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A COMPARISON OF THE GERMINATION AND NUTRITIONAL STATUS OF SEED FROM DUMP AND NON-DUMP SOURCES OF *ALLOCASUARINA FRASERIANA* AND *ACTINOSTROBUS PYRAMIDALIS*

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Abstract

Allocasuarina fraseriana and *Actinostrobus pyramidalis* are successful colonisers of abandoned coal mine dumps at Collie, Western Australia. Aspects of the germination and nutritional status of seeds from dump and non-dump populations were investigated to determine if disturbed environment was causing an adaptive response in the reproductive effort.

Germination was not different in seed collected from dump and forest populations. *A fraseriana* seed germination was less than 30% while *A pyramidalis* was greater than 80%. Seed from dump populations of both species had significantly greater cone and seed biomass than from forest populations. The contrast in *A fraseriana* seed biomass may be an adaptive response to the growth in the hostile coal overburden material.

Introduction

Seed size varies both within and between populations of a species (Baker 1972) and tends to be negatively correlated with seed number (Primack 1978). Allocation of resources to reproduction may be said to involve a compromise between seed number and size. At the extremes, either small seeds are produced in large numbers, or fewer, larger seeds may develop. The former strategy enables at least some seed to arrive at suitable sites where germination can occur, thus favouring dispersal. Fewer, larger seeds with more nutritional reserves represent a strategy enabling better seedling establishment in harsh or stressed environments (Baker 1972). Seed dispersal, germination patterns and early seedling growth are all affected by the allocation of available resources between the extremes of seed size and number made by the parent plant (Wulff 1986).

Prevailing environmental conditions and the general availability of resources can cause variation in seed size (Salisbury 1974). Variation in seed size has been postulated as a plastic, adaptive response to environmental conditions (Silvertown 1989). For example, it has been suggested that larger-seeded plants occur where water availability is low (Baker 1972). Larger seeds are able to produce faster root and shoot growth and may develop adequate roots to tap available water supplies before the onset of drought conditions (Baker 1972; Salisbury 1973). Previous work has indicated that a number of species growing on coal mine dumps have seed of greater mass than the same species growing under natural conditions (Fox *et al.* 1988; Hughes and Fox 1993; Fox *et al.* 1994).

An investigation was made into some aspects of seed biology in *Allocasuarina fraseriana* and *Actinostrobus pyramidalis*. Both species appear to be successful colonisers of coal mine dumps in the Collie area. *A fraseriana* is typically an understorey tree species (12-15 m tall) of the jarrah forest whereas *A pyramidalis* occurs on winter-wet sandy soils on the coastal plain as a smaller tree (<4 m). Seeds from dump and non-dump sources were examined to determine whether similar differences to those found in *Acacia* species could be identified (Fox *et al.* 1988). Of particular interest was a comparison of seed size, number and nutritional status and how these characteristics may indicate adaptive mechanisms for growth in harsh edaphic conditions such as those found on colliery spoil material.

Methods

Fruiting cones of both species were obtained from dump populations in the Collie area (33°22'S, 116°09'E) and from populations growing in undisturbed natural environments.

A fraseriana cones were collected from Ewington No. 1 dump (33°22'S, 116°12'E) while those from a natural forest population were obtained from jarrah forest at Walliston, 24 km east-south-east of Perth (31°57'S, 115°52'E). Sets of 60 cones from each population were placed into individual cups and allowed to dry and shed seeds. The numbers of seed were then counted for each cone. Cone masses, mean number of seed per cone and mean seed weight per cone were recorded.

Cones of *A pyramidalis* from dump populations were collected from the Centaur open cut mine (33°28' S, 116°20' E) and those from a non dump population were obtained from the locality of Wattle Grove, 18 km east-south-east of Perth. Sets of 80 cones were dried out and seed counted as for *A fraseriana*.

Germination tests and nutrient analyses of seeds for the four populations were made.

Seeds from a mixture of all cones were counted out into batches of 50 with three replicates per treatment. They were pre-treated by washing in hot water (*ca.* 40°C) with 0.005% Tween-20™ detergent to facilitate wetting. Seeds were then surface sterilised by shaking in a 3% sodium hypochlorite solution for two minutes and rinsed three times in distilled water. Batches of seeds were placed directly onto moistened filter paper resting on vermiculite in petri dishes. The vermiculite was treated with a dilute solution of fungicide (0.1% Previcure™). Petri dishes were placed in temperature incubation chambers set for 24 hours darkness. *A fraseriana* was incubated at 20°C, the optimum germination temperature for this species (Turnbull and Martensz 1982). *A pyramidalis* was incubated at 15°C, found to be the best temperature for germination in an earlier trial (Doronila 1995). Total numbers of germinants, defined as those seeds with 1-2 mm of protruding radicle, were recorded daily until 35 days had elapsed.

Germination percentages were converted to arcsine, prior to analysis of variance, to determine significant differences between batches.

The following germination parameters were calculated:

Germination rate (after Hartmann and Kester 1975).
This was calculated as follows:

$$\frac{\Sigma(n_1 \times t_1) + (n_2 \times t_2) + \ldots + (n_x \times t_x)}{\text{Total number of seed germinated}}$$

where:
n_1 = number of germinants at first day (t_1) of observed germination
n_2 = number of germinants at second day (t_2) of observed germination, *etc.*

Germination value

Peak value and mean daily germination were used to derive the germination value of Czabator (1962),

where:
Germination value (GV) = Peak value (PV) x Mean daily germination (MDG.)

Peak value is a measure of the steepest point in the germination gradient as determined by the maximum value for the following expression:

$$PV = \frac{\text{highest number of germinants in one day}}{\text{number of days from start}}$$

and mean daily germination is taken as the final germination percentage divided by the number of days required to reach that percentage:

$$MDG = \frac{\text{final \% germination}}{\text{number of days to final germination}}$$

Results

Germination in *Allocasuarina fraseriana* was comparatively low, with a maximum of 31% (Figure 1), whereas *Actinostrobus pyramidalis* attained 93% (Figure 2). Final germination percentage was not significantly different between the dump and non-dump sources (Table 1) for *A fraseriana* (F-value=1.3, p=0.37). Final germination of *A pyramidalis* dump origin was significantly lower than that of the natural population (F-value=48.4, p=0.02). Mean germination value for dump seeds was lower than for non-dump seeds in general.

First germination began seven days after commencement for *A fraseriana* and 13 days after commencement for *A pyramidalis*. Three to five days after first germination, were required to reach 50% germination in *A pyramidalis*.

A fraseriana seeds developed a mucilaginous gel on the seed surface with wetting. Even with the application of fungicides these seed had a higher inci-

Table 1. Mean germination parameters for *Allocasuarina fraseriana* and *Actinostrobus pyramidalis* from dump and non-dump seed sources (n=3 batches).

Germination Parameter	*A fraseriana* Dump	*A fraseriana* Non-dump	*A pyramidalis* Dump	*A pyramidalis* Non-dump
Final germination (%)	26	31	83	93
Days to 1st germination	7	7	13	13
Days to 50% germination	-	-	18	16
Days to final germination	33	32	28	33
Germination rate	13.8	13.0	18.1	17.0
Germination value	0.8	1.0	5.0	7.3

Table 2. Mean cone mass, seed massand number of seed per cone in *Allocasuarina fraseriana* (n=60 cones) and *Actinostrobus pyramidalis* (n=80 cones) from dump and non-dump seed sources ± standard error.

Species	Source	Mean cone mass (g)	Mean no. seed/cone	Mean seeds/cone mass (mg)
Allocasuarina fraseriana	Dump	4.62 ±0.29	14.0 ±1.2	5.22 ±0.27
	Non-dump	3.11 ±0.10	24.0 ±1.2	4.45 ±0.10
F-value		5.08	5.52	2.72
Significance		***	***	**
Actinostrobus pyramidalis	Dump	0.74 ±0.01	11.0 ±0.2	17.34 ±0.21
	Non-dump	0.40 ±0.01	10.0 ±0.2	15.75 ±0.28
F-value		25.99	6.1	4.57
Significance		***	***	***

Note: P <0.01**, <0.001***.

dence of fungal infection than the *A pyramidalis* seeds.

Dump populations had significantly higher mean cone mass and mean seed mass per cone than non-dump populations (Table 2).

In *A fraseriana* a negative correlation was observed between the number of seeds per cone and the mean seed mass per cone. *A pyramidalis,* on the other hand, had a positive correlation between the number of seeds per cone and the mean seed mass per cone, indicating that the higher seed mass was in part due to the greater number of seeds. Irrespective of the number of seeds per cone, the mean seed mass for the dump population was greater than the non-dump population of *A pyramidalis* (Table 2).

Dump seed was significantly heavier for *A fraseriana* but the difference was not significant at p <0.05 level (p=0.06) in *A pyramidalis.* Statistically significant differences were found between sources for nutrient composition of *A pyramidalis* seeds but not for *A fraseriana* (Table 3).

Table 3. Mean seed mass (mg ± standard deviation) and total seed nutrient content (µg ± standard error) of *Allocasuarina fraseriana* and *Actinostrobus pyramidalis* from dump and non-dump seed sources.

Species	Source	Mean seed mass (mg)	Nutrients (µg/seed) P	N	Na	K	Ca
Allocasuarina fraseriana	Dump	5.49 ± 0.26	23.18 ±1.90	161.20 ±15.15	5.03 ±0.27	3.53 ±0.54	83.61 ±3.34
	Non-dump	4.15 ±0.22	14.62 ±3.15	168.15 ±2.98	4.29 ±0.20	1.76 ±0.04	88.48 ±1.41
F-value		36.76	7.96	0.80	9.64	14.93	2.77
Significance		*	NS	NS	NS	NS	NS
Actinostrobus pyramidalis	Dump	16.49 ±0.52	23.89 ±3.92	464.22 ±12.39	20.77 ±0.14	9.95 ±0.06	259.62 ±7.25
	Non-dump	15.42 ±0.42	30.73 ±3.84	526.67 ±3.13	8.87 ±0.75	6.02 ±0.45	197.31 ±16.61
F-value		6.85	2.48	59.27	154.02	79.48	33.65
Significance		NS	NS	*	**	*	*

Note: P <0.05 *, <0.01 **, NS=Not significant

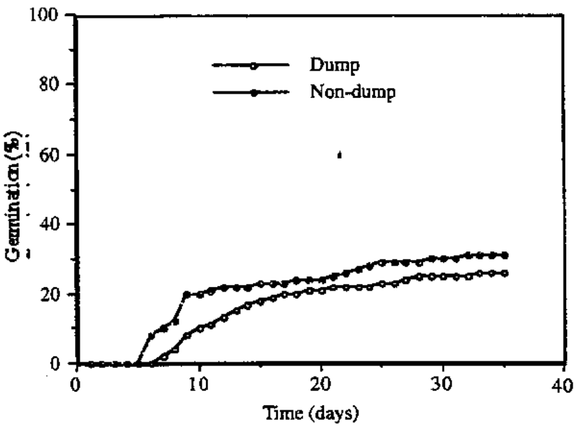

Figure 1. Percentage germination of *Allocasuarina fraseriana* seed from dump and non-dump population sources. Germinated at 20°C.

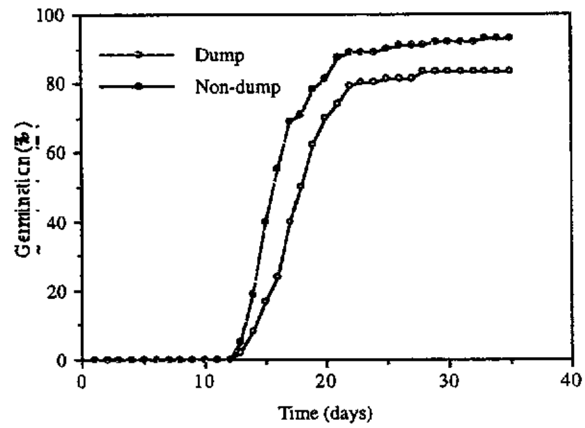

Figure 2. Percentage germination of *Actinostrobus pyramidalis* seed from dump and non-dump population sources. Germinated at 15°C.

Discussion

Both species produced larger cones and heavier seeds per cone in the dump populations than they did in non-dump populations. Under stressful conditions such as those found on the dumps (*eg.* low nutrient availability and soil moisture, and high soil acidity) plants may allocate more resources to production of fewer but heavier seeds. This adaptation could enhance seedling establishment. Several species of Myrtaceae, *Acacia* and Proteaceae growing in nutrient poor soils invest relatively large amounts of phosphorus into their seed (Bowen 1981; Kuo *et al.* 1982).

Seed mass of dump origin was greater in both species. This phenomenon is similar to that observed in *Acacia* species (Fox *et al.* 1988, Fox *et al.* 1994) and in *Paraserianthes lophantha* (Hughes and Fox 1993). Some Collie dumps have a number of severely stunted trees of *Allocasuarina fraseriana* which produce few seed (Fox *et al.* 1994). It is possible that dump trees producing seed may have avoided aluminium translocation to shoots, as shown by *Acacia decurrens* (Fox *et al.* 1994). Mean seed mass for the forest source of *A fraseriana* was similar to the value of 4.24 mg reported by Turnbull and Martenz (1982). It is possible that the enhanced level of elemental phosphorus found in the heavier dump seed of *A fraseriana* is an important consequence of growth on the difficult dump soils.

Seed germination for *A fraseriana* was low for both dump and non-dump seed progeny. The seeds of some *Casuarina* species are known to have an after-ripening period when they become more viable than immediately after harvest (Turnbull and Martensz 1982). This has not been well documented but it has been suggested that sowing seed a few months after storage may enhance germination (Turnbull and Martensz 1982). This may explain the poor germination and viability of freshly extracted seed reported here. No differences were observed in final percentage germination between the two populations of *A fraseriana*. Comparison of seed held for different storage times from the two sources might reveal differences in germination characteristics.

Final percentage germination of *A pyramidalis* was significantly higher for the non-dump population. This seed source had higher nitrogen and phosphorus concentration than seed from the dump population, despite the greater mass of the latter. Further investigations are required to determine whether dump progeny in this species are better adapted to dump conditions than plants from the natural sites. In contrast to *A fraseriana,* where cones are not persistent beyond the year of production, cones are held on *A pyramidalis* for several years. The species tends to occur naturally on seasonally moist, acidic white to grey sands, on the coastal plain near Perth. Such soils have low amounts of both nitrogen and phosphorus. However, nutrient status of the dump source soil is likely to be much poorer.

Conclusions

Differences in cone mass, number of seeds per cone and mean seed mass per cone were highly significant for both species between dump and non-dump populations. The greater contrast between dump and non-dump environments for *Allocasuarina fraseriana* may have lead to selection for an adaptive response (production of larger seeds) by dump trees.

There were differences in nutrient content of seeds of both species, although nitrogen and the major minerals were significantly different in *Actinostrobus pyramidalis*. All differences in nutrient content of seeds observed for *A fraseriana* were not significant.

If it is assumed that there is reduced availability of nutrients for uptake by plants in spoil material, then the greater sized seeds being produced on spoil-grown trees could be attributed to poor nutrient availability. In addition to nutrients, water availability on dump material during the drier summer months was lower than in a forest or natural environment, due to the sparse cover and the hard compacted nature of the spoil.

Acknowledgements

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SUCCESSFUL TREE AND UNDERSTOREY ESTABLISHMENT ON SALINE GOLD MINE WASTES: A PRELIMINARY OVERVIEW

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Abstract

Mining ceased in 1992 at the Westonia open-cut goldmine, 320 km east of Perth, Western Australia. The early May 1990 seeding of 40 ha of dump surfaces used a suite of species local to the area, and additional selected salt tolerant varieties. No fertiliser was applied. Stratified random sampling of the upper surface of a selected dump (Area C), was undertaken to evaluate the success of tree and understorey establishment. Eucalypts and other trees (*eg. Pittosporum phylliraeoides*) were prevalent and chenopods provided ground cover. Densities of eucalypts approximated 580 ha^{-1}, with individuals to 4 m not uncommon. Acacias and other woody perennial shrubs (*eg. Atriplex nummularia, Dodonaea viscosa*) were present. An extensive chenopod ground cover (approximately 15,680 ha^{-1}) was dominated by *Atriplex semibaccata, Enchylaena tomentosa* and *Maireana brevifolia*.

Introduction

Background

The Westonia open-cut goldmine is located 320 km east of Perth, Western Australia in the eastern wheatbelt (31°18'S, 118°42'E). Gold mining, and sheep and wheat farming have historically been the major economic activities for the Westonia district. During operational years (1986-1992) open-cut mining generated large volumes of saline waste rock, much of which was relatively soft and subject to weathering. The mine operator was obligated to rehabilitate waste rock dumps.

The native vegetation of the surrounds of the Westonia mine is low woodland dominated by a number of *Eucalyptus* species (Myrtaceae) including *Eucalyptus salubris, E salmonophloia, E lissophloia, E longicornis* and *E yilgarnensis*. A mid-level stratum is formed by *Melaleuca pauperiflora*, and *Acacia acuminata* which occur in dense thickets. Between these clumps of understorey growth is an open low shrub stratum of erect shrubs including *Acacia hemiteles* (Mimosaceae), *Eremophila decipiens* (Myoporaceae), and members of the Santalaceae; *Exocarpos aphyllus* and *Santalum acuminatum*, mixed with a variety of indigenous chenopods, *eg. Atriplex bunburyana, A vesicaria, Enchylaena tomentosa, Eriochiton sclerolaenoides, Maireana trichoptera, Rhagodia drummondii* and *Sclerolaena diacantha* (Osborne *et al.* 1988). *Acacia* species, including *A ancistrophylla, A coolgardiensis, A merrallii* and *A nyssophylla* occur with common understorey species such as *Brachysema aphyllum* (Papilionaceae) and *Ptilotus exaltatus* (Amaranthaceae), and members from the genera *Dodonaea* (Sapindaceae) and *Grevillea* (Proteaceae).

The semi-arid climate of the Westonia region has an average annual rainfall of 320 mm. The rainfall pattern gives reliable precipitation, dominant in the winter months. Sporadic thunderstorms make summer rains quite unpredictable. Average temperatures range from 18°C to 34°C for January, and 5.5°C to 16°C for July.

The strategy employed at the Westonia operation for rehabilitation of the waste rock dump surfaces involved the establishment of local indigenous species by direct sowing. Eucalypts, woody perennial species and chenopods were included in the seed mixtures. The suite of revegetation species included those tolerant of elevated salinities and a low and erratic rainfall regime (Osborne 1990; Osborne *et al.* 1993a).

When it is obtainable, a covering of topsoil or topsoil/caprock mix provides increased nutrients to establishing vegetation. Plant growth is facilitated and the revegetation cover assists with slope stability. An additional seed store is available from fresh topsoil. A topsoil or topsoil/caprock mixture is best used where average salinities of the under-lying materials are not greater than 20 dS m^{-1} (saturation extract) (Osborne and Brearley 1995a).

The presence of mycorrhizal fungi and *Rhizobium* bacteria in the topsoil covering can provide important and beneficial symbiotic associations with plants of semi-arid ecosystems. Mycorrhizal fungi provide a filamentous extension of the plant root, increasing the uptake of nutrients and in particular phosphorus (Bowen 1981). Legumes, such as acacias, possess the ability to fix atmospheric nitrogen into a form available for plant use. This symbiotic relationship between the plant root and *Rhizobium* bacteria occurs most readily on nutrient deficient soils. If soil nitrogen levels are artificially high, the formation of nodules on the plant roots is restricted (Hagin and Tucker 1982). Many *Eucalyptus* species have adapted to grow in soils of low phosphorus content (Fox *et al.* 1988). However, such species have nitrogen requirements which these arid soils do not provide (Crane 1978; Ellis *et al.* 1985). The establishment of *Acacia* and *Eucalyptus* species was favoured in the absence of a fertiliser application on the Westonia rehabilitation, because recently stripped topsoil was applied prior to seeding (Osborne 1995).

Suitable physical treatment of the compacted saline waste rock surfaces enhances gèrminant emergence by providing seed lodgement sites, and the establishment of seedlings through water harvesting. Spoil analysis prior to seeding in 1990, indicated dumps of waste rock at Westonia were typically saline, 4.2 (mildly saline)-37.9 dS m^{-1} (extremely saline) saturation extract (approximate equivalent 2,714-24,256 ppm salts in solution). Over the dump surfaces there were acidic to basic areas (pH range 4.9-9.2). The topsoil cover was non-saline (range 1.2 to 2.6 dS m^{-1} saturation extract, approximately 768-1,639 ppm salts in solution equivalent) (Osborne and Bouwhuis 1991).

Ecosystem recovery in semi-arid areas will be a slow process. Base-line information is necessary to establish whether direct seeding has been successful and the desired plant community is revegetating. Once there is an appropriate data base, comparison over time should be made, and predictions of longer term ecosystem development can be attempted.

Site preparations at Westonia

On all faces of the waste dump, Area C, angle of repose slopes were lowered to less than 20° and recontoured in early 1990. Topsoil was spread to a depth of 0.3-0.6 m and surfaces were ripped at 3 m intervals to a depth of 0.5-1 m.

Seeding at Westonia

The 10 ha surface of Area C was direct sown on 5 May 1990, as part of a larger, 40 ha, seeding operation. Co-ordinated by the senior author, seeding was performed manually by mine and local town and country persons. Seed was uniformly broadcast by pacing a pre-determined distance over which a weighed quantity was distributed. The majority of seed species were local to the eastern wheatbelt and the eastern goldfields of Western Australia. A suite of species was selected for Area C, as deemed appropriate from the sampled waste rock and soil attributes. Appropriate pre-treatment of the hard-seeded leguminous species was completed prior to broadcasting.

Over Area C, slopes were sown at a seed application rate of 5 kg ha^{-1} and the flat surfaces at 4.5 kg ha^{-1}. Trees, mallees and woody perennial shrubs including saltbushes and bluebushes were included in the mixtures for both slopes and upper surfaces. The flat upper surfaces of Area C were seeded at the species rates given in Table 1. Eucalypt seed sown at 600 g ha^{-1} comprised 13% of the total mixture by weight. Taller woody shrub and tree species made up 39% of the mixture. Chenopod seed made up the remainder (48%) by weight (2.2 kg ha^{-1}). The seed mixture included the prevalent local species, *Acacia acuminata, A hemiteles, Eucalyptus salubris, Pittosporum phylliraeoides* and *Enchylaena tomentosa* (Table 1).

A acuminata seed was placed in boiling water for 10 seconds, removed and dried prior to sowing. *A hemiteles, A nyssophylla* and *Cassia nemophila* seed was soaked for 60 seconds in boiling water, then dried. Pre-treatments of these hard-seeded leguminous species follow recommendations of Osborne *et al.* (1990) who identified the most successful pre-treatments for a number of species found in the area.

This paper details the successful establishment of tree and woody shrub species on a selected waste dump (known as Area C) at Westonia. Outcomes of seed broadcasting and subsequent eucalypt, shrub and perennial species establishment on the flat surfaces of this dump (Area C), rehabilitation age five years, are provided using data from the 50 m by 50 m block sampling. Revegetation has been evaluated, specifically in terms of the broadcast seed species.

Table 1. Seeded species, and seeding rates for the flat surfaces of Area C (approximately 4 ha) Westonia. a = *Acacia* spp. and *Cassia nemophila* seed heat treated.

Species	Life Form (common name)	Seeding Rate (g ha^{-1})
Trees or Mallees		
Eucalyptus loxophleba	tree (usually single-stem) 5-15 m (York gum)	100
Eucalyptus salubris	mallee (multi-stemmed) to 15 m (gimlet)	300
Eucalyptus sargentii	small tree to 8 m (salt river gum)	200
Melaleuca pauperiflora	shrub or tree 2-5 m (boree)	200
Pittosporum phylliraeoides	small tree to 6 m (native willow)	500
	TOTAL	**1,300**
Shrubs		
Acacia acuminata(a)	spindly shrub to 3-6 m (jam wattle)	200
Acacia hemiteles (a)	bushy shrub 1-3 m tall (tan wattle)	200
Acacia nyssophylla (a)	dense shrub to 3 m	180
Cassia nemophila (a)	shrub 1-3 m tall (desert cassia)	100
Dodonaea viscosa	upright shrub to 3 m (sticky hopbush)	300
Hakea multilineata	shrub to 4 m	62.4
	TOTAL	**1,042.4**
Salt and blue bushes		
Atriplex nummularia	perennial shrub 2-3 m (oldman saltbush)	800
Atriplex semibaccata	prostrate perennial herb to 1 m diam.	800
Maireana brevifolia	perennial shrub 1 m (small leaved bluebush)	500
Enchylaena tomentosa	perennial shrub to 1 m (ruby saltbush)	100
	TOTAL	**2,200**
	OVERALL	**4,542.4**

Particular attention is given to *Eucalyptus* and *Acacia* species, which have previously been difficult to establish on waste dumps in semi-arid regions. A comparison with adjacent woodland vegetation has been made

Methods

Revegetation sampling

The field vegetation assessment reported in this paper was conducted within a 50 m^2 block on the upper waste dump surface of Area C, between 28–30 April 1995, five years after sowing. Revegetation sampling employed a stratified random strategy, which is a combination of random sampling and systematic sampling (Mueller-Dombois and Ellenberg 1974; Kent and Coker 1992). The stratified random strategy considered the flat upper surface of Area C as a relatively homogeneous block. Within this block the commencement position of the assessment transects was randomly determined using random numbers (Zar 1984).

A field herbarium was prepared, and plant identifications follow the taxonomy of Green (1985; 1987). Plants were recorded in the field by 14 transects, each comprising 20 contiguous 2 m by 1 m quadrats. For each plant species the numbers present (*ie.* density) and percentage cover (*ie.* the percentage of the area covered by plants of each specie) were taken. Summaries of these data provide mean density values (numbers of plants per m^2), and a mean percentage cover for all species. A maximum height was recorded for each species within each quadrat.

An importance value index (IVI) with a maximum total of 300 (Mueller-Dombois and Ellenberg 1974); a Shannon-Wiener diversity index (H); and an evenness value (J) having a maximum value of 1 (indicating an even spread of individuals between species, Zar 1984; Magurran 1988), have been calculated for each transect (available on request from the senior author).

Soil sampling

Twenty-one soil samples were taken at 0.1 m depth from the 50 m by 50 m block in late April 1995. These were collected from each of the fourteen vegetation transects at 0 m, 10 m and 20 m points along the transect. Woodland soils were also sampled.

Soil samples were oven dried at 40°C for 48 hours (Rayment and Higginson 1992), passed through a 1.4 mm sieve and the resulting "soil" fraction was analysed for conductivity (EC_{1+5}) and pH using a 1:5 soil water extract. EC_{1+5} values were converted to a saturation extract conductivity (ECe). The EC_{1+5} conductivity reading is an estimate of the amount of soluble salts the soil contains, the value varying with "soil" texture because of differing moisture retention capacities. Readings are converted to saturation extract values (ECe) which range from a factor of six for a fine clay medium, to sixteen for a coarse sandy soil (George and Wren 1985). For the soil collected from the waste dump at Westonia a factor of eight was used (Osborne 1995).

Results and Discussion

Salinities over the 50 m by 50 m sampling area ranged from 2.8–30.5 dS m^{-1}, averaging 11.8 dS m^{-1} (s=13.60, n=21). The growth medium was alkaline (mean pH 8.1, s=0.26, n=21). Woodland soils were not saline (mean 3.4 dS m^{-1}, s=2.85, n=6), and were mildly acidic to neutral (pH 7.1, s=0.33, n=6), contrasting with the more alkaline waste dump soils.

Eucalypts and legumes (*eg*. acacias), important components of a functioning ecosystem, and a suite of chenopods resilient to grazing and protective of the soil surface, were sampled over the waste dump. Appropriate seed pre-treatments and the optimal late-autumn sowing time, combined to ensure successful revegetation. At age five years, revegetation plant density approximated 17,900 individuals ha^{-1} (introduced grasses excluded, see Table 2) with a surface cover of 17%.

Broadcast seed accounted for 77% (by number) of the revegetation (Table 2). Seeded perennial chenopods such as *Atriplex semibaccata*, *A nummularia*, *Enchylaena tomentosa* and *Maireana brevifolia* were prevalent over the dump (densities equivalent to 13,540 ha^{-1}) (Table 3). These species protect the surface soil, suppress dust and promote soil stabilisation. *Atriplex vesicaria* and *Maireana appressa* were consequential volunteer chenopods (1,340 and 590 ha^{-1} respectively) (Table 4). IVI's for these species were 12.4 and 3.8 respectively. Cover provided by introduced grass species (6%) was also protective of the dump surface.

Field germination indicated the perennial shrub *Atriplex semibaccata* (creeping saltbush) to be an economical ($80 kg^{-1}, 227 fruits g^{-1}), successful and useful, direct seeded species. Its almost prostrate or decumbent habit ensures good ground cover, protecting soil from erosive forces. From the 560 m^2 sampled over Area C of the dump, *A semibaccata* provided 16% of the total revegetation cover. On a saline area of the waste dump (ECe 105.8 dS m^{-1}), *A semibaccata* has continued through the fifth growing season, fruiting prolifically and reaching diameters of 1.5 m within two seasons (Osborne and Bouwhuis 1991; Osborne *et al.* 1993b). Testing of fresh cultivated fruits gave 92% germination at 20°C with a fast germination rate (3 mean days) and all seeds germinating within nine days (Osborne et al. 1993c). Laboratory testing showed germination will occur under elevated salinities with adequate moisture (Galea 1992).

Densities of *Atriplex nummularia* plants averaged 1,750 ha^{-1}, with average plant heights to 1.5 m. Fruiting was evident on this important revegetation species (mean IVI=48.2) and revegetation cover was 3% (19% of the total revegetation cover). *A nummularia* possesses a deep, robust root-system, which exploits a large soil volume.

Atriplex vesicaria was the most prominent volunteer species over the dumps now established to heights of 1.3 m. The unpalatability of some forms of *A vesicaria* to grazing animals is an additional favourable attribute for the longer term rehabilitation aims associated with waste rock dump stability and a self sustaining ecosystem. Harrington *et al.* (1990) comment that the most important role of perennial shrubs such as *A vesicaria* is as a stability element, preventing or reducing erosion.

Maireana brevifolia was the most important revegetation species (mean IVI=107.3). Another drought resistant perennial shrub, it is an early coloniser of disturbed lands (Cunningham *et al.* 1992), and on the Westonia dump density approximated 9,000 ha^{-1} with development of prolific fruitings. Plants were to 1 m in height, and provided 3% revegetation cover. Locally collected (30°44'S, 118°30'E) untreated *M brevifolia* seed gave 44% final germination within 14 days, with a relatively fast mean daily germination rate (four days). Recruitment from dump plants is occurring.

Eucalypts were present on the dumps (IVI=14.3) in densities equivalent to those recorded on the adjacent woodlands (Table 3). It was most encouraging to observe excellent growth where salinities were elevated (*eg*. range 1.7–15.8 dS m^{-1} at bases of

Table 2. Vegetation densities (broad plant groupings): waste dump (Area C) and adjacent woodland.

Plant Groups	Waste Dump (number ha^{-1})	Woodland (number ha^{-1})
Trees or Mallees	620	500
Shrubs	1,030	12,624
Chenopods	15,680	1,750
Annual	600	–
TOTAL	**17,930**	**14,874**
Seed Source	77%	–
Soil/Volunteer	23%	–

Table 3. Densities (ha^{-1}) of waste dump (Area C) seed species with densities of these species from the adjacent woodland sampling.

Species	Percent of mixture	Waste Dump (number ha^{-1})	Woodland (number ha^{-1})
Trees or Mallees			
Eucalyptus salubris and *E. loxophleba, E. sargentii*	13.2	580	-
Eucalyptus salubris	-	-	500
Melaleuca pauperiflora	4.4	20	–
Pittosporum phylliraeoides	11.0	20	–
	28.6	**620**	**500**
Shrubs			
Acacia acuminata	4.4	40	–
Acacia hemiteles	4.4	400	625
Acacia nyssophylla	4.0	40	–
Cassia nemophila	2.2	–	–
Dodonaea viscosa	6.6	190	–
Hakea multilineata	1.4	20	–
	23.0	**690**	**625**
Salt and blue bushes			
Atriplex nummularia	17.6	1,750	–
Atriplex semibaccata	17.6	2,640	–
Maireana brevifolia	11.0	8,860	–
Enchylaena tomentosa	2.2	290	–
	48.4	**13,540**	–

Table 4. Volunteer waste dump (Area C) species, and other woodland transect species with densities (ha^{-1}) provided (a from Mitchell and Wilcox 1994)

Species	Common Name a	Waste Dump (number ha^{-1})	Woodland (number ha^{-1})
Shrubs			
Acacia merrallii	Merrall's wattle	220	10,000
Eremophila decipiens	emu bush	20	625
Exocarpus aphyllus	leafless cherry	100	874
Grevillea acuaria	–	–	250
Santalum acuminatum	sweet quandong	–	375
		340	**12,124**
Chenopods			
Atriplex vesicaria	bladder saltbush	1,340	–
Maireana appressa	–	590	1,375
Rhagodia drummondii	lake-fringe rhagodia	40	375
Sclerolaena diacantha	grey copperburr	170	–
		2,040	**1,750**
Annual			
Olearia propinqua	daisy bush	600	–

Eucalyptus salubris). Bud collection and flower formation, already evident during this current growth season, will allow confirmation of species and thus accurate individual species counts.

Five of the six woody shrub species broadcast over these Westonia waste rock surfaces have established well, *ie. Acacia acuminata, A hemiteles, A nyssophylla, Dodonaea viscosa,* and *Hakea multilineata.* The overall density of these species was 690 plants ha^{-1}. In adjacent woodland transects the density of *A hemiteles* was 625 plants ha^{-1} equivalent. Over the waste dump *A hemiteles* averaged 400 plants ha^{-1} (IVI=7.6). The hard seeded leguminous species had not all germinated in the same season, as indicated by the range of plant and seedling heights for each species.

