.* of western New South Wales Condon[8] concluded that trees were dying from old age, and north-west of Adelaide Jessup[14] linked death with fire. In Western Australia patches of dead mulga trees seem to be more common on stoney ground with shallow soils (*e.g.* photographs in Beard[5] In south-western Queensland moisture conditions are more favourable to mulga.[16] and manipulation of stands by thinning may improve the carrying capacity of sheep[18] Preece[17] has reviewed stability of *A. aneura* in general terms and concludes '...ecologists working with mulga must beware of extrapolating too far

Table 1 : Stocking by species and size classes for 40 plots of 20 x 25 m at Yeelirrie.

All trees and shrubs of the genera *Acacia*, *Eucalyptus* and *Grevillea*. Total sample area 2 ha.

Height (m) / Species — Class	.1 1	.1-.49 2	.5-.99 3	1-1.99 4	2-2.99 5	3-3.99 6	4-4.99 7	5+ 8	Total
(a) July 1977									
Acacia aneura F. Muell.ex Benth.	1	192	133	92	120	109	88	56	791
Acacia craspedocarpa F. Muell.		1	-	2	5	2	2	-	12
Acacia linophylla W.V. Fitzg.		5	9	62	43	2	1	-	122
Acacia tetragonophylla F. Muell.				1	-	1	-	-	2
Other *Acacia* species		10	18	7	2	-	-	-	37
All other species						1	1	1	3
Total all species	1	208	160	164	170	115	92	57	967
(b) July 1978									
Acacia aneura	2	167	118	76	109	104	87	51	714
Acacia craspedocarpa		-	-	2	5	2	2	-	11
Acacia linophylla		2	7	58	40	-	1	-	108
Acacia tetragonophylla				1	-	1	-	-	2
Other *Acacia* species		8	11	4	2	-	-	-	25
All other species						1	1	1	3
Total all species	2	177	136	141	156	108	91	52	863
(c) Net percentage loss 1977-1978									
Acacia aneura	+100	13	11	17	9	4.6	1.1	9	9.7
Acacia craspedocarpa	-	100	-	0	0	0	0	-	8.3
Acacia linophylla	-	60	22	6.5	7	100	0	-	11.5
Acacia tetragonophylla	-	-	-	0	-	0	-	-	0
Other *Acacia* species	-	20	39	43	0	-	-	-	32
All other species	-	-	-	-	-	0	0	0	0
Total all species	+100	15	15	14	8.2	6.1	1.1	8.8	10.8

beyond the particular populations they study'.

Mulga at Yeelirrie

Yeelirrie is a 275,000 ha property 670km N.E. of Perth. Sheep were run there from 1925 until 1972, though the station was never overstocked[2]. In July 1977 a set of 40 plots was established at 8 locations around the boundary such that half fell in adjoining, still stocked properties. These were to the S.W. (24) and N.E. (16) of the only site for which meteorological records are available, the Yeelirrie Homestead. At the first measurement there were no discernable differences attributable to grazing between the sets of 20 plots[12]. Mulga plants of < 1m height averaged 214 ha^{-1} on grazed areas compared with 112 ha^{-1} inside Yeelirrie.
Rainfall in the area had been low (Fig.2) prior to the first measurement but the extent of losses at the second measurement one year later was surprising (Table 1). A total of 967 trees, shrubs and seedlings recorded in 1977 had fallen away to 863 in 1978, a net loss of 10.8 per cent. Attrition was greatest in smaller classes, plants < 2m height suffered a loss of 14.4 per cent compared with 6.2 per cent of those >2m height. Some 9.7 percent of all measured *Acacia aneura* died, with the greatest losses also amongst those < 2m (13.2 per cent) compared with those > 2m (5.9 per cent).

Mulga plants of < 1m height averaged 191 ha^{-1} on grazed areas, a net loss of 10.7 per cent compared with 96 ha^{-1} and a net loss of 14.3 per cent for the ungrazed areas inside Yeelirrie. The mulga tree shows a range of phyllode dimensions from terete to broad (>1cm across). The latter form * is frequent at Yeelirrie and incurred fewer losses (5.6 per cent) than did the other forms (14.1 per cent).

* var. *latifolia* of Fig. 3.

Table 2 : Stand Tables in relation to mapping units of Churchward.[7]

Height class*	1	2	3	4	5+	TOTAL
Bigida M.U.						
1977		137	78	51	234	500
1978		132	76	45	233	486
Percentage change		-4	-3	-12	<-1	-2.8
Bullimore M.U.						
1977	1	71	82	113	200	467
1978	2	45	60	96	174	377
Percentage change	+100	-37	-27	-15	-13	-19.3

*Classes as in Table 1.

Of the other species present *Acacia linophylla* lost proportionately more individuals than mulga, and there were comparatively high losses amongst 'Other *Acacia* species' mainly the sand plain shrubs *A. longispinea* A. Morrison and A.aff.*coolgardiensis* Maiden.

Soils of the area are described by Churchward[7]. Plots fell on two main units:deep red sands/sandy earths with hardpan at variable depths (Bullimore Mapping Unit); red earths/loams with hardpan closer than 1m to the surface (Bigida M.U.) Table 2 summarises stocking and losses for all measured perennials by these mapping units. Clearly those plots (24, including the 16 in the N.E.) on Bullimore contributed most to the changes reported. Losses were particularly high for the set of 8 plots illustrated in Fig. 3. These lost 40 per cent of their numbers, contributing 66 per cent of losses recorded for all 40 plots.

Discussion

Two questions arise. Why did so many plants die in such a short time period? and, how typical of the long term are these short term observations likely to be? Mulga appears to be able to tolerate lower soil moisture, as an established perennial, than most other plants[20]. Seedlings are different and the period 1977-78 was not conducive to seedling establishment or growth. Flowering and subsequent seed production of mulga are both dependand on good rains,[9] while germination occurs after torrential summer rains.[1]

The summer of 1974-75 had twice the mean rainfall, quite adequate to cause germination and follow up rain in March-May for establishment. It may reasonably be presumed that many of the smaller plants recorded in 1977 that had died by 1978 were new seedlings in February 1975.

Minor causes of death were wind damage in one plot (Fig. 3c) and the rust fungus *Uromycladium tepperianum* (Sacc.) McAlpine in two others (Fig. 3 g,h.). Some wind damaged trees were still alive in 1978, these may die; the rust killed three *Acacia linophylla* shrubs. The dead plants had symptoms in 1977. Infection occurs in patches. Other plants had symptoms in 1978 and deaths in the local area will continue.

Two plots in the S.W. had a number of mulga with bark damaged by wild horses in 1977. None of these died and all showed vigorous regrowth by July 1978. Sheep grazing was not a cause of death.

It must be assumed that 'average' conditions are satisfactory for at least maintenance of perennials, if not for increment or recruitment. The 49 year (1929-77) average rainfall for Yeelirrie is 211mm(Table 3). The seasonal year 1968, with 165mm of summer rainfall was the first year since 1962-63 that the mean summer rainfall had been exceeded. However a dry period then ensued and lasted until late summer-autumn of 1973. The next 3 years, until the winter of 1976, were 'good' years with rainfall above average. The summer of 1975-76 had slightly less than average rainfall, and marked the beginning of another dry spell. The most severe drought period was the 1976-77 summer with only 13mm of rain, ineffective for growth (Beard 1968). The first measurement took place after this and signs of stress must be

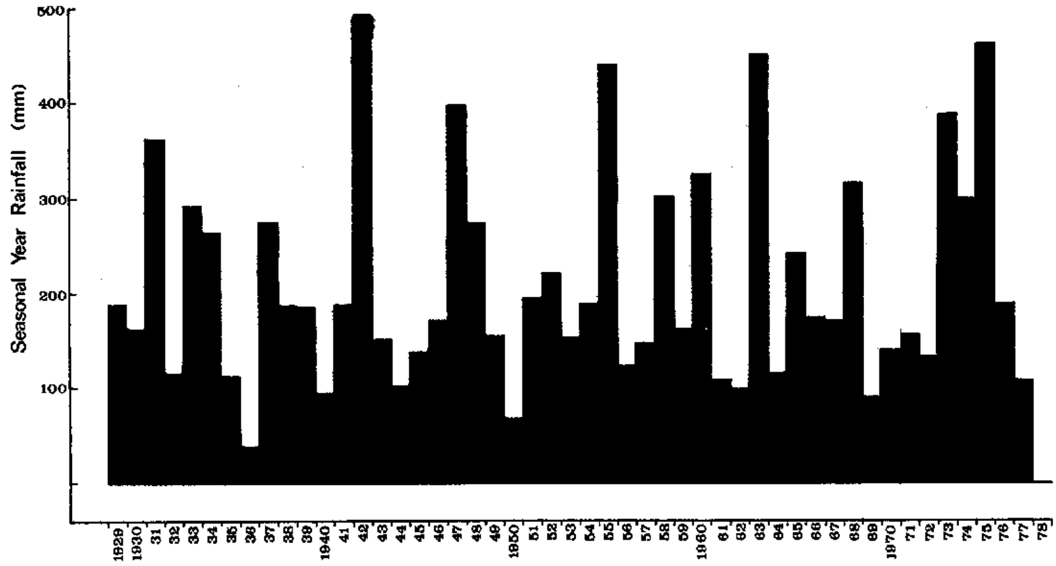

Fig. 2 Seasonal year rainfall at Yeelirrie 1929-1977.

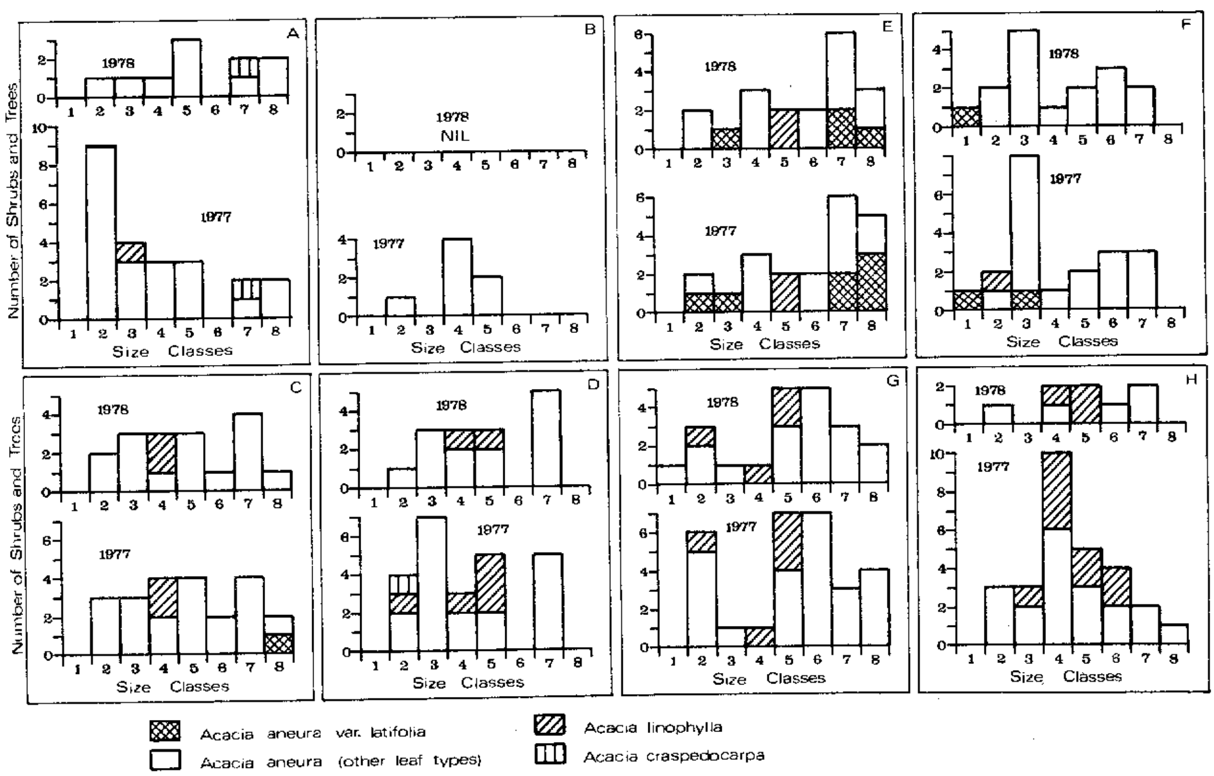

Fig. 3 Stand tables for 8 plots in the N.E. of Yeelirrie based on measurements taken at July 1977 and July 1978.

Table 3 : Seasonal* rainfall at Yeelirrie from 1968 until the second measurement (see text)

	Season				
	Summer	Autumn	Winter	Spring	TOTAL
49 year mean annual rainfall (mm)	106	19	74	12	211
					Seasonal Year
1968	165	35	97	20	317
1969	32	-	52	6	90
1970	35	33	66	6	140
1971	61	-	90	5	156
1972	68	-	60	5	133
1973	79	57	221	30	388
1974	83	58	145	14	300
1975	244	52	93	75	464
1976	96	9	30	48	184
1977	13	trace	85	8	107
1978	142	14			

*Seasons as defined by Davies (1976) *viz* Summer : November 1st of preceeding year to March 31st of calendar year; Autumn : April; Winter : May 1st to August 31st; Spring : September 1st to October 31st.

attributed to that period.

Drought stress was obvious in the 16 N.E. plots in 1977. Small mulga plants had brittle, greyish dry foliage. Larger specimens were leafless at the top. These 16 plots on Bullimore averaged 3 stressed plants each. A year later 61% of the stressed plants had died. Deaths appear obvious after drought-breaking rains.[8] Losses were higher on lighter soils (Table 2) at variance with Jessup[14] who reported a higher proportion of deaths on heavier soils. However we cannot compare the cases precisely as in Jessup's example competition may have been more severe on heavier soils, and we do not know whether the N.E. of Yeelirrie had marginally more effective rain than the S.W. in 1975 (more competition) or less in 1977 (more stress). It may be stated that plants which are going to die in drought succumb most rapidly on the lighter textured soils.