Acacia merrallii, an important component of the woodland vegetation (10,000 ha^{-1}), had volunteered onto the dump surfaces (220 ha^{-1}) and reached 0.5 m in height (IVI =4.5). From a nearby site (70 km due east of Westonia) seed collections gave germinations in the order of 66% when seeds were pre-treated by immersing in a water bath at 80°C for 30 seconds, then incubated in a constant temperature cabinet at 25°C. *A merrallii* seed was not available for the 1990 Westonia rehabilitation seeding. Remedial seeding should include this species, and local seed collections are underway.

Rehabilitation strategies that enhanced field establishment on saline rock materials at the Westonia site included the addition of a layer of topsoil, and ripping and harrowing of the topsoil and underlying rock materials. On saline waste rock materials at Kalgoorlie, Fletcher (1990) found deeper ripping (to 1 m) beneficial to establishment of acacias, with eucalypts assisted by the presence of ponding zones.

There has been limited systematic longer term collection of revegetation data from other semi-arid gold mine sites, thus comparison is confined to two sites where 2.5 year old revegetation was assessed. Comparisons between such sites must consider differences in seeding rates, waste rock materials, site preparation, species composition and seed quality, and rainfall patterns, temperatures and frost periods following seeding. Whilst recognising variation between sites, the following data provide an indication of the relative success of the Westonia waste rock revegetation:

1. Northern Goldfields, Western Australia (28°38'S, 122°24'E) - Rainfall averages 221 mm y^{1}, and it is a winter growing season. From seed broadcasting at 8.3 kg ha^{-1} in the absence of fertiliser on topsoil saline waste rock slopes, revegetation averaged 12,700 plants ha^{-1}. Low rainfall and higher than average temperatures were recorded during the preceding growing season and these saw densities decrease by 30% (Osborne and Brearley 1995b).

2. Gascoyne Region, Western Australia (25°08'S, 119°109'E) - At this mine site rainfall averages 237 mm y^{-1}, with a winter growing season. Seeding at 10 kg ha^{-1} with fertiliser (275 kg ha^{-1}) on topsoil-covered non-saline waste rock slopes gave plant densities equivalent to 16,100 ha^{-1}. Legumes (acacias and cassias) approximated 700 ha^{-1} (Osborne and Brearley 1994).

Conclusion

Initially the extensive cover of surface revegetation from the creeping saltbush *Atriplex semibaccata* stabilised the slopes of the waste rock dump (Area C) by minimising wind and water erosion, and air borne dust was suppressed. Broadcasting the seeds of salt tolerant plant varieties including *Atriplex* (saltbush), *Maireana* (bluebush), *Acacia* and *Eucalyptus* species has, over time, achieved revegetation cover from a suite of species on salt affected waste dumps. Indigenous revegetation species which are adapted to grow in low nutrient soils and persist through rainfall and temperature extremes, have dominated the revegetation.

A total of 22 species ranging from small annual shrubs to trees, were recorded over the 560 m^2 area sampled. The successful establishment of *Eucalyptus* and *Acacia* species to densities which reflect the surrounding woodland is encouraging in five year old waste dump rehabilitation. The Westonia dumps would now benefit from remedial seeding of locally collected (and pre-treated) *Acacia merrallii* seed.

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A COMPARISON OF KERNEL COMPOSITIONS OF SANDALWOOD (*SANTALUM SPICATUM*) SEEDS FROM DIFFERENT WESTERN AUSTRALIAN LOCATIONS.

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Abstract

Seed kernels of sandalwood (*Santalum spicatum*) gathered from a number of West Australian locations were analysed for proximate composition and fatty acid content and character. The kernels are typically very rich in a fixed oil (*ca.* 45-55%) and this oil is characterised by a high percentage of unusual acetylenic fatty acids such as ximenynic (34%) and stearolic (1%) acids. The deoiled seeds contain approximately 50% crude protein and are potentially a nutritionally rich food item. Proximate analysis of the seeds demonstrated little difference between them in the major nutritional categories, such as lipid, ash and protein. Analysis of the fatty acid profiles of the lipid fractions indicated statistically significant differences between some of the oils. Any changes due to centroid location of seed collection were not evident in predictable change in the fatty acid profiles, and therefore the observed differences were not considered to indicate different ecotypes of sandalwood. An inverse relationship has been demonstrated between the relative proportions of oleic and ximenynic acids in the fixed oil. It was speculated that this may originate from the biogenetic conversion of oleic acid to ximenynic acid.

Introduction

Sandalwood (*Santalum spicatum* RBr), a member of the Santalaceae family, is a parasitic shrub or tree characteristic of some vegetation zones distributed throughout most parts of southern Western Australia (Fox and Brand 1993). It has played an important part of the history, development and ecology of the region. The primary value of sandalwood, or Santalwood as it was known (Parry 1908), has been for its scented heartwood and the associated volatile oil, which is used in incense and was used in the treatment of gonorrhoea and other illnesses (Low 1990). Sandalwood bears significant numbers of a large fruit, which is a drupe, characterised by its firm brown mericarp (Barrett 1987). The seed has a hard shell and a large kernel which is typically very rich in a fixed oil (45-55%). This oil is characterised by containing a high percentage of unusual fatty acids such as ximenynic [I, sometimes called santalbic acid (*trans*-11-octadecen-9-ynoic acid), (34%)], and stearolic [II, octadec-9-ynoic acid, (1%)] acids occurring as triglycerides.

$$CH_3(CH_2)_5\text{-}CH{=}CH\text{-}C{\equiv}C\text{-}(CH_2)_7COOH$$

I

$$CH_3(CH_2)_7\text{-}C{\equiv}C\text{-}(CH_2)_7COOH$$

II

The kernels may be eaten (Barrett 1993) and have formed a valuable part of the traditional Aboriginal Australian diet (Low 1990), the food value being similar to other commercially available nuts (Isaacs 1987). Part of our current studies elsewhere is an investigation of the potential for toxicity after long term consumption. While there is no record of apparent harm through the consumption of the kernels, acetylenic fatty acids are potentially bioactive as enzyme inhibitors particularly in prostaglandin synthesis and fatty acid metabolism (Blain and Shearer 1965; Croft *et al.* 1987; Downing *et al.* 1972; Nugtem and Christ-Hazelhof 1987) and hence also have the potential to be used as therapeutic agents. The facts that macerated sandalwood kernels have been used by Aboriginal Australians as a topical application for skin lesions (Low 1990) and have been eaten to treat arthritis (Longmore 1987) may be part testimony to that action.

The biogenetic pathway for ximenynic and stearolic acids is presently unknown but may involve dehydrogenation of the corresponding saturated stearic acid or by a discrete separate mechanism arising from dehydrogenation of linoleic and/or oleic acids (Hilditch 1947; Kleinzeller 1948; Bu'Lock 1966). Some of the chemical aspects of the fixed oil have been studied by previous workers. For example, the ultraviolet absorption characteristics, infrared spectral analysis, and iodine, saponification and acetyl values, together with oxidation and reduction have been determined (Gunstone and Russell 1955).

This study sought to investigate the differences in proximate composition and fatty acid content and character of the kernels. Seeds had been collected from a number of locations in Western Australia as listed in Table 1, during the course of other studies (Brand 1993) and were provided for these analyses.

Table 1. Locations of sandalwood seed collection sites in Western Australia.

Location	Centroid			
	Latitude		Longitude	
Dryandra	32°	50'	117°	06'
Everade	25°	11'	125°	04'
Kalgoorlie	30°	45'	121°	28'
Koorda	30°	50'	117°	29'
Marvel Loch	31°	30'	119°	32'
Mt Wilkinson	26°	48'	120°	08'
Nanga	26°	15'	113°	49'
Norseman	32°	12'	121°	47'
Shell Beach	26°	12'	113°	46'

Methods

Several ripe seed samples were obtained from each of nine different locations (Table 1). Kernels were removed and crushed into small fragments using a pestle and mortar. Duplicate proximate analyses for moisture (loss on drying), lipid, ash (minerals), nitrogen (protein) and carbohydrate (by difference) were carried out for each sample.

Moisture was determined by drying 0.5-1.0 g samples of crushed kernel to constant weight at 105°C. Ash content was determined using the previously dried kernel samples by complete incineration in a silica crucible at a temperature not exceeding 450°C in a muffle furnace until completely free from carbon. The samples were cooled and weighed in the crucible to provide an ash value.

Lipid was determined as the total organic solvent extractive from approximately 0.2 g samples of dried seed kernel, accurately weighed, using cold hexane/isopropanol solvent [5 ml, (3:2)] in capped tubes. The reaction mixture was rotated in a vertical plane overnight and then centrifuged. The supernatant was removed by aspiration and replaced with a fresh volume (5 ml) of solvent. The combined extracts were passed through a small column of anhydrous sodium sulphate, the column washed with fresh solvent (2 ml), and the combined extracts evaporated in a tared tube at 60°C under a nitrogen stream.

Crude protein was calculated from Kjeldahl nitrogen using a Kjeltec Auto 1030 Analyzer; a conversion factor of 6.25 was used. The lipid fractions obtained during the proximate analysis were further analysed as their fatty acid methyl esters (FAMEs) using a rapid methylation/transmethylation method (Christie 1989). This method produces FAMEs as derivatives of both free and combined fatty acids. Hence an approximately 20 mg sample of the fixed oil, weighed accurately, was combined with toluene (2 ml), internal standard [1 ml hexane containing 1 mg C17:0 (margarinic acid)], and methanol containing 1% concentrated sulphuric acid (4 ml). The resulting mixture was heated in a capped tube at 50°C for 16 hours overnight. The reaction mixture was transferred to hexane solvent (20 ml), washed with water (2 x 20 ml), and dried over anhydrous sodium sulphate to yield a hexane solution of the FAMEs. The relative composition of the FAMEs was determined by gas chromatography of 1 µl volumes with mass selective detection using a DB23 column (J and W, 30 m x 0.25 mm i.d. x 0.25 µm film thickness) fitted to a Hewlett Packard (HP) #5890 Series II Gas Chromatograph (GC) with a HP #5971 series Mass Selective Detector. Helium at 25 kPa was used as carrier gas. The GC was programmed to run at an initial temperature of 50°C maintained for five minutes, then a temperature gradient rising at 5°C per minute to 240°C which was maintained for five minutes.

Identification of the individual FAMEs was carried out by mass spectral analysis of individual eluted peaks, comparison of mass spectra with the Wiley

Table 2. Mean values of proximate analysis of seed kernels from the different Western Australian locations. Same letters indicate samples which are not significantly different ($p<0.05$) using the Scheffe Test.

Location	Moisture %	Lipid %	Ash %	Protein%*	Carbohydrate%**
Dryandra	3.61 ab	52.33 a	1.83 a	18.13	24.10
Everade	4.15 a	48.43 a	1.73 a	20.23	25.46
Kalgoorlie	3.73 ab	44.40 a	1.86 a	23.38	26.63
Koorda	3.16 b	50.27 a	1.59 a	23.31	21.67
Marvel Loch	3.56 ab	52.65 a	1.64 a	22.43	19.72
Mt. Wilkinson	3.51 ab	52.87 a	2.00 a	24.66	16.96
Nanga	3.43 ab	51.36 a	1.84 a	20.84	22.53
Norseman	3.23 ab	54.55 a	1.96 a	19.32	21.24
Shell Beach	3.98 ab	49.17 a	1.95 a	25.21	19.69

* Determined as Kjeldahl N; conversion factor 6.25.

** Calculated by difference.

Table 3. Fatty acid composition of sandalwood seed oil from different Western Australian locations. Same letters indicate samples which are not significantly different ($p<0.05$) within a column, using the Scheffe Test.

Location	Fatty acid, relative percent occurrence							
	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3*	C18≡1**	XMY***
Dryandra	abc 4.36	b 0.63	bcd 2.73	a 58.74	ab 1.65	cd 2.73	bc 1.28	b 27.91
	(±) 0.19	0.09	0.07	1.24	0.10	0.25	0.01	1.22
Everade	abc 5.41	a 1.32	cd 2.47	ab 55.23	ab 1.47	d 2.41	dc 0.93	ab 30.51
	(±) 0.15	0.02	0.12	1.31	0.08	0.10	0.01	0.37
Kalgoorlie	abc 4.30	ab 0.79	a 3.29	ab 56.49	a 1.73	cd 2.92	dc 1.03	ab 28.79
	(±) 0.15	0.01	0.04	0.67	0.05	0.01	0.18	0.26
Koorda	ab 5.50	ab 0.86	e 1.83	ab 53.64	bc 1.41	abc 3.28	a 2.34	cb 31.66
	(±) 0.32	0.25	0.09	1.10	0.08	0.15	0.13	1.41
Marvel Loch	bc 3.97	ab 0.90	de 2.29	b 50.57	d 0.94	abc 3.16	d 0.82	a 37.27
	(±) 0.71	0.16	0.12	3.11	0.02	0.08	0.03	4.07
Mt. Wilkinson	c 3.9	b 0.6	e 1.9	b 50.78	ab 1.48	a 3.77	d 0.86	a 36.71
	(±) 0.10	0.03	0.10	0.04	0.04	0.13	0.04	0.14
Nanga	a 5.75	ab 0.85	abc 2.93	ab 55.47	d 1.09	bc 3.12	dc 0.90	ab 29.90
	(±) 0.40	0.18	0.00	0.72	0.01	0.06	0.04	1.20
Norseman	abc 5.16	b 0.55	ab 3.13	ab 54.17	cd 1.17	ab 3.67	b 1.53	ab 30.64
	(±) 0.04	0.02	0.06	2.07	0.01	0.04	0.05	2.02
Shell Beach	abc 4.67	ab 0.79	cd 2.44	ab 52.21	d 0.92	cd 3.01	d 0.86	ab 35.13
	(±) 0.11	0.02	0.19	0.60	0.03	0.11	0.05	0.81

* α - 9,12,15-Linolenic acid

** Stearolic acid

*** Ximenynic acid

electronic library data, determination of retention times relative to the C17:0 internal standard and by use of FAMEs synthesised from authentic samples of ximenynic and stearolic acids (Croft 1994).

Statistical analysis of results was carried out using SuperAnova[R] and the Scheffe's Test, where appropriate.

Results

The results of proximate analysis of Sandalwood kernels from several different West Australian locations are shown in Table 2. Analyses of moisture, lipid and ash were carried out on duplicate samples from each kernel, while nitrogen analysis to provide protein content was performed on single samples only due to sample size restrictions.

One-way analysis of variance was conducted on moisture, lipid and ash level results. Inspection showed that of the moisture results, the sample from Everade was significantly different from that of Koorda (p=0.0062). This conclusion arises partly because the Everade and Koorda results represent opposite outliers of the observed range of values, and may merely reflect different sample ages and storage conditions. Similar statistical treatment of the lipid and ash results showed that none were significantly different within their categories at the tested level ($p<0.05$). Protein results could not be tested using this procedure due to their derivation as single values. Overall inspection of the results shown in Table 2 suggest that the major proximate components showed no significant differences, and that in consequence there was little or no ecotypic variation in the samples.

The results of FAME analysis of the fixed oil of sandalwood kernels from several different West Australian locations are shown in Table 3. Inspection of the individual fatty acids (FA) using one-way analysis of variance demonstrates some significant differences between samples. Whether these differences have any real meaning could be a matter of some debate. However, examining each FA in turn, it can be seen that with regard to palmitic acid (C16:0; hexadecanoic), samples from Koorda and Nanga are significantly different from the other samples; the Nanga C16:0 content is significantly different from that of Mt Wilkinson and Marvel Loch.

The palmitoleic acid (C16:1; *cis*-9-hexadecenoic) contents are low and show few differences, however Norseman, Mt Wilkinson and Dryandra are significantly different from Everade.

The stearic acid (C18:0; octadecanoic acid) contents are also normally low. The main observation is that Koorda and Mt Wilkinson samples are significantly different to those from Shell Beach, Everade, Dryandra, Nanga, Norseman and Kalgoorlie. Oleic acid (C18:1n-9; *cis*-9-octadecenoic acid) is the major component in sandalwood seed oil occurring at about 54% average content. Marvel Loch and Mt Wilkinson representing the low value outlier of the range, are significantly different to that from Dryandra. The linoleic acid (C18:2n-6; *cis*-9, *cis*-12-octadecadienoic acid) content is low and with regard to the range extremes show significant differences between samples from Shell Beach, Marvel Loch and Nanga in comparison to those from Koorda, Everade, Mt Wilkinson, Dryandra and Kalgoorlie. *Alpha* linolenic acid (C18:3n-3; *cis*-9, *cis*-12, *cis*-15-octadecatrienoic acid) showed significant differences between Everade and the majority of the other samples, excluding Kalgoorlie, Dryandra and Shell Beach.

Finally with regard to the acetylenic stearolic and ximenynic acids, the Koorda stearolic acid (C18≡1) relative content is significantly different from the other samples, while Nanga, Everade, Kalgoorlie and Dryandra show significant similarity to each other. The second most abundant FA is ximenynic acid which occurs to about 32.5% over a range in the fixed oil. Dryandra, representing the low value outlier of the range, is significantly different from those from Mt Wilkinson and Marvel Loch which represent the highest values in the range.

One facet of the FA relative composition was the inverse relationship between the oleic and ximenynic acid contents of the fixed oil. A plot of oleic acid versus ximenynic acid content is shown in Figure 1, with associated polynomial regression analysis showing a correlation coefficient of $r = 0.9712$. It is interesting to speculate that this may indicate some causal relationship between these two fatty acids.

Discussion

Analysis of variance of the moisture, lipid and ash values for proximate analysis of sandal kernels has demonstrated little if any significant difference between the samples. Inspection of the protein values

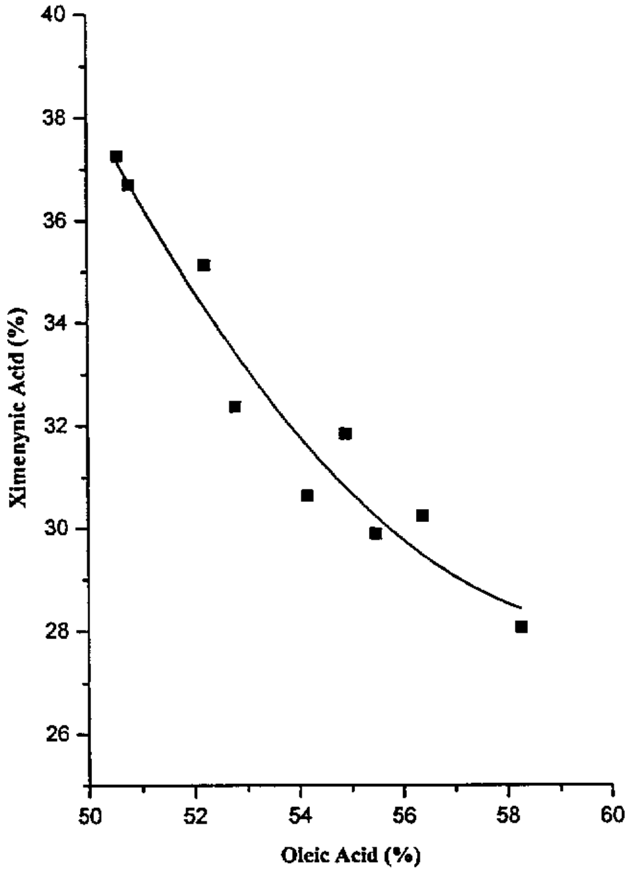

Figure 1. The relationship between oleic and ximenynic acids in sandalwood seed oil.

seems to be largely supportive of that conclusion. Thus the seeds from different Western Australian locations are similar in their general chemical makeup.

A more specific examination of the relative proportions of individual fatty acids again demonstrated some significant differences between samples. However, it should be expected that a lower level of a particular fatty acid will be compensated by a higher value or values elsewhere in the fatty acid profile. Bearing that in mind, the overall picture emerging indicates a lack of any distinctive pattern to the variation in fatty acid profile observed. Simple correlations, for example with particular regard to the most abundant acids, oleic (C18:1n-9) and ximenynic (XMY), occurring at an average of 54.14 and 32.06%, respectively, and constituting 86.2% of the whole, exhibit no particular comparative richness relatable to a geographic locality. Therefore, while the relative abundance of the fatty acids may vary, they may not be taken as indicators of a particular ecotype of sandalwood.

An inverse relationship between the relative concentrations of oleic and ximenynic acid was observed (Figure 1). The biogenetic origin of ximenynic acid is still unknown but this finding substantiates the suggestion that oleic acid could be the precursor of ximenynic acid (Bu'Lock 1966). Thus as the relative proportion of oleic acid falls, this may indicate takeup in the form of the new product ximenynic acid.

Unsaturated fatty acids normally arise by the introduction of double bonds into more saturated precursor acids (Garton 1992). Thus the action of 9-desaturase will introduce a single double bond into stearic acid (C18:0) at the 9,10 position to yield oleic acid (C18:1n-9). Linoleic acid (C18:2n-6) is biosynthesised in a reaction peculiar to plants rather than animals by the action of a 12-desaturase enzyme introducing a double bond at the 12,13 position. Further desaturation of linoleic acid will occur via 15-desaturase enzyme activity to yield α–linolenic acid (C18:3n-3). Thus the progress of desaturation occurs towards the C-methyl terminal end of the fatty acid molecule. Ximenynic acid (I) and stearolic acid (II) are evidence of the possibility of further desaturation at an existing double bond at C9,10. Indeed it has been speculated (Bu'Lock 1966) that stearolic acid may arise from oleic acid and is then converted to ximenynic acid by desaturation at C11,12. Bu'Lock states "the conversion of oleic acid into acetylenes literally replaces the usual conversion into linoleic acid" in plants such as the quandong (*Santalum acuminatum*) in which they found linoleic acid to be absent. However, other analyses (Jones 1994) have determined the presence of low concentrations of linoleic acid (1.3%) in quandong oil at levels similar to those of sandalwood seed oil. Both linoleic and stearolic acid are in low relative concentration in sandalwood (Table 3), with no indication of any apparent causal relationship to the concentration of ximenynic acid.

Finally, oleic acid is known to be a precursor of another acetylenic acid, crepenynic acid (*cis*-octadec-9-en-12-ynoic acid) in some plants (James 1969). Crepenynic acid was not detected in the course of these studies.

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A PRELIMINARY INVESTIGATION OF THE FLAVONOID COMPOUNDS FOUND IN FLORAL TISSUES OF *GELEZNOWIA VERRUCOSA* TURCZ (RUTACEAE)

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Abstract

Geleznowia verrucosa Turcz (Rutaceae), a purportedly monotypic genus, is endemic to the sand plain country of Western Australia. Recent field observations indicated at least two distinct plant forms occur but whether or not they represent different species requires further taxonomic evidence. Contributing to a suite of taxonomic criteria are flavonoid compounds. *Geleznowia* floral bracts are phenotypically bright yellow and invariant. A preliminary investigation using paper chromatography, however, has revealed some differences between populations in their composition of floral flavonoid compounds. Evidence of major differences in these compounds in two contrasting plant forms from two geographically isolated populations was corroborated by high performance liquid chromatography.

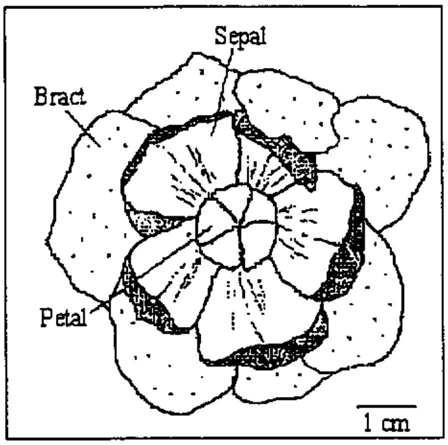

Figure 1. Unopened *G. verrucosa* flower.

Introduction

Geleznowia verrucosa Turcz. (Rutaceae), a purportedly monotypic species endemic to Western Australia, occurs on the sandplains of the Carnarvon, Irwin and Avon regions (Elliot and Jones 1986; Hnatiuk 1990). It is a small woody shrub with 2-3 bright yellow flowers clustered at the ends of branchlets, hidden by prominent yellow bracts which turn orange-brown with age (Fairall 1970; Elliot and Jones 1986) (Figure 1). In the wild, flower stems are regularly picked for the domestic and overseas cut-flower markets (Burgman and Hopper 1982). Over-exploitation in recent years, however, has brought about a rapid decline in this wildflower (Elliot and Jones 1986).

Three *Geleznowia* species-*G verrucosa, G macrocarpa* and *G calcina* were originally described by Bentham and Mueller (1863) and later authorities (Burbidge 1963). A revision of Western Australian Herbarium specimens for Green (1981) found no clear distinction between the species (Wilson 1994), and a monospecific status was adopted (Baines 1981; Armstrong 1983; Elliot and Jones 1986; Elliot 1990). Field observations, however, suggest at least two forms of *Geleznowia* exist - one which is relatively tall with straight upreaching branches, and the other which is smaller and highly branched. These two diverse forms may represent two different species, and thus the current monospecific status accorded to the genus is equivocal (Broadhurst 1993).

Classical systematics has traditionally relied upon morphological and anatomical differences to delineate taxa. Modern morphological analyses are now readily supplemented by biochemical techniques utilising molecules such as proteins, nucleic acids and secondary plant products (Martin 1985). Chemical variation in plants theoretically provides a useful suite of characters for taxonomic purposes (Smith 1978).

Flavonoids are a group of phenolic compounds structurally based upon flavone, a compound composed of two benzene rings joined by a three carbon link (Swain 1976b). Among chemical characters of taxonomic significance, flavonoids, particularly floral pigments, are arguably the most valuable of all secondary plant compounds due to their universal distribution in Angiospermae, great ease of detection and immense structural variation (Harborne 1973). Additionally, flavonoids do not actively influence cellular metabolism and variation is easy to expose.

The aim of this preliminary investigation was to obtain a qualitative profile of flavonoid compounds present in *G verrucosa* bract and sepal tissues, and to determine whether there is variation within and between populations for these compounds. Such variation may have taxonomic significance for any 're-examination of the genus' monotypic status.

Materials and Methods

Ten plants from study sites located at Red Bluff (one population) and Meanarra Hill (two populations) near Kalbarri, Ajana West (one population), Hutt River Province (one population), Spalding Park near Geraldton (one population) and Arinya near Dowerin (two populations) were randomly selected and floral samples collected during July, August and September 1993 as flowering occurred and transported to the laboratory where they were oven-dried at 33°C for four days.

The sites from which the samples were collected are shown in Figure 2.

Non-hydrolysed extracts

Approx 0.50 g of dried bract and sepal tissues from each plant was ground in 5 ml of acidified methanol (1% HCl v/v) and a small quantity of acid-washed sand. These quantities were halved for the smaller flowers of both Arinya populations. Lipids, chlorophylls and carotenoids were removed by agitating the extract with an equal volume of petroleum ether against a vibrating Thermolyne mixer (Type 37600). The lower methanolic fraction was removed and stored at −12°C.

Hydrolysed extracts

To remove sugar moieties from glycosidic flavonoids similar quantities of material, as described for non-hydrolysed extracts, were heated in 5 ml of 2M HCl in a water bath at 100°C for one hour. After cooling, the decanted hydrolysed extracts were stored at −12°C. The unstable nature of these extracts necessitated chromatograms be run within 24 hours of extraction.

Descending Paper Chromatography (PC)

Extracts were repeatedly spotted on 100 x 230 mm chromatography paper (Whatmans No. 3), and run (descending) for three hours in acetic acid:HCl:water (30:3:10) ('Forestal'). The chromatogram for each extract was duplicated in a concurrent run to avoid difficulties associated with reproducability of runs associated with this type of chromatography. The solvent front was marked and after drying the outline of each pigment was traced with a pencil. The pigments colour(s) in both natural and long wavelength ultra-violet (280 nm) were noted. The paper chromatograms were then fumed in concentrated ammonia and visualised under UV light for colour changes and new pigment spots. The R_f values of individual pigment spots were determined by dividing the distance to the middle of each flavonoid spot by the distance travelled by the solvent front. Comparison of colour changes and R_f values with published data enabled tentative identification of major flavonoid groups.

High Performance Liquid Chromatography (HPLC)

Four non-hydrolysed and hydrolysed extracts from Arinya 1 and Red Bluff populations were randomly selected and analysed using HPLC. Each extract was filtered through a 5 μm Millex (Millipore) membrane filter. A 20 μl filtrate of each sample was partitioned in a 3.9x300 mm *u*Bondapack C-18 reverse phase column with a solvent mixture of methanol:water:acetic acid (50:50:1 v/v) flowing at 1.379×10^4 kPa at a flow rate of 1.5 ml min^{-1}. The eluted compounds were detected at 230 nm (Waters 484-MS detector) and their retention times determined and quantitated (Hewlett Packard 3396A Series II integrator).

Results

PC-Non-hydrolysed extracts

Three or four compounds were separated from the non-hydrolysed extracts. The first compound was a pink pigment but comparison with hydrolysed extracts suggested it was a blend of three pigments, which were probably anthocyanins. The second compound was a more discrete, yellow pigment, which appeared brownish when visualised in UV light both before and after fuming with ammonia. Comparisons with published data (Mabry *et al.* 1970; Swain 1976a; Markham 1982) indicated this was either a flavone or flavonol. The third compound, which was not visible in normal light, appeared

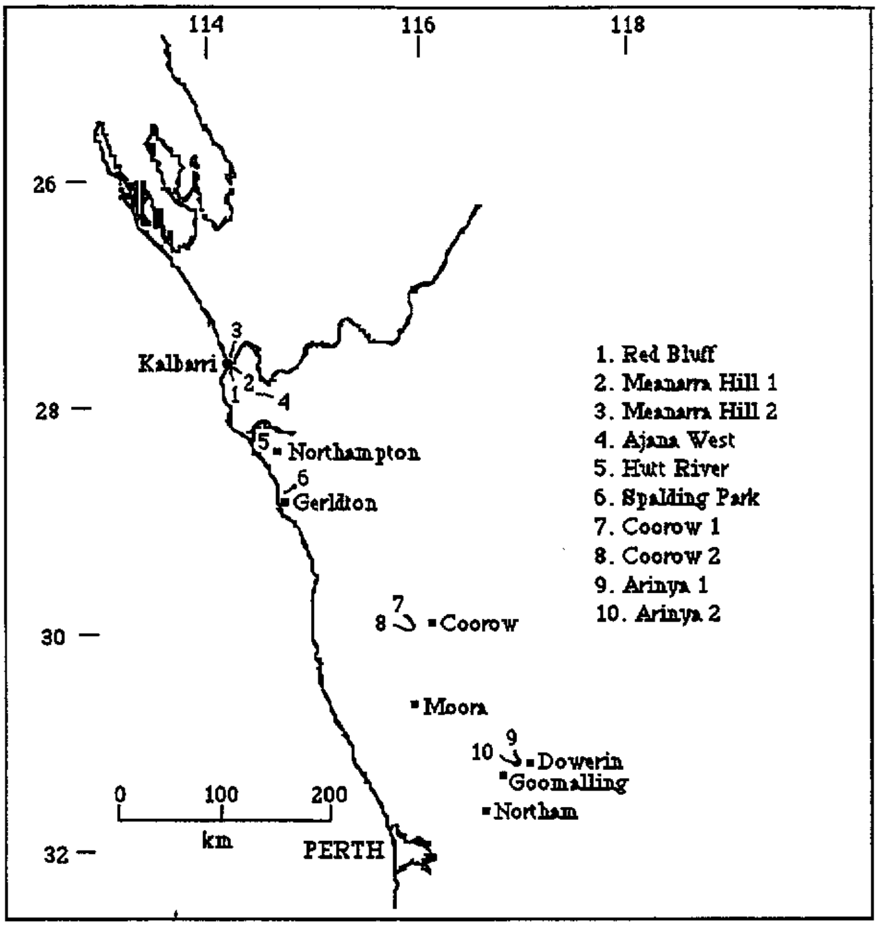

Figure 2. Location of field study sites.

fluorescent blue under UV light and bright yellow-green following fuming, suggesting that it was either a flavone/flavanone lacking a free 5-OH or a flavonol lacking a free 5-OH but with a 3-OH substituted. Published R_f values suggested it was a flavone but no comparative data for flavanones developed in Forestal was available. This pigment was difficult to detect in Meanarra Hill 2 samples. Following fuming a fourth compound became visible on chromatograms from Red Bluff, Meanarra Hill 1 and Spalding Park. It was fluorescent blue under UV light both before and after fuming, indicating that it was probably an isoflavone lacking a free 5-OH.

The average R_f values for each pigment or compound, apart from R_f1 which was poorly resolved, are summarised in Table 1. The R_f values for resolved compounds were similar across all populations.

PC-hydrolysed extracts

The hydrolysed extracts partitioned on PC to reveal three pigments and two other flavonoid compounds. The first compound was a pigment, which appeared pink both in white and UV light. It turned blue following fuming, indicating that it was an anthocyanidin, although its R_f value did not correspond with that of any anthocyanidin in published data. The next pigment was orange-pink in white light as well as in UV light, and yellow following fuming indicating that it was a flavonol. The third pigment behaved similarly to the first, although its higher R_f was closer to that of published anthocyanidin values. The fourth compound, which was not visible in white light, fluoresced blue in UVlight, and yellow-green following fuming. It was probably a flavanone or flavone lacking a free 5-OH, or flavonol lacking a free 5-OH but with the 3-OH substituted. A fifth compound was discernible only after fuming. Like the fourth compound it was fluorescent pale blue under UV light but remained unchanged after fuming, suggesting that it was probably an isoflavone lacking a free 5-OH. This could not be confirmed with published R_f values. The average R_f value for each of the five resolved compounds from the hydrolysed extracts is summarised Table 2. The values were similar across the eight populations.

HPLC-Non-hydrolysed extracts

HPLC non-hydrolysed extracts revealed up to twelve flavonoid compounds in Red Bluff samples and thirteen in Arinya 1; these are summarised in Table 3. Five flavonoids had retention times common to both populations - 1.48-1.79, 3.59-3.72, 4.00-4.13, 4.73-4.87 and 5.42-5.59 min with two others (2.80-2.87 and 3.31-3.72 min) possibly also common.

Some variation within populations was observed. Of the thirteen flavonoid compounds discernible in Arinya 1 samples, eight were common to all samples, with possibly one other as well (10.86-11.74 min). Four flavonoids did not occur across all Arinya samples, two were unique to to plant 4 (0.22 and 9.31 min), one unique to plant 12 (1.12 min) with the remaining compound (8.24 min) shared by plants 4 and 20. Of the twelve flavonoid compounds in Red Bluff samples, six were common to all samples and possibly three others as well (0.47-0.58,

Table 1. Average R_f values for non-hydrolysed compounds of *G verrucosa* from eight sites run in Forestal solvent (-=R_f not determined; ?=difficult to determine or missing).

Location	R_f1	R_f2	R_f3	R_f4
Red Bluff	-	0.73	0.84	0.92
Meanarra 1	-	0.71	0.85	0.94
Meanarra 2	-	0.72	?	0.95
Ajana West	-	0.72	0.83	?
Hutt River	-	0.71	0.83	?
Spalding Pk	-	0.72	0.83	0.91
Arinya 1	-	0.70	0.86	?
Arinya 2	-	0.70	0.87	?
Possible Flavonoid		Flavone/ Flavonol	Flavone/ Flavanone/ Flavonol	Isoflavone

Table 2. Average R_f values for resolved hydrolysed extracts of *G verrucosa* from eight sites run in Forestal solvent.

Location	R_f1	R_f2	R_f3	R_f4	R_f5
Hutt River	0.27	0.36	0.44	0.76	0.84
Ajana West	0.28	0.37	0.46	0.76	0.85
Red Bluff	0.28	0.37	0.46	0.71	0.81
Meanarra 1	0.28	0.37	0.47	0.74	0.83
Meanarra 2	0.30	0.39	0.48	0.75	0.86
Spalding Pk	0.29	0.38	0.46	0.75	0.84
Arinya 1	0.28	0.38	0.47	0.76	0.85
Arinya 2	0.27	0.38	0.48	0.77	0.85
Possible Flavonoid	Anthocyanidin	Flavonol	Anthocyanidin	Flavone/ Flavanone/ Flavonol	Isoflavone

Table 3. HPLC retention times (min) of non-hydrolysed extracts run in methanol:water:acetic acid (50:50:1) solvent (A=Arinya 1, R=Red Bluff; number indicates plant number; bold type indicates not common to both populations).

A4	A9	A12	A20	R1	R4	R9	R15
0.22	-	-	-	0.47	0.57	0.58	-
-	-	1.12	-	-	-	-	-
1.61	1.71	1.73	1.69	1.79	1.59	1.51	1.48
2.81	2.87	2.80	2.81	-	2.81	2.80	2.80
3.32	3.37	3.32	3.31	-	3.33	3.31	3.29
3.66	3.72	3.66	3.65	3.59	3.65	3.62	3.61
4.07	4.13	4.08	4.06	4.00	4.08	4.04	4.00
4.76	4.87	4.78	4.73	4.78	4.84	4.81	4.80
5.45	5.59	5.51	5.47	5.38	5.51	5.46	5.42
-	-	-	-	6.38	6.62	6.54	6.38
7.17	**7.36**	**7.20**	**7.13**	-	-	-	-
8.24	-	-	8.24	-	8.28	-	-
9.31	-	-	-	-	-	-	-
-	11.74	10.86	11.60	11.42	11.74	-	-
-	-	-	-	-	**13.45**	**13.34**	-

Table 4. HPLC retention times (min) of hydrolysed extracts run in methanol:water:acetic acid (50:50:1) solvent (A=Arinya 1, R=Red Bluff; number indicates plant number; bold type indicates compounds not common to both populations).

A4	A9	A12	A20	R1	R4	R9	R15
-	-	-	-	-	1.13	-	-
-	1.71	1.74	-	-	-	-	-
1.96	1.98	1.96	1.96	1.94	1.96	1.96	1.96
2.26	2.26	2.26	2.26	-	2.25	2.25	2.25
2.53	-	2.53	-	2.55	2.52	2.52	2.52
2.72	2.72	2.72	2.72	2.73	2.71	2.72	2.75
3.34	3.35	3.34	3.34	3.32	3.32	3.31	3.32
4.56	4.46	4.57	4.55	4.54	4.54	4.53	4.54
5.09	5.10	5.10	5.07	-	5.08	-	-
5.99	6.01	6.02	5.97	-	5.86	-	-
-	-	6.85	-	-	-	-	-
7.35	**7.06**	**7.39**	**7.38**	-	-	-	-
8.06	8.09	8.07	7.99	7.94	8.00	8.00	8.00

2.80-2.81 and 3.29-3.33 min). Plant 4 had one unique compound (8.28 min) while plants 1 and 4 (11.42-11.74 min) and plants 4 and 9 (13.34-13.45 min) also shared compounds not found in the other samples.

Although variation between populations was minimal, some differences were noted. A flavonoid compound eluted from Red Bluff samples at 6.38-6.62 min did not correspond with any flavonoid in Arinya 1 samples. The latter samples eluted a flavonoid at 7.13-7.33 min, which did not correspond with any of the flavonoid components in Red Bluff samples.

HPLC-hydrolysed extracts

HPLC hydrolysed extracts revealed up to 10 flavonoid compounds in Red Bluff extracts and twelve in Arinya 1; the results are summarised in Table 4. Five of these (1.94-1.98, 2.71-2.75, 3.31-3.35, 4.46-4.57 and 7.94-8.09 min) were common to both populations. Two others (2.25-2.26 and 2.52-2.55 min) are possibly common to both populations.

Again little variation was found within populations. Of the twelve flavonoid compounds eluted in Arinya 1 samples, nine were common. Plants 9 and 12 (1.71-1.74 min) and plants 4 and 12 (2.53 min) shared flavonoids not found in other samples while plant 4 had a unique flavonoid at 6.85 min. Of the ten different flavonoids eluted in Red Bluff samples, six were common, and possibly one other as well (2.25 min). Plant 4 again contained unique flavonoids at 1.13, 5.08 and 5.86 minutes.

The major difference between populations was a flavonoid at 7.06-7.39 min in Arinya 1 extracts which did not correspond to any flavonoid with a similar retention time in the Red Bluff extracts.

Discussion

Chemical variation within plant taxa can provide useful information for chemotaxonomists. Of all secondary compounds presently utilised for taxonomic identification, flavonoids are used most widely (Asen 1979) especially since they are universally distributed, easily detected and structurally diverse (Harborne 1973). Paper chromatography is a simple technique for *initial* flavonoid comparison (Hrazdina 1982). Although only limited separation of flavonoids is achieved, it provides a means of visually identifying compounds, particularly pigments such as anthocyanins and flavonols, through colour changes which broadly categorise resolved compounds. Visualised compounds can also be directly compared to each other.

The non-hydrolysed extracts of *G verrucosa* bracts and sepals probably consist of a group of unresolved anthocyanins with similar R_f values; a flavone or flavonol; a flavone, flavanone or flavonol; and an isoflavone. Hydrolysed extracts appeared to yield two anthocyanidins, a flavonol, a flavone/flavanone/flavonol and an isoflavone. Whilst removal of the sugar moieties by acid hydrolysis resulted in clearer separation and definition, comparison of both non-hydrolysed and hydrolysed extracts within and between *Geleznowia* extracts indicated little variation. A fourth compound in non-hydrolysed extracts and which occurred only in some populations may be significant, but further analysis is required.

In comparison with paper chromatography, HPLC revealed many more flavonoids. Clearly HPLC is a much more sensitive technique for analysing flavonoid composition. Some of the advantages of HPLC such as the use of small samples and rapid analysis to yield both qualitative and quantitative data were evident during this study. In the absence of authentic flavonoid standards, HPLC does not allow for broad identification of eluted compounds into their generic groups (*eg* anthocyanins, flavones, flavonols *etc*).

The age of Red Bluff hydrolysed extracts may have resulted in some of the anomalies noted. Although extracts were kept in the cold and dark, their instability may have resulted in some degradation. Similar but non-hydrolysed extracts are less prone to degradation. This stability is apparently confirmed by the sugar residues.

The finding of apparently unique retention times in the HPLC analysis is significant; it has revealed cryptic differences between plants from the two populations. This preliminary data justifies further analysis of more samples from different populations; fresh floral samples should be used in view of the instability of hydrolysed extracts. Although qualitative differences are perhaps the best indicators of taxonomic boundaries, particularly at the varietal level, quantitative differences may also prove useful (Hong and Wrolstad 1990). Quantitative data was not utilised in the present study but they may be an important adjunct for distinguishing between *Geleznowia* populations.

The present chromatographic investigation, which has indicated the presence of up to fifteen flavonoid compounds in the floral tissues of *Geleznowia*, has laid the foundation for further research in this area. Although compositional differences between populations has been clearly demonstrated in the present study, it is suggested that HPLC analysis should be extended to include more populations, to establish the extent of this variation within the genus. Secondly, in order to identify specific flavonoid compounds, comparisons with authentic flavonoid standards needs to be undertaken. Some of these standards are commercially available while common flavonoids can be extracted from known floral sources (Harborne 1982). However, Australian species possess some unusual and diverse floral characteristics and comparisons with data compiled on European species and standards extracted from such sources may or may not be relevant. It is conceivable that investigations into Australian floral flavonoids may indicate variation and/or compounds not found in species studied to date.

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REVIEW OF THE ECOLOGICAL CHARACTERISTICS OF *ACACIA ACUMINATA* BENTH

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Abstract

This paper is a review of available information regarding the biology, ecology and uses of *Acacia acuminata.* The species is endemic to the south-west of Western Australia, mainly in low semi-arid woodland communities. It is a shrub or small tree with a spreading crown, grey branches and narrow, bright green phyllodes. It bears yellow spike-like flower heads in winter and spring, followed by brown pendulous seed pods in early summer. *A acuminata* is considered poor for erosion control and rehabilitation programs. The tree has little economic importance although the phyllodes have some fodder value and the wood is used for fencing and craft work.

Introduction

Acacia acuminata is a shrub or small tree occurring naturally in the south-west of Western Australia (Bentham 1863-1867). The species, being of little importance in erosion control and rehabilitation programs, and having little economic value, has not been studied extensively.

Botanic classification:- class: Magnoliopsida; subclass: Magnoliidae; order: Fabales; family: Mimosaceae; division Phyllodinae; section: Juliflorae; subsection: Falcate. (Tindale and Roux 1969; Marchant *et al.* 1987).

Reclassification:- *A acuminata* and *A burkittii* have in the past been referred to as separate species. When the imminent name change (Maslin 1995) becomes effective *A burkittii* will be a subspecies of *A acuminata.* This article is concerned with *A acuminata* although reference is made to *A burkittii* either as a species in its own right or as a subspecies of *A acuminata,* depending on the nomenclature used by the authorities quoted.

Common names:- Raspberry Jam, Jam Wattle, Jam.

Morphology

Acacia acuminata commonly grows as a large, bushy shrub or small tree, usually 3-6 m tall with a wide spreading crown. The main stem is short with fissured and cracked bark at the base. The trunk divides, generally about 1 m from the ground, into numerous smaller, usually glabrous, grey branches. Young shoots are usually sericeous but may be strigose, the hairs being golden coloured. On favourable sites the species may reach 8-12 m with an undivided trunk, 2-2.5 m in length (Choularton 1995; Marchant *et al.* 1987; Simmons 1981; Hall and Turnbull 1976).

Stipules are caducous and scarious. Phyllodes are linear being 65-250 mm long x 5 mm wide (Hall and Turnbull 1976), or 70-150 mm long x 1-5 mm wide in the Perth region (Marchant *et al.* 1987) and length can vary even on adjacent trees. Phyllodes are sometimes falcate, narrowed at both ends, tapering at the apex into a long curved (but not sharp) tip and at the base into a curved stalk. They are bright green, glabrous or minutely strigose and have orange pulvinuses. Upper phyllode margins are normally fringed with dense, short, white hairs. The numerous veins are fine and longitudinally parallel, with the central midrib slightly more prominent (Hall and Turnbull 1976; Simmons 1981).

Flowers form fragrant, brilliant yellow, cylindrical spikes from 13-25 mm long x 6-7 mm broad (Hall and Turnbull 1976) or 12-25mm long x 3-4 mm broad (Marchant *et al.* 1987). Spikes may be sessile or have very short stalks and are borne singly or in pairs in the axils of leaves. There are numerous flowers per spike head and each is usually 4-merous. Corolla lobes are glabrous. The calyx is deeply lobed and hirsute, sometimes separating into distinct ciliate sepals, which bear yellowish hairs. Stamens are yellow. Seeds ripen from October to December

(Marchant *et al.* 1987; Mitchell 1995; Simmons 1981). The leguminous fruit is pendulous, light brown and glabrous. Pods are almost flat, linear or slightly curved with slightly thickened margins. They are narrow - approximately 50 mm long and 5 mm wide (Hall and Turnbull 1976) or 125 mm long and between 2.5-7 mm wide (Marchant *et al.* 1987). There are slight constrictions between the seeds.

Seeds are ovoids or ellipsoids lying longitudinally in the legume. They are more or less flattened, 3-6 mm long and 2-4 mm wide (Hall and Turnbull 1976) or 2.5-4 mm long and 2-3 mm wide (Marchant *et al.* 1987), dark brown to black and often shiny. The areole is distinct and the pleurogram discontinuous. The funicle thickens into a 2-3 mm long, fleshy aril, pale yellow to brown in colour and folded 2-3 times.

Distribution

Acacia acuminata occurs in the south-west of Western Australia, commonly in Irwin, Avon, Darling, Eyre, Austin and Coolgardie botanical districts (Beard 1981; Simmons 1981). It is very common in a belt from 50-300 km inland roughly paralleling the coast. The belt commences in the Murchison, about 300 km north of Geraldton (26°S), runs south to 34°30'S (in the region of Salmon Gums and Ravensthorpe) and east as far as the Kalgoorlie area and the Great Australian Bight. The northern and eastern limits are not easy to define because of the difficulty of separating *A acuminata* from *A burkittii*. It is not found in coastal areas between Perth and Albany. It has been recorded close to the north east boundary of the Perth region (Chittering) (Marchant *et al.* 1987; Hall and Turnbull 1976).

A survey of 846 inventory sites in the Sandstone-Yalgoo-Paynes Find rangeland area showed that *A acuminata* subsp. *burkittii* occurred in 332 sites, whereas *A acuminata* occurred at 32 sites and was dominant at 10 of them (Van Vreeswyk 1995). *A acuminata* is commonly dominant in the south of the surveyed area with other species of *Acacia* dominating more northern habitats and particular niches. *A acuminata* subsp. *burkittii* occurred throughout the survey area but *A acuminata* was restricted to the south west and southern edges of the survey area. Both *A acuminata* subsp. *burkittii and A acuminata* occurred together in a few sites. *A acuminata* occurred in the South Western Botanical Province on the west and south-west of the survey area and in the Southwestern Interzone in the south east of the survey area. Where this species occurs in the Eremaean Botanical Province it is always near the edges of the South-Western province or the Southwestern Interzone (Van Vreeswyk 1995). In the north-eastern Goldfields survey (Pringle *et al.* 1994) *A acuminata* was not recorded in any of the 742 inventory sites whereas *A acuminata* subsp. *burkittii* was recorded at 68 sites.

It grows from near sea level to about 375 m in altitude with the main occurrence being between 125-325 m (Hall and Turnbull 1976).

Habitat

Climatic and topographical limitations

Acacia acuminata attains its greatest development in the narrow sub-humid climatic zone. Prior to farming incursion it was common in the higher rainfall parts of the adjacent semi-arid zone but less plentiful in the rest of the semi-arid zone. It has not been noted in the arid zone, and from Kalgoorlie eastwards *A burkittii* is present. Summer temperatures are generally high where *A acuminata* grows. The mean maximum for the hottest month (January or February) is 32-34°C but in the northern inland areas, for example Mullewa, it rises to 36°C. The mean minimum for the coolest month (June or July) is 4.5-6.5°C. Frosts occur between one and five times a year except in near-coast situations which are frost free (Hall and Turnbull 1976).

The mean annual rainfall range for the species is 225-600 mm but in the area of optimum development rainfall is 350-450 mm. Growth is moderate in the 300-350 mm rainfall zone and excellent where rainfall is higher (Newbey 1982). In the main areas where *A acuminata* grows there is a well developed winter rainfall maximum between May and September. Average precipitation for the driest months may be as low as 6-8 mm. In the lower rainfall areas, for example Kalgoorlie, there is a moderate winter maximum but a much higher variability. Average monthly rainfall figures are rather deceptive along the northern and north-western parts of the occurrence, since cyclones which strike the west coast from Port Hedland to Onslow (around 20°S) may carry heavy rain further south than Geraldton and inland past Kalgoorlie. In summer, some places between Perth and Kalgoorlie typically have monthly rainfall averages of 10-15 mm, although this is exceeded on occasions when 20-50 mm of rain may fall in a few days (Hall and Turnbull 1976).

The topography in areas where *A acuminata* grows is mainly gently undulating or at times flat. Sometimes the species grows near the banks of intermittent streams or extends into pockets of soil among granitic outcrops (Hall and Turnbull 1976). It often grows along roadsides and in cleared and partly cleared lands.

Substrates

Soils on which *A acuminata* grows are often lateritic gravels or red-brown earths common in the drier parts but they encompass a wide range, from pale brown and darker clays on flats to red sands and granitic gravels. They may be duplex or uniform. It does not occur on coastal dunes (Lefroy *et al.* 1991; Newbey 1982). When planted in Australia, notably in the south-east, it grows best on moderately fertile loams. In common with other acacias it can colonise N and P deficient soils because of the synergistic effect of two symbionts, *Rhizobium* spp. and root inhabiting mycorrhizal fungi (Cavanagh 1985).

Communities

Acacia acuminata attains its best development in low semi-arid woodland formation, the original vegetation in what is now prime wheat/sheep country of Western Australia. It extends however, to areas of mixed low arid woodland and semi-arid mallee communities. Its distribution in the wheatbelt coincides closely with that of *Eucalyptus loxophloeba* (York gum). Soils are shallow, brown sandy loam (usually <300 mm thick), over shallow, sandy clay over granite and often occurring near granite outcrops. The surface soils are neutral to alkaline. They are relatively fertile and much of this land has been cleared for farming. Run off from the outcrops causes water erosion. Flat sites may be prone to long duration waterlogging. *Acacia microbotrya* (manna gum), *Allocasuarina campestris* (tamma), *A huegeliana* (rock oak), *Calothamnus gilesii* (claw flower), *Hakea recurva*, *Kunzea pulchella* (granite kunzea), *Leptospermum erubescens* (tea tree) and *Melaleuca uncinata* (broombush) are often found in association with *A acuminata* in these areas (Lefroy *et al.* 1991; Beadle 1981). *A acuminata* is present at the majority of wheatbelt sites where *Santalum spicatum* grows (Casson 1992).

In the south-eastern area the distribution of *A acuminata* overlaps that of *E wandoo* (wandoo/white gum) and *E capillosa* (inland wandoo) and is often found on the slopes below breakaways marking the eroded edge of the uplands. The soils are typically grey sand over grey, sandy clay over deep, white, kaolinitic clay. They are shallow and sloping and prone to considerable runoff and erosion: sometimes they are stripped almost down to the white kaolinite subsoil. *Acacia hemiteles* (tan wattle), *A merrallii* (Merrall's wattle), *Allocasuarina campestris* (tamma), *Cassia nemophila* (desert cassia), *E subangusta* (black marlock) and *Melaleuca uncinata* can occur in this association (Lefroy *et al.* 1991; Beadle 1981).

Towards the northern, drier areas of its occurrence in the southern Goldfields rangeland area, there are many mallees or small *Eucalyptus* trees, for example, the rough barked mallee, *E corrugata*. Numerous other species of *Acacia*, notably mulga (*A aneura*), grow in association with *A acuminata*, in the hotter northern fringe and the drier north-western area. Amongst shrubs of other genera are *Duboisia hopwoodii*, *Casuarina* spp. and *Pittosporum* spp. (Lefroy *et al.* 1991; Beadle 1981).

In a Sandstone-Yalgoo-Paynes Find rangeland survey (Van Vreeswyk 1995), acacias were found to dominate the overwhelming majority of tall shrublands (dominated by shrubs greater than 2 m tall). *A acuminata* is often found with *Callitris columellaris* (native pine) and/or *Eucalyptus* species. It is a component of the *C columellaris* woodland/*Acacia* tall shrubland association, which is common in the south and west of the survey area. Other *Acacia* species occurring with *A acuminata* in this association are *A ramulosa*, *A aneura* and *A acuminata* subsp. *burkittii*. The hardpan plains which, in the Eremean Botanical Province are characteristically dominated by *A aneura*, are frequently dominated by other acacias such as *A acuminata* subsp. *burkittii*, *A grasbyi* (mini-richie) or *A ramulosa* (bowgada) in the south and west of the survey area (Van Vreeswyk 1995). Other commonly conspicuous tall shrub species are *A tetragonophylla* (curara) on hardpan plains and drainage tracts, *A coolgardiensis* (sugar brother) on sandplains, *A masliniana* (spiny snakewood) (which occurs with chenopods) on alluvial plains, and *Melaleuca uncinata* around granite outcrops and on sandplains.

The sites where *A acuminata* occurs in the Sandstone-Yalgoo-Paynes Find area, mostly have sandplain soils (deep red earthy sands) or are shallow red loamy soils on granite or gravel. *A* *acuminata* subsp. *burkittii* is thought to favour areas with calcrete but is also common on stony, shallow soils on greenstone (metamorphic rock) hills and on loamy soils on red-brown hardpan (in association with *A aneura*) (Van Vreeswyk 1995).

A acuminata is considered to be moderately tolerant to salt and lime and has been successfully planted on mildly acidic (pH 6.5), neutral and calcareous soils (Hall and Turnbull 1976; Mitchell 1995).

Response to environment

Acacia acuminata is generally considered a fast growing species (Simmons 1981). Availability of the species from native plant nurseries and the Forests Department of Western Australia (now Department of Conservation and Land Management) has been good (Newbey 1982).

A survey by Langkamp and Plaisted (1985) found that *A acuminata* has not been used as a species in mining rehabilitation in Australia.

Selection of species for trials is made by matching soil and climatic conditions at natural and introduced sites. Only a few Australian acacias have been widely tested outside Australia. *A acuminata* has shown promise in some north African trials and in Iran (Hall and Turnbull 1976). It has not been used in planting programs in Algeria, China, Fiji, Hawaii, Malaysia (peninsular Malaysia and Sabbah), Morocco, Papua New Guinea, Tanzania and Thailand where some other species have been planted. Nor has it been used in specialised planting programs in saline soils in the hot, dry subtropics and tropics of Kenya, Senegal, Somalia, Sudan, Yemen Arab Republic and Peru (Thomson 1987). Western Australian *A acuminata* was planted in a number of trials in Zimbabwe between 1957 and 1960 (Gwaze 1987). Follow-up records show that after 65 months there was 25% survival at one plot only (Mtao: 1480 m above sea level; mean annual rainfall of 800 mm; deep, well drained soils) and the mean height was 3.5 m. *A acuminata* has not been extensively used in other parts of southern Africa (Hall and Turnbull 1976).

A acuminata is drought and frost tolerant but will not tolerate waterlogging.

Structure and Physiology

Morphology

The species is highly variable. In Western Australia *A acuminata* is taxonomically very close to *A burkittii* F Muell. *ex.* Benth. At the northern and eastern limits of its range the habit of *A acuminata* changes to a dense shrub with narrower phyllodes and it is this form which has been called *A burkittii* in Western Australia. Recently however, the latter species has been described as *A acuminata* subsp. *burkittii* by some authorities including the Western Australian Department of Conservation and Land Management. Another allied, but distinct species is *A oldfieldii* F. Muell. (Hall and Turnbull 1976).

Mycorrhizae

In an overview of *Acacia* nodulation Roughley (1987) noted that *A acuminata* is a promiscuous host with nodulation by 75-100% of 20 *Rhizobium* strains tested.

Chromosomes

The chromosome number is 2n=26 (Hamant *et al.* 1975).

Biochemical data

A acuminata belongs to the 3',4',7,8-tetrahydroxyflavonoid (Melacacidin) group of acacias. The 3',4',7,8 flavonoid pattern is shared by most Plurinerves (*eg. A excelsa, A melanoxylon, A trinerva*) and Juliflorae (*eg. A aneura, A holosericea, A longifolia*) sections of the Phyllodinae (Tindale and Roux 1969). The heartwood contains (-)-isomelacacidin in relatively large amounts; slightly lesser amounts of (-)-melacacidin, dihydroxyflavonol, and flavonol; less 3',4',7,8-tetrahydroxy-flavonone; a relatively small amount of chalcone (okanin) and none of the 2,3-trans-3,4-cis isomer. The bark is recorded as having only leucoanthocyanidins.

A acuminata is not listed among cyanogenic Australian species of *Acacia* by Maslin *et al.* (1987).

Phenology

Flowering occurs between July and October (Marchant *et al.* 1987; Simmons 1981; Hall and Turnbull 1976).

Hybrids

No references to hybridisation were found although the large variability within the species may allow this this to occur.

Seed production and dispersal

Not all trees in a single area are necessarily in fruit at the same time. There are 50,000-70,000 seeds kg^{-1} (Hall and Turnbull 1976). No references to seed dispersal were found.

Viability and germination

In general *Acacia* seeds retain a high level of viability for a very long time, possibly as long as 18-68 years if stored dry and sealed (Ewart 1908; Cavanagh 1980; Doran *et al.* 1983), but no data specific for *A acuminata* is available. Ungerminated *Acacia* seeds can exist for long periods in the soil, providing they are not removed by ants and other fauna. These seeds provide a continuing source of seedlings over time (Cavanagh 1985). Dormancy of *A acuminata* is due only to the water-impermeable seed coat, so the main aim of pre-treatments is to damage the seed coat to allow water entry. Seed coat dormancy can normally be broken by pre-treatment with boiling water (Hall and Turnbull 1975) but harsher treatments, such as with sulphuric acid, may be necessary in some cases. Cavanagh (1985) and Langkamp and Plaisted (1985) note that *A acuminata* is sensitive to prolonged heating and should be heated for a maximum of five seconds at 100°C. Larsen (1964-1967) in a small scale trial, found that germination was substantially improved by hot water treatment. Seeds were placed in ten times their own volume of boiling water, removed from the heat source and allowed to cool in the water. In contrast Lefroy *et al.* (1991) state that *A acuminata* seeds should have no heat treatment.

In a trial at Curtin University (Fox 1990) seed was collected at Sandford Rocks Nature Reserve, Westonia, Western Australia and tested for germination in March-May 1990 when seed was fresh. Results (Figure 1) suggest that the proportion of soft seed (*ie.* that which germinates with no hot water treatment) is 6-12%; that temperatures of 40-60°C make no difference to germination; that at 70°C and above, the seed coat dormancy is broken, and soaking in boiling water gives highest germination. Other results (Figure 2) suggest that 4% of seed is soft; that 10-20 seconds exposure to boiling water releases 75% of seed from dormancy (this may also kill the soft seed component); that exposure for 30 seconds is best (96% germination); that longer periods of time may damage more seed than the soft seed component, and at 70 seconds exposure there is a marked

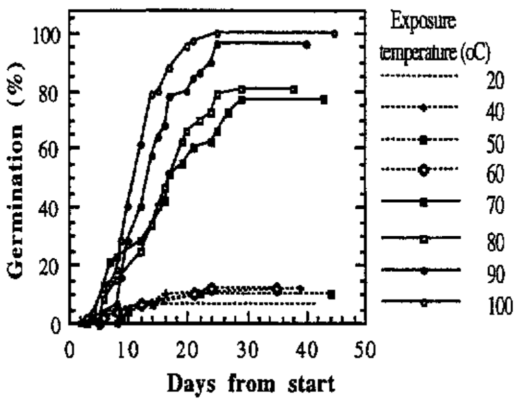

Figure 1. Germination response of *Acacia acuminata* seed from Westonia exposed to soaking for 30 s in one of eight water temperatures prior to incubation at 20°C. (Fox 1990)

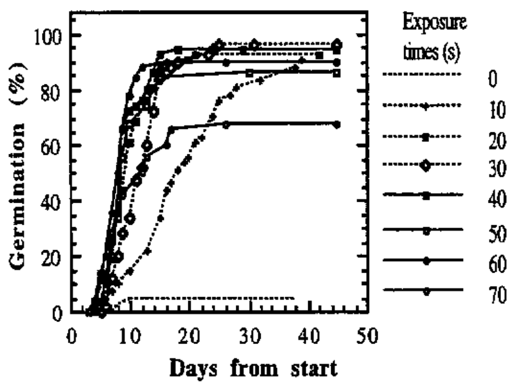

Figure 2. Germination response of *Acacia acuminata* seed from Westonia exposed to boiling water for differeing periods of time prior to incubation at 20°C. (Fox 1990)

mortality due to the severity of treatment.

In order to standardise seed testing Peterson (1985) collated available data which recommended testing germination of *A acuminata* seed at either 20 or 25°C using at least four replicate lots each of 100 scarified seed (hot water seed coat treatment is too unreliable for standardised seed testing), in specific light conditions. The final count should be made at 28 days and between 16 and 60 viable seeds g^{-1} could be expected.

Seedlings

Juvenile leaves of *A acuminata* are pinnate. These are replaced by alternately arranged phyllodes as seedlings develop.

Animal Parasites, Herbivores and Diseases

Bag-Shelter Moth (*Ochrogaster lunifer* Herrich-Schaeffer) can cause severe defoliation (and eventually death) of *A acuminata* trees from January to June when in its laval stages. Trees growing on roadsides are particularly vulnerable. Lavae always occur in a communal nest (bag-shelter). The average number of lavae per bag was 71 in a study by Van Schagen *et al.* (1992a, b) and the average number of nests per tree was more than two, with a maximum of 16. Caterpillars are gregarious, feeding mainly at night often on larger trees (>2 m tall). An individual colony during its lifespan may consume foliage equivalent to that carried by a tree 2 m tall (Van Schagen *et al.* 1992a, b). The caterpillars can be controlled and trees quickly recover (Newbey 1982). For a few years defoliation by *Ochrogaster lunifer* is soon followed by a large amount of new shoot growth, but repeated defoliation can be sufficiently stressful to cause premature mortality (Majer 1995).

Locusts, wingless grasshoppers, rabbits, native and feral animals and stock can cause severe grazing damage.

Plant Parasites and Diseases

Santalum spicatum (Western Australian sandalwood) a root hemi-parasitic tree, uses *Acacia acuminata* as a preferred host in the wheatbelt of Western Australia (Struthers *et al.* 1986). The parasite shows high levels of K and Na, with high K uptake relative to Ca. Other minerals may also be taken up (Struthers *et al.* 1986). Casson (1992) recorded that *A acuminata, Allocasuarina campestris, A huegeliana* and *Eucalyptus loxophleba* were chief hosts throughout the central and southern wheatbelt. The extent to which this parasitism limits the growth of *A acuminata* has not been studied although anecdotal evidence suggests that parasitised trees can be smaller and may die earlier than non-parasitised counterparts.

A acuminata is used as a host by *Santalum acuminatum* in Western Australia (Herbert 1921, 1925) and in the Jam Paddock area, Dryandra, Western Australia, *A acuminata* is the most probable host of *S murrayanum.*

Amyema preissii (Miq) Tiegh, an Australian mistletoe, is an aerial parasite whose major host is *A acuminata* (Lamont and Southall 1982). These authors suggest that selective uptake of Na and K, and to a lesser extent Cu, Zn and Mg occurs across the haustorium from the xylem and phloem of infected *A acuminata.* The mineral drain from the host is significant. Nitrogen and Ca concentrations were the same in host and parasite. This parasite also accumulates relatively large amounts of tyramine, an amino acid derived uniquely from *A acuminata* (Pate *et al.* 1991).

Uromycladium tepperianum (gall rust) is autoecious upon *Acacia* species and may produce conspicuous elongate or globose galls and in some cases witches' brooms and juvenile foliage on mature parts. Stem, phyllode, peduncle and fruit may be affected. In *A acuminata* only globose galls were noted by Gathe (1971) and they occurred on stems and phyllodes. Severe infection ultimately kills the tree.

History

The original botanical description was published by Bentham (1842). The type material was collected in Western Australia, from near the Swan River, Perth by Drummond and at King George's Sound, Albany by Baxter. The species name 'acuminata' comes from the Latin 'acuminatus' meaning pointed, elongated or tapering into a long narrow point and probably refers to the tips of the phyllodes. The common name 'Raspberry Jam' refers to the strong, crushed raspberry smell of the heartwood when freshly cut (Hall and Turnbull 1976).

Uses

In Western Australia, South Australia and New South Wales *Acacia acuminata* is considered poor for shelter, wind breaks and wind erosion control but it has nevertheless been used for these purposes (Hall and Turnbull 1976; Simmons 1981). Newbey (1982) notes that it is completely unsuitable for control of water erosion, wind erosion, waterlogging and salinity. The species is used as an ornamental in areas with a minimum annual rainfall greater than 375 mm but it is totally unsuited for cut flowers. It is poor for honey production. It is unsuitable for growing in deep sands and clay profiles; moderately suited to deep, sandy loams and to shallow sands; excellently suited to deep loams and shallow loamy clays (Newbey 1982).

Some reports state that phyllodes make excellent fodder although others place little value on the species as drought fodder (Hall and Turnbull 1976). The species is not poisonous to animals. Reported poisoning of animals is attributed to *Gastrolobium* sp. growing in association with *A acuminata* (Hall and Turnbull 1976; Simmons 1981).