The reason for such a heavy loss over a one year period seems to be that the period was one of low summer rainfall, and that most losses were on sandy soils. Summer rainfall lower than 13mm was only recorded once before, in 1956 (9mm) when the seasonal year had 121mm. It is possible then that losses of the scale observed are unusual. Similar effects may have been associated with drought years in general. The seasonal year total of 107mm for 1977 was not reached in six of the 49 years 1929-77 *viz*. 1969, 1962 (98mm), 1950 (67mm), 1944 (102mm), 1940 (93mm), and 1936 (38mm) (See Fig. 2).

In the long term we must expect some cyclical pattern. The habitat at any time must be supporting its maximum density related to moisture availability, with the proportion of survivors determined by competition for moisture. However survival through temporal drought patterns may not permit the carrying of perennial densities sufficient to exploit abundant moisture when it is available. The latter role is that of the annual plants. It will be interesting to observe the extent of perennial recruitment during future periods of high summer rainfall.

Conclusions

Despite an apparently stable appearance mulga communities may show dramatic change over relatively short time periods. Individual mature specimens of *Acacia aneura* may show little or no change over many years but stands as a whole are dynamic and respond remarkably to changes in soil moisture availability. At Yeelirrie over 1977-78 the particular sites examined suggest that attrition in drought is localised, is greatest amongst smaller plants and is seen more strikingly on lighter soils. Minor differential losses that may be associated with grazing or other factors are overshadowed by drought effects.

Given stands may be wiped out at intervals to regenerate when drought breaks. Such growth from wet periods is not likely to survive in competition with fully stocked stands. Each patch of ground will differ in moisture availability and will hold the woody plants that can survive. Following a drought stands may build up to decline again as the next drought takes effect. Herbage growth may well have some effects on shrubs and seedlings, just as the perennials affect herbage. There seems to be a need to separate out seedling, shrub and tree competition by density studies related to soil moisture and in particular to pursue the question of plasticity in mulga seedlings. Even dead trees may play a role in soil stability. Consideration of stability should encompass a time period sufficient to include the life cycles of component species and the occurrence of major perturbations. '*There are no short cuts - unless one knows all the independent variables*'[4]

Acknowledgements

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VESICULAR-ARBUSCULAR MYCORRHIZAE IN JARRAH FOREST - A PRELIMINARY NOTE

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Introduction.

Efficient mycorrhiza formation with forest tree roots has been suggested as a biological control method to limit or inhibit spread and infection by *Phytophthora cinnamomi*. Basidiomycetous mycorrhiza formers have been investigated and although found effective in the USA on pines, their use in control is still in the very early stage. There are also other mycorrhizal types, such as vesicular-arbuscular (VA), associations of fungal species of *Endogonaceae* with many plants throughout the world. The present work is a preliminary account dealing with initial studies in examining the presence of VA understorey and ground flora plants of the jarrah forest.

Review

Mycorrhizae can be described as "fungus - roots"[2] through which many plants absorb water and nutrients. Endotrophic mycorrhizae have a network of hyphae in the soil surrounding the root, and within the root cortex an extensive growth of hyphae. They can be divided into two groups, firstly, those produced by septate fungi, and secondly, those produced by non-septate fungi. The latter type is called vesicular-arbuscular (VA) or phycomycetous mycorrhizae[2].

The mycorrhizal fungus (VA) grows most abundantly in the small lateral roots which produce little or no secondary thickening. The primary cortex is readily penetrated and within it the fungus develops extensively. VA mycorrhizal infection produces either very little or no modification in the external morphology of the roots[2,5].

The characteristic structures of VA mycorrhizae have been designated mycelium, arbuscules and vesicles. The external hyphae are dimorphic and composed of irregular, thick-walled, non-septate hyphae (up to 20μ diameter) with smaller, thin-walled lateral branches, which are 2-5μ diameter. Hyphae produce appressoria on the root surface prior to penetration, and enter the epidermal cells of the young rootlets.[2,3,5,6].

Following penetration, hyphal growth may be intercellular or intracellular, depending on the host species. The hyphae are 6-13μ diameter[5]. The fungus grows throughout the cortex, but does not reach the root meristem, stele, or endodermis.[2,6]

Inside cells, the complex haustoria, called arbuscules, arise from branches of the longitudinally running hyphae. The arbuscules present a series of forms from simple protuberances of the mycelial wall to branched structures of great complexity. The hyphae branch until a complex tree-like mass forms that may nearly fill the lumen of the cell. The ultimate branches are less than 1μ diameter.[2,3]

The vesicles are usually terminal and intercellular in position in the outer cortex. The number produced varies greatly in different roots of the same plant and also in different species, and are generally more frequent in old mycorrhizae.[5,6] Vesicles are usually spherical when outside the root and inside cells, and about 10μ diameter.[3] Intercellular vesicles are distorted to fit the spaces they occupy and may be much larger, varying in length 75-150μ, and width, 25-65μ.[3,5] Vesicles at first contain granules and later droplets of yellowish oil. They function as food storage organs, or if they develop into chlamydospores, they function as reproductive structures.[2]

There is evidence that VA mycorrhizae can increase plant growth, especially in infertile soils, resulting from increased nutrient uptake and water transport by the hosts.[2,8] It has been shown that total phosphorous uptake and concentration in plant tissues is higher in vascular plants with endomycorrhizae.[6]

There are instances where presence of mycorrhizae increase the resistance of the plant to soil pathogens, for example, orchids infected with mycorrhizal fungi produce a phytoalexin, orchinal, which may protect the plant against pathogens. Certain ectotrophic mycorrhizal fungi can produce antibiotics, and it has been shown that this type of fungi in pine protects the roots against infection of *Phytophthora cinnamomi*.[2]

Materials and Methods

The jarrah forest, in the locality known as 'Churchman' near Kelmscott, was surveyed and evaluated for the presence of vesicular-arbuscular mycorrhizae. This site is located in the Canning Dam water catchment area, approximately equidistant between the Canning Dam and the Albany Highway. The area is on an upper slope facing north-east, in a medium-high (>1000mm) rainfall zone. Soil is a yellow to orange, heavy lateritic gravel with a loamy sand matrix.[4]

Vegetation consists of a moderately tall tree stratum, with moderately sparse understorey.

At the study site, two major community types can be observed. One is a *Phytophthora cinnamomi*-infected area, where the overstorey of *Banksia grandis* has died, and the major ground flora species include *Phyllanthus calycinus*, *Conostylis setosa*, *Hibbertia cunninghamii*, *Hibbertia huegelii*, *Adenanthos barbigera*, and *Dryandra nivea*. The other area is uninfected forest, which surrounds the above area in an arc. The tree stratum is composed predominantly of *Eucalyptus marginata* with some *Eucalyptus calophylla*, and a second storey of *Banksia grandis* and *Dryandra sessilis*. Dominant ground flora species include *Conostylis setosa*, *Hibbertia cunninghamii*, *Hibbertia montana*, *Leucopogon oxycedrus*, *Phyllanthus calycinus*, *Adenanthos barbigera* and *Dryandra nivea*.

An intermediate zone exists where a number of species susceptible to *P. cinnamomi* are believed to be infected, without expression of above ground symptoms of dieback. Root samples of understorey plants were collected from (i) *P. cinnamomi* infected area, and (ii) infection free area, by carefully digging up the plant to be studied. Where possible three speci-

TABLE 2 Summary of results obtained in the survey for the occurrence of vesicular-arbuscular mycorrhizae in plants of the jarrah forest.

Plant species	Susceptibility[a]	Degree of Presence (as in Table 1) Healthy						Unhealthy					
		Age[d] (Years)	Ht./Wdth. (cm)	V[b]	A[b]	H[b]	R-H[b]	Age[d] (Years)	Ht./Wdth. (cm)	V[b]	A[b]	H[b]	R-H[b]
AMARYLLIDACEAE													
Conostylis setosa	High	>10	2/1	-	-	-	-	>10	5/12	-	-	2	2
			8/7	-	-	-	2		15/4	3	-	3	1
			12/5	-	-	3	2		16/13	-	-	-	1
			15/5	-	-	-	-						
DILLENIACEAE													
Hibbertia cunninghamii	Medium	>10	12/5	-	-	1	-	>10	8/3	2	3	3	-
			14/5	-	1	1	-		14/5	2	-	2	1
			22/8	-	1	1	-		16/5	3	5	4	-
Hibbertia heugelii	High	>10	14/14	1	5	4	2	>10	11/12	3	3	3	2
			19/27	4	5	4	3		17/23	-	-	-	2
			23/16	-	-	-	3		18/13	-	4	3	3
H. montana var Major	High	5-10	16/9	-	5	4	3						
			17/6	1	3	3	-						
			18/8	1	5	4	-						
Hibbertia sp. nov	High	5	2/1	1	5	4	-						
			11/2	-	2	2	-						
			15/4	1	2	4	1						
			16/10	-	5	5	1						
DROSERACEAE													
Drosera erythrorrhiza	Slight	<1	-/2	-	-	-	-						
			-/2	-	1	3	2						
			-/3	-	-	3	3						
			-/4	1	-	2	4						
EPACRIDACEAE													
Leucopogon oxycedrus	Medium	5	11/5	-	-	-	-						
			12/4	-	-	-	1						
			15/6	2	3	4	4						
EUPHORBIACEAE													
Phyllanthus calycinus	Slight	5	6/4	-	-	-	1	>10	13/8	3	4	5	-
									17/13	2	4	4	-
			11/2	-	2	2	-						
			15/4	1	2	4	1						
			16/10	-	5	5	1						
DROSERACEAE													
Drosera erythrorrhiza	Slight	<1	-/2	-	-	-	-						
			-/2	-	1	3	2						
			-/3	-	-	3	3						
			-/4	1	-	2	4						
EPACRIDACEAE													
Leucopogon oxycedrus	Medium	5	11/5	-	-	-	-						
			12/4	-	-	-	1						
			15/6	2	3	4	4						
EUPHORBIACEAE													
Phyllanthus calycinus	Slight	5	6/4	-	-	-	1	>10	13/8	3	4	5	-
									17/13	2	4	4	-
									21/22	5	3	4	-
LOGANIACEAE													
Logania serpyllifolia	Resistant	5	3/2	1	4	4	1						
			5/3	2	3	4	-						
MYRTACEAE													
Eucalyptus marginata	Medium	<1	7/3	-	-	4	3	>10	9/10	1	-	1	5
			7/3	-	-	3	2		11/7	-	-	-	3
			8/2	3	-	4	-		17/11	1	-	1	3
PAPILIONACEAE													
Kennedia coccinea	Slight	<1						1-2	5/5	3	1	4	-
									12/8	-	-	-	2
PROTEACEAE													
Adenanthos barbigera	High	5	7/2	-	-	-	-	>10	14/15	-	-	3	4
			9/3	-	-	1	-		16/10	-	-	-	5
			11/6	-	-	-	-		16/18	-	-	-	3
			17/10	-	-	-	-						
			25/6	3	3	3	-						

CTD.

Plant species	Susceptibility[a]	Degree of Presence (as in Table 1)											
		Healthy						Unhealthy					
		Age[d] (Years)	Ht./Wdth. (cm)	V[b]	A[b]	H[b]	R-H[b]	Age[d] (Years)	Ht./Wdth. (cm)	V[b]	A[b]	H[b]	R-H[b]
Banksia grandis	High							>1	8/5	-	-	-	1
									8/7	-	-	-	3
									9/7	-	3	3	2
Dryandra nivea	Slight	<1	6/5	-	-	-	3	>10	3/3	-	-	-	2
			6/6	-	-	-	5		9/9	-	3	3	4
			8/6	-	-	4	2		[c]11/15	-	-	1	4
Dryandra sessilis	Medium	<1	7/3	-	-	-	-						
			7/3	-	-	1	-						
Adenanthos barbigera	High	5	7/2	-	-	-	-	>10	14/15	-	-	3	4
			9/3	-	-	1	-		16/10	-	-	-	5
			11/6	-	-	-	-		16/18	-	-	-	3
			17/10	-	-	-	-						
			25/6	3	3	3	-						
Banksia grandis	High							>1	8/5	-	-	-	1
									8/7	-	-	-	3
									9/7	-	3	3	2
Dryandra nivea	Slight	<1	6/5	-	-	-	3	>10	3/3	-	-	-	2
			6/6	-	-	-	5		9/9	-	3	3	4
			8/6	-	-	4	2		[c]11/15	-	-	1	4
Dryandra sessilis	Medium	<1	7/3	-	-	-	-						
			7/3	-	-	1	-						
			8/5	-	-	1	-						
RUBIACEAE													
Opercularia hispidula	Slight							<1	4/4	1	4	4	-
									4/4	2	4	5	-
									12/6	1	5	5	-
RUTACEAE													
Boronia spathulata	Medium	>10	32/16	4	3	5	-	>10	8/5	4	2	3	-
								5-10	12/20	5	1	4	-
								>10	31/14	5	2	5	-
STYLIDIACEAE													
Stylidium sp.	Slight	1	-/1	-	-	2	2	>1	-/1	-	3	3	-
			-/1	-	1	3	3		-/1	-	3	4	-
			-/2	-	-	2	2		-/1	2	2	4	-
			-/2	-	1	3	2						
ASTERACEAE													
Senecio hispidulus	Resistant							<<1	6/6	1	4	5	-
									10/5	2	4	5	-
									13/5	3	4	3	-

a Susceptibility of plant species to *Phytophthora cinnamomi*[9] (McGann, unpub. data)

b Type: V vesicles, A arbuscles, H internal hyphae, R-H rhizoplane hyphae

c Pathogenic fungi present

d Approximate age of specimens (McGann. pers. comm) mens of a particular species were collected from each area, with height and width measurements of the plant taken. The roots were washed in water, harvested, and cut in approximately 1cm segments, and immediately placed in formalin-glacial acetic acid-ethanol fixative. Roots were cleared with KOH, and stained with trypan blue in lactophenol, using the method of Phillips and Hayman.[7] Permanent whole mounts were prepared using the mounting medium of Cunningham.[1] Root segments were viewed under the microscope at X200 and scanned for vesicular-arbuscular mycorrhizae infection. A positive identification consisted of the observation of arbuscules and/or vesicles. The degree of presence was assessed visually as in Table 1.

Table 1 Degree of Presence of VAM infection in plant roots.