The wood has an unusually attractive grain, often with fiddleback and a dark red heartwood. It is used for craft and wood turning (making small ornamental items), fencing (it is hard, heavy and durable in the ground and resistant to white ant attack), specialty saw logs and occasionally charcoal. Formerly it was used for machinery bearings, sheave blocks, heavy turnery and yokes (Hall and Turnbull 1976; Simmons 1981).

Identification

Identifying characteristics include phyllodes with many, faint veins and curved tips, the upper margin fringed with short white hairs, and orange pulvinuses. The flowers occur in spikes and are usually sessile. The tree usually has a definite trunk. In the northern and eastern part of its range its habit changes to an often dense, rounded, wide spreading shrub with narrower phyllodes (1-1.5 mm broad). After the forthcoming name change it is the latter form which will become known as *Acacia acuminata* subsp. *burkittii*.

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A REVIEW OF THE ECOLOGICAL CHARACTERISTICS OF *ACACIA SALIGNA* (LABILL) H WENDL

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Abstract

This paper provides a review of published information pertaining to the species *Acacia saligna*, endemic to south-western Australia. *A saligna* is a small tree whose present-day importance extends well beyond the area of its natural occurrence. In recent years it has been largely neglected as a species of direct value in Western Australia, apart from roadside screen planting. Its comparatively rapid early growth and tolerance of sandy, coastal soils provided stimulus for its use in fixing of sand dunes in many countries. Consequently it has also been cultivated for fodder in countries with a Mediterranean climate and is an important weedy species in South Africa. The absence of predatory insects in South Africa stimulated research into methods of biological control. This has provided considerable information on insects associated with *A saligna* in Australia. More recently, *A saligna* is being advocated as a fodder shrub for alley planting on farms in Western Australia.

Material is included on the biology and ecology of the species. Published vegetation surveys are used to describe the natural communities in which it occurs and to provide lists of associated species. Growth and regeneration studies are reported.

Introduction

Acacia saligna (Labill) H Wendl is a characteristic small tree or large shrub of the Perth metropolitan area (31°56'S, 115°58'E). It is variously known as orange wattle (Blackall and Grieve 1954), black wattle (Abbott 1983) and golden-wreath wattle (Lazarides and Hince 1993). An Australian Aboriginal name is cujong (pronounced kudjong), according to Abbott (1983). In South Africa it is known as Port Jackson willow. The name *Acacia saligna* incorporates the obsolete taxon *A cyanophylla* Lindl (Maslin 1974). It is heliophilous and its rapid growth makes it attractive for securing quick cover. It has been particularly favoured as a roadside plant by the Main Roads Department and local authorities. It is most common on the Swan coastal plain where it is an early colonising species, locally dominating the regeneration facies following disturbance to tuart (*Eucalyptus gomphocephala*) woodlands of the Spearwood dune system (Smith 1975).

The following description is after Maslin (1974), to which reference should be made for taxonomy. Key characters are given in Pettigrew and Watson (1975). *A saligna* is a shrub or small tree 2-6 m tall, young bark is smooth, grey to reddish-brown on young, glabrous branchlets. The bole becomes dark grey and fissured with age. Phyllodes are variable, flat, coriaceous, linear to lanceolate, 80-250 x 4-20 mm but often much larger near the base (to 200-320 x 40-80 mm), 5-10 times as long as wide, straight or falcate and often pendulous (*saligna*=willow-like); glabrous, green to glaucous (*cyanophylla*=bluish phyllodes) in colour, dull to shiny; with a conspicuous midrib, lateral veins fine (absent on narrow phyllodes); pulvinus 1-2 mm long, rugose. A solitary oblong to circular gland, 1-2 mm diameter, occurs on the upper margin of the phyllode, near the distal end. This secretes fluid, more so on newly expanding phyllodes (Majer 1979). The inflorescence is racemose, axillary or terminal, peduncles 2-10 per raceme, 5-15 mm long and to 25 mm in fruit. Flower heads are bright yellow, globular, 7-8 mm at anthesis, with 25-55 flowers. Flowers are 5-merous, the glabrous petals have a prominent midrib; sepals are pubescent with pointed tips; the polyad is circular, 16 grained. Legumes (pods) are flat, linear, 80-120 x 4-6 mm, slightly constricted between seeds. The seeds lie longitudinally in the pod and are oblong to slightly elliptic 3-6 x 2-4 mm, dark brown to black, shiny; the pleurogram is prominent, continuous, often bordered by light coloured tissue; the areole is 3-3.5 x 1-1.5 mm; the funicle is clavate, straight or occasionally folded, yellowish-white, narrowed and brown at the hilum.

Distribution

Acacia saligna is endemic to the south-west of Western Australia, generally occurring west of a line from Ajana (27°57'S, 114°38'E) in the north (to the north of Geraldton, 28°46'S, 114°37'E), and Mt. Ragged (33°27'S, 123°29'E) in the south (east of Esperance, 33°52'S, 121°53'E) (Maslin 1974). It occurs from near sea level to about 325 m, with isolated occurrences at higher altitudes (Hall and Turnbull 1976).

It is naturalised around the Mediterranean Sea, in South Africa and California. In South Africa it is an important pest species where it is described as feral (Taylor 1969; Milton and Siegfried 1981). The South African distribution is given by Hall (1961). *A saligna* is also considered a problem in Spain and Portugal (De la Lama 1977). It has been introduced to Chile (Vita 1977); Libya and Tunisia (Dumancic and Le Houérou 1981); Iran (Shaybany and Kashirad 1978), Morocco, Algeria, Egypt and elsewhere. In North Africa it is the most important of some eight introduced Australian species (El Lakany 1987). In Jordan, Israel and Syria it is an important ornamental and shade tree and was introduced to Kuwait in the 1960's for this purpose. It has been tested recently at Formentera, Baleric Islands (Haas 1993).

Habitat

Climatic and topographical limitations

Acacia saligna does not occur in the tropics nor in the dry inland parts of Western Australia. The climate of the south-west of Western Australia is described in relation to the occurrence of vegetation by Beard (1981). The area experiences a Mediterranean climate with most rainfall in the cooler winter months. Summers are hot and dry. Figure 1 provides ombrothermic diagrams for Perth (in the centre of the range of *A saligna*), Esperance (in the south-east), Geraldton (in the north of the range) and Merredin (inland).

At present, it is believed that best growth of *A saligna* occurs in the vicinity of Perth, and that the species is more often of shorter stature elsewhere, particularly in lower rainfall areas. Mean annual rainfall at Perth is 870 mm; less than 9% is received in the period November to March and 71% falls between May and August (Bureau of Meteorology 1986). Geraldton is drier, receiving 470 mm in total with 9.6% and 74% in the corresponding drier and wetter months. Rainfall at Esperance is intermediate. The mean annual rainfall of 623 mm is more equably distributed with 55% between May and August and 20% between November and March. Merredin may be taken as typical of some inland locations (see below) where the climate is described as extra dry Mediterranean (Beard 1981). The total mean at Merredin is 327 mm with 23% between November and March and 57% May-August. The occurrence of summer rain is less predictable and the relatively high mean summer rainfall inland is mainly due to the effects of remnant, irregular, decaying cyclones passing through the interior. At many inland locations *A saligna* occurs near the base of granitic inselbergs where effective rainfall is enhanced by water shedding. Consequently a minimum annual rainfall figure for the occurrence of *A saligna* is probably of the order of 350 mm.

Mean maximum temperatures of the hottest month are higher to the north and inland with 32.2°C (February) at Geraldton and 33.6°C (January) at Merredin. Mean maximum monthly temperatures are highest at Perth in February (29.9°C) and January (25.9°C) at Esperance.

The mean minimum of the coolest month has a smaller range, between 4.6°C (August) at Merredin and 9°C (July) at Perth. Coastal locations are generally frost-free but frosts occur inland with a mean of 20 days per annum at Merredin.

An important topographical limitation is in relation to occurrence in the coastal dune systems. At Sorrento, an exposed beach dune system, north of Perth, *A saligna* is predominantly found in the sheltered swales, with some minor presence on the lee slopes of the dunes (Fox *et al.* 1983), where it is out-competed by *Acacia rostellifera*. It is absent from dune crests and slopes facing the sea, suggesting it is less tolerant to salt-laden winds than is *A rostellifera*. West of Busselton (33°33'S, 115°04'E) where the beach is less exposed and *A rostellifera* is replaced by *A cyclops*, trees of *A saligna* to 2 m with broad phyllodes, can be seen adjacent to the high water mark.

Substrates

Acacia saligna is common on sandy soils of the Swan coastal plain from Gingin (31°21'S, 115°54'E) to Busselton (33°39'S, 115°20'E). Near the coast it forms thickets in dune swales where the soil is generally moister and enriched with organic matter. In *Eucalyptus gomphocephala* woodlands/open forest near Perth it is found on Cottesloe or Karrakatta sands of pH (1:5 in water) 6.7-7.1, 11-30 mg 100 g^{-1} Ca and 1-2.3% organic matter in the surface 300

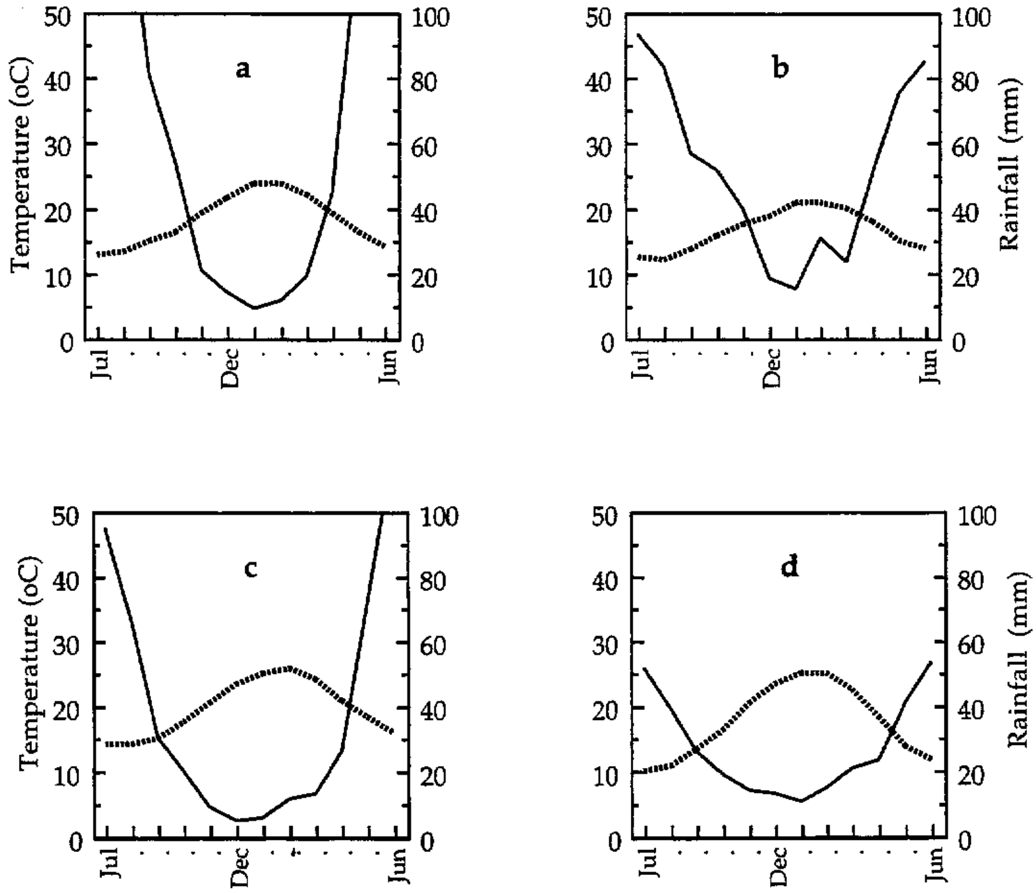

Figure 1. Ombrothermic diagrams of four localities: a. Perth (31°56'S, 115°58'E); b. Esperance (33°52'S, 121°53'E); c. Geraldton (28°46'S, 114°37'E); d. Merredin (31°29'S, 118°17'E). Temperature is dotted line, rainfall solid line.

mm (Fox 1981). Analysis of attributes for 150 circular plots of 0.01 ha at Yalgorup National Park suggest that *A saligna* is more common on sites with higher organic matter (Hides 1985). These sites are described as Yoongarillup or Cottesloe sands over limestone (Churchward and MacArthur 1980). At some coastal locations (*eg* Yallingup 33°39'S, 115°02'E) it may be displaced by *Acacia cochlearis* on limestone soils, or when present (*eg* Canal Rocks 33°41'S, 114°59'E) may be relatively short (<1.5 m) and rapidly affected by gall rust (see below). It is locally common in open facies of the tuart woodland, generally on sand over limestone at depth. I have observed it as a local understorey to *Eucalyptus wandoo* on dolerite dykes in the Darling Scarp, where loamy soils retain moisture well into the summer.

McArthur (1991) recorded *A saligna* at his site SCP 7A (32°50'S, 115°38'E) in Yalgorup National Park, at 2-4 m tall with *Agonis flexuosa* and occasional trees of *Eucalyptus gomphocephala* (tuart). Companion species <1 m tall include *Acanthocarpus preissii*, *Phyllanthus calycinus*, *Conostylis candicans*, *Loxocarya flexuosa* and *Isotoma hypocrateriformis*. Here the soil is a calcareous sand (31-49% $CaCO_3$) of the Quindalup series, grey-brown at the surface and yellowish brown at depth, pH (1:5 in water) 8.2-8.8. *A saligna* is recorded at only two other sites in McArthur (1991). At site BTN 1 (32°50'S, 115°38'E), some 12 km south-east of Bridgetown, it occurs as a shrub <1 m tall in a jarrah/marri/blackbutt forest (*Eucalyptus marginata*, *E calophylla* and *E patens* respectively) where the trees are 24 m tall. Other small shrubs are *Acacia* *pulchella, Leucopogon capitellatus* and *Xanthorrhoea preissii* with ground cover species of *Stipa variabilis, Themeda australis, Conostylis* sp., *Dampiera* sp., *Ptilotus manglesii* and *Phyllanthus calycinus*. Here the soil is a loamy red earth, developed on Pre-cambrian basic crystalline rock, dark reddish-brown in colour, pH at the surface 5.6 and 6.7 at depth (700-950 mm). At site BTN 3 (33°53'S, 116°19'E), some 19 km north-east of Bridgetown, *A saligna* is present as a shrub 1-2 m tall with *Melaleuca rhaphiophylla*, in a wandoo (*Eucalyptus wandoo*) woodland, with trees 8-20 m tall. Companion species <0.5 m, are *Baeckea camphorosmae, Hypocalymma angustifolium, Daviesia decurrens, Dianella revoluta, Neurachne alopecuroidea, Ptilotus manglesii, Lepidosperma angustatum, Conostylis* sp. and *Xanthorrhoea preissii*. The substrate is a yellow duplex soil (sand over clay), derived from decayed granite, greyish-brown to brown at the surface over yellowish-brown at depth, pH 5.0-5.8.

Soil attributes for three collections used in a comparative growth trial are summarised in Table 1. In many localities elsewhere it is neither particularly common nor widespread. It is often more or less restricted to sites adjoining creeks and rivers, particularly north of Gingin, in the Darling Range east of Perth, the Great Southern from Williams (33°02'S, 116°53'E) south to Manjimup (34°15'S, 116°09'E) and Mt. Barker (34°38'S, 117°40'E). Along the south coast between Albany (35°02'S, 117°53'E) and Esperance (33°52'S, 121°53'E) it is common, but also best developed on soils associated with water courses (Maslin 1974).

In South Africa, *A saligna* is now found in the west, south-west, south and east Cape, occurring on all substrates where adequate moisture is available (Milton 1980). It is said to do better on neutral to alkaline soil (Roux and Middlemiss 1963).

Communities

Acacia saligna is not usually present in the dense, tall jarrah and karri forests or in closed banksia woodlands, three of the main, distinctive vegetation formations of south-western Western Australia. It is not sufficiently important to have featured in the vegetation systems described by Beard (1981) for the Swan coastal plain, except in the Rockingham system. In this system, the beach ridge country near Rockingham (32°17'S, 115°43'E), consists of thickets and scrub of *A saligna* with *Jacksonia furcellata* and *Xanthorrhoea preissii*. However, at a more detailed level it is described as a shrub in the Spearwood system under *Eucalyptus gomphocephala* along with *Acacia cyclops, Anthocercis littorea, Dodonaea aptera, Dryandra sessilis, Grevillea vestita, Hakea prostrata, Jacksonia furcellata, J sternbergiana, Logania vaginalis, Melaleuca huegelii, Myoporum tetrandrum* and *Templetonia retusa* (Beard 1979b). It is also present on Garden Island, off Rockingham. Elsewhere on the Spearwood system, Hides (1985) indicates that of 41 common shrub species in Yalgorup National Park (centred on 32°45'S, 115°11'E), *A saligna* is mainly associated with the following eight shrubs: *Acacia cochlearis, A lasiocarpa, A rostellifera, Agonis flexuosa, Banksia littoralis, Jacksonia furcellata, Logania vaginalis* and *Pimelea ferruginea*. *A saligna* is present in five of 20 *Eucalyptus gomphocephala* sites between latitudes 31°44' and 32°14'S, within 10 km of the coast near Perth (Fox 1981). At these sites, associated species include *Acacia cochlearis, A pulchella, Allocasuarina fraseriana, Banksia attenuata, B grandis, B menziesii, Dryandra sessilis, Jacksonia*

Table 1. Surface characteristics (top 150 mm) of three soils supporting *Acacia saligna* near Perth. (Data from Davies *et al.* 1989).

Attribute/ Locality	Lesmudie	Jandakot	Yalgorup
Bulk density	1.61	1.65	1.41
Field capacity	27.4	28.9	30.4
pH (1:5)	5.2	7.5	6.2
Organic matter (%)	6.3	2.8	2.3
P (ppm)	0.85	0.72	0.75
N (%)	0.06	0.04	0.03
Landform soil+	Darling Scarp	Bassendean sand	Yoongarillup

+ source: Churchward and McArthur (1980).

furcellata, J sternbergiana, Hardenbergia comptoniana, Macrozamia riedlei and *Xanthorrhoea preissii.*

Cresswell and Bridgewater (1985) describe a *Jacksonia sternbergiana-Pimelea rosea* community (A3) on dune slopes of the eastern Karakatta and western Bassendean soils of the Perth area. This has *A saligna* as a constant species. Other species include: *Acacia huegelii, Banksia attenuata, B menziesii, Burchardia umbellata, Dasypogon bromeliifolius, Dianella revoluta, Diplopogon setaceus, Dryandra nivea, Eryngium rostratum, Eucalyptus calophylla, Gompholobium tomentosum, Hakea prostrata, Hibbertia hypericoides, Hybanthus calycinus, Hypocalymma robustum, Macrozamia riedlei, Mesomelaena stygia, Oxylobium capitatum, Petrophile linearis, Stirlingia latifolia,* and *Xanthorrhoea preissii.*

Of 29 "Vegetation Complexes" mapped on the Swan coastal plain, *A saligna* is considered typical of four (Heddle *et al.* 1980). In the Abba Complex it occurs in flood-plain fringing vegetation of *Eucalyptus rudis-Melaleuca preissiana-M rhaphiophylla.* Other typical species are *Agonis juniperinum, Astartea fascicularis, Beaufortia sparsa, Hakea varia, Leptospermum ellipticum, Regelia ciliata* and *Viminaria juncea.* It is found with *Melaleuca* scrub on flats of the Serpentine River Complex and also with various *Melaleuca* species and *Casuarina obesa* amongst *E rudis-Melaleuca* fringing woodland and open forest of *E gomphocephala-E marginata-E calophylla* of the Vasse Complex. In the Karakatta Complex of *E gomphocephala-E marginata-E calophylla* open forest it is an understorey shrub along with *Acacia cyclops, Allocasuarina humilis, Calothamnus quadrifidis, Grevillea thelemanniana, Jacksonia furcellata* and *J sternbergiana.*

It is represented in the scattered understorey of *Eucalyptus calophylla/E wandoo* tall woodland of the Jingalup system, 30 km south of Kojonup (33°50'S, 117°09'E), (Beard 1979a). Here it occurs with *Allocasuarina lehmanniana, Brachysema praemorsum, Dampiera lavandulacea, Dryandra formosa, D sessilis, Hakea prostrata, Hypocalymma angustifolium, Jacksonia sternbergiana, Leptospermum erubescens, Lechenaultia formosa* and *Stypandra imbricata.* It occurs as a shrub, along with a dozen other species of *Acacia,* in eucalypt woodland (*Eucalyptus wandoo, E loxophleba, E salmonophloia* and *E salubris*) in the Kellerberrin area (Beard 1980c). Further east, at Sandford Rock Nature Reserve, 11 km north-east of Westonia (31°18'S, 118°42'E) some 20 species of *Acacia* are present in various associations of eucalypt woodland, melaleuca thicket and scrub. Here, *Acacia saligna* occurs as a scattered tall shrub around the base of a massive granite inselberg, associated with *A lasiocalyx.*

It is present in mallee (main species *Eucalyptus tetragona*) of the Qualup system, 55 km east of Cranbrook (34°18'S, 117°33'E) as a tall shrub (Beard 1979a). Associated species include: *Agonis spathulata, Allocasuarina humilis, Banksia sphaerocarpa, Beaufortia schaueri, Dryandra falcata, D proteoides, D sessilis, Gastrolobium spinosum, Grevillea brownii, Hakea corymbosa, H prostrata, H trifurcata, H undulata, Kunzea preissiana, Lambertia ericifolia, Melaleuca scabra, Nuytsia floribunda, Petrophile serruriae, Regelia inops* and *Xanthorrhoea gracilis.* On the Pikaring system (Beard 1980b), it occurs as an understorey component with mallee (mainly *Eucalyptus foecunda*) in reserves 23141 (33 km north-west of Corrigin) and 16104 (23 km north of Corrigin, 32°20'S, 117°52'E).

In the Beaufort system Beard (1980a) records *A saligna* in scrub-heath 25 km north of Kojonup (33°50'S, 117°09'E) with *Nuytsia floribunda* as a tree and the following shrubs: *Adenanthos cygnorum, Allocasuarina corniculata, A humilis, Baeckea preissiana, Daviesia polyphylla, Eremaea pauciflora, Hakea incrassata, H trifurcata, Hibbertia acerosa, Isopogon latifolius, Kunzea recurva, Leptospermum erubescens, Lechenaultia biloba, Petrophile squamata, Verticordia habrantha* and *Xanthorrhoea preissii.*

A saligna is a shrub in heath of *Dryandra* species and *Allocasuarina campestris* of the Pingelly system, in Reserve 13797, located 50 km west of Corrigin (Beard 1980b). In this vegetation, companion species include; *Acacia lasiocarpa, A stenoptera, Banksia sphaerocarpa, Calothamnus quadrifidus, Daviesia brevifolia, Gastrolobium hookeri, Hakea baxteri, H varia, Isopogon drummondii, Lysinema ciliatum, Persoonia striata, Santalum acuminatum, S spicatum* and *Xanthorrhoea reflexa.*

In the Mount Caroline system of the Kellerberrin (31°38'S, 117°43'E) area *A saligna* is present as a tall shrub in the *Banksia-Xylomelum* association (Beard 1980c). Other tall shrubs are: *Acacia* *multispicata, A stereophylla, Actinostrobus arenarius, Banksia attenuata, B prionotes, Allocasuarina huegeliana, Eucalyptus drummondii, E loxophleba, Grevillea excelsior, Santalum acuminatum* and *Xylomelum angustifolium.*

Response to Biotic Factors

Acacia saligna is favoured in many countries as an ornamental or shade tree. Crowding will result in a decline in growth but the onset of competition varies with growing conditions (Fox and Wallman 1979). Biomass production of *A saligna* is thrice that of Fynbos vegetation (Milton and Siegfried 1981). Established trees suppress both native vegetation and seedlings of *A saligna* (Roux and Middlemiss 1963). Some seedlings germinate each year but cannot survive under a mature canopy. It can be invasive elsewhere and has shaded out eucalypt plantations in Spain and Portugal (De la Lama 1977). Both root and shoot dry mass are inhibited in shade (Milton 1978).

Regeneration

A saligna will coppice if cut at ground level in South Africa (Roux and Middlemiss 1963). This is not observed in Western Australia but dense seedling regrowth will follow fire (Baird 1984). Basal sprouts can be produced after fire (Fox *et al.* 1983). Fire favours its spread in South Africa (Roux and Middlemiss 1963) through removal of competitors and stimulation of germination. The resultant dense stocking requires five years for thinning out to the level of a mature stand (Milton and Siegfried 1981).

Coastal dune fixation

A saligna was introduced to South Africa in 1870 for stabilizing drifting coastal dunes (Smith 1966). It is also used for this purpose in New South Wales (Aveyard 1968); Cyprus (Couppis 1956, Ramadan 1957); Libya (Puecher-Passavalli 1935, Messines 1952); Palestine (Sale 1948); and in Egypt (Abd el Rahman 1967). Year-old nursery-raised plants are considered best for fixing sand dunes in Libya (Messines 1952). Big pot-plants (1-2 m tall) and deep pits (1 m) were used in Palestine and plants buried, covering all but the upper twigs (Sale 1948).

Grazing

Ironically, the goat is the source of soil deterioration in many regions (Messines 1952) yet it is as goat fodder that *A saligna* has been mainly used. Both sheep and goats take fresh foliage in reach, and also fallen leaves and seeds in Cyprus (Ramadan 1957). Lopped branches, hand fed to sheep and goats, are more acceptable than fresh material. The mean weight loss on air drying for 24 h is 8.7%, with a resultant dry matter content of *ca.* 54%. This can contribute 12% of the total feed requirement during October-December in Libya, when green forage is scarce or absent (Dumancic and Le Houérou 1981).

Goats lost weight when fed *ad lib* on *A saligna* only, in a Cyprus trial, taking 2.18 kg day^{-1}. The protein was considered probably indigestible due to a high tannin content (Table 2). The goats gained weight when 0.5 kg d^{-1} of concentrates were added, and then ate 2.6 kg d^{-1} of *A saligna* (Director, Department of Agriculture 1979). This compares with 3.26 kg day^{-1} per animal of mixed sheep and goats in Libya (Dumancic and Le Houérou 1981). Relevant data are shown in Table 2.

Goat farming based on *A saligna* in South Africa is uneconomic (Milton and Siegfried 1981). Angel and Glencross (1993) suggest *A saligna* planted for cattle grazing, with *Chamaecytisus palmensis* and perennial grasses, on the Swan coastal plain of south-western Australia could yield 7.5-8 t ha^{-1} of edible dry matter. Sandplain alley farming, using *A saligna* and *C palmensis* at Dowerin (31°12'S, 117°02'E) increases sheep carrying capacity three-fold (Lefroy and Scott 1994).

Other uses

In the early colonisation of south-western Australia it was an important source of tan bark (Maiden 1889), yielding nearly 30% of tannin. Other uses include livestock shelter, fuel and small agricultural timber. Seeds have been fed to chicks in Cyprus (Ramadan 1957). The gross protein value of *A saligna* seed is similar to groundnut meal. A cereal seed mixture with 22% *A saligna* seed gives best results. It is grown in highland Tanzania for windbreaks, fencing and fuelwood (Kesy 1987). A firewood harvest can be taken from dune plantings at 10-15 years (Sale 1948). In dry parts of Tunisia and Libya it produces up to 3.5 t of dry fuel-wood ha^{-1} y^{-1}. It is used for particle board in Tunisia (El Lakany 1987).

Response to Environment

Gregariousness

Acacia saligna is capable of forming dense thickets in disturbed areas (Holmes *et al.* 1987). These may be mixed with other Australian species of *Acacia* in

Table 2. Fodder characteristics reported for *Acacia saligna*.

Country	DM (%)	Crude values (%)			Ash (%)	Tannin (%)
		protein	fibre	fat		
Libya	52.9	12.8	22.7	7.3	10.3	n/a
Cyprus	58.5	12.0	22.9	2.7	9.1	6.0
General*	50-55	12-16	20-24	6-9	10-12	n/a

* General values from El Lakany (1987).

South Africa (Milton and Siegfried 1981), but this is not common in Western Australia. Its superior growth favours its dominance over native South African species (Roux and Middlemiss 1963).

Performance in various habitats

There is a probable relationship between rainfall and height growth in Western Australia, with plants generally smaller inland. *A saligna* grows to 3 m in Kuwait (Salem 1977). Irrigation can double height growth over the first 17 months from planting (Haas 1993).

It is intolerant and grows rapidly on open waste land sites, characteristics of a pioneer species. These attributes suggest suitability for the early stages of mine-site rehabilitation towards a system containing woody perennials. In pot trials with coal-mine inter-burden materials from Muja, Collie (33°26'S, 116°19'E), differences in yield become evident at eight weeks (Table 3). In the absence of added fertiliser, growth is poor and best results are on the least acidic (Class 1) inter-burden (Fox *et al.* 1987).

In Class 1 with NPK the top/root ratio attained 1.45 after 78 days growth with the percent N in tops at 2.81. The latter is greater than for both *A extensa* and *A pulchella*.

A field trial with seed sown into prepared surfaces on an interburden dump at Muja, indicates best height growth at two years (2.3 m) on Class 1 with topsoil, lime and low phosphorus (Doronila and Fox 1990). Class 111 (with topsoil, no lime and high P) heights are comparable with the least toxic substrate (Class 1 with topsoil). *A saligna* cannot grow on the most acidic material in the absence of topsoil. The order of significant differences between main treatments in height growth suggests that topsoil substitutes for slow release fertiliser used in the earlier pot trial (Table 4).

Persistence of established plants is greater on unlimed Class 1 with topsoil and the higher phosphorus rate. On these relatively inhospitable substrates all plants became rusted (see below) by five years. The majority of plants collapsed by seven years from sowing.

Milton and Siegfried (1981) provide the following

Table 3. Mean yields of *Acacia saligna* grown in coal-mine interburden materials (SD in brackets) at 30, 56 and 78 days from potting. Harvest masses with the same letter do not differ (p <0.05) using the Scheffé test.

Material	Mean dry masses (mg)		
	30 days	56 days	78 days
Class 1 + NPK	61 (21)	190 (77) a	390 (80) a
Class 1	31 (1)	53 (8) b	47 (8) b
Class 111 + NPK	51 (20)	105 (53) ab	149 (72) b
Class 111	28 (16)	36 (10) b	47 (14) b

The NPK source was Osmocote™ (18:3:10, 90 day release); the Class 1 inter-burden of pH 6.1 has no contained N and the Class 111 material of pH 4.6 has 0.03% N.

data on wood production: the ratio of dry to wet biomass of wood >20 mm diameter is 0.610; foliage is 0.361; mean moisture content of trees is 47%; and wood occupies 72% of biomass. The following regressions relate biomass (y, in g) to stem diameter at 100 mm height (x, in mm):

Total dry mass	$\log y = -1.42 + 2.82 \log x$
Wood dry mass	$\log y = -1.61 + 2.85 \log x$
Foliage dry mass	$\log y = -3.12 + 3.17 \log x$

Fertiliser response

Early seedling growth (100-day) is depressed by omission of nitrogen from a standard potting mixture. Supply of the standard level of N supports better growth than twice or half that level (Fox and Wallman 1979). Growth responses occur with increased P availability up to 5 g P m^{-2} (Witkowski 1994). At low levels of P, foliar N is >3% and P is 0.11-0.15%; at levels of P >5 g P m^{-2}, foliar N is 2.3-2.8% and P is 0.19-0.21%. Foliar N: P is 18.0 at 5 g P m^{-2} (Witkowski 1994).

Effect of frost, drought and flooding

Frost

Acacia saligna is somewhat frost tender (Department of Forestry, South Africa, unpublished data).

Drought

Fahn (1959) indicates it is successful in both Mediterranean and desert parts of Israel. Shaybani and Kashirad (1978) erroneously suggest that *A saligna* is an arid zone species. Its ability to tolerate high levels of salinity (in pot trials) and to accumulate Na and Cl to a greater extent than other arid zone species, led them to suggest that it may be a useful species for arid and semi-arid, salt-affected areas. Although it tolerates moderate drought (El Lakany 1987), its natural distribution within a Mediterranean climate suggests that it is unlikely to do well in arid zones without a water supply at depth.

Flooding

It will not grow in saturated soil (Roux and Middlemiss 1963). It does not occur in swamps but is found in swamp fringes (Watson and Bell 1981). Seedlings are able to respond to additional moisture. This is consistent with good growth of *A saligna* along road-sides where trees benefit from water-shedding (Fox and Wallman 1979).

Salt

Kuwait experience suggests that it is not tolerant of high salinity (Salem 1977). However, it is believed to have high salt tolerance and potential for use in salt-affected areas in Iran (Shaybany and Kashirad 1978). Salt treatments reduce all growth components except the stem tip to stem base diameter ratio. Salt reduces cell elongation but lateral enlargement is less affected. Decreased shoot:root ratio is an adjustment to increasing salinity as the proportion of water absorbing organs is increased (Shaybany and Kashirad 1978). Salt concentration in sand culture of 96-144 meq l^{-1} is required for a 50% reduction in growth. At increased salt levels, the content of Na increases more in roots and Cl more in shoots, suggesting that *A saligna* can take up more salt than some other salt-tolerant species and that Na is less mobile within *A saligna* (Shaybany and Kashirad 1978). Spent phyllodes do not accumulate but are blown away so that if salt has been accumulated it is not deposited locally as

Table 4. Numbers and mean heights (m) of *Acacia saligna* at two years from field sowing into coal-mine inter-burden materials, by treatment categories. *

Category	Class 1 + TS		Class 1		Class 111 + TS		All	
	$\bar{x}$ height	n	$\bar{x}$ height	n	$\bar{x}$ height	n	$\bar{x}$ height	n
All plants	1.47 a	11	0.44 b	8	0.89 a	12	0.98	31
High P * (46.6 kg ha^{-1})	1.31	9	0.26	3	0.92	10	1.00	22
Low P * (23.2 kg ha^{-1})	2.05	2	0.54	5	0.77	2	0.93	9
+ Lime *	1.53	3	0.65	3	0.97	6	1.03	12
No lime *	1.45	8	0.31	5	0.82	6	0.95	19

*Numbers of plants too few for significance between individual treatment comparisons, and no plants established on Class 111 without topsoil (TS = topsoil added).

with other plants of smaller foliage (Litav 1957).