Score	Degree	Percentage presence
5	constantly present	80-100
4	mostly present	60-80
3	often present	40-60
2	seldom present	20-40
1	rare	1-20

The specimens, minus their roots, were pressed and mounted on herbarium sheets. Plant age was estimated from experience on dealing with dieback vegetation of the area for past 10 years and from known fire history of the area. Susceptibility of plant species was known from previous work.[9]

Results and Discussion

Table 2 summarises the degree of presence of VA mycorrhizae on roots taken from the field in September and October 1979.

In some roots, hyphae were present, but neither vesicles or arbuscules were apparent. It was also difficult, in some roots, to distinguish between massed, branching coils of hyphae and arbuscles - where this phenomenon occurred, it was recorded as arbuscules. The presence of rhizoplane hyphae was recorded as well.

Since the measurements were made for only one time period, the list should not be considered complete, but should give a good indication as to the commonness of the plant species and endophyte association.

Discussion

The species showing the greatest VA mycorrhizal infection were *Boronia spathulata*, *Opercularia hispidula*, *Senecio hispidulus*, *Logania serpyllifolia*, and *Hibbertia* spp.

A Mann-Whitney U test was used to determine whether there was any significant difference in VA distribution between the area infected with *Phytophthora cinnamomi* and the uninfected area. In the most abundant genera, *Hibbertia*, a high degree of VA presence was evident (Table 2) but there was no significant difference between infected and uninfected areas in the case of arbuscules, and the difference was significant only at p0.20 in the case of vesicles. Thus, vesicles differ more than arbuscules between infected and uninfected areas and they (vesicles) may be seen less frequently in uninfected areas (6/13) than in infected areas (4/6). Arbuscules on the other hand were more consistently seen in the uninfected area (11/13) with the same occurrence (4/6) as vesicles in infected areas, but at a higher level of presence (Table 2).

The family Proteaceae was also tested with the Mann-Whitney U test in relation to arbuscules. Despite the low overall presence of arbuscules the higher level of arbuscular occurrence in the infected area was significant: U, = 54, when $.05<p(U>54)>.10$.

Other groups were not tested as sample sizes were inadequate. However, it may be noted that 46 per cent of plants sampled in the healthy area had some degree of VA infection (presence of vesicles and/or arbuscules), which compares with 68 per cent of plants in the *P. cinnamomi* infected area.

To determine whether the presence or absence of VAM is dependant on a plant's susceptibility to *P. cinnamomi*, a Chi-squared test was used.

In the healthy area, VA mycorrhiza was independant of a plant's susceptibility to *P. cinnamomi*. The unhealthy area, however, showed plants with lowest susceptibility to *P. cinnamomi* having the highest presence of VA mycorrhizae. This suggests that in the presence of *P. cinnamomi*, some species may have been able to survive the presence of the fungus due to high levels of VA mycorrhizae in their roots. A Chi-square comparison of all levels of susceptibility to *P. cinnamomi* suggested that presence of VA mycorrhizae was greater in infected areas ($p<.10$). More resistant and slightly susceptible plants had VA mycorrhizae in the unhealthy area than did the same species in healthy areas (14/17 versus 6/14). A further Chi-square test on age and VA mycorrhizal presence/absence suggested that VA infection is independant of plant age.

Conclusion

The presence of VA mycorrhizal infection has been demonstrated on a range of species and appears to be more frequent in some plants than in others; for example, Dilleniaceae had more than Proteaceae. Infection is independant of plant age. An area known to be infected with *P. cinnamomi* appears to be associated with an increased presence of VA infection in those plants thought to be resistant to infection by *P. cinnamomi*.

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SOIL MOISTURE STUDIES IN RELATION TO *ACACIA ANEURA* AND ASSOCIATES AT LEINSTER DOWNS

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Introduction.

Agnew Mining Company's nickel mine shaft at Leinster requires pumping to remove water seepage at depth into the mine workings. This water eventually finds its way into a channel draining to the south-east. In this note we give a preliminary account of studies in hand to assess the effects of mine dewatering on the perennial vegetation of the study area shown in Fig. 1. Species present in this study area include *Acacia aneura*, *A. tetragonophylla* and *Eremophila* sp (1966 coll. no.)

The channel illustrated in Fig. 1 though well defined for the first 5-6 km from the mine, debouches onto a broad level plain at about 7 km. In July 1979 patches of water occurred at various places and salt crusting pointed to where water had stood earlier. Termination of the extent of standing water as at July 9th, 1979 is shown in Fig. 2.

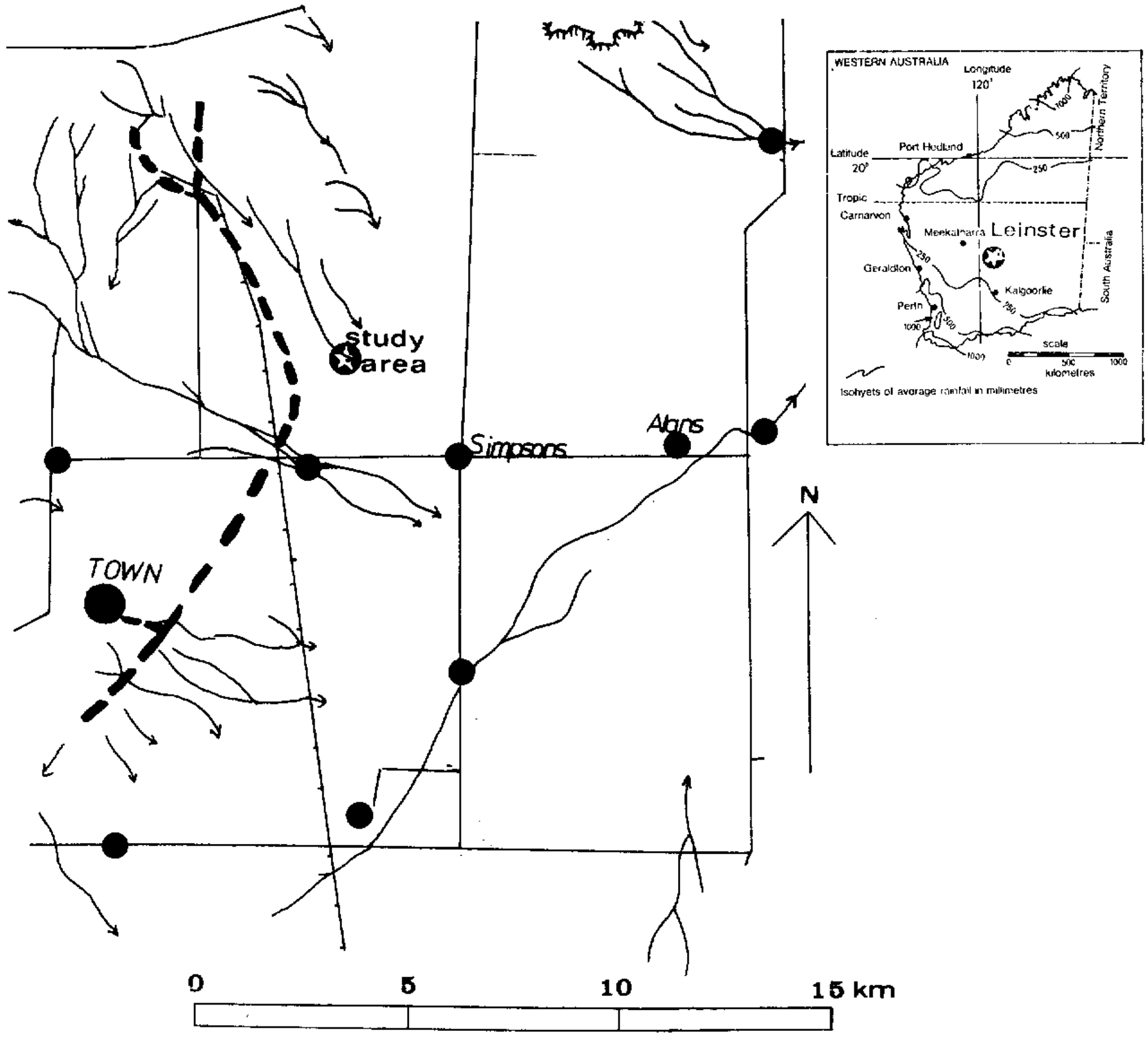
Several other sites have been examined further to the north. These are not discussed in the present account.

Preliminary Observations

Seventy-three perennials were tagged, plotted and measured for height and crown width within a study area of about 0.75ha in July 1979. Species, heights and phenological status are shown in Table 1.
Soil samples were taken for gravimetric determination of moisture content at 10-15cm depth, at 5m intervals along 5 transect lines. Four of these traversed the width of the southerly limit of standing water, the fifth ran from south to north across the main arm (Fig.2,4) Soil depth to the indurated layer was measured along each transect and at a number of intermediate points.
Soil samples for moisture content were again taken in December 1979 when the limit of the standing water zone had retreated northwards several km under the influence of high evaporation rates.

Species tagged were 58 *Acacia aneura*, 7 *Eremophila* sp., 6 *Acacia tetragonophylla* and 1 each of *Solanum*? *lasiophyllum* and a small saltbush (Chenopodiaceae). Four recently dead individuals of *A. aneura* are shown in Fig. 2

Fig. 1 Part of Leinster Downs Station showing the new town of Leinster and the study area approximately 7 km south east of the mine.



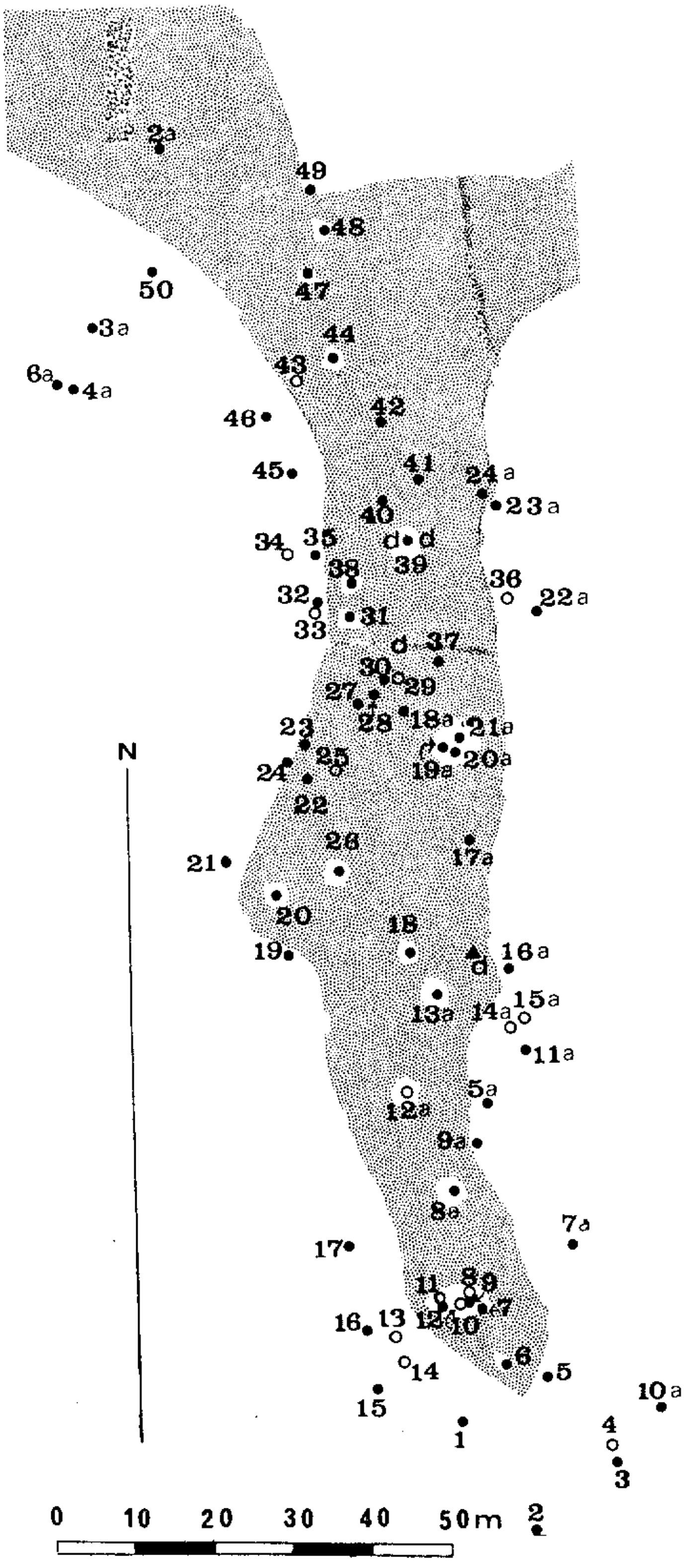


Fig. 2 Study Site, Leinster Downs, showing the extent of standing surface water at July 9th 1979 [stippled] and location of measured perennial plants listed in Table 1.

Table 1 Perennials Measured July 1973 (Positions on Fig.2)

No.	Species	Height (m)	Notes*
1.	*Acacia aneura*	5.10	
2.	"	3.40	YF
3.	"	1.90	P
4.	*Eremophila sp.*	1.35	
5.	*Acacia aneura*	1.40	
6.	"	3.00	
7.	"	3.60	
8.	*Eremophila sp.*	0.84	
9.	*Acacia aneura*	3.90	
10.	*A. tetragonophylla*	1.65	
11.	*Eremophila sp.*	0.87	
12.	*Acacia aneura*	1.90	
13.	*Eremophila sp.*	0.74	
14.	"	0.49	
15.	*Acacia aneura*	1.28	P
16.	"	3.40	P
17.	"	3.60	
18.	"	3.20	
19.	"	0.99	
20.	"	4.70	
21.	"	3.25	
22.	"	1.94	
23.	"	3.50	
24.	"	0.90	
25.	*Solanum sp.*	0.46	
26.	*Acacia aneura*	4.30	M
27.	"	3.30	OF
28.	"	3.60	
29.	*A. tetragonophylla*	2.25	
30.	*Acacia aneura*	2.95	P
31.	"	3.25	F
32.	"	4.00	F
33.	*Eremophila sp.*	0.89	
34.	*A. tetragonophylla*	4.00	
35.	*Acacia aneura*	3.30	P
36.	*A. tetragonophylla*	1.51	
37.	*Acacia aneura*	3.59	OF
38.	"	2.80	P
39.	"	3.50	OF
40.	"	2.00	P
41.	"	4.70	YP
42.	"	3.30	M
43.	*A. tetragonophylla*	3.36	
44.	*Acacia aneura*	4.10	OF
45.	"	1.60	P
46.	"	3.20	F
47.	"	3.80	F
48.	"	1.37	
49.	"	3.20	OF
50.	"	2.10	F
2A	*Acacia aneura*	3.25	YP,M
3A	"	2.33	P
4A	"	4.30	F
5A	"	2.84	YP
6A	"	4.30	F
7A	"	3.07	YP
8A	"	2.67	YP
9A	"	1.67	YP
10A	"	2.81	YP
11A	"	2.23	YP
12A	*A. tetragonophylla*	1.68	F
13A	*Acacia aneura*	3.10	F
14A	Chenopodiaceae	0.02	
15A	*Eremophila sp.*	0.33	
16A	*Acacia aneura*	3.79	
17A	"	1.82	YP
18A	"	3.49	OF
19A	"	0.81	
20A	"	2.90	
21A	"	3.29	
22A	"	1.92	
23A	"	4.90	OF
24A	"	3.80	OF

*Notes F flowers, P pods; Y young, O old; M mistletoe present.

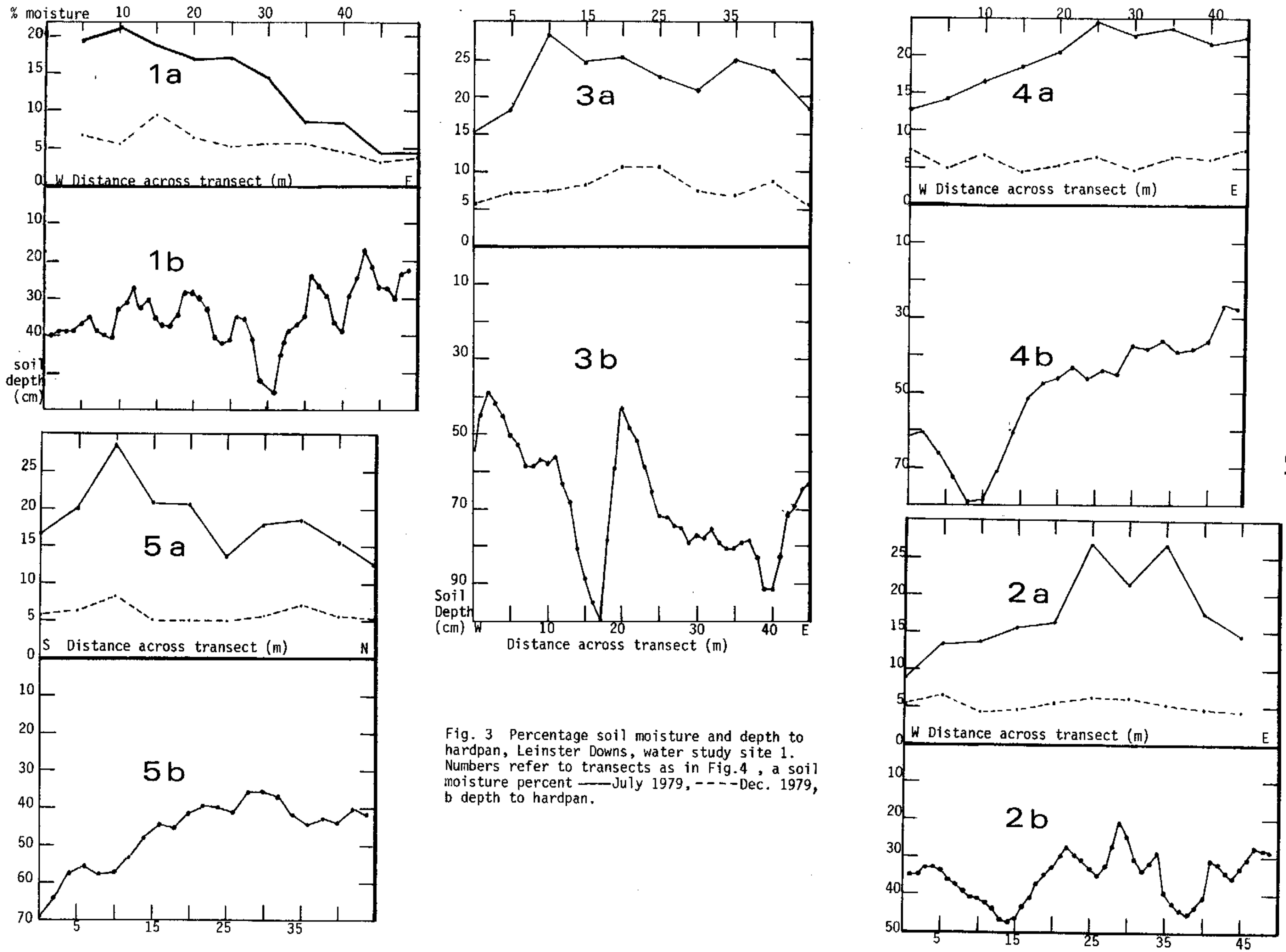


Fig. 3 Percentage soil moisture and depth to hardpan, Leinster Downs, water study site 1. Numbers refer to transects as in Fig.4 , a soil moisture percent ——July 1979, - - - -Dec. 1979, b depth to hardpan.

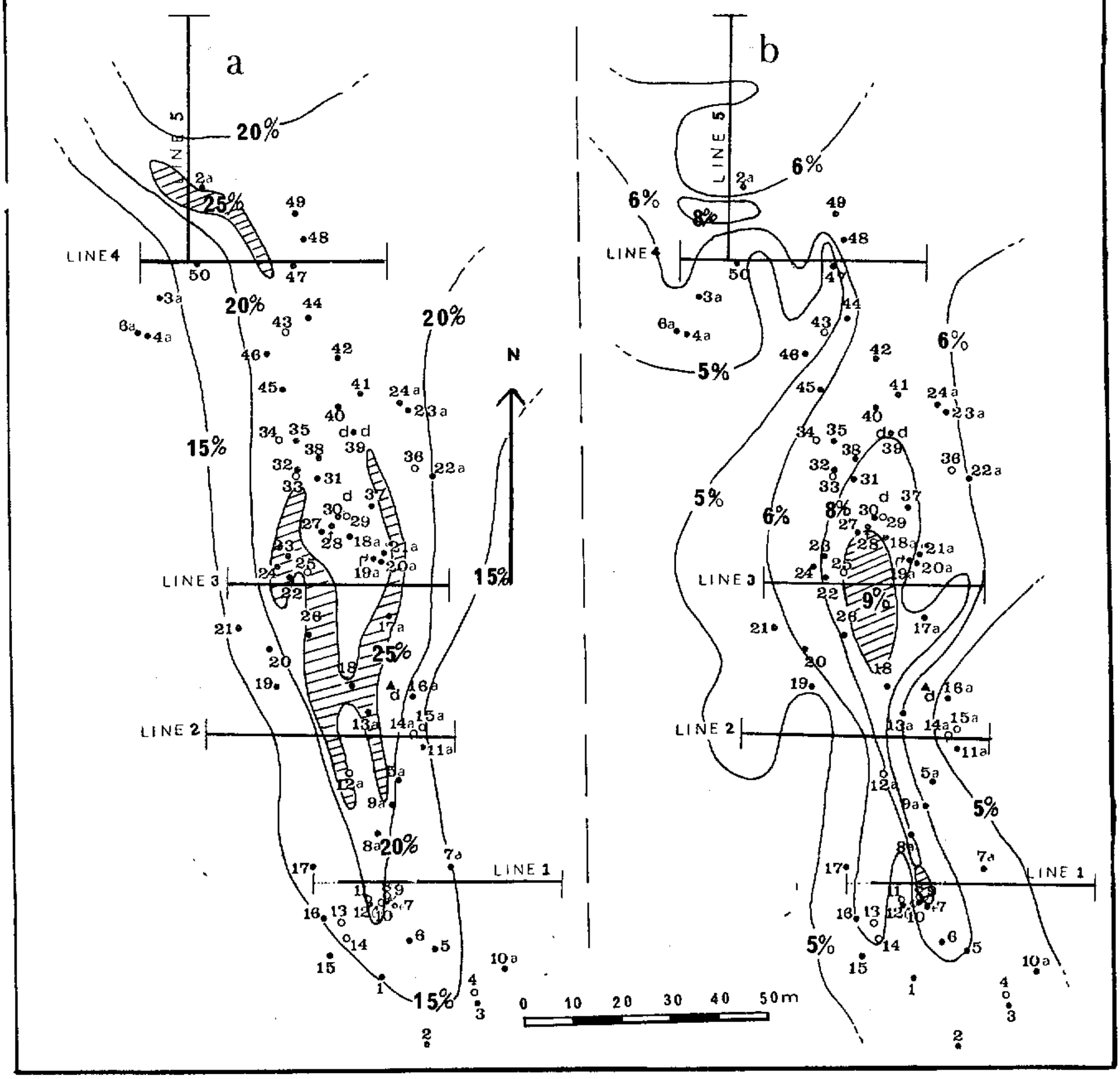


Fig. 4 Study site, Leinster Downs, showing percentage soil moisture in a July, b December, 1979. Contours drawn are based on gravimetric samples taken from 10 positions at 5m intervals on each of the five transects shown.

as 'd'. One recently deceased termite mound is shown (west of 16a) as a black triangle.

Soil moisture at the two sampling times is shown in graphical form, together with depth to indurated layer in Fig. 3. Indurated layer graph points are given as the means of three values on the moving average principle. Soil moisture contents in July were highest in the areas of free standing surface water, at in excess of 25 per cent, for four sampling positions. Moisture content fell below 5 per cent only at the eastern end of Transect 1. There was considerable variation across each transect line.
Moisture contents in December 1979 were uniformly lower, in the range of 3-11 per cent, with the majority of samples around the 5 per cent level. This is probably around the permanent wilting point for the soil of the area.[6]

Contours showing areas of equal moisture levels have been drawn for both periods, with wettest places cross hatched (Fig.4).
Soil depth across transects does not seem to be related to the pattern of moisture content, however it will affect total moisture available about a point.
Soil samples for pot trials at Bentley were collected from salt crusted areas formerly inundated and from nearby, higher, ground not affected by the mine outflow water.

Effects of Soil Moisture on *Acacia aneura*

Clearly *Acacia aneura* and associated species growing in the area are adapted to the historical soil moisture regimes that have prevailed. Additional water available in an area may provide growth stimulus, or if present for any length of time may asphyxiate root systems. Seasonal availability and duration of additional water

are likely to be factors of importance. Periods of soil water deficit alter species proportions at the ground flora level[3] and changes may also affect perennial composition.
It may be anticipated that recruitment would occur towards areas of high soil moisture status.[15]
Availability of water is the major ecological factor in determining the productivity of plant communities.[16]
Variability in water potential is dependant on soil saturation and air humidity with a strong diurnal variation under natural conditions.[10] *Acacia aneura* is a less active (physiologically) species and may not rehydrate fully at dawn.[14]
Maximum rates of transpiration are reduced under stress,[8] and no growth can occur at very low soil moisture levels, all production going to maintenance. The more severe the stress the slower the resumption of activity following rainfall.[14]

Phyllode Hydrature

Slatyer[12,14] examined 'mature' and 'immature' *Acacia aneura* plants in respect of soil water. Some plants received weekly irrigation 'at a level which eliminated severe water stress', others received natural rainfall alone. He reported that there was no evidence of treatment affecting water potential/osmotic pressure relationships to leaf hydrature.[12] However the irrigated plots were small and the soil surface was dry before measurements took place.[12,13]

Preece[9], by contrast, was able to show that trees, not previously irrigated, had generally lower water potentials than irrigated trees. Additional water in the winter period of low evaporation appears to have raised the water potential sufficiently to carry the plants over from one watering to the next. Trees artificially watered[14] reached the maximum foliage water content by dawn on the day following rain whereas 3-4 days were required for trees receiving natural rainfall only. Comparatively stable values for relative turgidity in artificially watered trees suggested the progressive decline in turgidity of naturally watered trees was primarily determined by declining soil moisture under continuous evaporation.[14]

Initial decline in relative turgidity commenced within 7 days of the last rain, and when no further rain fell, progressively reduced to 35-40 per cent. Immature trees had a consistently, slightly lower, relative turgidity than the mature trees.[14]
There was progressively less diurnal fluctuation and slower recovery of turgidity as water stress became more severe. Under severe stress there was virtually no diurnal fluctuation suggesting stomatal regulation of transpiration was highly effective and cuticular transpiration low.

In the artificially watered treatments relative turgidity remained high but the diurnal depression was more pronounced in immature trees and the recovery towards dusk was more rapid in these.[14]

Vegetative Growth

Preece[9] tested the response of *Acacia aneura* to added water. In a controlled experiment he used the equivalent of 200mm of rain as an initial application on an area of 3m square about the test plants.
His regime called for subsequent monthly waterings of half the initial volume. For plants watered for 12 months this gave about 8 times the long term mean annual rainfall of 191mm. He found a strong relationship between irrigation and height growth. The effect of higher water status was largely expressed in vegetative growth.
The peak of the growing season for *Acacia aneura* as measured by shoot extension appeared to be in the summer months.[9]
In the closely related species *Acacia craspedocarpa*, young brownish unlignified phyllodes developed in late spring and also at the beginning of winter after rainfall of 25mm.[7]
Phllode growth in *Acacia harpophylla* commenced when mean minimum temperature exceeded 10°C[17].
The phyllode tissue of this species seems to be more resistant to dessication than *A. aneura*[4], possibly it has a different response time, but we may note that once growth commences in these arid country wattles then both the duration of the spring flush and subsequent summer growth are related to soil moisture conditions.
Extreme summer temperatures combined with dried out soil may result in phyllode death following dessication. The heat resistance limit for *Acacia craspedocarpa* phyllodes is 55°C.[7]
It is probably similar for some phyllode types of *A. aneura*.