It is currently under trial in Pakistan, with 1-year old seedlings planted at Peshawar, attaining a mean height of 2.06 m at 16 months on sodic to saline-sodic soil subject to seasonal water-logging (Hussain and Gul 1993). Survival is reported as 60%. This performance is poorer than for several other Australian species trialled, including the tropical analogue *A ampliceps*.

Structure and Physiology

Morphology

Seed coat thickness is 190 µm. Cavanagh (1980) stresses the importance of the strophiole or lens in imbibition. This is a specific area of short epidermal cells forming a small raised area of the seed coat close to the hilum on the opposite side of the micropyle.

Epidermal cells between veins of the phyllode are thin walled, the epidermis is smooth in transverse section and the main vascular strands are united to form bicollateral bundles (Pettigrew and Watson 1975).

Wood structure is described by Fahn (1959) as diffuse-porous with growth rings absent. Vessels prevail in multiples of 2-4 (9), radially, diagonally or even tangentially oriented; maximum tangential diameter is 200 µ and vessel lengths are from (60) 100-270 µ. Perforations are simple and mostly transverse but diagonal perforation plates also occur. Intervascular pitting is alternate and pits are vestured, medium-sized with a linear aperture. Tyloses are absent but gummy deposits occur. The wood parenchyma stores starch and is paratracheal, of the aliform-confluent type. Vertical strands of cells contain rhomboidal crystals. Rays are homogeneous with cell diameters 10-33 µ, 1-3 (4)-seriate, 2-30 cells high and occur at 3-6 per µm. Ray cells contain yellow gummous deposits but no starch grains. Fibres are moderately thick-walled with groups or solitary gelatinous, thick-walled fibres amongst them. Fibre lengths are 0.37-1.0 µm (Fahn 1959).

Mycorrhiza

Nakos (1977) gives the rate of C_2H_2 reduction (mm g^{-1} FM h^{-1}) as 4.0. The rate declines with droughting. Nodulation is evident in pot culture by 8-9 weeks and is not hindered by low levels of applied nitrogen (Fox and Wallman 1979). There is some evidence that nodule formation on seedlings is faster for plants grown in their native soils (Davies *et al.* 1989). It is associated with vesicular-arbuscular mycorrhiza (Reddell and Warren 1987).

Perennation, reproduction

It is a short-lived evergreen species, in contrast with the winter deciduous habit of most native South African species (New 1984). Newbey (1968) noted an ability for rapid growth and indicated *A saligna* may only live for about eight years in Western Australia. On coal mine waste dumps seven years is noted above. It has a life-span of 17-18 years in Libya (Puecher-Passavalli 1935).

After pre-sowing treatment, mean days to emerge from sowing at 5 mm is 18-23 days (Davies *et al.* 1989). Densities of up to three million seedlings ha^{-1} occur nine months after fire in South Africa (Milton and Siegfried 1981). Young plants can reproduce by suckers (Messines 1952). Sale (1948) reports harvesting by uprooting trees in winter, leaving a hollow that becomes surrounded by a ring of root shoots and seedlings to renew the stand.

Chromosomes

Chromosome number is presumed to be 2n = 26.

Physiological data

Photosynthesis

Cambium is active all year, peaking in spring with shoot and foliage growth. A broad starch-free zone is present in peripheral xylem during periods of relatively low cambial activity (Fahn 1959). Exposure to increased salt results in more rapid decline in photosynthesis than in respiration, with equal rates of net CO_2 fixation and evolution at higher salt levels. Salt effects are due more to Na and Cl ions influencing photosynthesis than to a loss of chlorophyll content (Shaybani and Kashirad 1978). Reduced P uptake in shoots at high salt is attributed to specific inhibitory effects of NaCl on the metabolic carriers responsible for anion absorption. A decrease of K and Ca in both roots and shoots is related to Na uptake. Salt is also associated with preferential accumulation of P, Mn, Fe and Mg in root tissues (Shaybani and Kashirad 1978).

Chlorophyll

Leaf chlorophyll is reported as 5.8 mg dm^{-2} (Shaybani and Kashirad 1978).

Relative growth rate

Mean relative growth rate (RGR) for seedlings at 40-55 days from sowing is 0.0328 g g^{-1} d^{-1} (Davies *et al.* 1989). At this early stage there is correspondence between mean seed weight and RGR, plants from lighter seed having higher RGR.

Root growth

In pot culture, root depth penetration is rapid at *ca.* 7 mm d^{-1} (Witkowski 1994). Both extensive surface roots and main roots to considerable depths are developed in sand (Messines 1952). Roots apparently develop from branchwood when plants are buried in sand (Sale 1948).

Biochemical data

Seed N is 4.96% of dry mass (Witkowski 1994), marginally greater than for other *Acacia* species (Caffin *et al.* 1980). Seed P is 0.208% of dry mass (Witkowski 1994). Germinating seed of *Acacia saligna* emits a distinct odour of rotten fruit. Jones *et al.*(1963) demonstrated that cold-water extracts of newly germinated seed produce zones of inhibition of *Bacillus subtilis* and *Staphylococcus aureus* on agar medium. Cyanogenic glycosides are absent (Ramadan 1957).

Seed protein is 28.1% and oil content 13.6% (Pettigrew and Watson 1975). Lopped material has a crude protein content of 12.8% (Dumancic and Le Houérou 1981). Foliage contains 3 major groups of 18 polyphenic compounds (El Sissi and El Sherbeiny 1967). Maiden (1889) reported that it produced a gum arabic. Several informants have told me this was used by early settlers in the West Australian wheatbelt for chewing and sticking paper. A clear gum will exude from wounds but is not consistent. It has a molecular weight of 189,000 (Anderson and Dea 1969) and contains high levels of uronic acid and rhamnose (Kaplan and Stephen 1967).

Phenology, Floral and Seed Characters

In Western Australia, flower buds form in May and grow for three-four months. Flowers open in August-September (October), pods grow for three-four months and dehisce in November to December (January). A similar pattern occurs in South Africa (Milton and Moll 1982). In Egypt, flowers occur in March and pods take 95 days to mature in June (Mahmoud Hussein 1984). Inflorescences appear in January in Israel and maximum shoot and foliage development in March-May (Fahn 1959). In Western Australia, new foliage growth is greatest in spring (Majer 1979) and early summer. A dramatic flush of new growth occurs in spring (Milton 1980). Most litter fall occurs in late summer and litter fall in established thickets is *circa* 700 g m^{-1} y^{-1} (Milton 1980).

Some trees have predominantly large phyllodes and others predominantly narrow. Maslin (1974) notes that De Candolle commented on a narrow phyllode variety in 1825 but a trial using progeny from parents of differing phyllode size discounted this (Fox 1980). Broad phyllode forms appear to be particularly common in plants growing on limestone soils near the sea. Seedlings watered to excess produce narrower phyllodes (Fox and Wallman 1979). In South Africa, both forms occur side-by-side and phyllode size and shape appear related to age and vigour (Milton 1978). Shape and size of mature phyllodes vary considerably and recognition of varieties is not warranted (Maslin 1974). Environmental factors appear to influence phyllode size.

Hybrids

Sale (1948) refers to a possible hybrid with *A longifolia* in Gaza. The closest species to *A saligna* is probably *A pycnantha*. These are allopatric in nature (Hopper and Maslin 1978), but in recent years *A pycnantha* has become naturalised on roadsides in the hills east of Perth. *A saligna* may be confused with *A rostellifera* near the coast and *A microbotrya* further inland, but fruit and seeds are distinctive (Maslin 1974). In the tropics of Western Australia, *A ampliceps* has a similar form, appearance and also grows mainly in moist habitats.

Seed production and dispersal

Seed production

In South Africa, seedfall is estimated at 5,400 seeds m^{-1} y^{-1} in *A saligna* stands. Most seeds in the ground are in the surface 80 mm and a period of eight years is necessary for the seed bank to accumulate 10,000 seeds m^{-1} (Milton and Hall 1981). Soil seed banks build up more rapidly than in Australia due to the absence of natural seed predators (Milton 1980). Seed yields are 170 kg ha^{-1} in Cyprus plantations (Ramadan 1957). In Australia, perhaps 80% of seed produced may be predated on the plant. Seeds fall directly from the tree and ants re-distribute them (Cavanagh 1980). In South Africa, seeds are partly dispersed by water (Milton and Hall 1981), by red-wing starlings (Smith 1966) and by baboons (Taylor 1969).

Seed mass data

Hall and Turnbull (1976) indicate there are 50-60,000 seeds kg^{-1}. This range corresponds to mean seed mass between 16.7 and 20 mg. In 1975 the FAO Forest Tree Seed Directory quoted *A saligna*

Table 5. **Mean seed masses reported for *Acacia saligna*.**

Source of seed	$\bar{X}$ mass (mg)	SD	Reference
Beersheva (Israel)	14		Kaul and Ganguli (1965)
Purchased (W Australia)	15.4		Doronila and Fox 1990
Jandakot (W Australia)	15.8	(3.5)	Davies *et al.* (1989)
Ilanoth (Israel)	16		Kaul and Ganguli (1965)
Bentley (W Australia)	16.2	(2.6)	Fox *et al* (1987)
South Africa	17.0	(2.6)	Witkowski 1994
Lesmurdie (W Australia)	17.7	(3.7)	Davies *et al.* (1989)
Australia	18		Kaul and Ganguli (1965)
Yalgorup (W Australia)	18.6	(3.4)	Davies *et al.* (1989)
South Africa	20.9		Roux (1961)

as 39,000 seeds kg^{-1} (mean 25.6 mg) and *A cyanophylla* as 58,000 seeds kg^{-1} (mean 17.2 mg) (Milton 1978). Other examples of seed mean masses reported are given in Table 5.

Mean seed mass does not appear to affect viability (Kaul and Ganguli 1965; Davies *et al.* 1989). Of whole plant dry mass, seed N is 4.96% and seed P is 0.208% (Witkowski 1994). Seed used in feeding by Ramadan (1957) had percentage composition: moisture 7.3; crude protein 30.7; ether extract 12.9; nitrogen free extract 30.9; crude fibre 13; and ash 5.

Viability and germination

Dormancy

Seed of *A saligna* in Western Australia is damaged by insect larvae (see below). The viability of freshly collected seed varies with the effectiveness of sorting to remove such damaged seed and undeveloped or aborted seed. The seed coat is impervious to water, restricting imbibition and functioning as a physical barrier to germination. A generally accepted method to remove this seed-coat dormancy is to treat seed with hot water (Larsen 1964). This and other treatments damage the testa allowing water to be taken up (Shaybany and Rouhani 1976). In nature, weathering results in the seed coat weakening with time.

The proportion of seeds able to germinate without any pre-treatment to damage the testa may be termed "soft seed". Cavanagh (1980) attributes soft seed to picking green and suggests that the condition may be maintained if stored at low temperature. Larsen (1964) obtained (2)-3.2-(6)% germination from five batches of untreated seeds. Shaybany and Rouhani (1976) report (1.5)-4.0-(7.5)%. Milton and Hall (1981) indicate that 2.3% of fresh seeds germinate without pre-treatment and that 3.6% of buried soil seeds do so, compared with 83% after treatment. Fresh seeds taken from the pod give 82% germination in ten weeks without pre-treatment, suggesting an after-ripening period is necessary for the testa to develop water impermeability (Milton and Hall 1981). Variability in the proportion of soft seed and the degree of ripeness implies that seed batches differ in both viability and the speed of germination. Figure 2 illustrates mean germination of three batches with five replicates, all pre-treated with boiling water and then subjected to one of three incubation temperatures (Davies *et al.* 1989).

Viability and ageing

There is no significant loss of viability between fresh seeds and six- and 12-month old seed (Shaybany and Rouhani 1976). Aveyard (1968) reports 20% germination from untreated 12-month old seed and only 4% from 24-month old seed, using the same batch (*ex* Albany 35° 02'S; 117° 53'E). This is attributed to an intensification of secondary dormancy with ageing. Hot water treatment increases germination to 62% and 24% for 12- and 24-month seed respectively. Mechanical scarification significantly increases germination in 12-month seed to 95% but is less effective (16%) than hot water with 24-month seed. The best result with older seed (51%) is with a more severe pre-treatment of soaking for 10 minutes in 36N H_2SO_4. This treatment also enables 50% germination of 12-month old seed (Aveyard 1968). There is an inevitable loss of viability with time although it is possible that the ageing process involves seed becoming more resistant to germination and this form of dormancy may require the more severe pre-treatment.

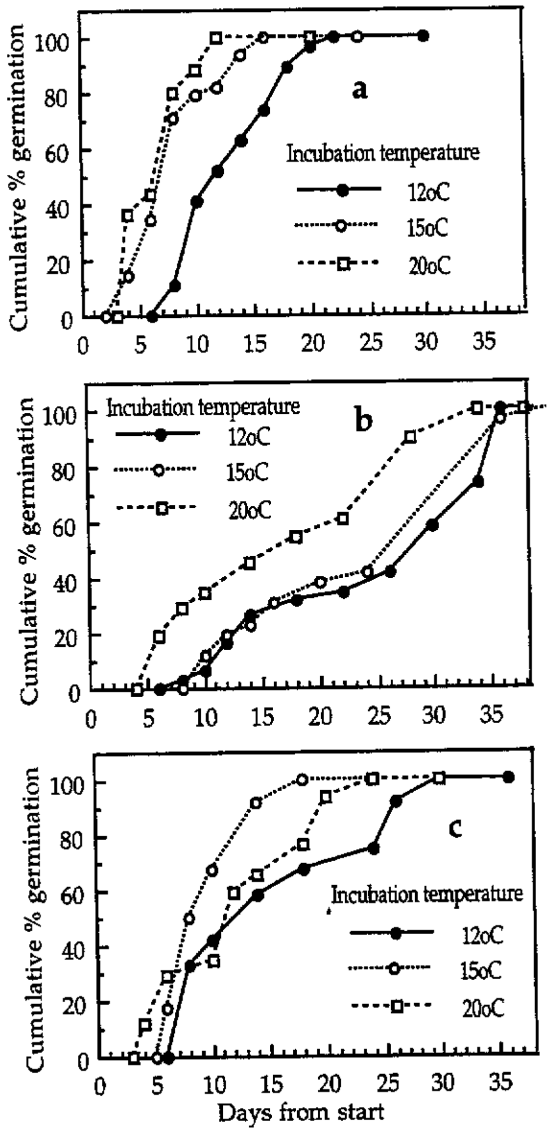

Figure 2. Time course of germination in unsorted seed of *Acacia saligna* incubated at three different temperatures. Values are percentage germination of the seed which germinated only. Seed sources a- Lesmurdie; b- Jandakot; c- Yalgorup (Davies *et al.* 1989)

Germination techniques

In the field, establishment of new plants from seed can occur naturally between May and September (southern hemisphere). In the laboratory, germination is inhibited if seeds are incubated at the extremes of 5 and 35°C (Shaybany and Rouhani 1976). These authors obtain best germination results with incubation at 15°C. Germination rate increases with temperature (Figure 2). Shaybany and Kashirad (1978) boiled seeds for ten minutes then incubated them at 15°C. Higher temperatures are reported by: Larsen (1964), with a mean result fromfive batches of 57%, at an incubation temperature of 25°C; and Kaul and Ganguli (1965) with up to 93% germination at 27°C, and no pretreatment reported.

Shaybany and Rouhani (1976) trialled a number of pre-treatments to break seed-coat dormancy. Best germination (98.5% in six days), follows soaking in concentrated H_2SO_4 at 50°C for 90 minutes. Exposure to boiling water for five minutes is slightly poorer (94.5%) and takes slightly longer for completion. Pouring boiling water on the seeds and allowing them to cool in the water, gives poorer results than boiling for five-ten minutes. Seed commences germination two days after soaking in 18N H_2SO_4 for 1 hour (Witkowski 1994). For most experimental purposes, and for field sowing, boiling seed for five minutes. is recommended. This is less likely to damage seeds than more severe treatments (such as acid treatments) and the proportion not germinating is likely to represent the soft seed component. Immersion in boiling water is widely used (Milton and Hall 1981; Larsen 1964). Micropylar chipping is favoured to ensure fast germination of seed extracted from soil (Holmes *et al.* 1987).

Light

Light does not affect the rate or level of germination (Milton and Hall 1981).

Seedling morphology

The first leaves produced are pinnately compound and tend to lie flat on the soil surface. Phyllodes commence development before all pinnate leaves are shed. Juvenile leaves can be lost by two months from sowing (Shaybany and Kashirad 1978). Seedling morphology is affected by light (Milton 1978). Seedlings in shade retain juvenile leaves to six months compared with four months in sun. Phyllode production is greater in shade at six-eight months but not thereafter. In darkness, hypocotyl elongation is promoted at the expense of root development and seedlings develop a broad flange of tissue between the hypocotyl and the root. This flange may hinder the seed being moved deeper into the soil by the upward thrust of the growing shoot (Milton and Hall 1981).

Herbivores and Disease

Animal feeders and parasites

Acacia saligna is believed to support a more diverse and abundant range of invertebrate herbivores than other species of *Acacia* in south-western Western Australia (Majer 1979). Between mid-September and early November, 10 trees at Manning, Perth (32°01'S, 115°55'E) of mean height 1.8 m, sampled by beating, on six occasions, yielded a total of 121 invertebrate taxa. Nine ant species accounted for 41% of the total catch and herbivores comprised 69 taxa and 46% of the catch. The most numerous groups of apparent foliage feeders were Hemiptera 19 taxa (38%), Coleoptera 23 taxa (33%), and Lepidoptera 14 taxa (21%).

Sucking bugs are perhaps the most important insect feeders on *A saligna*. It supports some 40 species of Hemiptera (Berg 1980c). In the Perth area, large numbers of the Crusader bug (*Mictis profana* Fabricius (Hemiptera: Coreidae [Coreinae]) can be seen on tall specimens of *A saligna* during spring and summer. These suck sap from phyllodes resulting in yellowish foliage. They may also damage pods in late spring. Rutherglen bug-*Nysius vinitor* Bergroth (Hemiptera:Lygaeidae [Orsillinae]) is migratory (Farrow and Drake 1991) and capable of building large populations following a wet winter and a mild spring. It is considered a possible pest of cultivated stands, sucking sap from young shoots and causing severe wilting (Angel and Glencross 1993). Other hemipteran herbivorous taxa reported by Majer (1979) include Aphididae, Cicadellidae, Delphacidae, Derbidae, Margarodidae, Membracidae, Nogonidae, Pentatomidae, Piesmidae and Psyllidae. Heavy infestation of the Daspididae scale *Lindingaspis rossi* Mask is reported from Zagazig, Egypt in autumn and early winter (Swailem *et al.* 1980).

Some 55 species of beetle occur on *A saligna* (Berg 1980b). Seed eating weevil larvae of *Melanterius* and *Diethusa* collectively reduce seed numbers by a fifth of annual production (Berg 1977). *Melanterius* species (Coleoptera: Curculionidae [Cryptorhynchinae]) attack seed pods (Lawrence and Britton 1991). The larvae of *Pyrgoides* sp. (Coleoptera: Chrysomelidae [Chrysomelinae]) feed on developing flowers (Berg 1977) and adults of other chrysomelids (Coleoptera: Chrysomelidae [Cryptocephalinae: Cryptocephalini]), are foliage feeders of *Acacia* generally. Larvae of the latter feed on dead leaves on the ground and live in close-fitting portable cases (Lawrence and Britton 1991).

Macrobathra bigerella Walker (Lepidoptera: Oecophoridae) feeds on *A saligna* (Berg 1977). Larvae of the inous blue, *Jalmenus inous* Hewitson, (Lepidoptera: Lycaenidae) feed at night on *A saligna* in October-December. Larvae rest along stems, just below ground level during the day and are attended by numerous small black ants (*Iridomyrmex gracilis*). Pupae are attached to the stem, also just below ground level or to fallen leaves or other ground debris (Common and Waterhouse 1972). A leaf miner, *Labdia* sp. (Lepidoptera: Cosmopterigidae) attacks it in Australia (New 1979) and another species, *Parectopa citharoda* Meyrick, occurs on *A saligna* in New Zealand (Watt 1920). At least 36 species of Lepidoptera are recorded on *A saligna* (Berg 1980a).

A species of Atoposomoidea (Hymenoptera: Eulophidae) is a gall former in pods and phyllodes (Berg 1977).

The comparatively soft wood of *A saligna* breaks down rapidly, partly due to the activities of borers, although bark from large specimens is often long-lasting. *Maroga melanostigma* Wallengren (Lepidoptera: Oecophoridae [Xyloryctinae]) may ring bark stems (Nielsen and Common 1991) and also feeds on bark (Berg 1977). *Ancita* species (Coleoptera: Cerambycidae [Lamiinae]) tunnel in sapwood and branchwood of *Acacia* species (Lawrence and Britton 1991).

Some 18 species of ants have been noted as present on *A saligna* and some, at least, appear to forage for nectar extruded from the phyllode gland (Majer 1979). Introduced snail species can be seen on short specimens at coastal locations *eg.* Woodman Point (32°08'S, 115°44'E) and Eagle Bay (33°33'S, 115°04'E).

Plant parasites and plant diseases

The mistletoe *Amyema preissii* occurs on *Acacia saligna* at Clackline (31°43'S, 116°31'E) but is more frequently found on *Acacia acuminata*, a slower growing species with finer foliage (Southall 1978).

Uromycladium tepperianum (Sacc) McAlpine is a rust fungus common on *A saligna*. It is manifested by brown, globose, corky galls 5-70 mm diameter on stems, phyllodes, peduncles and fruit (Gathe 1971). Inflorescences may be deformed, witches brooms develop and juvenile foliage produced. The latter symptom suggests hormonal dysfunction. Berg (1977) reports >90% infestation as common on *A saligna* in Western Australia. In New South Wales, *A saligna* trees are not infected whereas adjacent specimens of *A mearnsii* De Wild are badly affected. This phenomenon suggests the occurence of species specific races of the rust. Galls may be utilised by Lepidoptera and Curculionidae (New 1984).

Other diseases (Shivas 1989) are caused by *Acremoniella verrucosa* Tognini (a leaf spot); *Armillaria luteobubalina* Watling and Kile (root rot); *Camarosporium* sp. (phyllode spot); *Schizophyllum* sp.; and *Septoria* sp. (phyllode spot). A ring spot disease of *A saligna* in Sardinia may be viral, it is transmitted by grafting (Marras 1962).

Lime induced iron deficiency causing chlorosis is reported from Israel (Karschon 1964). The phenomenon occurs on soils high in calcium carbonate and also on saline alluvial soils with a high water table. Soil application of chelated iron produces greening of foliage in five weeks.

History

The first collection is attributed to Labillardière in 1792-93 by Maslin (1974). Labillardière named the species as *Mimosa saligna* in 1807. It was renamed as *Acacia saligna* by Wendle in 1820. Until the elegant revision of Maslin (1974), the name *A cyanophylla* was commonly used for plants in the Perth area (Blackall and Grieve 1954), and the southwestern botanical province generally, whereas *A saligna* was used for the occurrence of the species in the Eyre district, centred on Esperance in the south-east (Beard 1970). Maslin (1974) considered *A cyanophylla* var *dorrienii* to be *A rostellifera* and that *A leiophylla*, formerly considered synonymous with *A saligna* is a distinct species. The latter was later confirmed (Maslin and Whibley 1977).

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ECOLOGICAL NOTES ON *ACACIA* SPECIES. *ACACIA TETRAGONOPHYLLA* F MUELL.

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Abstract

This article summarises biological and ecological information on *Acacia tetragonophylla* with respect to habitat; communities; response to biotic factors and environment; structure and physiology; floral and seed characteristics, herbivores, disease, related species and uses. *A tetragonophylla* has a wide distribution across central and southern Australia. It is mainly a species of the drier interior, often associated with *A aneura* (mulga). The phyllodes are four-sided and spiny which gives the shrub a prickly appearance. The plant bears yellow, rounded heads of flowers in winter and papery curved or twisted pods in late spring and summer. It has some value as a fodder but has not been cultivated. It has been used in traditional Aboriginal medicine.

Introduction

Acacia tetragonophylla is a species of the Australian arid zone. Its common names are dead finish or kurara (curara) (Simmons 1988). Aboriginal names for this species in Western Australia are Tjilkaru in the Ashburton region and Wakalpuka in the Warburton Range (Reid 1977). The species name describes the four sided phyllodes, and is derived from Greek words (tetragonous meaning with four angles and phyllous meaning leaf-like) (Sharr 1988). *A tetragonophylla* is often a subordinate species to *A aneura* (mulga) that may become dominant on areas of greater moisture availability. It is used in rehabilitation of some mine sites (Barrett and Jennings 1994; Osborne *et al.* 1994).

A tetragonophylla is a prickly, much branched, shrub (occasionally with a small single stem) of 1.5-4.0 m in height. Bark at the base of the trunk is fissured while that on younger stems is smooth and grey. Phyllodes of *A tetragonophylla* are bright green, angular and spiny, typically fascicular. The phyllodes are often 30 mm long, terete and usually clustered in fascicles of three or four. Phyllodes are soft when young but tips become rigid and sharp with age (Mitchell and Wilcox 1988).

Geographical Distribution

A tetragonophylla is a wide-spread arid zone species. It is found in all states of Australia with the exceptions of Victoria and Tasmania (Mitchell and Wilcox 1988). It occurs between latitudes 21 and 33°S (Thomson 1986). In Western Australia it is found in the southern Kimberley, north-west, north, central south-west and southern Eremean zone and the central and northern wheatbelt (Maslin 1982). In Queensland it is restricted to the south-western subtropical part of the State (Pedley 1979) and in western New South Wales it is common throughout the north-western section of the region (Cunningham *et al.* 1981).

Habitat

Topographical and climatic limitations

Acacia tetragonophylla occurs in areas with a median annual rainfall of 100-450 mm with a reasonably high incidence of frost (Thomson 1986). It is commonly found growing on heavy loams along water courses and on lighter soils in creek lines (Tame 1992; Davies 1976). It assumes dominance over *A aneura* on areas receiving more concentrated run on.

Substrates

A tetragonophylla is associated with a variety of soils (Simmons 1988) from sands to clays, both acidic and alkaline (Thomson 1986). It is a component of tall open shrublands of *A ramulosa/A linophylla* (horse mulga/bowgada) on sand dunes and sandy rises in claypans in Western Australia (Neldner 1986). It may occur on soils with reasonable levels of soluble salts (Thomson 1986). In Western Australia it is most common and abundant on loams and lighter textured, infertile, base deficient soils (Curry *et al.* 1994). It also occurs on shallow soils, flood plains and skeletal soils of hills and rocky slopes of Western Australia (Mitchell and Wilcox 1988). In New South Wales it occurs on red earths in mulga communities and on sand plains and gravelly ridges in bimble box communities (Cunningham *et al.* 1981).

Communities

This species is often associated with mulga (*Acacia aneura*) and appears to be replacing mulga on some sites in the Fortescue Valley (Fox and Dunlop 1983). It is common in mulga groves *eg.* with trees of *A aneura, A pruinocarpa* and *Hakea suberea* and shrubs of *Eremophila forrestii, E latrobei, Canthium latifolium* and *Cassia desolata* of the Coondiner land system (Wilcox and Fox 1995) on Marillana Station (22°38'S, 119°24'E). Where this species occurs with mulga it is often less common than the mulga. It also occurs with *A victoriae* on moister sites where stock have removed the more palatable perennial shrubs (Fox 1986).

Drainage tracts are a common arid zone habitat for Curara in Western Australia. At Mileura (26°15'S, 117°11'E) Fox (1979) reported it in such sites subordinate to trees of *A aneura* and *Grevillea striata* with other perennial shrub species including *A kempeana, Eremophila fraseri, E. longifolia, E spathulata, Cassia helmsii, Pittosporum phylliraeoides, Santalum lanceolatum* and *Scaevola spinescens.* At Albion Downs (27°17'S, 120°23'E) *A tetragonophylla* is an understorey to *A aneura* on red earth with hardpan. Associated shrubs include *Eremophila* species and *Canthium lineare.* Ground cover at this site includes *Ptilotus exaltatus, Maireana triptera, Rhagodia* sp., and *Spartothamnella teucriiflora* with the grasses *Aristida arenaria, Danthonia bipartita* and *Eragrostis setifolia* (Fox 1981).

In the Wiluna (26°35'S, 120°14'E)-Meekatharra area (26°36'S, 118°30'E), Speck (1963) described five communities with *A tetragonophylla* as forming a sub-alliance with mulga. The *A aneura-A tetragonophylla* community is somewhat variable, open and depauperate. The upper storey of these two is seldom taller than 3 m. Associated shrubs include *Eremophila fraseri, E margarethae, E georgei* and *Cassia* species. Often the understorey is restricted to *Solanum ellipticum* and *Ptilotus obovatus.* Characteristic grasses are the short annuals *Aristida arenaria, Eragrostis dielsii* and *Eriachne pulchella.* Small chenopods and succulents may be present. This community occurs on shallow red earths on hard-pan in alluvial plains. A second community, *A pruinocarpa-A aneura-A tetragonophylla,* is similar floristically but less depauperate with *A pruinocarpa* trees to 6 m in height. It occurs on slightly deeper soils of alluvial plains and fans. The *Hakea lorea-A tetragonophylla-Triodia basedowii* community consists of a moderately dense spinifex (*T basedowii*) layer with *Danthonia bipartita* and sparse forbs in spaces between spinifex clumps. The tree layer is very open and shrubs of *Eremophila fraseri* and *E maitlandii* are few. It is restricted to broad sandy tracts. The *Grevillea striata-A aneura-A tetragonophylla* community is an open woodland with trees of *G striata, Hakea lorea* and *Acacia pruinocarpa* to 7 m tall. *A aneura,* as a small tree (4 m), and *A tetragonophylla* as a tall shrub, form clumps within the community. *Eremophila fraseri* and several *Cassia* species form an open shrub layer. The short annual grasses *Aristida arenaria* and *Eragrostis dielsii* are present. This community occurs on alluvial and drainage floors, and where these floors grade into saline alluvial plains halophytic species are present in lower layers. The fifth community is of *A tetragonophylla-A burkittii-Atriplex rhagodioides-Rhagodia* sp. Speck (1963) notes that this community has suffered considerable degradation and formerly carried a denser tree layer and more palatable saltbush and bluebush. It now carries a sparse upper tree layer (*A burkittii*), a sparse tall shrub layer (*A tetragonophylla*) and an open shrub layer of halophytes or salt tolerant species (*Atriplex rhagodioides, Rhagodia* sp., *Eremophila laanii, E macmillaniana* and *Cassia sturtii*). This community is limited to saline or slightly saline alluvial flats and flood plains.

Of 36 site types described for the north-eastern Goldfields of Western Australia (Pringle 1994), 30 contain *A tetragonophylla.* In 20 sites it is not present as a dominant species. In four sites it is recorded as a tall shrub (>2 m) and in another six as a mid-shrub (1-2 m tall). In the Murchison River catchment *A tetragonophylla* occurs as one of the dominant species on eight of 23 major vegetation types (Curry *et al.* 1994). These types account for 49% of the area surveyed. *A tetragonophylla* is mainly described as a tall shrub of *Acacia*-dominated shrub lands, on non-saline loamy soils, but is a mid-shrub on granitic mulga shrub lands.

Response to Biotic Factors

Caterpillars are commonly found on this shrub following high summer rainfall. As a consequence it often loses many phyllodes. This can lead to reduced fruit production in years when rainfall is heavy in comparison to years in which rainfall is only moderate (Davies 1976). In the Pilbara, Western Australia, we have observed the spur-throated locust (*Nomadacris guttulosa*) in high numbers on *A tetragonophylla*. *A tetragonophylla* is readily grazed by sheep in the Ashburton and Gascoyne regions but less readily in the Goldfields. Feral goats graze the species heavily.

Response to Environment

Gregariousness

Dense thickets of *Acacia tetragonophylla* are uncommon (Pringle 1994). It is a hardy, slow growing plant and persists under difficult conditions. Plant numbers increase rapidly in some mulga communities after their exclosure from grazing. It may be regarded as a decreaser species but should not be regarded as a sensitive indicator of range condition (Mitchell and Wilcox 1988).

Salt tolerance

This species is said to be somewhat salt tolerant and may be useful for growing in warmer climates (Simmons 1988). It is not usually found in saline habitats.

Effect of frost, drought and fire

A common name, dead finish, probably refers to the ability of *A tetragonophylla* to resist defoliation in drought conditions. Whilst this species loses some of its phyllodes in drought, these are replaced rapidly and the lower branches are never denuded as in many other species suffering water stress. As a result *A tetragonophylla* is grazed by stock during droughts (Mitchell and Wilcox 1988). It has the ability to produce new branchlets from lower limbs, an uncommon feature in arid zone *Acacia* species.

Fire in both the Pilbara (West Angeles: 23°05'S, 118°40'E) and the Goldfields (Menangina: 29°50'S, 121°55'E) will burn the tops out of *A tetragonophylla* shrubs but regeneration occurs from root stock (Fox and Dunlop 1983; Fox 1985). Seedling growth after fire has not been observed.

Structure and Physiology

Morphology

The slender, 4-angled, needle-like phyllodes are initially soft becoming rigid as they mature. The phyllodes are crowded on short lateral branches and are surrounded at the base by obtuse, ciliate bracts 0.5 mm long. Phyllodes are 10-30 (60) mm long and 1 mm broad (Cunningham *et al.* 1981) or up to 28 mm long and 3 mm in diameter at Lakeside (27°35'S, 117°30'E) (Hellmuth 1971). Phyllodes possess a thick cuticle and sunken stomata. Green phyllodes are soft whereas yellowish phyllodes are stiff (Hellmuth 1971). There is one prominent vein (rarely two) on each face. Each phyllode is pungently tipped with the point being up to 1 mm long.