It has been noted that defoliation and foliation tend to be synchronised in native Australian perennials.[16] We face the possibility then that, assuming vegetative growth starts in the spring, when winter low evaporative levels lead water down again to the study site, more foliage may be produced than can be supported when the water retreats again with the onset of summer. Will the turnover of phyllodes increase? Will the conditions prevailing allow more hydrature of the foliage for longer periods?

Flowering

Other things being equal we may expect more vigorous flowering from a more vigorous tree. The most comprehensive analysis of flowering in *Acacia aneura* is that due to Preece.[9]
He noted that in nature flowering is somewhat irregular but the strongest and most consistent effects follow spring and late summer rain, with the latter alone giving rise to seed production.
His irrigation experiment showed that greatest number of flowers were produced on only 5 out of 30 trees examined in November. This was not related to irrigation directly and fruit developing from November flowering generally aborted spontaneously or with the assistance of a gall midge. Flowers stimulated by summer rain produced fruit with ripe seed the following November. Flowering did not take place on irrigated trees at regular intervals after first watering. Flowering occurred more or less equally in irrigated and un-irrigated trees, suggesting the over-riding operation of a seasonal factor.
However Preece suggests[9] that extra water may have allowed flowering to occur more rapidly and perhaps more heavily once the seasonal trigger was pulled.

Table 1 illustrates considerable variation in flowering stage between individuals at the study site. A total of 36 *Acacia aneura* (62 per cent of those enumerated) showed some activity. Neighbouring localities unaffected by water showed no activity. Galling and general insect disturbance was frequent on most of the study site trees.

Fruiting

Preece[9] suggested that irrigation made seeding heavier once a seasonal trigger had occurred. Improved water status may allow more successful fruiting at the normal time of the year. Irrigation used by Preece did not result in fruiting at an unusual time. In the case of the related *Acacia craspedocarpa*, Hellmuth[7] observed flowering flushes in October and in May. Observations at Leinster suggest that fruit of both species is ripe in October-November. In 1979 strong winds in late November blew all ripening pods from the trees of the study site prior to the December visit.

Mistletoes

Three trees were noted with mistletoes in their crowns in July 1979 (Table 1). These (2a,26,42) all occur in the central zone of standing water at July (Fig.2) with high soil moisture contents (Fig. 4).
Hydrostatic pressures in mistletoes are higher than in their hosts.[10] It is a common occurrence for both *Acacia aneura* and *A. tetragonophylla* in the vicinity of bores and mills to be liberally endowed with mistletoes. They can persist for longer on well watered plants and it is clearly not a coincidence of birds roosting more frequently in trees near bores. Upstream from the study site (Fig.1) a number of large trees with numerous mistletoes were observed to be completely dead.
Are trees killed by dependance on ample water which then disappears at the time of greatest stress? This is what seems to happen with mistletoes on mulga in areas not receiving additional moisture.

Water Quality and Roots

Water Quality

Soil of the study site described is shallow (Fig. 3) with a relatively impermeable subsoil. This impedes downward movement of soil water such that the surface soil water may exceed field capacity until waterlogged with free water on the surface. We have referred to salt crusting earlier. This particularly appears at margins of wet areas, suggesting that on drying out rather more would be seen.
Water reaching the study site will have become progressively more salt enriched as evaporation has taken its toll on the way.[16] In addition to taking salts into solution from the soil passed over it was anticipated that water to be used for tailings slurry would have a pH of 9.5 with dissolved sulphates, magnesium and chlorides, with minor traces of Fe, Ni, Cu and Co. Recirculation of this water was envisaged[1] for economic reasons prior to the necessity for dewatering became apparent. Should tailings slurry water be involved it will contain minor amounts of residual flotation reagents.[1]

Effects of salt crusted soil on root growth will be examined in pot trials with *Acacia aneura*, *Acacia craspedocarpa* and *Eucalyptus camaldulensis*. Both the former are found in the general area of study while the latter occurs further south (9km SE on Fig. 1) lining deep sandy channels. Its distribution is very dependant on water channelling.[16]
It is possible that water draw from underground aquifers may have an effect on the perennial plants of the area. Preliminary studies suggest this is unlikely as the plants are mainly shallow rooted and water is taken at depth.[11] Should phreatophytic species be affected by water table draw then it would seem to be of little utility to pump mine dewatering water onto affected areas. Evidence of the effects of pumped water onto native vegetation is available from Albion Downs, to the northwest of Leinster.
Here salty water was piped out on to the soil surface of an established vegetation community. The soil surface became loose, crusty and crabholed. Perennials died to the edges of salt water spread.[2] Under such circumstances revegetation depends on seed availability; temperature and nutrient availability may control species composition.[3]

Roots

Slatyer[13] noted the groving of mulga and examined rates of evapotranspiration in relation to soil water storage. As soils dried the decline in water storage was most rapid close to tree trunks, where root density was highest, and least where root density was lowest. Dry areas around the boles in the study site (Fig. 2 e.g. 8a,12a,13a) in July reflect this but also, partially a mounding effect common in mulga.[6]
Root density is high where mulga is groved[13] and of interest is the area east of tree 48 (Fig.2) with no trees and standing water extending some 80m east of that mapped in July, 1979.
On drying out summer drought tolerance will be affected by differences in vertical root distributions and shoot/root ratios[3] in terms of which invading species survive. Specht[16] for example discusses a lack of co-existence between Chenopodiaceae (saltbush) species with different rooting habits.
While the soil is wet it is possible for plants with differing rooting characters to fully exploit the soil moisture environment.

Of interest here will be the relative representations of the roots of the three most abundant species (*A. aneura*, *A. tetragonophylla*, *Eremophila* sp.) within the soil profile.

Other Sources of Differential Response

Grazing

Of the three most abundant species *Acacia tetragonophylla* is probably the most palatable to herbivores.[8] However *A. aneura* is also grazed when within reach by domesticated animals. Sheep are not present but goats have been attracted to the water, and red kangaroo is present in the area. Water usage by goats is higher than that of the red kangaroo and goats are more likely to browse shrubs and trees.[5] If goat browsing increases due to water attraction we may expect smaller shrubs

to remain small and a greater differential in size class distribution to develop.
In the study area flooding seems to have destroyed termite colonies so that should soil moisture favour herbage it is unlikely that termite numbers would be able to respond to remove the increased herbage.

Phyllode Type

Ecologists working with mulga have been cautioned not to extrapolatefindings too far beyond the populations studied.[9] In particular it has been noted that the range of 'phenotypic variability' in phyllodes may affect comparative physiological performance in *Acacia aneura*.[4] Connor and Tunstall's experience that their mulga was not as resistant to stress as that used by Slatyer[14] leads us to utilize *Acacia craspedocarpa* with *A. aneura* in pot trials.
Within the species there may also be differences in behaviour between phyllode types. For example Preece[9] found that narrow phyllode trees appeared to flower over a longer period than did broad phyllode trees. This could not be confirmed statistically. Within the study area we have enumerated trees by phyllode type.

Acknowledgments

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PROTEIN AND MINERAL CONTENT OF SEVERAL SPECIES OF *ACACIA* SEEDS

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Introduction

Acacia seeds are among the traditional desert foods used by Australian Aborigines. The seeds are prepared in a variety of ways. In the Musgrave Ranges, Aborigines are said to grind and eat the seeds raw[2]. Alternatively, the seeds are buried under hot embers and half cooked then winnowed, ground dry and mixed with water to make a damper. Seed cakes can also be prepared by grinding the seeds on stones to form a coarse flour. The flour is mixed with water, patted into a round shape and baked in bot sand or ashes. When a particular variety of *Acacia* is plentiful the flour will be made from that alone but usually it is made from a mixture of all suitable seed found in the area. The latter two methods entail much preparation for a small return in food volume. Meggitt[3] describes the result as 'a heavy, tasteless, evil-looking but nutritious cake'.

The majority of Aborigines living in remote communities (i.e. missions, reserves and pastoral properties) prepare damper in a similar fashion to the traditional seed cakes, using plain or self-raising wheat flour rather than native seeds. This change in food habits, along with other dietary alterations introduced by Europeans, has reduced the overall nutritional status of Aboriginal outback populations[1]. A programme of resettlement of these people, known as the outstation movement, is aimed at making greater use of traditional desert foods.

Little information is available on the nutrient content of some of the traditional desert foods. The benefit of a diet including such foods to the nutritional status of Aboriginal populations and the move to reintroduce such foods has stimulated interest in their composition. The work reported here was designed to measure the level of protein and several minerals in *Acacia aneura* and other *Acacia* seeds to determine their value as sources of these nutrients.

Materials and Methods

The *Acacia aneura* seeds analysed came from the COSMO-Newberry area and were collected in late 1975. Other seeds examined were as follows:

- *A. browniana, A. extensa, A. pulchella* from the jarrah forest near Dwellingup
- *Acacia* sp., unknown, from Port Hedland
- *A. melanoxylon* (introduced) from Shannon townsite

The number of protein and mineral determinations done on each species of *Acacia* was dependent on the amount of that seed available. The amount of *A. melanoxylon* was so small that analyses for all minerals could not be completed.

Protein content was determined by a semi-automatic micro-Kjeldahl procedure using a Tecator Digestion System 20 and a Tecator Automatic Distillation Unit. The total nitrogen measured by this method was converted to

	PERCENTAGE			MINERALS mg $100g^{-1}$				
Species	Moisture	Ash	Protein	Ca	P	Fe	Na	K
A. aneura								
mean	4.0	4.3	25.7	240	2344	7.0	48	958
range	2.0-6.0	3.9-4.6	24.7-26.9	174-328	1878-2727	5.2-9.1	38-58	813-1189
samples	2	7	4	6	5	4	3	4
A. extensa								
mean	8.1	5.5	27.3	336	1889	5.3	90	967
range	6.4-9.7	5.0-5.8	27.0-28.2	300-367	1712-2066	4.4-5.8	85-94	826-1106
samples	3	5	4	3	2	4	3	2
A. browniana								
mean	8.0	4.6	29.4	332	1566	4.6	48	700
range	7.0-8.8	4.3-5.0	27.8-31.0	302-386	1423-1771	3.7-5.5	38-68	625-818
samples	4	5	4	3	3	2	6	3
A. pulchella								
mean	8.4	3.7	30.1	315	1902	6.3	37	796
range	7.2-10.4	3.3-4.0	29.1-30.7	247-393	1666-2048	4.9-7.4	30-49	626-990
samples	3	5	5	4	3	4	3	5
A. sp.								
mean	6.9	3.6	16.3	204	1385	7.0	29	810
range	6.1-7.9	3.1-4.1	15.1-17.0	172-252	1220-1516	5.4-8.8	25-37	666-1028
samples	3	7	5	8	4	5	4	7
A. melanoxylon								
one sample	-	-	28.6	-	-	7.2	-	1286

protein content by multiplying by the factor 6.25 which assumes the protein contains 16 per cent nitrogen.

Total ash, sodium, potassium, calcium, iron and phosphorous were measured on samples which had been ashed in a muffle furnace at 450°C overnight. The resulting ash was weighed, dissolved in dilute HCl and diluted to 25 ml with deionised water. Sodium and potassium were measured with a Corning 400 flame photometer. Calcium and iron were determined using a Varian Techtron Model 1100 flame atomic absorption spectrophotometer. Phosphorous was measured spectrophotometrically by a modified phosphomolybdate method.

Results and Discussion

All *Acacia* samples tested with the exception of *Acacia* sp. were high in total protein, ranging from 25.7 to 30.1 per cent (Table 1). *Acacia* sp. contained only 16.3 per cent protein. These seeds are 2 to 3 times larger than the other species tested. The larger size may reflect a greater carbohydrate storage and therefore could account for the lower protein content when expressed on a weight basis. Protein was determined on 4 or 5 samples of each species except for *A. melanoxylon* (1 sample). Results were generally reproducible as evidenced by the small ranges of values determined in multiple measurements on each species. With the exception of *Acacia* sp. *Acacia* seeds have a protein content similar to that of other legumes such as dried split peas (23.5%), soy beans (35%), or peanuts (25.7%). White wheat flour has a much lower protein content (11%)[4] than the *Acacia* and other native seeds which it replaces in the diet of many Aborigines living in remote communities. While the protein content of *Acacia* seeds is high, further studies need to be done to evaluate the quality of the protein for human use.

The moisture content of *Acacia* seeds ranged from 4.0 to 8.4 per cent and is similar to the low values seen in other dried seeds and cereal grains. Total ash content of the *Acacia* species tested was similar and ranged from 3.6 to 5.5 per cent.

Acacia seeds contain substantial amounts of calcium (204-336 mg $100g^{-1}$) but they also contain large amounts of phosphorous (1385-2344mg $100g^{-1}$). The Ca/P ratio of *Acacia* seeds is 0.125 which is much lower than the ratio of 1 considered most desirable in the diet.

The iron content of the *Acacia* species tested ranged from 4.6 to 7.2 mg $100g^{-1}$ and is comparable to the iron content present in other legumes such as dried split peas (5.0 mg $100g^{-1}$) and soy beans (8.8 mg $100g^{-1}$)[4]. The iron content of *Acacia* seeds, however, is much higher than that of white wheat flour (1.4 mg $100g^{-1}$)[4].

As with most foods of plant origin, the potassium content was considerably higher than the sodium content. The sodium content ranged from 29 to 90 mg $100g^{-1}$ while potassium varied from 700 to 1286 mg $100g^{-1}$.

Acacia seeds could contribute substantial amounts of protein, iron and calcium, nutrients which may be limiting in the diet of Aborigines. The usefulness of *Acacia* seeds as a source of these nutrients depends on the amount of seeds which is incorporated into the diet, the quality of the protein present, and the bioavailability of the minerals. Information on protein quality or bioavailability of minerals from *Acacia* seeds is lacking.

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OBSERVATIONS ON THE GERMINATION AND EARLY GROWTH OF ACACIA ANEURA

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Introduction

Availability of *Acacia aneura* seed is very dependant on prior rainfall patterns. Preece[10] has reviewed the pattern of seed production for this species and also reported a number of germination tests designed to show what happens to the seed in nature.

The present study reports the results of germination tests undertaken on Western Australian seed batches during 1977-1979. Although seed was not available in reasonable quantities when this work commenced an attempt was made from the start to restrict individual tests to the seed from single parent trees.[2] Progeny obtained thus form the nucleus of a living field collection maintained at the Western Australian Institute of Technology, Bentley.

The more detailed experiments reported were performed on a large batch of seed obtained from the Cosmo-Newberry area, Laverton in 1975. This became available to the Mulga Research Centre only in late 1978, but we may note that it has retained its viability under laboratory storage for 5 years so far, an extension of the time (2 years) reported by Preece.[10]

Germination Testing Procedures.

Siao-Jong has given an elegant justification for the use of boiling water to promote imbibition.[13] The actual time held in water at 100°C may be critical for some seed, but time in excess of 5 minutes is likely to be harmful.[12] Preece[10] used boiling water poured over seeds, with the water being left to cool to room temperature. This practice has been followed for all experiments reported here.

MacKay has summarised test procedures[7]. In the present instance seeds have been grown on top of filter paper in petri dishes, in controlled temperature cabinets.

Though it has been shown[10] that mulga seed will germinate equally well in the light or dark, all experiments have been performed in the dark to ensure consistency.

Preece[10] germinated mulga seed under a range of temperature conditions with day cycle temperatures between 15 and 36°C, with night temperatures 5°C lower in each case. He concluded that there may be a temperature optimum around 27°C but that there was little difference in germination attained between 20° and 30°C. Burrows[2] has examined temperature and germination interaction over a range of constant and alternating temperatures from 7 to 45°C using the method of Preece.[10] His results confirm the latter's estimates of optimum values, and showed complete suppression of germination at 40°C.

Radicle growth in *Acacia aneura* is extremely rapid. The accepted definition of germination is the emergence of those essential structures which indicate the ability of a plant to develop into a normal plant under favourable conditions (in soil).[7] Mulga may imbibe moisture, dry out and imbibe again.[10] However once the radicle emerges then an irreversible stage has been reached. Burrows defined germination as radicle> seed diameter.[2] In the tests reported here a length of 2mm of exposed radicle has been used to define germination. This is applicable also to the notion of 'germinability'.[8]

All 'undersized' seeds were removed prior to treatment to eliminate those with aborted embryos or other physiological malformations. Removal of obviously damaged seed preceeded hot water treatment. Seed which floated on treatment were also removed. These precautions eliminated most seed infested by larvae of the chalcid wasp *Mesopolobus* sp.[10]

Only a small percentage of seed is 'soft' and capable of germination without pre-treatment. Preece has reported 0.7 to 4 percent of seed falling in this category.[10] It is possible that some seed which fails to germinate with the hot water treatment may be 'soft' seed which is killed by the treatment.

Seed Weight

As might be expected the weight class distribution of a batch of *Acacia aneura* seed (Fig.1) shows a normal distribution pattern.

The implications of seed weight for success in regeneration are reviewed by Rorison[11] and Heydecker.[5]

Although mean seed weight may be constant, the range of weight around the mean may vary considerably and the proportions and absolute sizes achieved in any one year may be a reflection of environmental factors.[11]

Heydecker[5] has discussed the use of the term vigour to describe the ability of seeds to produce seedlings. For distinctions in vigour it is the weight and density, rather than volume of seeds that are important.

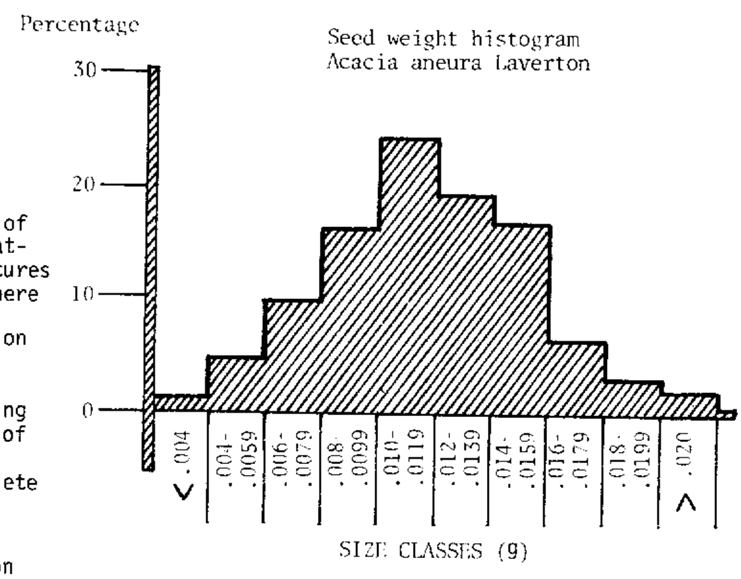

Fig. 1 Size class distribution of seed batch used for germination study summarised in Fig. 2.

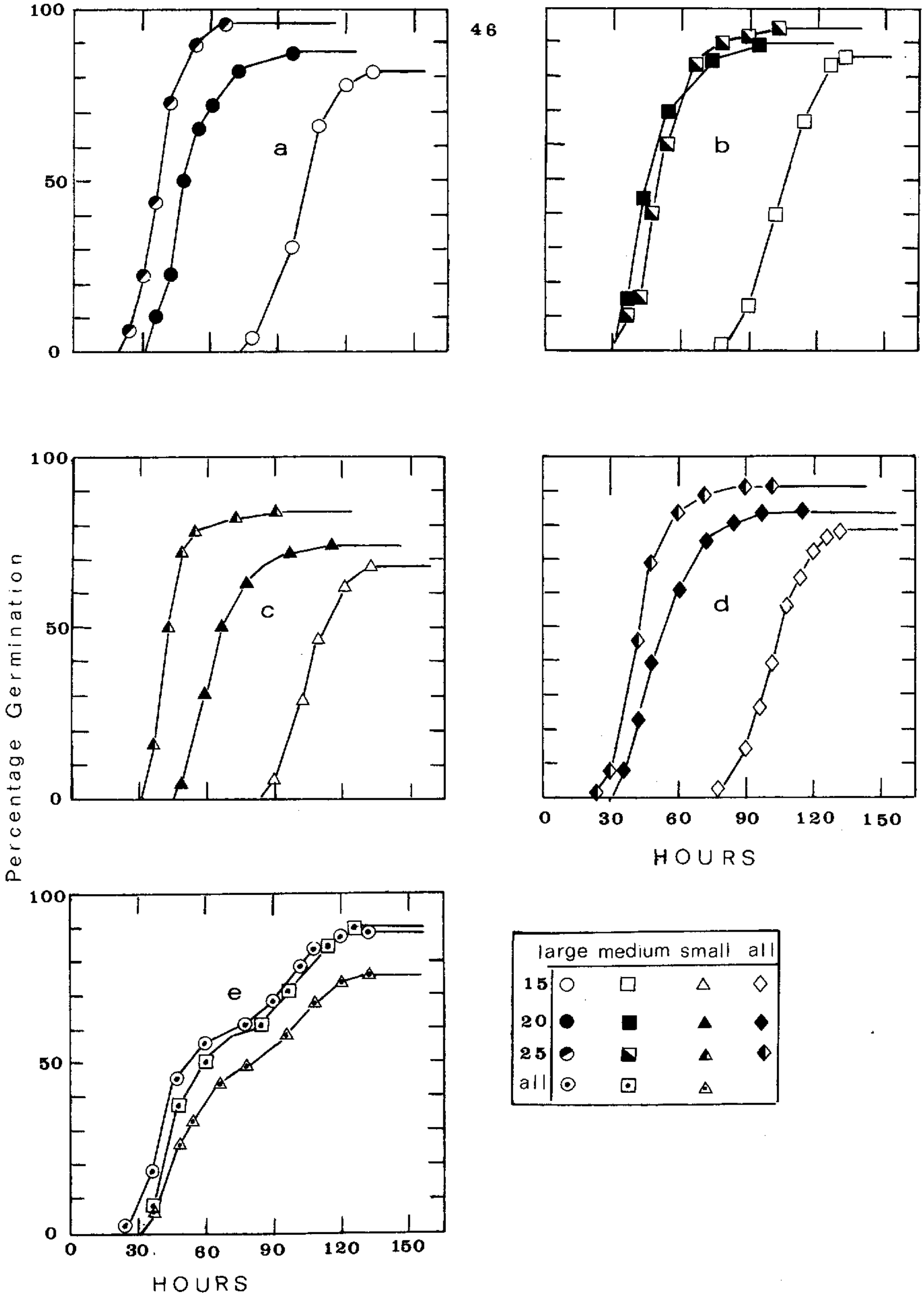

Fig. 2 Percentage germination by hours from treatment for *Acacia aneura* (ex Laverton) seed by size classes and growth cabinet temperatures.
a large seed; b medium; c small; d by temperature, summed; e by size classes, summed.

If differences in seed size involve differences only in weight and volume, but not in stage of development, then relative growth rates are often equal.[11] Absolute rates however will vary with differences in initial endosperm capital. Under optimal competition, individuals from larger seed have a greater chance of survival than do those from smaller seed.[5,11] This assumes that all seed would have the same degree of affinity with soil pore spaces available.[11]

Seed weight may be related to the efficiency of conversion of endosperm reserves to seedling length. Between the initial stage of subterranean growth, during which the seedling lives on its seed reserves, and the autotrophic, photosynthesising phase, there is an important transition phase. During this, prior to photosynthesis an appreciable amount of reserve material is intact and drawn on to boost above ground growth.[5]

Seed Size and Temperature

Method

Uniform sets of 50 seeds from the Laverton batch (Fig.1) were sorted into weight categories as shown in Table 1. These were then given the hot water treatment and placed in three growth cabinets at 15,20 and 25°C, in early May 1979.

Table 1 Mean Weight and Percentages for Temperature/Size experiment.

Size	Temperature		
	15	20	25
	Mean Wt (g) and percentage (Fig. 1)		
Large	0.0187 2.5%	0.0193 2.5%	0.0197 2.5%
Medium	0.0110 24%	0.0122 18%	0.0120 18%
Small	0.0062 9	0.0061 9	0.0057 4.5

Results

The time course of germination for these seed batches is illustrated in Fig. 2. Analysis of variance of the final germination percentages, at 132 hours from treatment, showed the following levels of significant difference using students 't' for critical differences

$25^{0} > 20^{0}$ p .02

$25^{0} > 15^{0}$ p .01 **

$20^{0} > 15^{0}$ p .05 *

medium > large NS

large > small p .01 **

medium > small p .01 **

Table 2 presents a comparative range of seed quality measures given by Hartmann and Kester.[4] Milthorpe and Moorby[8] suggest that the time distribution of the number of individuals reaching a defined stage (in this case 2mm of radicle) of the form illustrated in Fig. 2 may be described approximately by the following equation -

$$p = A\left[1 - \exp\left\{-k(t-to)\right\}\right]$$

where

p = proportion germinated at time t

to = time to germination of first seed

A = maximum proportion to germinate

k = a measure of spread of time to germination.

The rate at which germination progresses is given by the reciprocal of the time required e.g. the fastest seed is $\frac{1}{to}$; the median seed is $\frac{k}{kto + 0.693}$. When $p = \frac{A}{2}$

i.e. half of those that can germinate have done so, time is $\frac{to + 0.693}{k}$

Values for parameters of this equation are given in Table 3. These show that A increased with temperature over the range used and with increasing seed size. The value of k, a

Table 2 *Acacia aneura* ex Laverton, Summary of Germination Characteristics by Seed Size (Wt) and Temperature.

Temperature		Large	Medium	Small	All
15°	MD	101.7	105.8	107.5	104.9
	CV	0.98	0.95	0.93	0.95
	GV	0.40	0.44	0.27	0.35
	%	82	86	68	79
	t	132	132	132	132
20°	MD	52.6	50.1	66.8	51.8
	CV	1.90	1.99	1.50	1.93
	GV	1.12	1.21	0.53	0.75
	%	88	90	74	84
	t	96	96	114	114
25°	MD	40.3	54.2	45.6	38.4
	CV	2.48	1.85	2.19	2.91
	GV	2.49	1.17	1.40	2.71
	%	96	94	84	91
	t	66	102	90	102
All temperatures	MD	63	56	71	68
	CV	1.58	1.80	1.41	1.48
	GV	0.62	0.67	0.55	0.64
	%	89	90	75	85
	t	132	132	132	132

MD, mean days (in hours) as defined by Hartmann and Kester[4]; CV, coefficient of velocity, Kotowski[6]; GV, germination value of Czabator[3]; %, final germination percentage after 132 hours of observation; t, time (hours) of last germination.

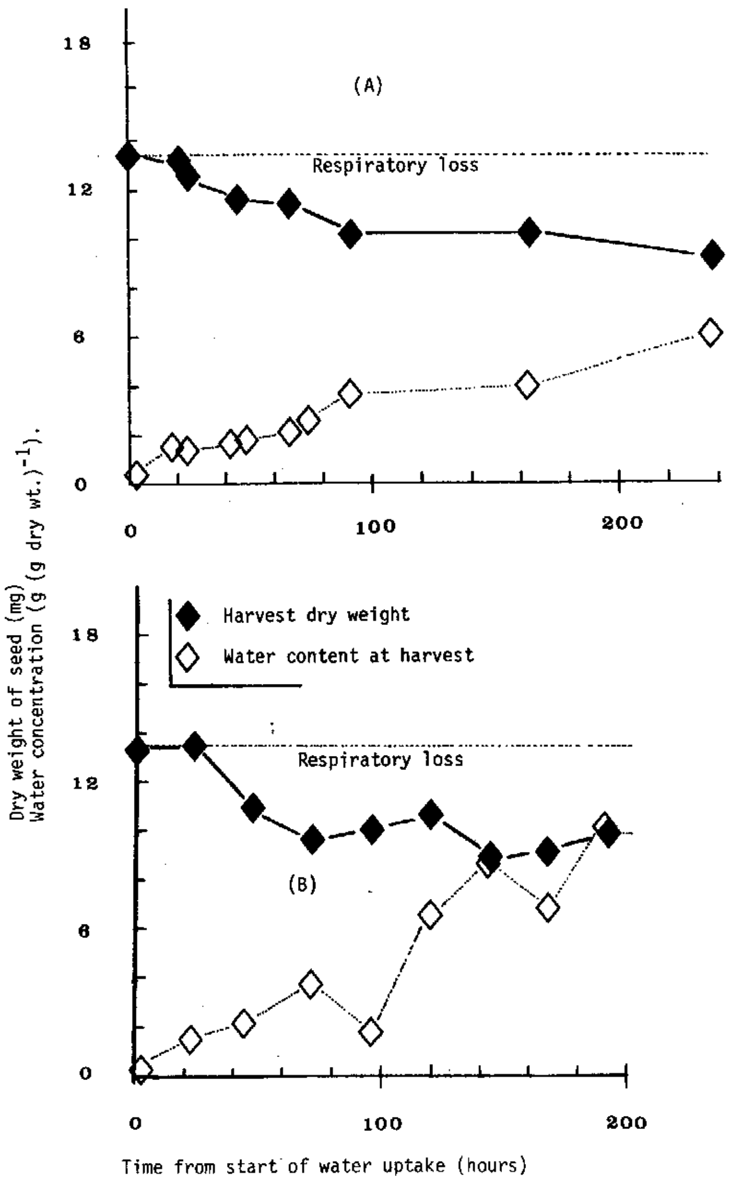

Fig. 4 Decline of seed dry weight and increased water uptake following hot water treatment in *Acacia aneura*. Experiment 1 (A), 2 (B).