A form of *A tetragonophylla* near Advale, Queensland is a tree to 6 m tall. The branches are pendulous and weeping and the phyllodes are less sharp and brittle than usual (Simmons 1988). Fox (1979) reported shrubs of *A tetragonophylla* at Mileura reaching 6 m tall.

Reproduction

Only a small amount of seed is produced despite heavy flowering. However, numerous seedlings have been observed during a sequence of good years (Cunningham *et al.* 1981). *A tetragonophylla* can be successfully grown from either cuttings or seeds.

Growth rate

Relative growth rate (RGR) of *A tetragonophylla* is reported as 0.017-0.028 g g^{-1} day^{-1} (Fox *et al.* 1987). Seedlings are believed to be moderate to fast growing (Fox 1986). However, as it matures the tree is generally believed to be slow growing. Jurado, Westoby and Nelson (1991) suggest *A tetragonophylla* may have a life span of >50 but <100 years.

Biochemical data

The heartwood of *A tetragonophylla* contains the following flavonoids; flavonol, chalcone, flavanone, 3-methoxyflavone, 3-hydroxyflavanone, flavan-3,4-diols and 7,3',4'-trihydroxy-8-methosyflavan-3,4-diols (Clark-Lewis and Porter 1972). The seeds of *A tetragonophylla* have crude protein levels ranging from 6 to 16% (Mitchell and Wilcox 1988).

Physiology

At Lakeside, both net photosynthesis and transpiration are higher in late summer than in winter for *A tetragonophylla*. The increase in net photosynthesis is higher than in transpiration (Hellmuth 1971). These patterns differ from *A acuminata* and *A craspedocarpa* where both net photosynthesis and transpiration decrease under late summer soil moisture stress, but photosynthesis declines less than transpiration. Increased daily net photosynthesis in *A tetragonophylla* may be related to age of phyllodes or high temperature dependence. In the study by Hellmuth (1971), phyllodes of *A acuminata* and *A craspedocarpa* were yellowish in summer in contrast with green phyllodes on *A tetragonophylla*. Net photosynthesis did not peak for *A tetragonophylla* in winter but the plant assimilated near its maximum capacity at optimal and near-optimal phyllode temperatures (39°C) in late summer. The decline in CO_2 uptake in more mature, yellowish phyllodes may be due to increased phyllode resistance (Hellmuth 1969). Such phyllodes, tested in winter, assimilated CO_2 at only half the rate of green phyllodes (Hellmuth 1971).

Phenology

The flowering period of this species is generally from late winter through to spring (Tame 1992). Legumes are produced from September to December, but cold weather at flowering may prevent any fruit set (Davies 1976). The twisted, papery pods remain on the bush after the pod has dehisced. The separate valves of the open pod act as shelves on which the seed is displayed to possible distributors (Davidson and Morton 1984). The pods remain on the bush for a long period of time, often until the next flowering period (Pedley 1979).

Floral and Seed Characteristics

Floral morphology

The yellow flowers are 5-merous with linear sepals. The calyx is 0.9-1.0 mm long and united for about two thirds of its length. Both petals (1.5 mm in length) and ovary are glabrous. Stamens are 3-4 mm long. Flowers are arranged in dense rounded heads that can occur singly or in clustered groups of up to five heads. The heads are on glabrous axillary peduncles, 10-15 mm long and the bracteoles are petiolate (Pedley 1979). Each head is approximately 10 mm in diameter and contains 50 or more flowers (Simmons 1988).

Seed production and dispersal

Seeds are produced in pods 30-100 mm x 4-8 mm, evenly constricted between the seeds. The papery pods are convex and curved or twisted. The seed is 4-5 mm x 3 mm and has a mean weight of 13-20 mg (*eg.* 13 mg: Oliver and Fox 1992; 17 mg: Fox *et al.* 1987; 20 mg: Osborne *et al.* 1994). Seed is black, roundish and flattened and arranged in a longitudinal manner in the legume. A thick, orange-red to yellow funicle circles the seed (Tame 1992). The red colour is considered attractive to birds.

Seed matures from October-January. Zebra finches (*Poephila guttata*) have been observed to take seeds from immature pods on plants growing near water (Fox 1995) and may disperse seeds. Davidson and Morton (1984) implicate several species of birds, including the singing honeyeater (*Lichenostomus virescens*) and the spiny-cheeked honeyeater (*Acanthagenys rugfogularis*) as possibly contributing to seed dispersal. Several ant species including the *Rhytidoponera mayrii* species group, *Rhytidoponera metallica* species group and *Melophorus* species are also noted as moving seed (Davidson and Morton 1984). We have observed that numbers of small *A tetragonophylla* shrubs are often highest under perch trees (such as *Atalaya hemiglauca*) used by dispersing birds, or on ant mounds.

Viability and germination

As with many *Acacia* species, seeds of *A tetragonophylla* are hard-coated. The conventional treatment prior to sowing is to pour boiling water onto seeds which are allowed to cool in the water to room temperature. Larsen (1964) obtained 58% germination after this pre-treatment. Seed batches treated in this way at Curtin University have given germination of 30-60% (Fox and Dunlop 1983), and 60-80% (Oliver and Fox 1992). Higher germination levels within a batch tend to be obtained when seed is incubated at 20°C (Figure 1). It is likely that there is an optimum temperature range for maximum germination. A certain proportion of a seed batch will germinate without pre-treatment, generally 10%, *eg.* Newman seed (Fox and Dunlop 1983) and Tom Price (22°42'S, 117°47'E) seed (Osborne *et al.* 1994). This may be referred to as the soft-seed proportion. It may vary between batches of differing original quality and with time of storage.

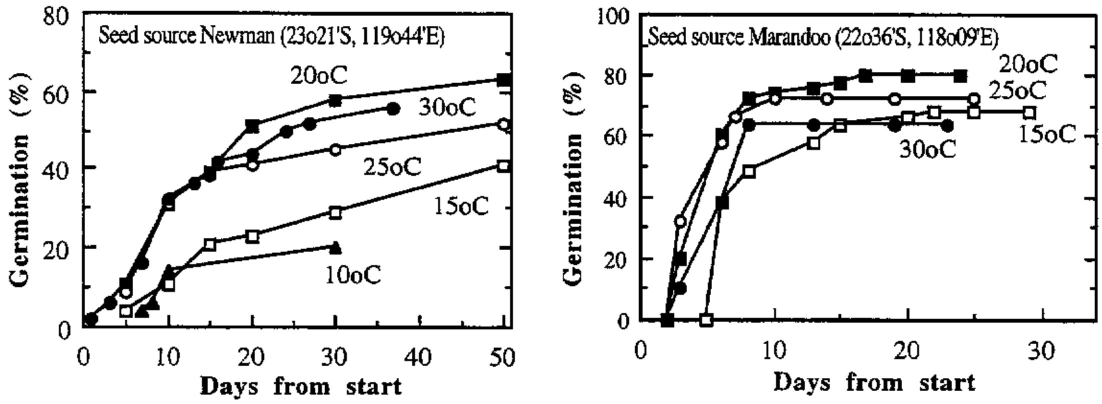
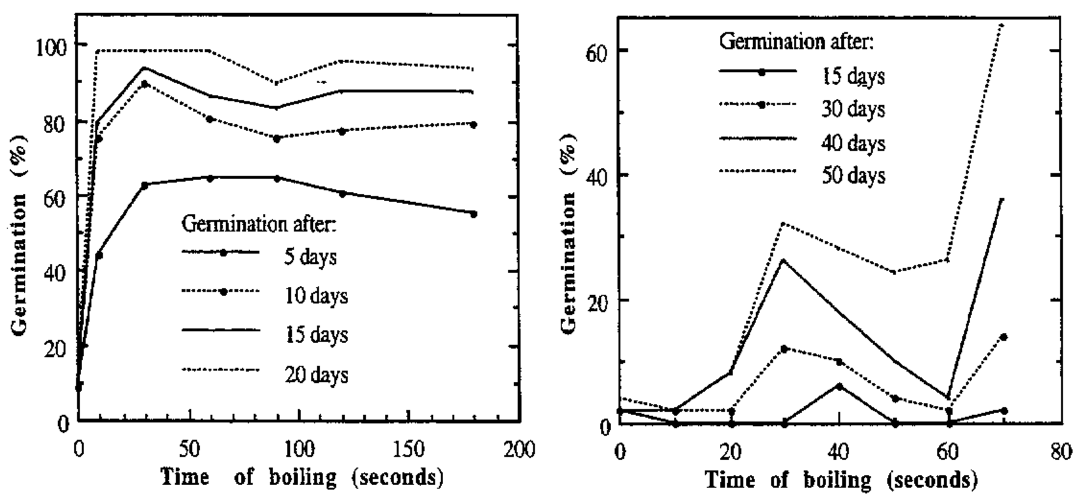


Figure 1. Percentage germination from Pilbara seed incubated at different temperatures following hot water treatment.

Seed exposed to increasing severities of heat pre-treatment will result in the harder seeds remaining capable of germination, mortality of the soft-seed proportion and increasing mortalities of intermediate seeds. Trials with different periods of time of exposure to boiling water are illustrated for two batches (Figure 2).

Two year old seed from Newman germinated up to a maximum of 90% after boiling times from 10-180 seconds, whereas fresher seed from Westonia (31°18'S, 118°42'E) germinated best after boiling for 70 seconds. The latter batch had only 4% soft seed and may have been either less viable or contained less intermediate seed. A batch of seed from Mt Keith (27°17'S, 120°31'E) on the other hand, with a high proportion of soft seed, germinated poorly whichever boiling times were used (Osborne *et al.* 1994). Similarly, Stewart (1991) reported that seeds boiled for 20 seconds did not germinate as well as an untreated control. A batch of Westonia seed (Figure 3) had a very small amount of soft seed (2%) and attained 80% germination when boiled for between 30-90 seconds.



Two year old seed from Newman

Six month old seed from Westonia

Figure 2. Percentage germination after various times of exposure to boiling water. Newman seed incubated at 20°C; Westonia seed incubated at 25°C

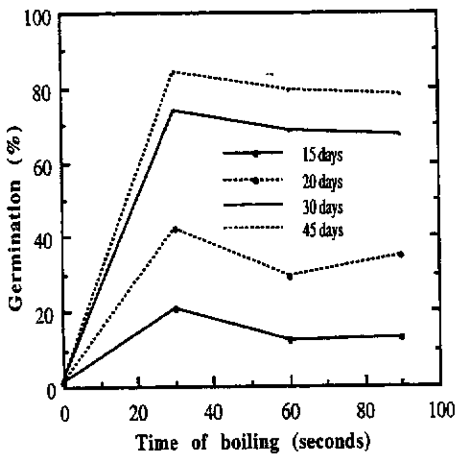


Figure 3. Percentage germination of three year old Westonia seed incubated at 20°C, after boiling for various lengths of time.

Manually nicking the seed coat increased germination of *A tetragonophylla* seed from the Goldfields (Barrett and Jennings 1994).

Seedlings

Seedlings grow well in fertilised clay soils compared with unfertilised clay and shale materials (Fox *et al.* 1987).

Herbivores

This species is a useful fodder for stock, feral goats and emus during drought periods when there is little else available for animals to eat, particularly since the lower branches retain foliage. Phyllodes are generally grazed only when young and soft. Foliage contains low levels of protein and a high proportion of fibre giving phyllodes low nutritional value. In western New South Wales *A tetragonophylla* is regarded as a valuable drought fodder plant (Cunningham *et al.* 1981). *Acacia tetragonophylla* is grazed by caterpillars resulting in severe defoliation.

Related Species

Taxonomically *Acacia tetragonophylla* belongs in the Phyllodineae and is one of few relict taxa with no close relatives in the arid zone (Maslin 1982).

History

The lectotype of *Acacia tetragonophylla* was collected by Dalley and Goodwin on the Darling River in 1859 (Tame 1992). Syntype specimens were collected from Coopers Creek by Murray and from Gaginga Mountains by Beckler in 1960.

Uses

Aboriginal peoples of the arid zone use *Acacia tetragonophylla* for many purposes including using wood ash for treating wounds and phyllodes for treating warts (Bodkin 1990). Ash from bark-free wood is applied as an antiseptic to wounds after circumcision. Acute pain follows the application but after about half an hour the pain disappears and the wound heals rapidly (Reid 1977). Sepsis was apparently rare when ash was used to treat spear wounds. Warts are treated by inserting the points of about three phyllodes under the wart. The wart is said to wither after about an hour and can then be pulled out. Phyllodes of *A tetragonophylla* are chewed to cure dysentery (Reid 1977). Seeds can be ground to make cakes and a cough medicine can be obtained by soaking the roots and bark in water (Urban 1990). The aril of the seed has a high oil content. Honey has been made from this species (Lazarides and Hince 1993). Cossid moth (*Xyleutes leucomochla*) lavae, known as witchetty grubs and widely eaten, are often found in the roots of *A tetragonophylla* (O'Connell *et al.* 1983).

The wood of *A tetragonophylla* was probably used for timber. The timber is close grained, heavy and tough, reddish brown with pink stripes and smells of violets when cut (Simmons 1988). Boomerangs are made from the wood (Van Vreeswyk 1995).

A tetragonophylla can be a useful soil-binding plant in sandy areas (Cunningham *et al.* 1981).

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REVIEW OF THE ECOLOGICAL CHARACTERISTICS OF *ACACIA VICTORIAE* (BENTH) IN MITCH

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Abstract

This article summarises biological and ecological information on *Acacia victoriae* with respect to habitat; communities; response to biotic factors and environment; structure and physiology; floral and seed characteristics; herbivores and disease; related species and usefulness. *A victoriae* has a wide distribution across Australia, mainly between latitudes 8° and 18°S in hot, arid and semi-arid areas. It is most commonly found on alluvial plains, in open woodlands and shrublands. *A victoriae* grows as a shrub or tree rarely to 8 m in height. Its phyllodes, though variable, are generally thin, short and flattened with a pair of basal spines. The plant bears small cream to lemon-yellow flowers, clustered in paired inflorescences in spring. Papery, oblong to linear pods are borne in late spring and summer. It has some potential as a food for humans, and its salt tolerance and rapid growth have made it a useful species in land reclamation and minesite rehabilitation.

Introduction

Acacia victoriae (Benth) in Mitch has been placed in an informal group of ten species. In a recent review Maslin (1992) provides keys to this group. In the past *A victoriae* has been confused with the newly described taxon *A synchronicia*. The account presented in the present paper applies to *A victoriae sensu* Maslin (1992).

Acacia victoriae is a very variable species growing as a shrub or tree from three, to occasionally eight, meters in height. The bark is grey-green, smooth or rough to fibrous. Branchlets are often pruinose, terete, ribbed and usually glabrous. The species has spiny stipules 2-12 mm long, phyllodes alternate, subsessile, linear to elliptic (15-80 mm x 2-10 mm) and usually glabrous, rarely sparsely hairy. Usually only the midvein is prominent and the phyllode apex ranges from acute to obtuse and sometimes mucronulate. Inflorescences are pale lemon-yellow to creamy-white, globular (4-6 mm across) and normally occur in pairs on long slender racemes. Peduncles are glabrous and 10-15 mm long. Sepals are narrowly spathulate, *ca* 0.5 mm long, glabrous and more or less free. The corolla is *ca.* 1.5 mm long, smooth and glabrous, apart from a minutely ciliolate-papillose margin of lobes. Seed pods are narrowly oblong (45-60 x 9-12 mm), glabrous, chartaceous and moniliform, with thickened margins. Seeds are globular to ellipsoid (3.5-6 x 2.5-4 mm), with a thickened funicle and small aril (Wheeler *et al.* 1992).

Distribution

Acacia victoriae occurs in all mainland states of Australia (Wheeler *et al.* 1992) although it is rarely found in north-west Victoria (Simmons 1987). It is found mainly between latitudes 8 and 18°S but does occur as far south as 35°S and is found at altitudes of 50-750 m (Turnbull 1986). In Western Australia it occurs from the Goldfields to the Kimberley (Mitchell and Wilcox 1988). The species has been introduced to Israel, Tunisia (El-Lakany 1987), Iran, Pakistan and, with little success, to West Africa (Thomson 1991).

Habitat

Topographical and climatic limitations

Acacia victoriae has a very wide distribution, most commonly growing on alluvial plains, gentle slopes and on sandy soils along watercourses. It generally occurs in open woodlands and shrublands but may form thickets. The species is distributed in hot to warm arid and semi-arid climatic zones with some populations extending further south into the warm sub-humid zone. Mean maximum temperatures range from 35-39°C and mean minimum temperatures from 5-10°C. *A victoriae* occurs in areas where the 50 percentile rainfall is mainly in the range 125-300 mm (Turnbull 1986).

Substrates

The species will grow on a variety of soils from sand to clay. It has been found growing on soils with high levels of soluble salts in the upper horizons (Thomson 1991) and is capable of growing on acidic to alkaline and shallow or deep soils (Turnbull 1986).

In South Australia *A victoriae* grows mainly on shallow, loamy and brown calcareous earths, neutral red duplex soils or crusty alkaline soils. In New South Wales it is found on heavy clay soils, sand plains, sand hills and the sandy alluvium of water courses. In Queensland the species grows on fine textured soils and grey-cracking clays (Turnbull 1986) and in Western Australia it is found on valley floors and floodplains with saline soils (Mitchell and Wilcox 1988).

Communities

Acacia victoriae occurs in a wide range of communities. It is found in hummock grasslands and mulga woodlands in the Pilbara of Western Australia with *Acacia pruinocarpa, A bivenosa, A tetragonophylla* and *Eucalyptus terminalis* (Van Etten 1987). In the southern shrublands of Western Australia it occurs with halophytes and calcioles. Commonly associated species include *Atriplex vesicaria, Maireana tomentosa, Stipa nitida* and *Dissocarpus paradoxus* (Van Vreeswyk 1995), *Maireana pyramidata, Hakea preissii, Rhagodia eremaea, Atriplex* spp., *Cenchrus ciliaris, Eremophila maculata, Cassia* spp. (Mitchell and Wilcox 1988), *Eremophila pterocarpa* and *Scaevola spinescens* (Speck 1963).

Response to Biotic Factors

If conditions are favourable for *Acacia victoriae*, it may out-compete the more palatable species such as *Atriplex* spp. and *Maireana* spp. (Mitchell and Wilcox 1988). *A victoriae* is described as a secondary species following the loss of *A aneura* in the Pilbara (Beard 1975).

Response to Environment

Gregariousness

Acacia victoriae is a rapid grower, often occurring as an isolated tree or in small groups. It may form dense thickets if it regenerates following high rainfall (Turnbull 1986). The species is able to colonise bare alluvial plains and if dominant in a community, it is an indicator of poor range condition (Mitchell and Wilcox 1988). The species may become a nuisance, particularly around watering points (Everist 1969).

In a study of changes in an *A victoriae* community over time, plants which started as similar sizes varied greatly in growth rate. Size is not a good indicator of age and it is unreliable to identify cohorts of *A victoriae* by examining size-class frequency distributions (Grice *et al.* 1994). This species is rather short-lived, senescing after 10-15 years (Cunningham *et al.* 1981) and tends to lose its leaves with age (Jessop 1981). After 11 years of study, only 27% of original individuals had survived (Grice *et al.* 1994).

Salt tolerance

A victoriae is considered salt tolerant by Simmons (1987). On saline mine wastes *A victoriae* was one of the most salt tolerant species tested (Stewart 1992).

Effect of drought, flooding and fire

In Australia the species is not tolerant of severe droughts (Turnbull 1986), although it has exhibited a high drought tolerance in trial plantings in Israel, Iran and Pakistan (Thomson 1991). If subject to moisture stress, the plant loses its phyllodes. A much branched species, *A victoriae* often has fine twigs that appear dead at the end (Everist 1969). Denuded branches generally fail to resprout after drought (Mitchell and Wilcox 1988). *A victoriae* has been grown in the north Negev (an area of low erratic rainfall) without irrigation (Forti 1983). In flooded areas establishment and growth of transplanted seedlings of this species is very good (Forti 1983).

A victoriae is moderately fire tolerant when young although mature plants have a low resprouting ability after fire (Turnbull 1986).

Structure and Physiology

Morphology

Phyllode morphology is sometimes very variable although phyllodes are generally thin, short, flattened, curved and yellow/green, measuring up to 30 mm long and 5 mm wide. At the base of most phyllodes are a pair of spines up to 5 mm long (Mitchell and Wilcox 1988). Phyllodes are attached by a small stalk with a gland near the base of the spines. Plants growing on sandy soils in central Australia generally have densely tomentose phyllodes and branchlets, and a Kimberley variant has pale yellow flowers and thin phyllodes (Thomson 1991).

Mycorrhiza

There are no reports of mycorrhiza in *A victoriae.*

Perennation and reproduction

A victoriae is a fast grower with a very high coppicing ability, particularly following high rainfall (Thomson 1991). With respect to shoot growth phases, arid zone species of *Acacia* generally tend to fall into two groups. Those such as *A victoriae,* show seasonal growth after spring flowering. Others grow mainly in response to summer rain (Maconochie 1973).

A victoriae often occurs along watercourses where seeds shed from pods may be carried by water to favourable sites for germination (Davidson and Morton 1984). Populations of the species are characterised by relatively frequent germination events and large viable seed banks in the soil. Seedling emergence is possible in both cool and warm seasons, given sufficient soil moisture. High levels of seedling mortality are common and only a small number of seedlings are recruited into adult populations during each recruitment event. Further study needs to be undertaken to determine if these recruitment stages are intermittent or frequent (Grice and Westoby 1987).

Biochemical data

Seeds of *A victoriae* have moderate levels of protein (17%) and fibre (29%) and a low fat content (3%) (Thomson 1991; Orr and Hiddins 1987). They are rich in carbohydrates (41%) (Thomson 1991) and have 1082 kJ of energy (Orr and Hiddins 1987). The heartwood flavonids of *A victoriae* contain 7,4'-flavan-3,4-diols and 7,3',4'-flavanone, 3-hydroxyflavanone and flavanone-3,4-diols (Clark-Lewis and Porter 1972).

Phenology, Floral and Seed Characters

In central Western Australia, *A victoriae* flowers from August-October with mature seed produced between October and December (Mitchell and Wilcox 1988). The northern populations flower between September and December with peak seed collecting around November-December (Thomson 1991) and in Victoria the species flowers November-December (Rogers 1993). Mature seeds are shed gradually from the pods (Thomson 1991).

Floral morphology

The flowering peduncles usually occur in pairs in the phyllode axils or along the raceme axis. Flowers are perfumed and clustered in numerous, small, paired inflorescences of 22-34 flowers (Jessop 1981) or 15-30 flowers (Maslin 1992). They are cream to pale lemon-yellow. The sepals are *ca.* 0.5 mm long and more or less free (Wheeler *et al.* 1992).

Seed production and dispersal

A victoriae has oblong to linear, fawn-coloured, papery legumes. These may be shed unopened or may open on the plant with seeds still attached by the funicle (Davidson and Morton 1984). Legumes are 9-16 mm wide (Maslin 1992). A proportion of seed-bearing pods may be retained on the bush after maturity (Thomson 1991). Seed may be carried by water in those populations associated with watercourses. The usually thick testa and spherical shape may be adaptive for this form of dispersal (Davidson and Morton 1984).

Mature seeds are dark brown and glossy with lighter brown mottles (Maier and Fox 1992). Seeds are 4-6 mm long, 2.5-4 mm wide and 2-4 mm thick and transverse in pod. The seed stalk is straight or folded, thickening into a small aril (Simmons 1987). Mean diaspore mass recorded for *A victoriae* collected at Fowler's Gap (New South Wales) is 26.50 mg (Grice 1979); from Alice Springs is 46.50 mg (Jurado *et al.* 1991) and from Sandhill (Pilbara, Western Australia), 9.62 mg (Fox and Davies 1982). Seed of the species is obviously very variable although the larger seeds collected from Alice Springs may be *A victoriae* subsp. *arida* found in the area (Pedley 1979).

Viability and germination

Seed of *A victoriae* can retain a relatively high percentage viability after a number of years storage. Some results obtained from investigation of the longevity of seed lots stored for 14 and 18 years indicated a decrease in viability from 96% (pre-storage) to 86% after 14 years and from 80% (pre-storage) to 60% after 18 years (Doran *et al.* 1983). Germination of 1.5, 2.5 and 3.5 year old seed suggests storage for two or three years may give better germination than fresh seed (Fox and Davies 1982).

During germination events observed in the field, large numbers of *A victoriae* seedlings have emerged, but represent a small proportion of the total viable seed bank, due to high levels of seed dormancy (Grice and Westoby 1987). To overcome dormancy, seed coats may be nicked with a sharp instrument, scarified, or boiling water may be poured over the seeds which are left to cool in the water. Two replicates in a germination test indicate that treatment of *A victoriae* seed with boiling water can increase germination by 36% (Larsen 1964). In sowing trials, initial germination with no pre-treatment occurred after 12 days and was completed after 79 days, with a 19.4% germination percentage (Kaul and Ganguli 1965).

There is some evidence to suggest *A victoriae* is adapted to germinate under summer conditions. Trials conducted at Curtin University (Figure 1) with seed collected from north-western Western Australia, indicate that germination tends to increase with temperature of incubation (Fox and Davies 1982). However, elsewhere 100% germination in four days is recorded at incubation temperatures of 12, 20 and 28°C (Jurado and Westoby 1992).

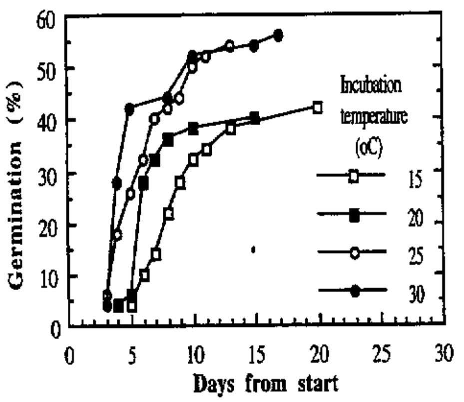

Figure 1. Percentage germination of A victoriae incubated at four temperatures after a hot water treatment to break dormancy.

Seedlings

Juvenile leaves on seedlings of *A victoriae* are true pinnate leaves. As the seedlings develop these are replaced by alternate, sub-sessile phyllodes.

A victoriae seed lots from Israel and Australia grown at a mean temperature of 27°C, in a mixture of sand and well decomposed manure, had seedling survivals of 37% for Australian seed and 63% from Israeli seed (Kaul and Ganguli 1965).

Application of fertiliser on topsoil does not appear to affect the growth of *A victoriae* seedlings on saline mine wastes, other than to reduce the time period over which seedling emergence occurs (Stewart 1992). An increase in growth however, was observed in plants growing in uncontaminated soil from Meekatharra (26°36'S, 118°30'E) (Fox and Davies 1982).

Herbivores and Disease

Animal feeders

Acacia victoriae is a useful fodder supplement for stock in semi-desert areas. Phyllodes are moderately palatable, being used as a grazing reserve during dry periods (Mitchell and Wilcox 1988) while seeds are a good source of protein. Zebra finches have been observed to eat seeds from *A victoriae* growing near water.

Shrubs of *A victoriae* are sparsely foliated, but phyllodes are generally retained throughout the year. Plants tend to recover well after browsing but may be killed if this is severe. Some forms are very prickly and not favoured for grazing (Turnbull 1986). The flowers of *A victoriae* are readily eaten (Mitchell and Wilcox 1988).

Plant parasites and diseases

Until recently, there were no recorded pests or diseases of the species (Turnbull 1986). Studies have since found however, that a number of *Acacia* species, including *A victoriae* grown in an arboretum, are particularly susceptible to root rot. In these studies infection was through stumps colonised by the root rot. Of 18 *Acacia* species investigated, five including *A victoriae*, were more susceptible than the remaining species (Harsh *et al.* 1993). In arid central Australia, *A victoriae* is parasitised by mistletoe and there appears to be a relationship between mistletoe volume and tree mortality (Reid *et al.* 1992).

Related Species

The desert species *Acacia murrayana* appears similar to *A victoriae* having in common broad pods with transverse seeds and narrow, more or less free calyx lobes, but it lacks paired peduncles and spines (Turnbull 1986). In a recent review of the informal *Acacia victoriae* group, five new species are described *(A alexandria, A aphanoclada, A chartacea, A ryaniana* and *A synchronicia)* and the taxon *A glaucocaesia* is reinstated. The other species in the group are *A pickardii, A cuspidifolia* and *A dempsteri*. *A victoriae* differs from *A glaucocaesia* and *A* *alexandria* in that it has fewer flowers per head. Of these 10 taxa, only *A synchronicia* has been confused with *A victoriae* in the past. *A victoriae* flowers are borne on racemes whereas the inflorescences of *A synchronicia* are simple (Maslin 1992).

The as yet formally unnamed taxon *A aff victoriae* and *A dempsteri* are closely related to *A victoriae*. *A dempsteri* and *A victoriae* are allopatric (closely related enough to interbreed, but are geographically separated). *A* aff *victoriae* and *A victoriae* are sympatric in the Little Sandy Desert Area (Maslin in Jessop 1981).

History

Acacia victoriae is named after the Victoria River in Queensland, which has since been renamed the Barcoo River, where the first type specimen was collected. It is variously called prickly wattle, elegant wattle, royal acacia, acacia bush, pin bush, narran, bohemia bush, bramble wattle, gundabluey (Turnbull 1986), Ngatunpa (Bennett 1991) or bardi bush (Mitchell and Wilcox 1988). In addition to the widespread typical species, a subspecies is recognised as *A victoriae* subsp. *arida* Pedley (*eg*. Northern Territory, Queensland and New South Wales) (Pedley 1979).

A victoriae is believed to have spread or increased in abundance in the arid zone of Western Australia since settlement (Curry and Hacker 1990), replacing valuable *Atriplex* species and *Maireana* species. communities (Mitchell and Wilcox 1988).

Uses

Acacia victoriae is a high seed yielding and easily harvested species whose seeds have some food potential for humans. Fully formed green pods of *A victoriae* were lightly roasted by aborigines and hard-coated mature seeds ground before eating (Thomson 1991).

Since it has a rapid growth rate, it is an effective coloniser on alluvial plains and may provide niches in which more palatable grazing species (*eg. Rhagodia eremaea*) may establish (Mitchell and Wilcox 1988).

It is also salt tolerant (Simmons 1987, Fletcher 1992) and therefore often suitable for minesite rehabilitation. Pot trials have been undertaken to investigate its potential for revegetation operations (Fox and Davies 1982; Fox *et al.* 1995). Of several species trialled on mine waste, *A victoriae* had greatest seedling survival (80%) and the best overall growth rate on tailings material (Yates 1989). In the absence of added superphosphate fertiliser *A victoriae* grows poorly on overburden (Oliver *et al.* 1992). It has some potential for reclaiming degraded areas in some pastoral regions of Western Australia (Fox and Davies 1982). *A victoriae* is recommended as a shade tree or windbreak in gardens in the drier regions such as Alice Springs (Simmons 1987).

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AUTHOR AND CONTENTS INDEX

MULGA RESEARCH CENTRE JOURNALS 1-12 (1977-1995): ARTICLES PUBLISHED, WITH BRIEF SUMMARIES

MULGA RESEARCH CENTRE JOURNALS 1-12 (1977-1995): ARTICLES PUBLISHED, WITH BRIEF SUMMARIES

DR Barrett, School of Environmental Biology, Curtin University of Technology
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Anon (1977). Summary of: Lands of the Wiluna-Meekatharra area, Western Australia, 1958 in Land Research Series no. 7 by Mabbutt *et al.* CSIRO Melbourne, 1963. *Mulga Research Centre Annual Report* no. **1**, 17-28.
The survey area lies between latitudes 26° and 27°S and longitudes 117° and 123°E covering 64,750 km^2. Forty eight land systems (containing areas with a recurring pattern of topography, soils and vegetation) were recognised and described. Vegetation alliances and sub-alliances were summarised. Mulga was the dominant and most widespread plant.

Barrett DR (1987). Germination and planting out techniques for the Western Australian sandalwood (*Santalum spicatum*). *Mulga Research Centre Journal* **9**, 31-32.
A simple method for germinating sandalwood seed is described and illustrated. Seed must be as fresh as possible, the hard endocarp should be incised, placed in coarse sand and kept moist (but not sodden) in a warm place. Germinants should be planted when the radicle is 10-20 mm long. Precautions to avoid mortalities (the use of fungicides and watering regimes), and best conditions for planting out (age of seedlings, season of planting, shade regime, host availability) are given.

Barrett DR (1987). Initial observations on flowering and fruiting in *Santalum spicatum (R.Br.)* A. DC. the Western Australian sandalwood. *Mulga Research Centre Journal* **9**, 33-37.
The time and progress of flowering from bud formation through to senescence is described and illustrated. For the six trees under study, large numbers of flowers were dropped resulting in poor fruit initiation. Many fruit are not held to maturity. Up to 700 flowers were lost for every mature fruit formed. Nut diameters (up to 20 mm), kernel diameters (up to 13 mm) and nut production per tree, were recorded.

Barrett DR (1995). Review of the ecological characteristics of *Acacia acuminata* Benth. *Mulga Research Centre Journal* **12**, 31-38.
This paper is a review of available information regarding the biology, ecology and uses of *Acacia acuminata*. The species is endemic to the south-west of Western Australia, mainly in low semi-arid woodland communities. It is a small tree with a spreading crown, grey branches and narrow, bright green phyllodes. It bears yellow spike-like flower heads in winter and spring, followed by brown pendulous seed pods in early summer. *A acuminata* is considered poor for erosion control and rehabilitation programs. The tree has little economic importance although the phyllodes have some fodder value and the wood is used for fencing and craft work.