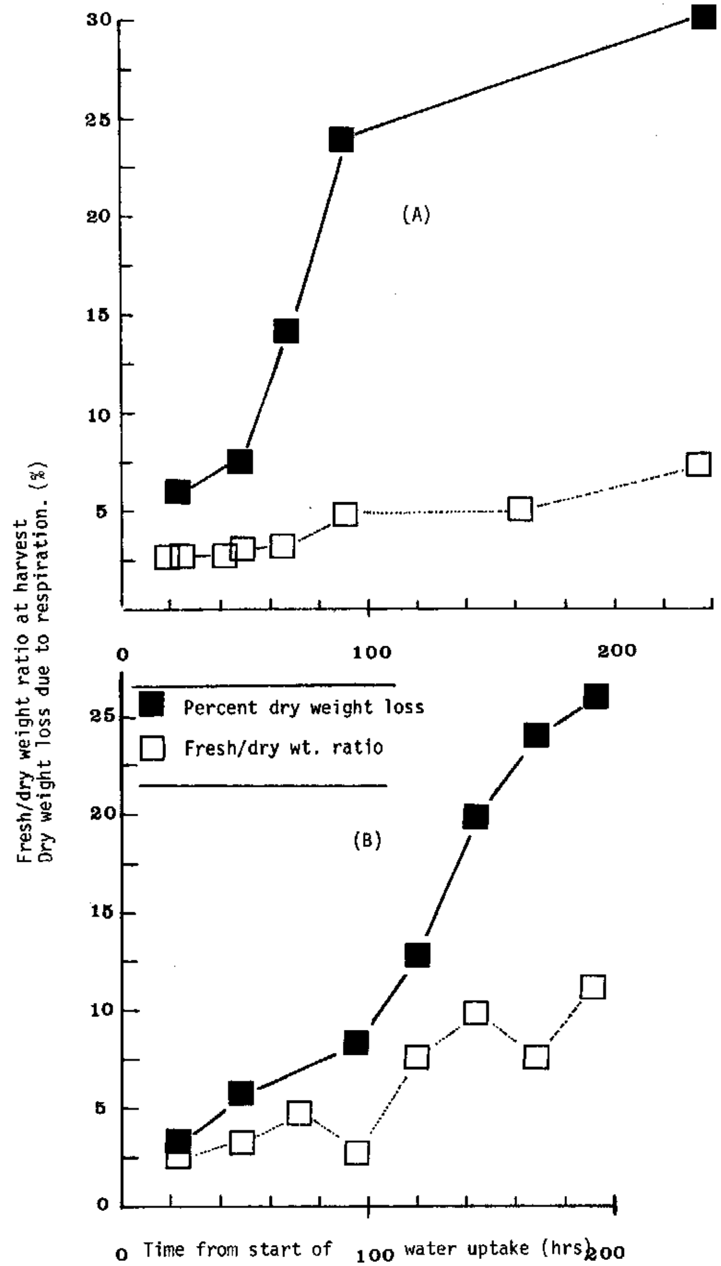

Fig. 5 Changes in percentage dry weight and fresh/dry weight ratio following hot water treatment in *Acacia aneura*. Experiment 1 (A), 2 (B).

Table 3 Values of Parameters in the Time Germination Equation[8]

Category	°C	to (h)	k (h^{-1})	A (%)	1/to (h^{-1})	1/ta/2 (h^{-1})
Large seed	15°	78	.029	82	.013	.010
	20°	36	.058	88	.028	.021
	25°	24	.039	96	.042	.024
Medium seed	15°	78	.023	86	.013	.009
	20°	36	.058	90	.028	.021
	25°	36	.058	94	.028	.021
Small seed	15°	90	.039	68	.011	.009
	20°	48	.039	74	.021	.030
	25°	30	.058	84	.033	.024
All seed		24	.022	85	.042	.018

measure of the degree of steepness of the germination curves was lowest at the lower temperature and the smaller seed size. The rate of germination taking both the first seed to germinate and the median seed, increased with temperature but not seed size. The ultimate germination percentage (Fig.3) was related more to seed size.

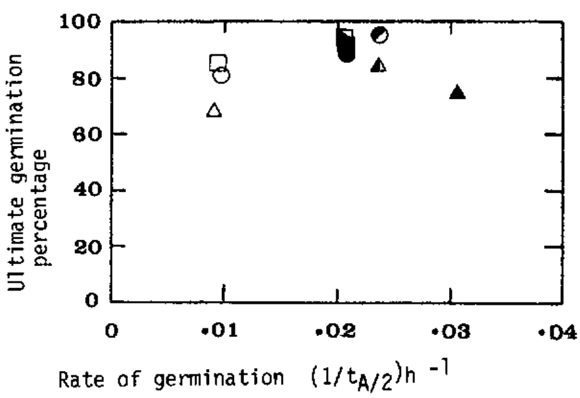

Fig. 3 Ultimate germination percentage and rate of germination (after Milthorpe and Moorby 1974, p120) Legend as in Fig. 2, 15°C open symbols, 20°C closed symbols, 25°C half-closed symbols.

Imbibition and Water Relations

Water uptake may commence immediately or there may be a few hours lag in some species, a phenomenon more pronounced if seed is less than 0.10 - 0.12 g (g dry weight)$^{-1}$ moisture content.[8] Imbibition shows an asymptotic pattern and will also depend on seed permeability[1]

In the field mulga seed may require moist conditions at the surface for a minimum length of time, sufficient to allow radicle extension well into the soil.

Methods

Two experiments were undertaken in January 1979 using seed from the Laverton batch (Fig. 1). In the first experiment 100 seed were treated and left to soak for 5 hours, then placed in constricted spaces in a plastic container, prior to transfer to a growth cabinet set at 30°C in darkness. Batches of six were harvested randomly at intervals over the following 10 days and individually weighed. In the second experiment 100 seed were treated and left to soak for 2 hours prior to first sampling. The remainder were then treated as before, with pre-determined sets of 10 placed in petri dishes, and harvested at intervals over 192 hours subsequent to treatment. Seedlings were weighed in batches of 10.

At harvest fresh and dry weights were taken, the dry weight following 24 hours in an oven at 80°C. The average moisture content of stored seed was 4.65 percent. All contaminated seed and seedlings showing abnormalities were excluded.

Results

Results are presented graphically in Figs 4 and 5. It is assumed that after 10 days under field conditions germinated seedlings would be capable of photosynthesis. The decline in dry weight (Fig. 4) taken as a measure of respiratory loss, suggests that one quarter to a third of seed weight is used in this establishment period (Fig. 5) Water content increased to 1.5g (g dry wt)$^{-1}$ in 24 hours in each experiment. Uptake was, on the whole, more sustained in the second experiment reflecting the constricted growing spaces available in the first. However after 10 days we may assume that mulga can absorb 6-10g (g dry wt)$^{-1}$ (Fig. 4) with a fresh to dry weight ratio of 7-10 (Fig. 5).

Single Tree Seed Batches

Small quantities of seed collected in the Meekatharra area in November 1977 from individual trees were germinated at 25°C in the dark in January 1978. Larger quantities of a mixed batch of seed kindly supplied from Charleville, Queensland formed a control.

Results

Eight batches failed to attain 50 percent germination (Fig. 6) whereas four reached 75 percent or better. Preece[9] reported viability of around 20 percent for a number of individual tree batches, with seed tested 6 months after collection.

Acknowledgements

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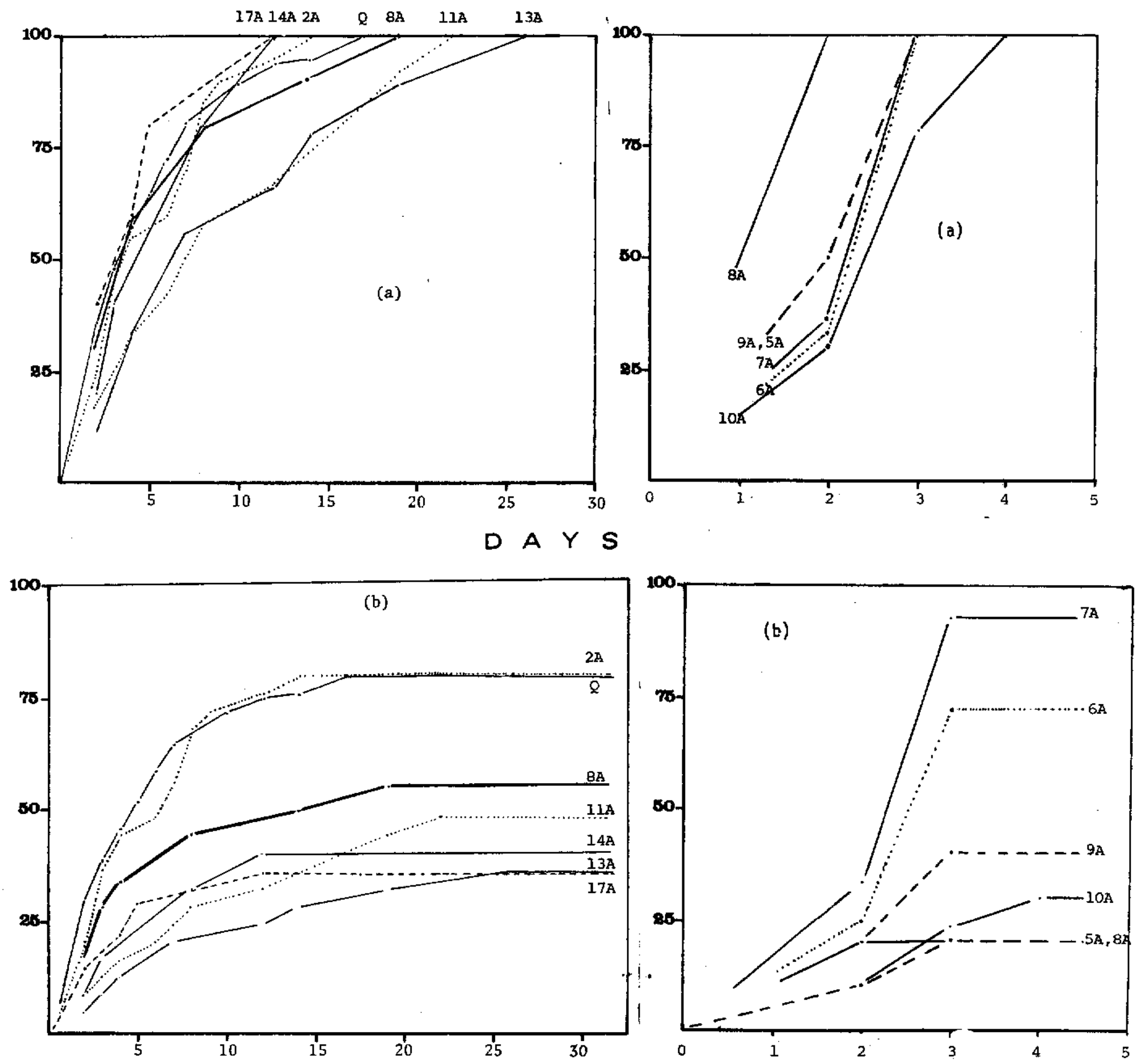

Fig. 6 Time course of germination *Acacia aneura*.
(a) percentage germination of those that germinated only;
(b) percentage germination of total seeds used in test.
Q = *seed from Department of Primary Industry, Charleville, Queensland;*
2A, 8A etc = *Western Australian seed collected from individual trees mainly at 'Hillview', Meekatharra, in November 1977.*
All seed germinated at 25°C in the dark.

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SOME THOUGHTS ON LAND USE FOLLOWING MINING IN WESTERN AUSTRALIA

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Introduction

In terms of land use mining is clearly the main use while ore is being extracted.

When the mining activity has ceased in an area then mining ceases to be the land use. Since the land is not being used for mining then something else must describe its use.

Land use may be examined before, during and after mining. Management responsibility, legislation and control may also differ during these three phases:[10]

Pre-operational	-decision to mine or not if yes under what conditions.
Operational	-the conduct of mining
Post-operational	-when production ceases, rehabilitation and long term care and maintenance of the site may be required.

In discussing land use after mining (post-operational phase) there are two stages. Firstly that intimately associated with the mining operator and, secondly, that related to the operator's departure from the scene. Legislation and control measures may delineate these stages neatly or untidily, in respect of the particular mining company or enterprise, in terms of management responsibilities. For some operations the change over may be quite clear cut as for example the abandonment of a worked out mine. Here the community as a whole will be concerned with such features as abandoned towns and unsafe mine sites[9]. Where mining *per se* has ceased two cases may arise where mining could be termed the land use. Firstly if known ore is still present and winnable in the area then mining may remain the land use (*e.g.* gold mines in mothballs awaiting a change in the economics of gold mining). When mining is still possible and leases are intact then it may be presumptuous to talk about other land uses. Clearly the lease holder is responsible until the lease is surrendered or lost. The second case occurs when all the mopping-up operations, that may be involved after ore extraction, may be included as part and parcel of the operation. That is, if topsoil is being replaced, if land contouring is being undertaken, or if such ancillary works as drainage, dust containment or stabilisation are not completed, then mining, at least in so far as the mining operator is concerned, may be seen to be the present use for the land.