Barrett DR (1995). Mulga Research Centre Journals 1-12 (1977-1995): Articles published, with brief summaries. *Mulga Research Centre Journal* **12**, 73-95.
Each article in all the journals published to date, is listed in alphabetical order of authors and a short outline of the material presented is given.

Barrett DR, Wijesuriya S and Fox JED (1985). Observations on foliar nutrient content of sandalwood (*Santalum spicatum* R.Br. DC). *Mulga Research Centre Journal* **8**, 81-91.
This is a summary of nutrient analyses of leaf and shoot tissues of *S spicatum*, with and without fertiliser treatment, and in nutrient omission studies. A large variation in elemental concentrations (K, N, Zn, Ca, Na,

Cu, Mg, P, Fe) was found. The growing seedling appeared to rely heavily on its mineral seed reserves and its own uptake for about a year but mineral concentrations declined with time. It was suggested that haustorial connexions should be made within the first two years. As nutritional intake from the host occurred, mineral concentrations rose. Approximate levels of nutrient in healthy, vigorous two and four year old sandalwood leaves were: N, 2.5%; P, 2 mg g^{-1}; Ca, 8 mg g^{-1}; K, 14 mg g^{-1}; Na, 6 mg g^{-1}. These concentrations could provide a guide to fertiliser requirements.

Berlandier F and Fox JED (1987). Preliminary observations on germination and seedling in *Erodium cygnorum. Mulga Research Centre Journal* **9**, 1-8.
The study examined the influence of temperature and moisture on germination and establishment of *E cygnorum.* The fruit is described and illustrated. When water is imbibed the awn twists like a corkscrew driving the end of the mericarp containing the seed into the ground. Removal of the awn did not reduce germination but delayed seedling emergence. Mericarps with cut awns germinated at a greater rate than whole or awnless mericarps. Germination was best at 20°C.

Betts TJ (1979). Western Australian native plants used by aboriginals as medicinal treatments. *Mulga Research Centre Annual Report* no. **3**, 21.
The medicinal or therapeutic value of five species (*Codonocarpus cotinifolius, Euphorbia drummondii, Pittosporum phylliraeoides, Scaevola spinescens, Leichhardia australis)* from arid areas is briefly considered. These species form the basis of common Aboriginal treatments called 'bogeys'.

Black RF (1987). The propagation of *Adenanthos cygnorum* by cuttings as an aid to heavy mineral sand mining rehabilitation at Eneabba. *Mulga Research Centre Journal* **9**, 45-48.
Shoot tip cuttings of *Adenanthos cygnorum* were examined as a means of producing large numbers of plants for mine rehabilitation in the kwongan (heath) of the northern sandplain of Western Australia. Application of 5 ppm indole butyric acid, mineral nutrients and appropriate heating regimes, appeared to produce an 'auxin benefit' to cuttings 12-weeks from setting out and a 'nutrient benefit' after 27-weeks.

Black RF, Spice JF and Fox JED (1984). Slow release fertilisers and growth of *Banksia hookerana* seedlings. *Mulga Research Centre Annual Report* no. **7**, 61-69.
The effect of slow-release (persistent) fertiliser compounds (various combinations of N, P, K, Ca, S, Mg) on the growth and nutrition of *Banksia hookerana*, a slow growing native shrub from the low fertility soils of Western Australian coastal heath soils, is described. Nitroform fertiliser was beneficial; rock phosphate was not (a positive result since seedlings on the these soils can show P toxicity); potassium sulphate was toxic at the concentrations used; limestone and particularly magnesium carbonate, had beneficial effects on growth and elemental uptake.

Brand JE (1993). Preliminary observations on ecotypic variation in *Santalum spicatum*. 2. genotypic variation. *Mulga Research Centre Journal* **11**, 13-19.
Sets of seedlings grown from nuts collected from eight distinct populations from the species' range were used for an isozyme study. Six enzyme systems were examined and the following three were found to be useful for differentiating between populations: glucose-phosphate isomerase, glutamate-oxaloacetate transaminase), and Menadione reductase. There were significant genetic differences between *Santalum spicatum* ecotypes, and a geographical trend was observed. Genetic distance between sandalwood ecotypes increased linearly with increases in geographic distance.

Broadhurst L and Tan B (1993). Induced germination and germinant survival in the many-flowered fringe lily (*Thysanotus multiflorus* R BR., Anthericaceae). *Mulga Research Centre Journal* **11**, 31-34.
Germination of this species is sporadic in the wild due to a high percentage of infertile seeds and impervious seed testas. The efficacy of techniques to weaken the hard seed coat (scarification by rubbing with sand paper; soaking in sulphuric acid; dry heating at 60°C; scalding with boiling water; seed nicking near the elaiosome; seed nicking opposite the elaiosome) is reported. In addition, to remove possible inhibitors to growth after germination, batches of un-nicked and nicked seeds were washed in water for varying lengths

of time. Three temperatures for germination (15, 20, 25°C) were tested. Nicking near the 'top' of the embryo was the most effective means of inducing germination. Washing nicked seed for one or more days produced significantly better germinant survival than when seeds were not washed. The highest germination response was at 15°C.

Broadhurst L and Tan B (1995). A preliminary investigation of the flavonoid compounds found in floral tissues of *Geleznowia verrucosa* Turcz (Rutaceae). *Mulga Research Centre Journal* **12**, 23-29.
Geleznowia verrucosa Turcz. (Rutaceae), a purportedly monotypic genus, is endemic to the sand plain country of Western Australia. Recent field observations indicated at least two distinct plant forms occur but whether or not they represent different species requires further taxonomic evidence. Contributing to a suite of taxonomic criteria are flavonoid compounds. *Geleznowia* floral bracts are phenotypically bright yellow and invariant. A preliminary investigation using paper chromatography, however, has revealed some differences between populations in their composition of floral flavonoid compounds. Evidence of major differences in these compounds in two contrasting plant forms, from two geographically isolated populations, was corroborated by high performance liquid chromatography.

Burrows R and Fox JED (1981). Phyllode profile for 'Charleville' *Acacia aneura* grown in Western Australia. *Mulga Research Annual Report* no. **5**, 25-34.
Narrowly oblong to lanceolate, greyish blue leaves with rounded apices characterise the phyllodes of three year old trees growing at Curtin University, Perth. Phyllodes were contrasted at different positions within trees (only minor differences) and between trees (distinct profile differences).

Burrows R and Fox JED (1982). Some observations on early development in *Acacia aneura* seedlings from different localities. *Mulga Research Centre Annual Report* no. **6**, 1-11.
Examination of the early developmental morphology of seedlings revealed differences in seedling morphology for *Acacia aneura* populations that are comparatively close to one another geographically, as well as those that are more distant. In sets with broader adult phyllodes the second eophyll tends to be more phyllodinous and non leafy phyllodes appear sooner. This tendency is not related to the number of leaflets on the first eophyll and appears to be independent of temperature.

Bywaters TK, Osborne JM and Fox JED (1984). Observations on direct sowing of four native plant species at Eneabba, Western Australia. *Mulga Research Centre Annual Report* no. **7**, 1-15.
Suitable depth of sowing was related to seed size in the case of *Acacia blakelii* (large seed) which germinated best if sown between 10 and 45 mm deep. *Casuarina humulis* and *Eucalyptus tetragona* (small seed) and *Banksia attenuata*, although having a large (triangular) seed, emerged in greater numbers if sown on the surface or at 10 mm depth. The most suitable sowing depth overall for the species tested was 10 mm.

Caffin N, Bell R, Nitchie G and Ho N (1979). Protein and mineral content of several species of *Acacia* seeds. *Mulga Research Centre Annual Report* no. **3**, 43-44.
Levels of protein and several minerals were determined in seeds of *Acacia aneura, A brownii, A extensa, A pulchella, A melanoxylon* and an unknown *Acacia* species from Port Hedland, Western Australia. All species (except the latter) are potential food sources. They are high in total protein (25.7-30.1%) and would contribute substantial Ca and Fe to a diet. Moisture content ranged from 4.0-8.4%.

Crossland T (1980). Preliminary investigations into germination and establishment of sandalwood, *Santalum spicatum* (R.Br.) DC. *Mulga Research Centre Annual Report* no. **4**, 61-65.
Different seed batches showed differences in germination parameters with cracked Yeelirrie seed starting to germinate after 10 days, and after 60 days 80% had germinated. Haustorial attachment probably occurred 5-12 months after germination. The addition of combined N (as ammonium sulphate) or slow-release N, P, K, S fertiliser (Osmocote®) had little effect on seedlings over two months.

Crossland T (1981). Response to fertiliser treatment by seedlings of sandalwood, *Santalum spicatum* (R.Br.) DC. *Mulga Research Annual Report* no. **5**, 13-16.
Superphosphate (with and without trace elements) was not a suitable fertiliser for sandalwood, *Santalum*

spicatum. Agran™ ($NaNO_3$) was not beneficial to seedlings of up to 60 days, but this fertiliser may have promoted growth in older seedlings. 'Hoof-and-horn' and 'blood-and-bone' fertilisers were also not advantageous. The most promising fertiliser was Osmocote® nine month release fertiliser (18% N, 2.6% P, 10% K, 4% S) applied at a rate of 50 kg ha^{-1}.

Crossland T (1981). Germination of sandalwood seed. *Mulga Research Annual Report* no. **5**, 49-50.
A very simple and effective germination method, in which a split is made in the hard endocarp with a band saw, is described.

Davies G, Fox JED and Lamont BB (1984). Observations on seed germination for some species of the northern sand plain heath. *Mulga Research Centre Annual Report* no. **7**, 17-33.
Seed germination conditions are considered (pre-treatment, temperature, water availability, water quality, concentration of applied fertiliser) for ten species (*Acacia auronitens, A latipes, A pulchella, Kennedia prostrata, Jacksonia floribunda, Gompholobium knightianum, Petrophile macrostachya, Grevillea polybotrya, Conospernum triplinervium*) found in the Eneabba area, Western Australia. The most suitable conditions for each species are given.

Davieson G and Majer JD (1982). Recolonisation by invertebrates in rehabilitated mineral sand mines at Capel, south-west Western Australia. *Mulga Research Centre Annual Report* no. **6**, 89-95.
Invertebrates, particularly ants, colonising six sand mined areas (rehabilitated between three and 15 years previously) and two unmined woodland sites at Capel, Western Australia were investigated. Rehabilitation was found to encourage a grassland invertebrate community of characteristic ant composition, low ant species richness and low species evenness. One ant species was extremely abundant. The levels of certain Collembola (springtails), Coleoptera (beetles), Dermaptera (earwigs), Acarina (mites) and Aranaceae (spiders) were also high in the mined areas.

Doronila AI and Fox JED (1990). Factors contributing to the presence and persistence of bare patches in pasture on a rehabilitated coal mine dump at Chicken Creek Area 4, Collie. *Mulga Research Centre Journal* **10**, 9-13.
Bare patches were found to be more acidic and saline suggesting a net migration of toxic ions up from the lower substrata of the dump. Electrical conductivity of the bare areas exceeded 400 mS m^{-1}, a level considered to be saline and restrictive to growth. Liming ($CaSO_4 \cdot 2H_2O$) may be necessary in these areas, followed by cultivation and re-seeding.

Doronila AI and Fox JED (1990). Tree and shrub establishment on coal mine interburden. *Mulga Research Centre Journal* **10**, 28-37.
Seed of 16 native woody trees and shrubs was sown onto a mine dump to contrast two overburden types with and without combinations of topsoil, lime and phosphorus addition. *Acacia* species survived best on class 1 material (pH 4.75, uniform texture, grey-white interburden) with topsoil. *A latericola* was the most abundant acacia. *Eucalyptus* and *Melaleuca* species were more numerous on class 1 with no topsoil. *E wandoo* was the most abundant eucalypt present. The tallest eucalypts were *E gomphocephala* and *E wandoo*.

Dunlop NJ (1990). The small vertebrate ground fauna of mulga habitats near Wiluna, Western Australia. *Mulga Research Centre Journal* **10**, 19-27.
The study was based on the live-trapping of small ground living and scansorial vertebrate animals in three apparently distinctive mulga (*Acacia aneura*) habitats, near Mt Lawrence Wells (26°48'S, 120°12'E). The highest densities of small vertebrates in the Mt Lawrence Wells area occur where mulga co-dominates with a mid-dense understratum of hummock grass (*Triodia*). A species/species similarity dendrogram produced a classification reflecting the key habitat factors influencing the distribution of species.

Dunlop NJ and Fox JED (1987). Germination and seed weights of unusual forms of *Acacia aneura* from the Northern Territory. *Mulga Research Centre Journal* **9**, 17-21.
Characteristics of seven *Acacia aneura* seed batches, including those from two unusual forms of the species known as 'weeping mulga' and 'Christmas tree mulga', are described, and germination tests reported.

Dunlop JN and Galloway R (1984). The dispersal and germination of seed in the weeping pittosporum (*Pittosporum phylliraeoides DC*). *Mulga Research Centre Annual Report* no. **7**, 75-80.
Pittosporum phylliraeoides has a dry coastal and semi-arid to arid distribution. Birds, principally Meliphagid honeyeaters, are agents of seed dispersa.. Passage through avian gut helps to break seed dormancy. Germination was affected by chemical inhibitors. Seed loses viability rapidly with time and it is unlikely that viable seeds persist from one season to the next. Ingestion by birds affects both seed viability and germinability and it appears that co-adaptation with birds is an integral part of the ecology of this plant species.

Dunlop JN, Majer JD, Morris CJ and Walker KJ (1985). A preliminary assessment of minesite rehabilitation in the Pilbara iron ore province using ant communities as ecological indicators. *Mulga Research Centre Annual Journal* **8**, 25-31.
Ants were sampled by pitfall trapping at Pannawonica on the Robe River Mesas (treated and untreated mined mesa tops and an overburden dump) and at Mt Whaleback, Newman (treated waste dump). When appropriate rehabilitation is undertaken significant ecological recovery can take place in six-seven years.

Egerton-Warburton LM (1990). Techniques for assessing isozyme activity in *Santalum album* L. and preliminary results. *Mulga Research Centre Journal* **10**, 56-60.
Twelve enzyme systems were assessed and of these, eleven were observed to exhibit activity. Those most suitable for assessing provenance variation within *Santalum* species were shikimate dehydrogenase, menadione reductase, glutamate oxalo-acetate transaminase and glucose-phosphate isomerase in juvenile leaf tissue and alcohol dehydrogenase in seed. Alcohol dehydrogenase was the only enzyme assayable in dry or moist seed.

Flanagan F and Barrett DR (1993). Sandalwood nuts as food. *Mulga Research Centre Journal* **11**, 21-26.
The kernels of the fruit of *Santalum spicatum* can be used in cooking as a nutritious and acceptable substitute for more traditional nut ingredients such as peanuts. The kernel can also be dry roasted and made acceptable as a snack food. Further studies on the preparation of the nut should be aimed at improving its subtle flavour. A partial chemical analysis of kernels is given.

Fletcher D (1990). Ant succession in Pilbara borrow pits. *Mulga Research Centre Journal* **10**, 1-8.
The vegetation surrounding the borrow pits was a mixture of hummock grassland (with mixed *Eucalyptus* spp.), mulga (*Acacia aneura)* woodlands and some mixed *Acacia* thickets. The most common genera found inside the pits were *Iridomyrmex, Melophorus, Camponotus* and *Rhytidoponera.* July data showed a significant positive correlation between percentage vegetation cover and ant density. The species dendrogram revealed that most of the ant species were restricted to distinct vegetation types. The exceptions were seven ubiquitous species which occupied a wide variety of vegetation types. Ant fauna of surrounding areas have the most significant influence on which plant species are will become established.

Fowler KM and Fox JED (1995). Ecological characteristics of *Acacia victoriae* (Benth) in Mitch. *Mulga Research Centre Journal* **12**, 65-71.
This article summarises biological and ecological information on *Acacia victoriae* with respect to habitat, communities, response to biotic factors and environment, structure, physiology, floral and seed characteristics, herbivores, disease, related species, and usefulness. *A victoriae* has a wide distribution across Australia, mainly between latitudes 8° and 18°S in hot arid and semi-arid areas. It is most commonly found on alluvial and coastal plains, in open woodlands and shrublands. *A victoriae* grows as a shrub or tree to 8 m in height. Its phyllodes, though variable, are generally thin, short and flattened with a pair of basal spines. The plant bears small cream to lemon-yellow flowers, clustered in paired inflorescenses in spring, and papery oblong to linear pods in late spring and summer. It has some potential as a food for humans, and its salt tolerance and rapid growth have made it a useful species in land reclamation and minesite rehabilitation.

Fox JED (1977). Goldfields felling area. *Mulga Research Centre Annual Report* **1**, 3-6.
A brief historical account of felling episodes and regulations applicable is given. Regrowth in 18 plots in

areas where the cutting history was known, was measured in terms of height. *A aneura* was the dominant species. Most *A aneura* trees were 4-5 m tall but the maximum height attained was 7.25 m.

Fox JED (1977). Fire regeneration study. *Mulga Research Centre Annual Report* no. **1**, 7-8.
The study investigated regeneration and growth of *Acacia aneura* and associated species at Mileura, Western Australia following fire. The regeneration time after fire ranged from a few months to 60 years. In some cases there was more than one episode of fire. Current numbers, stem diameters and heights of target species were recorded.

Fox JED (1977). Hail damage and regeneration. *Mulga Research Centre Annual Report* no. **1**, 29-30.
Mulga (*Acacia aneura*) at Mileura Station and Sherwood Station in the Murchison region of Western Australia were damaged by hail at various times in the past. The nature of the damage and extent of regrowth of mulga and associated species were documented. Considerations important to future effects of hail on these communities are noted.

Fox JED (1977). Stand structure and grazing. *Mulga Research Centre Annual Report* no. **1**, 33-36.
In July 1977 a study commenced at Yeelirrie, Western Australia, to examine the long term effects of destocking on perennials. Locations were mainly limited to where mulga (*Acacia aneura)* occurred and consisted of 44 plots covering 2.2 ha. The study attempted to correlate regeneration to stem numbers, basal tree area, cover of crowns and heights. Some results of the establishment work are presented to illustrate the stands involved.

Fox JED (1978). Variation in phyllodes within individuals of *Acacia aneura. Mulga Research Centre Annual Report* no. **2**, 19-29.
The extent of variation in foliage between many positions in the crown from three individual trees at Mileura Station in the Murchison region of Western Australia, were examined. Foliage of the three trees differs between trees (leaf lengths: 15-103 mm; 25-114 mm; 14-96 mm). Differences within a tree are not considered sufficient as to unduly distort'classification by sampling, provided samples are taken consistently in a representative manner. Transverse sections at the mid point of typical phyllodes are illustrated.

Fox JED (1978). A general account of the Trifid site, Mileura. *Mulga Research Centre Annual Report* no. **2**, 41-57.
Numbers, density and frequency of species at the site were determined from five transects, each of which was described. Heights, crown area and biovolume were measured and topography, climatic influences and soils were described. Previous findings in the area are reviewed. This work is in itself not conclusive, but the material presented can be elaborated and further tested.

Fox JED (1979). Effects of fire on the mulga (*Acacia aneura*) community. *Mulga Research Centre Annual Report* no. **3**, 1-19.
Many plant species of the mulga zone are killed by fire. A fire history of the Menaninga pastoral lease, Western Australia and a set of 27 sample plots is described emphasising how previous fire influenced the present status. *Acacia aneura* seems to be adapted to occasional fire that appears to be sufficient to crack hard seeds. Low-intensity fire may kill the plants but may be insufficient to stimulate the seeds to germinate. Germination is stimulated by wet conditions. The desert poplar shows phenomenal growth after fire and is a useful indicator species for fire.

Fox JED (1979). Stability in mulga stands in times of drought. *Mulga Research Centre Annual Report* no. **3**, 23-28.
Reasons for, and the significance of, the many deaths of mulga (*Acacia aneura*) stands are considered in terms of rainfall (seasonal and yearly variation), wind damage, disease, grazing and browsing. Whilst individuals may show little change over many years, stands are dynamic and respond remarkably to changes in moisture availability. Drought attrition is localised and is greatest amongst smaller plants and on lighter

soils. Particular stands may be wiped out at intervals and regenerate when the drought breaks. Grazing and other factors are overshadowed by drought effects.

Fox JED (1979). Observations on the germination and early growth of *Acacia aneura. Mulga Research Centre Annual Report* no. **3**, 45-51.
Individual seed weights were determined for many batches of seed. Different classes of seeds (by mass) were germinated at 15, 20 and 25°C. The rate of germination increased with temperature but not with size. Imbibition and water relations studies gave information on seed water uptake and seed dry weight loss.

Fox JED (1979). Some thoughts on land use following mining in Western Australia. *Mulga Research Centre Annual Report* no. **3**, 53-56.
Different scenarios are given covering temporary or permanent cessation of mining and short-term and long-term rehabilitation. Conflicting options (whether to restore to the original landscape or to change it in some perceived beneficial way), methods and standards (including completion standards) of rehabilitation, future management, and responsibility, should there be future unforseen problems, are discussed.

Fox JED (1980). Stocking and growth of *Acacia aneura* following overwood thinning. *Mulga Research Centre Annual Report* no. **4**, 1-9.
The effects of complete removal, one third removal and no removal of tree cover upon grass and herbage production of a mulga association at Albion Downs were evaluated. Crown cover, stocking and growth rates (stems ha^{-1}, mean heights, percent crown cover) species present and their numbers were recorded over a two year period. The environment of each site and its species dynamics were considered. Despite variation between plants, the overall average increments in height were similar for the range of plots when comparable size classes were considered.

Fox, JED (1980). The status of tuart (*Eucalyptus gomphocephala* DC.) in the Perth metropolitan area. *Mulga Research Centre Annual Report* no. **4**, 11-18.
Observations were made on 76 tuart trees from 20 sites 5-10 km inland, and at three different latitudes in the vicinity of Perth. It was concluded that increased frequency of fire is associated with changes which may lead to loss of this species in some areas. Inflammable exotic grasses are encouraged by fire and in turn lead to frequent fires which destroy tuart seedling regeneration and prevent the accumulation of material for ashbed regeneration. Trees are progressively damaged by frequent fire and become unable to set seed. Progressive crown deterioration caused by a number of environmental factors may be accelerated by frequent fire.

Fox JED (1980). Germination characteristics of some species of *Eucalyptus* from the Hamersley Plateau, Pilbara region. *Mulga Research Centre Annual Report* no. **4**, 25-34.
The germination of seven species of eucalypt (*Eucalyptus dichromophloia, E gamophylla, E kingsmillii, E leucophloia, E oleosa, E patellaris and E setosa*) from the Hamersley plateau, Pilbara region of Western Australia, were studied at 10, 15, 20 and 25°C. The germination performance of each species is individually tabled. A sketch illustration of seed and seedling is also given for each species.

Fox JED (1980). A growth and competition study involving the sympatric species *Acacia aneura, A craspedocarpa, A linophylla* and *A pruinocarpa* in pot trial. *Mulga Research Centre Annual Report* no. **4**, 35-48.
Pot growth and competition between *Acacia aneura* and three associated species, *A craspedocarpa, A pruinocarpa* and *A linophylla* in four different soils for one year, was investigated. Survival, height, number of phyllodes and dry weight were recorded. The 'heavier' soil media produced greatest growth and highest relative yields. Heights and numbers of phyllodes were examined as predictors of dry matter production.

Fox JED (1980). Changes in a stand of *Acacia aneura* caused by a hail storm. *Mulga Research Centre Annual Report* no. **4**, 49-60.
Short term effects of hail on *Acacia aneura* stems in a sample plot at Yeelirrie Station, Western Australia were assessed. Initial measurements, made 18 months before hail damage, were for height, crown diameter and stem diameter and plants were classified by phyllode type. Two years after establishment and seven

months after hail, trees at the site were remeasured. There were no dead trees although visual inspection soon after the hail had led the author to predict that many trees might die. Hail provided a major boost to drought lands and new growth was produced quite rapidly, making estimates of percentage leaf loss difficult. Evidence suggests that damage was not confined to trees of particular sizes but occurred on trees from all categories. Distortion of individual tree height/crown ratios occurred. Terete and broad-leafed mulga forms have different levels of tolerance to hail. Despite an early boost to seed germination after hail, seedling recruitment and establishment was disappointing.

Fox JED (1980). Variation in *Acacia aneura* - notes on specimens from Gindalbie. *Mulga Research Centre Annual Report* no. **4**, 73-83.
A description of pods, seed weight and germination characteristics is given for *Acacia aneura* material collected from 10 trees at Gindalbie (30°17'S, 121°46'E). Phyllodes and seed pods are described and illustrated. Seed mass and germination characteristics are recorded. There is a tendency for heavier seeds to show a higher germination across the phyllode types.

Fox JED (1985). The potential growth of Kikuyu grass and the usefulness of ammonium sulphate as a source of fertiliser nitrogen - a review. *Mulga Research Centre Journal* **8**, 41-57.
Various fertilisers and application rates are considered. Mobile nutrients such as N are concentrated in young tissues and are exported to other growing tissues as this tissue ages. Hence a continuous removal of new young growth could theoretically tie up maximum amounts of N in plant material. Mowing at a particular time or stage of regrowth is inevitably a compromise between removal of tissue and N with the resupply of N and recommencement of growth. Nitrogen from ammonium sulphate in solid form may become available two or more weeks after application. Regrowth is generally rapid from about four weeks and the total annual harvest yield appears to be at a maximum when cutting is taken at intervals greater than six weeks and up to 10 weeks from previous cutting.

Fox JED (1985). Ecological notes on *Acacia* species. 2 *Acacia cyclops*. *Mulga Research Centre Journal* **8**, 59-68.
This paper considers the geographical distribution (entirely coastal, in Western Australian and South Australia), habitat (climate and topography, soils), associated communities, response to biotic factors, performance (gregariousness; performance in various habitats, effects of extreme conditions), drought, frost, adaptive features (morphology, mycorrhiza), phenology, life history (floral biology, hybrids, seed production and dispersal, viability of seeds, germination), other biotic factors (animal feeders, plant parasites, diseases) and nomenclature history. Gross morphological sketches of a branch, a seed pod and seeds are given.

Fox JED (1995). A review of the ecological characteristics of *Acacia saligna* (labill) H Wendl. *Mulga Research Centre Journal* **12**, 39-56.
This paper provides a review of published information pertaining to the species *Acacia saligna*, endemic to south-western Australia. *A saligna* is a small tree whose present-day importance extends well beyond the area of its natural occurrence. In recent years it has been largely neglected as a species of direct value in Western Australia, apart from roadside screen planting. Its comparatively rapid early growth and tolerance of sandy, coastal soils provided stimulus for its use in fixing of sand dunes in many countries. Consequently it has also been cultivated for fodder in countries with a Mediterranean climate and is an important weedy species in South Africa. The absence of predatory insects in South Africa stimulated research into methods of biological control. This has provided considerable information on insects associated with *A saligna* in Australia. More recently, *A saligna* is being advocated as a fodder shrub for alley planting on farms in Western Australia. Material is included on the biology and ecology of the species. Published vegetation surveys are used to describe the natural communities in which it occurs and to provide lists of associated species. Growth and regeneration studies are reported.

Fox JED and Black RF (1981). Germination and early growth of *Banksia attenuata* R.Br. with different fertiliser treatments. *Mulga Research Annual Report* no. **5**, 51-67.
Standard fertiliser treatments were contrasted with no treatment, using potted nursery raised plants of *Banksia attenuata* (seed *ex.* Eneabba). Potting soil was fertilised in one of seven treatments prior to sowing seed.

Germination characteristics were noted and fresh and dry masses were recorded for each of five harvests over 150 days. Fertilisers had no effect on germination. Survival was poorest in the 'no fertiliser' control, due to temporary droughting and in treatments with N alone or N with high P. Severe chlorosis occurred with high P in the absence of N, but with K and trace elements present. Treatment with high P, N plus trace elements but without K, produced plants with highest shoot/root ratios. The low P treatments with N and K were similar.

Fox JED and Brand JE (1993). Preliminary observations on ecotypic variation in *Santalum spicatum*. 1. phenotypic variation. *Mulga Research Centre Journal* **11**, 1-12.
Santalum spicatum is distributed over a broad geographical range in Western Australia and is thus subject to many environmental conditions. Populations were examined from several soil types, a latitudinal range of 22-32°S and a mean annual rainfall from 206-526 mm. Attributes considered included potential phenotypic variation in nut and kernel size, seed viability, germination time, seedling growth rate, and adult leaf characteristics. There were significant differences in mean values for both nut and kernel sizes between different *S spicatum* ecotypes. Nut dimensions were larger in ecotypes from near coastal locations but were smaller and lighter in those from inland locations. Both seed viability and germination times were highly variable between ecotypes. Seed batches of higher viability commenced germination sooner and among these some 50% of nuts germinated in about three weeks. The ecotype with lightest nut weight germinated most rapidly. There was a tendency for ecotypes with heavier fruit to require a longer time to germinate. For the progeny sets examined from germinated nuts there were significant variations in 60 day growth expressed as seedling height, leaf number and hypocotyl diameter between ecotypes. Leaf samples taken from adult trees of *S spicatum* revealed that the leaf characteristics of length, width, length/width ratio, area and dry weight were all significantly different between ecotypes. Ecotypes from the drier inland regions had higher leaf length/width ratios and smaller leaf areas than those of the milder, more coastal regions. This is believed to be an adaptive feature related to dry environments. Leaves taken from ecotypes from higher latitudes had significantly higher chlorophyll contents than those from lower latitudes.

Fox JED and Davies G (1982). Establishment of *Acacia victoriae* germination and early growth. *Mulga Research Centre Annual Report* no. **6**, 31-39.
The study looked at whether *Acacia victoriae* is a summer or winter germinating species; whether scarification increased germination percentage; whether small seedlings benefit from fertilisation treatment; and whether inoculation was necessary to increase seedling growth rates. Evidence suggests *A victoriae* germinates under summer conditions in arid Australia. Scarification enhances germination potential as does boiling water pre-treatment. Fertilisation with N, P, K, and trace elements, particularly if combined with inoculation gives a clear increase in growth rate.

Fox JED and De Rebeira P (1977). Seedling studies at Mileura. *Mulga Research Centre Annual Report* no. **1**, 13-16.
Seedlings of mulga (*Acacia aneura*) were measured at four locations (all between 26°and 26°30'S and 117°and 117°20'E). Numbers, heights and leaf types were recorded. Each location was considered in some detail. Growth measurements at particular locations suggested that plants with similar heights were not necessarily of similar age. This was in part attributed to localised moisture levels and association with ant mounds. Some browsing was noted. Some individuals showed a reduction in height over the 16 months of observation.

Fox JED and Doronila AI (1995). A comparison of the germination and nutritional status of seed from dump and non-dump sources of *Allocasuarina fraseriana* and *Actinostrobus pyramidalis*. *Mulga Research Centre Journal* **12**,1-6.
Allocasuarina fraseriana and *Actinostrobus pyramidalis* are successful colonisers of abandoned coal mine dumps at Collie. Aspects of the germination and nutritional status of seeds from dump and non-dump populations were investigated to determine if a disturbed environment was causing an adaptive response in the reproductive effort. Germination was not different in seed collected from dump and forest populations. *A fraseriana* seed germination was less than 30% while *A pyramidalis* was greater than 80%. Seed from

dump populations of both species had significantly greater cone and seed biomass than from forest populations. The contrast in *A fraseriana* seed biomass may be an adaptive response to growth in the hostile coal overburden material.

Fox JED and Hansen CJ (1982). Observations on the early growth of *Trachyandra divaricata. Mulga Research Centre Annual Report* no. **6**, 49-53.
Trachyandra divaricata is a lily found growing on the coastal dunes of south west Western Australia. Germination characteristics at four different temperatures (10, 15, 20 and 25°C) were contrasted. The growth of five month old plants, subjected to five salinity levels (fresh water or diluted sea water) superimposed on three levels of fertiliser (N, P, K, S), was studied. Fresh and dry masses were recorded after 38 and 66 days of treatment. *T divaricata* germinated freely when moisture was available at 10-15°C. It is suggested that the salinity tolerance of *T divaricata* is about 10% that of sea water. There was a dramatic growth response to fertiliser in the absence of sea water.

Fox JED and Kaljuste DJ (1979). Soil moisture studies in relation to *Acacia aneura* and associates at Leinster Downs. *Mulga Research Centre Annual Report* no. **3**, 35-41.
This is a preliminary study on the effects of mine de-watering on the perennial vegetation (including *Acacia aneura, A tetragonophylla* and *Eremophila* sp.) at Leinster in the arid zone of Western Australia. A list of perennials measured (height) and details of percentage soil moisture and depth to hardpan are given. Observations on phyllode hydrature, vegetative growth, flowering, fruiting, mistletoes, water quality, roots, grazing and termite activity in the area of added water, are discussed.

Fox JED and Kaljuste DK (1981). Observations on comparative growth and survival of *Acacia aneura, Acacia craspedocarpa* and *Eucalyptus camaldulensis*. *Mulga Research Centre Annual Report* no. **5**, 1-8.
Early pot growth of seedlings of three tree species present at Leinster (27°55'S, 120°41'E) in typical Leinster soils was studied. Dry weights were measured, nutrient (N, P, K, Na) analyses made, survival in desert loam versus salty soil assessed, and the effects of waterlogging observed.

Fox JED and Kanganas A (1985). Germination and early growth of the dune wattles: *Acacia littorea, Acacia cyclops* and *Acacia rostellifera* in ash-bed soils after wet heat treatment. *Mulga Research Centre Journal* **8**, 113-121.
The response of the seed of three *Acacia* species occurring on Rottnest Island, Western Australia, to conditions prevalent during, and after, fire were examined. Germination tests sought to determine optimum germination temperature following the breaking of dormancy by heat treatment. Plants were also grown on ash bed and non-ash bed soils. After a fire the number of *Acacia* plants probably increase. Once soil moisture becomes adequate *A rostellifera* probably appears first, closely followed by *A littorea. A cyclops*, being less fire sensitive, would commence germination about two weeks after *A rostillifera*. The acacias probably do not require extreme temperatures to break dormancy and a mild burn during the cooler season would condition the seeds. Initial plant growth is quite slow and seedlings must be protected from herbivore grazing and trampling. All species responded well to ash bed soils and the growth rate was increased. Nutrient analysis showed more Ca and K taken up by plants in ash soils.