Bauxite mining in the Darling Range could be classed as an example of the second case. The pattern of mining entails a large lease held for a long time and at present the point in time at which land ceases to be held in the lease is not defined. Should the company retain lease rights over worked out pits until the major lease expires or relinquish pits shortly after mining? Conversion of a mined area to an annual crop (e.g. legume based pasture) is a very different enterprise to the creation of a perennial tree plantation. There is inevitably a longer period of time involved before the latter can be termed successful. Some plants inevitably die the first year and the first problem is that of stocking - at what level of failure should the area be filled in with replacement trees? Can a time scale be set for proposed transfer of responsibility? Should this be based on the passing of time or on performance of the trees?

Importance of Land Use

Mining operations differ in the relative values that can be attributed to land use questions. Table 1 compares public interest (submissions) in three recent programmes with the operators perceived evaluation of land use problems (wordage).

Table 1 : A comparison of public interest in three projects

Project	Year of Release	Submissions No.	Pages	Wordage in document on land use	Distance from Perth(km)
Agnew[14]	1976	0	0	700	650
Yeelirrie[16]	1978	28	143	1,600	625
Wagerup[1]	1978	63	482	11,000+	130

Importance may be taken to refer to the level of conflict between competing land uses.[13] In the arid interior of W.A. competition between pastoralism and mining is a non-event, if we exclude Aboriginal leases. In the higher rainfall south-west of Western Australia the land can be used for a number of purposes and, in some cases, several uses may exist in conjunction. Public interest may be related to values, complexity or the level of competition between uses. It may also be a function of distance, population density, or other factors but surely public interest is a valid measure of importance. In the case of the bauxite mining proposals the suggestion here is that public interest was (and is) particularly concerned with land use after mining.

The year 1978 was an exciting one for students of the development process in W.A. The Wagerup proposals were presented to the Minister of Industrial Development on May 19th, at which time he called for a report on the document from the Environmental Protection Authority (E.P.A.). The E.P.A. formed a technical advisory group to examine the proposals. It's terms of reference were written on June 22nd, it was briefed on June 28th and reported, as requested, on August 4th.[15] The E.P.A. noted '*Public participation and interest in this proposal has been of a high level*' in its report to the Minister of September 6th.[11] This report was followed in September 1978 by two documents from Alcoa, one a revised ERMP to the State, the other a similar, but fuller document (including responses to public comment) to the Commonwealth as a final E.I.S.[2]

Change of Land Use

Mining often offers the opportunity of improving land in terms of its economic productivity. When this can be achieved it may justifiably be said that the new land use is more beneficial to society than the old. Conventionally we tend to rank land use in ordinate terms related to values. Thus urban land is considered superior to industrial and agricultural land superior to forest land. Another convention is that return of a land surface to productive use after mining is seen as a long term objective.[5] Restoration, defined as achieving a condition similar to the original, is rarely possible, and, indeed is seldom required. Reclamation in the sense that at some future time a particular piece of land will become once again capable of carrying organisms originally present is often possible. These definitions are after Box,[6] following U.S. terminology. Box used the word 'rehabilitation' to mean bringing the site to a determined, stable condition such that it is compatible with a chosen land use. Its connotations include that the chosen land use is both ecologically stable and desirable.

In considering bauxite mining particular attention must be given to land use for water supply. Where water supply catchments are mined this land use continues through mining and afterwards. Changes that occur may affect yield and quality of water. If amelioration is seen as a long term objective then water supplies emanating from particular pit areas may detrimentally alter yield and/or quality over wide areas. Surely where water supply is the land use (one of overriding importance) the management efforts at the post-operational phase must lay emphasis on securing a continuing useful and useable water yield in the short term. The question of increased value may arise if a greater quantity of water was desired and attainable.

Water is not the only land use to which the land is put prior to mining however. Others are timber, conservation and recreation. Some areas carry more timber than others, some areas have little conservation value and recreation values are difficult to quantify. These land uses, as well as water yield, are variably affected by the varied incidence of jarrah dieback. The time scale to replace a mined area with a mature stand of jarrah is long to say the least. Indeed by now no one who knows anything at all about *Eucalyptus marginata* should entertain the notion that a conceivable land use after mining for mined jarrah forest is jarrah forest. If such land is to be described then *'jarrah forest'* is not a term that can be employed. Certain land uses then are precluded by mining. Bauxite mining precludes bauxite mining whereas gold mining may not preclude gold mining. Most, if not all, mining precludes fauna/flora conservation/preservation however delicately we may tap out definitions of these terms, notoriously differently defined by differing sets of word users.

At some particular point in time a decision has to be taken about change in responsibility. If the mining company believes it has met all the terms and conditions imposed on it in respect of a particular land area it will seek to divest itself of its responsibility. This is particularly so if continuing rents or taxes of one form or another fall due even though no production is coming forth. Exceptions to the generalisation would include examples where access is required through or around worked areas, where adoption of a new land use could lead to problems of conflict with the new users or any case where the cost of continuing to hold the mined land is less than any reasonably predictable cost which may arise from surrender. On the other hand the point in time at which the government (or any arm of the government) will seek to assume, or resume, control of the particular land area will not be until it believes that the company has done all that can reasonably be done towards meeting the terms and conditions imposed.

The concern here is with 'after-mining' and clearly this stage is difficult to plan if options are not delineated. A group was formed early in 1979 to assess Alcoa's mining and management plans (MMP) but the establishment of a body *'for the formulation and assessment of long term land use policies for the Darling Range area'* has not yet eventuated.[13] A set of rehabilitation standards may be more desirable than having a clear idea of the land use objective prior to mining. That is if a general vegetation-type effort is included in rehabilitation standards, all the ancillary planning (i.e. storage of topsoil, growing of trees, collection of seed) can be executed. If a given pit is later declared to be designated as a trail bike area little is lost because the topsoil and plants can be used elsewhere. Clearly a mutually acceptable inspection is necessary. For this to be reasonably undertaken then a set of objective standards should exist. Thus one side will seek to achieve the standards, the other side will examine performance against the standards. When both sides agree then the stage is set for the new land use.

Rehabilitation Standards

A series of proven practices has been developed over the years to rehabilitate bauxite mine pits. Generally the company must progressively restore and reforest the area cleared, to the reasonable requirements of the State.[15] The problem over standards persists because only time will show whether the practices used to date will persist in achieving stability. It has been noted that current techniques are insufficiently *'proven for the final outcome to be predicted with confidence'*.[15] Alcoa recognises the problem e.g. *'Procedures to be adopted will depend on the specific rehabilitation objectives selected by the State Government for any particular area'*[1] and, apart from concentration on surface water yield *'there is a wide range of options for other types of rehabilitation which, depending on land use priorities and directions given by the Government authorities could be implemented in particular areas'*.[1] At the present time the Company accepts its role in rehabilitation, that is it will 'do' it. The Government cannot be emphatic about precisely what should be done in any particular mined pit. Indeed it may be that selection of the most appropriate technique for a particular site may await future results.[15] In the final E.I.S. the following summary of the position appeared: *'In the past, land use objectives for mined areas have not been clearly defined. Alcoa agrees.......that it is desirable for* *the State to establish a means of developing land use policies....options, and for co-ordinating land use planning. Until such means are established and functioning it is not possible to propose firm objectives and prescriptions for rehabilitation of mined areas*'[2] A mining enterprise is more likely to be able to reshape the land surface than, say agriculture, due to its command of resources. It is potentially able to produce something different from the landscape than before. For example the liquidation value paid to the Forests Department is $813 ha[15] whereas Alcoa spends $10,000 ha on rehabilitation.[1] The problem is : what should be attempted? Amelioration of the multiplier effect of dieback due to mining is accepted as a responsibility by Alcoa in what may be referred to as Alcoa's Adjoining Area Principle (AAAP). This is contained in the following quotation, '*Alcoa is prepared to rehabilitate, to standards agreed with the State Government, any degraded sites within its envelope of operations. In addition to the areas directly affected by mining, rehabilitation will include dieback-affected areas outside mine pits, both before and after mining*'[1] Early work at Broken Hill (e.g. Harris & Leigh[12], Black & Trudinger[5]) provides a historical precedent for the above commitment. Alcoa goes much further than any similar undertaking made before. In theory it is an offer to manage the bulk of the northern jarrah forest on behalf of the State. It has been enthusiastically received[15] especially in view of the fact that some feel that dieback will infect much of the forest in due course.[15]

Future Management

'*Even when rehabilitation has been carried out the aftermath of mining poses considerable management problems*'[11]
As mining proceeds through State Forest then pit-location, age and size are going to increasingly dominate management within forest blocks. It has been suggested that dispersed clearing will increase management problems[15] but I believe that to be a simplification. Providing given catchments are worked through in sequences and the AAAP is applied then management may be less complex, particularly if lower grade ores were taken.

A major decision that had the potential to simplify management has already been made. That is to restrict mining in the drier eastern zone of the forest. There are theoretical reasons for suggesting that this decision should be changed. Firstly it puts off to the next generation the problem of deciding if and how the zone can be mined. Perhaps we of this generation should preserve more of the high rainfall forest. Exploitation of the eastern zone could rapidly generate some very basic knowledge sooner than it otherwise will eventuate. The risks would be spread between zones and by careful planning e.g. designation of broad mining wedges from west to east in bands to supply the three refineries, we would more nearly approach the island theory of Diamond[8]. Unmined belts many kilometres wide could be left between mining swathes maintaining the integrity of fauna and flora (e.g. greater value to Management Priority Areas). Secondly it would seem that lower rainfall in the east suggests slower dieback spread and clearly the overall rate of timber production must be less in lower rainfall areas. Thirdly such a decision could lead to economies in mining and it would allow all parties to know where they stood. A notional 25 per cent or 35 percent of the total forest could be retained spread in broad inter-connecting bands throughout its area. Should 'protectable' or 'high-grade' areas be left as unmined pockets then management will be more complex. Indeed any system of dividing forest areas on present condition will perpetuate the dispersal of mining areas along contiguous patch routes. The Management Priority Areas[15] would have greater integrity for longer if held within broad belts of forest.

Land tenure must remain crucial to any discussion of land use after mining. Where land is owned freehold by the mining company the company itself will have a major interest in deciding the new land use, and in ensuring maximum utility in use. Mined land held privately but not by the company would generally be compensated solely in cash. The land owner then may have a role in nominating how much investment is put into any amelioration works on the conclusion of mining. Nowhere is this problem of land ownership more difficult than in the case of the jarrah forest. Here all the agencies will have their own criteria as to acceptable standards. As these will differ, then any compromise package will include all things considered useful, so that obligations could exceed any envisaged by a single private owner. Hopefully these will be simplified *via* the MMP.

Where land is vested in the State then the Company will not, usually, be able to benefit from any investment in the land following mining. Such investment may generate future costs to the State and it would be to the advantage of both parties to know something about future costs and returns. It is conceivable that $10,000 ha is too much to spend at present. Where the company owns the land it has few limitations imposed on what it may or may not do. Other private ownership may bring forth some very interesting possibilities. For example an area mined for sand may be profitable to the landowner. If he can obtain rents later for using the mine as a rubbish tip that too can be profitable. If when full of rubbish the land can be developed as a housing estate or a light industrial area then the private owner has run through sequential valuable land uses, all to his advantage.

To resolve management problems related to bauxite mining a Darling Range Area Management Authority could be set up[13]. This would effectively control the region and all its resources. A useful start-up point could be on the completion of mining in a given pit or on the completion of Alcoa's rehabilitation effort.

Responsibility Should Something Go Wrong

A number of problem areas can be predicted in advance and guarded against. Other unforeseen or unavoidable problems require to be insured against in some way. The responsibility for restoring structures following accidents is of particular importance to water supplies and the costs of such things as fire prevention and control are important in the jarrah forest. Examples where the Wagerup proposals have led to delineation of responsibilities include compensation for damaged pine plantations[15]; bonding to safeguard maintenance of engineering structures[15]; and integrity of red mud lakes.[11] Some things are inherent in the operation. For example dust suppression on haul roads requires a lot of water. This may spread dieback[15]. I have alluded to some broad possibilities in the previous section, with specific reference to the local bauxite scene. Elsewhere and with other mining enterprises governments have sought to be particularly cautious in case companies go broke. In South Australia a royalty from all materials mined is paid into an 'Extractive Areas Rehabilitation Fund'. A trust fund in case of uranium company collapse has been put forward[7]. In Western Australia it has been suggested that mining companies could contribute to a fund to rehabilitate mined areas to safeguard against the operating company folding up.* The suggestion was mooted that regular small amounts could be paid until the fund reached an agreed maximum. Monies could be drawn to maintain rehabilitation programmes started before the company went out of business. A similar suggestion, specific to one industry, includes a levy on production throughput.[3] Such funds could also be used to provide compensation funds to cover mining related disease (silicosis, asbestosis, *etc.*) which may not show up for some years after mining has ceased. These sorts of schemes may be useful when the following conditions[10] are met :

1. short time between production and rehabilitation.
2. few technical problems.
3. costs can be predicted and equated with the levy.
4. different operators face similar problems.

They may also be particularly useful in ensuring that plans are formulated for the time of closure of single pits so that both a potential use and funding are considered prior to abandonment of the operation. Bauxite mining in the Darling Range seems to require a special format and the Darling Range Area Management Authority seems to have a lot going for it. In particular funding generated could be used elsewhere for compensatory pine plantations - if used wisely the Forests Department could '*grow more timber than could be grown on the area that was cleared*'[4]

Acknowledgements

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* Colin Porter, Director, Department of Conservation and Environment, W.A. speaking to the W.A. Mining Club on March 16th 1978 (reported in the West Australian of March 17th 1978).