Fox JED and Mathie MH (1981). Glasshouse trials with legume species on Nakina formation overburden material. *Mulga Research Centre Annual Report* no. **5**, 35-48.
Survival and growth (height and dry weight at different harvest times) of several legume species (*Kennedia coccinea, Cytisus proliferous, Hardenbergia comptoniana, Acacia extensa* and *Apulchella*) were examined on acidic (pH 4.6), nutrient poor, non-toxic, unamended overburden, which is considered important in rehabilitation programs. The results were compared with the same species grown in pots on the same overburden, but which had been limed to increase the pH by one or two units. Dry matter production was higher at the intermediate lime level than without any amendment. The higher lime level and the unamended soil gave about the same level of dry matter production. The relative growth of species differed with different acidity levels. The acid tolerance of *A pulchella* was confirmed. *C proliferous* may behave similarly. Both *K coccinea* and *H comptoniana* performed best on non-acid soil and *A extensa* responded to a slight change in pH.

Fox JED and Meney KA (1984). Mitchell Freeway extension hydroseeding on the road verges. *Mulga Research Centre Annual Report* no. **7**, 53-60.
Rates of field germination and establishment were determined for two different plant species mixes after hydroseeding on road verges near Perth (using four different mulches). Germination temperature requirements and glass house growth of the same species were investigated. The species were *Beaufortia squarrosa, Calistemon speciosus, Calothamnus quadrifidus, Eucalyptus camaldulensis, Kunzea baxteri, Leptospermum ellipticum, Melaleuca adnata, M huegelii, M lanceolata, M lateritia, M pressiana, M viminea.* Blue metal mulch was significantly more effective than the other mulch treatments and control. Woodchip mulch was next most successful but paper mulch was not suitable for sites exposed to adverse conditions. Timing of seeding and seed mix composition need further assessment.

Fox JED and Rhodes RL (1980). Early response to fertiliser treatment by three species of *Eucalyptus* of interest in bauxite mining rehabilitation. *Mulga Research Centre Annual Report* no. **4**, 67-71.
Comparative early pot growth of three species (*Eucalyptus maculata, E saligna, E wandoo*), which have been considered as showing good adaptation to growth in disused bauxite pits in former jarrah (*E marginata*) forests was studied. The response to five different fertiliser regimes using N, P, K, Zn, Mo, Cu and a control were studied. *E wandoo* should be able to establish better than the other two species even without added fertiliser. The standard fertiliser (containing all nutrients tested) was best for growth of *E saligna* and this fertiliser, or none at all, was probably best for *E maculata.*

Fox JED and Van Leeuwen SJ (1985). Observations on germination and early development of several Pilbara species in relation to environmental variables. *Mulga Research Centre Journal* **8**, 93-100.
The effects of aspect on early seedling development of *Acacia aneura, A bivenosa, A inequilatera, A pyrifolia, Eucalyptus oleosa, E setosa* and *E socialis*, and different acidity levels on germination and early growth, were studied. The results were not conclusive but aspect may contribute to differences in distributions of *A aneura. E setosa* and *E socialis* grew well in shade but other environmental variables were not sufficiently controlled to distinguish effects. *A bivenosa* and *E socialis* showed a clear preference for basic soil. *E setosa* attained best early seedling growth in more acidic soils.

Fox JED and Wallman JS (1978). Pot trials with *Acacia saligna. Mulga Research Centre Annual Report* no. **2**, 9-14.
Up to four seedlings of *Acacia saligna* were planted per pot and harvested progressively at five dates between one and three months from planting. There was no clear-cut disadvantage in growing up to four plants per pot although dry weight values indicated competition was present. A tendency of fresh mass/dry mass ratios to decline with increasing plant density and with time, may have become more significant in the longer term. Nodules formed between 50 and 64 days after potting out and were most numerous on the plants in the four-plant pots at the 85 and 99 day harvests. *A saligna* can take advantage of abundant water and increase net growth more rapidly than with only adequate water. Root nodules were twice as abundant on excess water plants compared with control plants. At final harvest, waterlogged plants developed more phyllodes than the control set, and had larger individual nodules at a shallower depth. The response to varying N levels (ammonium sulphate given in multiples of the standard mix level of $0.22g\ l^{-1}$) was observed. Significant dry mass differences became apparent between no added N and 0.5, 1, 2 and 3 times the standard level.

Fox JED and Wijesuriya SR (1985). Sandalwood planting with property owners. *Mulga Research Centre Journal* **8**, 123-127.
Santalum spicatum (Western Australian sandalwood) seedlings were supplied to pastoralists and farmers for planting in rural situations where sandalwood used to, or does, occur naturally. Despite a great deal of enthusiasm and effort over three years, the results were generally disappointing, with low survival. Transit damage, wind damage, clay soil, locusts/grasshoppers, late planting, accidental damage and unsuitable, friable, potting mix, were reasons given by planters for the lack of success. Survival percentages after the three year program of planting were up to: 0.6% for those planted in 1982; 5% for those planted in 1983 and 14% for those planted in 1984. Planting cut seed rather than seedlings, around May, would probably be the

most economical and successful planting method. Survival beyond the first summer would be dependent on good, early attachment to suitable hosts.

Fox JED, Barrett DR and Osborne JM (1987). Growth of *Acacia* and *Eucalyptus* seedlings in potential overburden materials from the West Angeles iron ore prospect. *Mulga Research Centre Journal* **9**, 55-62.
Should an iron ore mine be established at West Angeles, Pilbara, eventual rehabilitation of the site will be necessary. Overburden material from depth will be brought up and dumped. Particular strata may be used as the main superficial dressing, or alternatively, top soil could be placed over the depth materials as the primary growth stratum. Growth of 12 locally occurring *Acacia* and *Eucalyptus* species in fertilised and non-fertilised materials from different depths, was assessed. Records were obtained for seedling plant height, leaf numbers, plant dry weight and relative growth rate over a 75 day period. Each material was ranked according to the growth performance of each species. Non-fertilised plants, except for *Acacia citrinoviridis* and *A victoriae* in dark reddish-brown shale, did not produce as much dry matter as plants in fertilised soil materials. Fertilised yellowish-brown shale and clay, promoted best overall growth in the pot trials. *A ancistrocarpa, E leucophloia, E patellaris, A hamersleyensis* and *A tetragonophylla* grew particularly well in fertilised shale: *A hamersleyensis, A tetragonophylla* and *E patellaris* grew best in fertilised clay. If unamended overburden material were to be used as a rehabilitation surface, then of those strata examined, dark reddish-brown shale material would be the most suitable.

Fox JED, Colquhoun MP and Leone J (1987). Comparative performance of four *Eucalyptus* species grown on two coal mine interburden materials. *Mulga Research Centre Journal* **9**, 39-44.
Seedlings of four eucalypt species were grown in two interburden materials from a coal mine near Collie, Western Australia. Half of the seedlings received fertiliser (N,P,K) and the other half grew in unamended material. Significant growth responses to the addition of fertiliser were observed on both types of material for three species. Greatest relative increases in dry matter for fertilised seedlings were obtained for *Eucalyptus camaldulensis* and *E wandoo*. *E patens* grew well but showed a lesser response. Low, possibly incipient, responses to fertiliser may be improved by later application.

Fox JED, Doronila AI and Owens BK (1990). Growth of three subterranean clover (*Trifolium subterraneum*) cultivars on coal mine interburden material amended with fly ash. *Mulga Research Centre Journal* **10**, 45-49.
The growth response of three cultivars of *Trifolium subterraneum* (Esperance, Northam, Trikkala) grown in three highly acidic, coal spoil materials with various amendments of fly ash, a waste product from coal fired power stations, was investigated. Fly ash was found to ameliorate the coal spoil materials. It may provide an inexpensive acid neutralising material and be a source of nutrients essential to plant growth. Concentrations of 2-5% appear most beneficial to *T subterraneum* growth. The response at these fly ash levels is considered to be comparable to that of dump material amended with about 200 kg ha^{-1} of 3:2 superphosphate/potash fertiliser. Differences in response to fly ash occur between each cultivar and each substrate material.

Fox JED, Frost BE and Doronila AI (1993). Early growth of *Eucalyptus patens* on coal waste in response to nitrogen and phosphorus fertilisation. *Mulga Research Centre Journal* **11**, 43-55.
The growth response of *Eucalyptus patens* seedlings to various levels of fertiliser N and P when grown for 75 days in pots using two waste materials (pH about 4.5) from the Muja open-cut coal mine at Collie, Western Australia is reported. *E* patens is considered an acid tolerant species. Height growth, leaf development, dry matter production and foliar N and P contents were measured. Results confirm that P is the primary limiting factor to growth in both overburden materials. Nitrogen is ineffective in stimulating growth in the absence of P. The greatest response was to the lowest level of fertiliser applied (15 kg ha^{-1}) although biomass tended to rise steadily with increasing levels of N at each level of P and to peak at 15-30 kg ha^{-1} P. The most appropriate fertiliser application was 30 kg ha^{-1} P with 40 kg ha^{-1} N when seedlings were about one month old. A possible additional application of N in the second growing season might be beneficial. Vigorous legume understorey growth may provide additional N.

Fox JED, Gazey C and Barrett DR (1987). Growth of *Acacia* species in coal mine interburden materials. *Mulga Research Centre Journal* **9**, 49-53.
Growth and survival of *Acacia* species (*A saligna, A extensa* (two ecotypes), *A pulchella* (two ecotypes)) in fertilised (Osmocote®) and unfertilised coal mine interburden materials (Ate-Bellona, pH 4.6 and Ceres-Diana, pH 6.1) were compared in controlled pot trials. Plants were from two Western Australian seed sources: *ex.* Yalgorup (coastal sand) and ex Harvey (lateritic gravel). After 78 days plants had grown best (greater height and dry matter production) in Ceres-Diana with fertiliser. Plants in Ate-Bellona with fertiliser showed better growth than plants in both non-fertilised interburdens, for which responses were generally both equally poor. *A extensa* and *A pulchella* (*ex.* Harvey) appeared most suitable for use in field trials.

Fox JED, Grey JA, Smith KN and Dunlop NJ (1982). Further notes on *Eucalyptus* species of the Pilbara region, Hamersley Plateau. *Mulga Research Centre Annual Report* no. **6**, 81-87.
Information is given on the response to fire of *Eucalyptus dichromophloia, E gamophylla, E kingsmillii, E leucophloia, E oleosa, E patellaris, E setosa* and *E microtheca*. In addition, some tree details, fruit and seed load estimates, seed dimensions and germination values are given.

Fox JED, Hides DG and Craig G (1982). *Acacia aneura* at Leinster Downs: perimeter vegetation and the role of grazing. *Mulga Research Centre Annual Report* no. **6**, 55-73.
The status of vegetation inside a fenced station on which grazing was excluded for five years (after 65 years of sheep grazing) was compared to vegetation in immediately adjoining, stocked country. A list of plant species in the area is given. A clear distinction was evident between the two major land types in the area Bullimore and Bigida. Bullimore is characterised by an orange-brown sandy soil with less dense *Acacia aneura* and fewer recruits; bowgada (*A linophylla*) and spinifex (*Triodia basedowii*) are associated. Bigida is characterised by red-brown clay/loams with more *A aneura* (commonly less than 1 m tall) and bowgada and spinifex are less numerous. Thirty one plots were set up. No species differences were apparent between grazed and ungrazed plots but there was an increase in foliage cover in grazed plots.

Fox JED, Maddocks TI and Black RF (1984). The problem of weed species in rehabilitation of native heath vegetation. *Mulga Research Centre Annual Report* no. **7**, 43-51.
Alien species are undesirable components of regrowth in rehabilitation sites where the aim is to restore native plant species. The four weed species with which this report is concerned are *Brassica tournefortii* Gouan, *Arctotheca calendula* (L) Levyns, *Hypochoeris glabra* L and *Ursinia anthemoides* (L) Pior. The population of viable seed in the soil was estimated by counting and identifying germinants arising from soil samples. Undisturbed first-cut topsoil (from virgin heath and stock-piled for two years) was sampled in July and September, put into germination trays and tended in a glass house. Cover crop seed lots were germinated in a similar way using coarse sand as a medium. Rehabilitation sites, topsoil stock-piles and surrounding virgin heath at Eneabba mine were examined for weed species. These are listed with their numbers and heights or diameters. Few seedlings germinated in the glass house germination tests and it was considered that they originated from contaminant seed introduced during the experiment. Field stock-pile topsoil samples and undisturbed virgin heath tested contained no weed seeds but insufficient soil was tested to allow clear conclusions. The estimated density of weeds in rehabilitation sites was 0.02 plants per square metre. *B tournefortii* may become a significant weed in rehabilitation plots unless an eradication program is undertaken. The impact of weed species at a rehabilitation site decreases with passage of time. Trends in the relative numbers of dicotyledonous and monocotyledonous weeds were unclear

Fox JED, Majer JD, Sanford P, Day JE and Glossop BL (1981). Plant species successfully recolonising rehabilitated bauxite mines. *Mulga Research Centre Annual Report* no. **5**, 17-23.
Details (in numbers and abundance) of colonising plants were recorded in mined sites at Jarrahdale and Del Park, about 45 and 90 km SSE of Perth, Western Australia. Both areas are jarrah (*Eucalyptus marginata*) forest localities. Thirty rehabilitated plots and three forest controls were surveyed. A discussion is given of how seeding mixtures affect subsequent plant diversity, balances between low herbaceous and shrub contents, the ready colonisation by fire-weeds, and the poor colonisation by members of Proteaceae.

Fox JED, O'Dea D and Patroni V (1985). A preliminary trial of various trees and shrub species for growth in coal interburden materials. *Mulga Research Centre Journal* **8**, 69-80.
A short term trial of ten species (*Acacia aneura, A baileyana, A extensa, A myrtifolia, A pulchella, Albizia lophantha, Cytisus proliferous, Eucalyptus camaldulensis, E gomphocephala,* and *Melaleuca radula*) on amended and unamended coal interburden materials showed depressed growth on unamended material of low pH (3.7-3.9). Of the species tested *C proliferous* and *A lophantha* gave best growth. The more acidic material when amended to 5.3-5.7 gave best growth for most species tested. *A pulchella* and *Eucalyptus* species growth was poorer in the less acidic material (pH 5.1-4.0) and the same material amended with lime (pH 6.8-7.6). Small seedlings of Myrtaceae are unlikely to grow well in any of these materials. Both *A baileyana* and *A extensa* show promise for revegetating unimproved mixed interburden material.

Fox JED, Pepper C and Craig G (1982). Vegetation and reaction to fire in coastal heath at Sorrento, Western Australia. *Mulga Research Centre Annual Report* no. **6**, 97-109.
The regeneration pattern after a particularly hot fire razed the coastal dune heath 27 km north of Perth in March 1981, was documented. This was compared with strip plots established in an adjacent reserve, some of which received additional water from watering of nearby lawns. The study covered two years. Species present and frequency of occurrence at intervals of time were recorded. Soil moisture levels were noted. Recommendations for future management are presented.

Fox JED, Sawyer A and Frisina P (1982). Usefulness of topsoil for coal mine spoil revegetation. *Mulga Research Centre Annual Report* no. **6**, 23-29.
The usefulness of topsoil (pH >5.5) in coal mine spoil revegetation was assessed. Four topsoil samples were taken from jarrah forests within the Collie mineral field and three from Kelmscott jarrah forests nearer Perth. Some of the Collie soils were fertilised but those from Kelmscott were not. Numbers of germinants, and numbers of plants which survived to harvest and their fresh and dry masses, were recorded. It is possible that biomass yield, especially in the short term, could be predicted from a count of germinants. This would obviate the need to grow plants after germination except for identification purposes. The results provide a guide to availability of seed in the topsoil.

Fox JED, Surata IK and Suriamidhardja (1990). Nursery potting mixture for *Santalum album* L. in Timor. *Mulga Research Centre Journal* **10**, 38-44.
Growth of *Santalum album* at Kupang, Timor, Indonesia, is considerably enhanced when sand is added to local soil materials. The best mixture in terms of dry matter production, height of seedlings and collar diameter, was three parts sand to five parts local soil. Soil from Sikumana (lithosol) was superior to that from Oilsonbai (grumosol) as the preferred local soil. The type of clay in the potting medium influences plant growth considerably, whereas calculated percentages of sand achieved in mixtures were similar for both basic media. A linear relation occurs between seedling height and dry weight over the range of potting mixtures used. Despite this useful correlation, seedling height may not indicate the best condition as it is desirable for root growth and consequent haustorial development with pot host, to be strong in relation to top growth.

Grein S, Schatral A and Fox JED (1993). Preliminary observations in laboratory and field on effects of vesicular arbuscular mycorrhizal associations and phosphorus application in *Hibbertia hypericoides*. *Mulga Research Centre Journal* **11**, 75-81.
Young plants of *Hibbertia hypericoides* were inoculated with vesicular-arbuscular mycorrhizae (VAM) and supplied with P at different concentrations to determine whether VAM affects plant establishment and growth, and to examine mycorrhizal associations in several different natural habitats. Mycorrhizal colonisation in roots in the natural habitat varied between 30 and 40% for young plants and infection was likely to be by *Acaulospora laevis* rather than by *Glomus* fungus. Infection appeared to benefit root growth but not shoot growth. Mycorrhizal colonisation of roots was not related to soil pH and the VAM of *H hypericoides* apparently tolerate a wide range of acidity. High P levels in the soil (40 kg ha^{-1}) suppressed mycorrhizal colonisation. The P level in plant material of *H hypericoides* was found to increase with higher mycorrhizal colonisation. No relationship was found between mycorrhizal colonisation of the roots and K or N concentration in the shoot material of plants.

Groom PK, Fox JED and Dunlop JN (1993). Salt tolerance in *Rhagodia eremaea*. *Mulga Research Centre Journal* **11**, 35-42.
Salinity tolerance trials were used to determine the suitability of *Rhagodia eremaea* seedlings for revegetation of gold mine waste dumps. Four levels of salinity (NaCl) were tested against a control, using small seedlings grown under glasshouse conditions for six weeks. Seedling deaths occurred in the two stronger treatments (100 and 200 mM), with losses of 15 and 75%, respectively, over the experimental period. These treatments produced characteristic symptoms of salt injury including necrosis of leaf margins and incurving, thickening and succulence of leaves. Increased growth at the lower treatment levels provides evidence that *Rhagodia eremaea* is a halophytic species. Significant differences were not detected between adjacent treatments for dry matter yields, but were apparent between extremes. *R eremaea* showed an initial response to sodium (25 mM NaCl) in shoot growth, followed by enhanced root growth at 50 mM. Higher levels (100 mM) inhibited root growth before shoot growth was affected. The highest level used (200 mM) depressed both shoot and root growth. Seedlings irrigated with 50 mM salt solution had more numerous side shoots and branches, as well as a more vigorous root system. Revegetation of saline mine waste dumps with *R eremaea* should be possible when soil conductivity is between 5 and 9 dS m^{-1} (NaCl concentrations >25 mM and <100 mM).

Harvey D, Tacey WH and Fox JED (1980). Biomass production of volunteer native understorey on bauxite mined sites. *Mulga Research Centre Annual Report* no. **4**, 19-23.
The objective was to determine which of two topsoil handling treatments for mined land (using stockpiled topsoil or fresh, double-stripped overburden) yielded the most successful re-establishment of volunteer native understorey. Volunteer vegetation which grew in representative plots on the mined land and in control forest sites, was sampled. Species numbers, density, diversity, biomass and litter were all measured. Double-stripped topsoil handling was considered the better of the two minesite treatments.

Hides DG (1985). The efficiency of three ordination techniques. *Mulga Research Centre Journal* **8**, 13-24.
The usefulness of a number of popular ordination techniques (reciprocal averaging, principal components analysis, polar (Wisconsin) ordination) were compared. Criteria of evaluation were: freedom-of distortion in formation of resemblance matrix; range-extent of community variation without distortion; lucidity-clarity of ordination; efficiency-account for variation in the data; heuristic function-recognition of unknown relationships in the data and computational expense. No single method emerged as a solution to all the problems of describing and explaining patterns of compositional variation in natural communities. The effect of sample set characteristics is an important factor when evaluating the efficiency of ordination techniques. The information resulting from ordination within groups could not be obtained by subjective consideration of the data. The procedure of using ordination as a check on classification and an extension of it, thus seems a potentially valuable one.

Hoffmann HP, Barrett DR and Fox JED (1987). A preliminary investigation into the plant-water relationships of species occurring in the Hamersley Ranges. *Mulga Research Centre Journal* **9**, 23-30.
Aspects of plant-water relationships were investigated. Transpiration rates of five species (*Acacia aneura, A pachyacre, A pruinocarpa, Eucalyptus terminalis* and *E leucophloia*) were measured in the laboratory over a 24 hour period under three conditions (high temperatures-high water availability; high temperatures-limited available water; low temperatures-little available water). The *Acacia* species showed a clear depression in transpiration between 1100 and 1400 h during summer conditions when available water was limited. The transpiration rates of the eucalypts did not decrease during the daylight period. *Acacia* species wilted at lower soil moisture percentages than the *Eucalyptus* species. It appears that of the species used, the acacias were more drought resistant than the eucalypts. Minimum and maximum evapotranspiration ranged from 0.1-1.4 mm d^{-1} and 3.8-14.7 mm d^{-1}, respectively, for the *A aneura* communities.

Hoy MJ, Lamont BB, Fox JED and Craig GF (1982). The importance of soil variables on establishment of *Cakile maritima* on Perth beaches. *Mulga Research Centre Annual Report* no. **6**, 13-22.
The importance of season, salinity, nutrients and water on the establishment of *Cackile maritima* in the zone

between the high water mark and the seaward edge of the incipient fore-dune was investigated. Seedling plants, collected from many beaches near Perth, were grown in beach sand (collected in winter and summer) in a glass house. Different batches of plants were given different chloride and nitrate treatments. Leaf numbers and other growth characteristics were measured weekly and plants were harvested after 11 weeks. Soils were also analysed. Nutrient availability limited growth of *C maritima* in the trials reported. Growth (and probably succulence) was positively correlated with N levels. There was no correlation between growth and P levels, but chloride positively influenced succulence and reduced root weight. Plants were shown to mature more quickly with increasing soil moisture. Thus the establishment of *C maritima* in the vicinity of Perth depends on a number of interacting factors. Seedlings establish during winter months when there is increased water in the soil (which has a diluting effect on chloride ions) and higher N levels. Plants flower and set seed in summer as conditions become less favourable for growth.

Hughes MP and Fox JED (1993). Phytotoxic effects of aluminium on *Paraserianthes lophantha* and *Acacia decurrens. Mulga Research Centre Journal* **11**, 57-73.
Soils of the Collie area of Western Australia (pH less than 5) have a potentially high concentration of Al. *Acacia* and *Paraserianthes* species, reported to be Al excluders, may be useful species for rehabilitation. Seedlings of these species from dump and non-dump sources were subjected three times a week to various levels of $AlCl_3$ (200, 500, 700, 900, 1000, 1100 ppm Al) in pot culture. Nutrients were supplied once a week. Height and dry masses (at ten weeks) were recorded. Concentrations of Al, P, N, K, Ca, Mn, Zn, Fe and Cu were determined for leaves, shoots and roots of all samples. Addition of Al to the soil had significant direct or indirect inhibitory effects on the plants as demonstrated by changes in morphology and physiology. Aluminium tended to collect in the roots of the plants, with relatively small amounts translocated to shoots and leaves. Seed from dump parents was heavier and contained more N, P, Mn, Zn, and Al than seed from non-dump areas which contained more Fe and Cu. It is recommended that seed for dump planting should be collected from parent plants growing on dumps.

Joyce G (1987). Preliminary establishment trials on *Cassia notablis* examining response to various water regimes and two soil media. *Mulga Research Centre Journal* **9**, 9-13.
Cassia notabilis is widely distributed in arid and semi-arid northern and central Australia. Small plants are unable to survive conditions of water stress. However, with a water regime which supplied a plentiful and constant supply of water from below, 100% survival was obtained in pot trials.

Kagi R, (1977). Jarrah dieback and *Acacia pulchella. Mulga Research Centre Annual Report* no. **1**, 31-32.
This is a short note regarding research into chemical components extracted from *Acacia pulchella* which may be active against the jarrah dieback fungus, *Phytophthera cinnamomi.*

Lamont B (1977). The role of extrafloral nectaries in mulga. *Mulga Research Centre Annual Report* no. **1**, 9-12.
Leaves and phyllodes of Mimosaceae have one or more nectaries (glands) on the adaxial surface of the petiole or rachis. Such nectaries have been thought to be important in guttation and/or attracting ants and insects and/or birds. Exudation was observed on *Acacia aneura, A saligna* and *A cyclops* but not on *A graffiana, A lasiocalyx* or *A pulchella.* Exuding nectaries are only apparent when the plant bears young growth, especially when flowering. In *A aneura,* exuding nectaries were clearly associated with mature inflorescences but not with buds or old heads. A multi-pathed relationship between exuding nectaries, flowers, foliage, ants, flying insects and birds may be evolutionally significant.

Lamont B (1978). Extrafloral nectaries in Australian plants with special reference to *Acacia. Mulga Research Centre Annual Report* no. **2**, 15-18.
This is discussion (with scanning electron micrographs) of the role of extrafloral nectaries, particularly those of plants from south-western Australia. Their taxonomic distribution, morphology and function is considered.

Lamont B (1981). Specialised roots in the genus *Acacia*: a review. *Mulga Research Annual Report* no. **5**, 9-11.
Root nodules (for maximising N uptake), mycorrhizae (for maximising P uptake), and other specialised proteoid roots of acacias, are considered.

Liu Y, Longmore RB, Fox JED and Kailis SG (1995). A comparison of kernel compositions of sandalwood (*Santalum spicatum*) seeds from different Western Australian locations. *Mulga Research Centre Journal* **12**, 15-21.
Seed kernels of sandalwood (*Santalum spicatum*) gathered from a number of Western Australian locations were analysed for proximate composition and fatty acid content and character. The kernels are typically very rich in a fixed oil (*ca.* 45-55%) and this oil is characterised by a high percentage of unusual acetylenic fatty acids such as ximenynic (34%) and stearolic (1%) acids. The deoiled seeds contain approximately 50% crude protein and are potentially a nutritionally rich food item. Proximate analysis of the seeds demonstrated little difference between them in the major nutritional categories, such as lipid, ash and protein. Analysis of the fatty acid profiles of the lipid fractions indicated statistically significant differences between some of the oils. Any changes due to centroid location of seed collection were not evident in predictable change in the fatty acid profiles, and therefore the observed differences were not considered to indicate different ecotypes of sandalwood. An inverse relationship has been demonstrated between the relative proportions of oleic and ximenynic acids in the fixed oil. It was speculated that this may originate from the biogenetic conversion of oleic acid to ximenynic acid.

Majer JD (1977). The mulga ant fauna. *Mulga Research Centre Annual Report* no. **1**, 2.
The influence of vegetation on the geographical variation of ants was assessed. A reference check list of species collected at each of three Western Australian sites (Dale, near Port Hedland; Yoothapina; Mileura) is given.

Majer JD (1978). The possible protective function of extrafloral nectaries of *Acacia saligna*. *Mulga Research Centre Annual Report* no. **2**, 31-39.
Acacia saligna, an endemic Western Australian wattle, has conspicuous glands which secrete actively, especially in autumn. Activity decreased in winter, rose in spring and appeared to decrease in summer, although evaporative effects may have complicated observations during hot, dry weather. Species lists and numbers of invertebrates and ants noted on *A saligna* are given. It is tentatively concluded that extrafloral nectaries have a protective effect on the plants.

Majer JD and Bergl S (1984). Studies on soil structure and soil invertebrates in rehabilitated mine sands at Eneabba. *Mulga Research Centre Annual Report* no. **7**, 71-74.
Soil structure and abundance of soil invertebrates in some rehabilitated minesite plots at Eneabba, Western Australia, were studied. Trends in soil structure and large invertebrate (>2 mm long) populations were studied in six plots selected to represent a time span ranging from 1977-1982. Soil moisture, bulk density, penetrability and infiltration rate values as well as invertebrate numbers and classification categories, were determined. All parameters indicated that although there was some evidence of recovery in large soil animal density over the six years, the density in older rehabilitated plots did not approach that in the native vegetation. When these animals do appear they are able to bring about improvements in soil properties and associated plant growth. Mulch additions may be important in encouraging the build up of soil fauna.

Majer JD and Sawyer A (1981). Competition between understorey and planted *Eucalyptus* species in rehabilitated bauxite mined areas. *Mulga Research Centre Annual Report* no. **5**, 69-70.
Competitive influences of seeded understorey on the growth of planted eucalypts were investigated at a bauxite rehabilitation site in Jarrahdale, near Perth, Western Australia. A pit planted with *Eucalyptus marginata, E patens, E saligna* and *E wandoo* was simultaneously seeded by air with seven *Acacia*, two *Kennedia*, two *Eucalyptus* and one *Callistemon* species, and a number of other species. Traverse-seeding by

aircraft resulted in swathes of dense understorey growth with intervening sparsely vegetated ground. This enabled comparisons to be made of eucalypt growth in densely and sparsely vegetated areas. Tree height and girth, and percentage and density of plant cover, were assessed. Growth of the four eucalypts was probably suppressed by understorey of the density experienced in parts of the site. *E marginata,* in particular, may be competitively disadvantaged by understorey growth.

Majer JD, Walker TC and Berlandier F (1987). The role of ants in degraded soils within Dryandra State Forest. *Mulga Research Centre Journal* **9**, 15-16.
The abundance and role of ants in degraded farmland within Dryandra State forest was investigated by measuring soil compaction, rate of water infiltration and soil moisture. Ant numbers and species were determined. Farmland was found to be of inferior physical quality to that under native vegetation and there was less shade. Ants were relatively abundant (at least 5.4 nests m^{-2}) although the diversity was less than in woodland areas. Ants were, at least in part, responsible for soil mixing and improved physical properties of the soil around their nests.

O'Connell KA and Fox JED (1995). Ecological notes on *Acacia* species. *Acacia tetragonophylla* F Muell. *Mulga Research Centre Journal* **12**, 57-64.
This article summarises biological and ecological information on *Acacia tetragonophylla* with respect to habitat; communities; response to biotic factors and environment; structure and physiology; floral and seed characteristics, herbivores, disease, related species and use. *A tetragonophylla* has a wide distribution across central and southern Australia. It is mainly a species of the drier interior, often associated with *A aneura* (mulga). The phyllodes are four-sided and spiny which gives the shrub a prickly appearance. The plant bears yellow, rounded heads of flowers in winter and papery curved or twisted pods in late spring and summer. It has some value as a fodder but has not been cultivated. It has been used in traditionalAboriginal medicine.

Osborne JM (1990). Environmental assessment following sand mining: a case study from Eneabba, Western Australia. *Mulga Research Centre Journal* **10**, 50-55.
This paper reviews the problem of establishing an assessment regime for the rehabilitation such that:
 the assessment evaluates revegetation success, as established by the Government Committee
 the assessment is repeatable and accurate
 the assessment is cost, labour and time effective.
The development of an appropriate sample size for broad acre rehabilitation assessments at Eneabba, is also addressed. A stratified random sampling covering an area of 180 m^2 provided estimates of species richness and plant density comparable with a random sample regime of 400 m^2, for a one hectare rehabilitation site. On considerably larger rehabilitation blocks, seven or eight 20 m line transects provided an accurate estimate of plant parameters with 95% statistical confidence.

Osborne JM and Brearley DR (1995). Successful tree and understorey establishment on saline gold mine wastes: a preliminary overview. *Mulga Research Centre Journal* **12**, 7-14.
Mining ceased in 1992 at the Westonia open-cut goldmine, 320 km east of Perth, Western Australia. The early May 1990 seeding of 40 ha of dump surfaces used a suite of species local to the area, and additional selected salt tolerant species. No fertiliser was applied. Stratified random sampling of the upper surface of a selected dump, was under-taken to evaluate the success of tree and understorey establishment. Eucalypts and other trees (*eg. Pittosporum phylliraeoides*) were prevalent and chenopods provided ground cover. Densities of eucalypts approximated 580 ha^{-1}, with individuals to 4 m not uncommon. Acacias and other woody perennial shrubs (*eg. Atriplex nummularia, Dodonaea viscosa*) were present. An extensive chenopod ground cover (approximately 15,680 ha^{-1}) was dominated by *Atriplex semibaccata, Enchylaena tomentosa* and *Maireana brevifolia.*

Osborne JM, Klomp NI and Burke MR (1985). Post-fire regeneration of heathland, Rottnest Island: a preliminary investigation. *Mulga Research Centre Journal* **8**, 129-133.
Post-fire regeneration in an *Acanthocarpus-Stipa* low dense heath community where enclosures, control burning and ploughing have been used as management tools was documented. *Acanthocarpus-Stipa* asso-

ciations are not the preferred plant cover yet they now cover 33% of the island at the expense of other woodland scrub species. Plant species and numbers were recorded in quadrats set up on Rottnest Island. Seed of species endemic to the locality were sown in ashbed study plots and counted three months after sowing. Enclosure fencing prevented quokka grazing. Ploughing damaged root crowns and rhizomes present in the soil. Minimum soil disturbance during control burning allows colonisation of other endemic heath community species amongst the *Acanthocarpus-Stipa* association. Present management procedures should be continued but dicotyledonous heath and other shrub species should be actively established.

Pedrotti D and Fox JED (1978). Chemical contents of the foliage of mulga. *Mulga Research Centre Annual Report* no. **2**, 1-7.
Fresh foliage of 10 *Acacia aneura* plants covering the range eaten by cattle, were tested for cyanogenic glucosides, saponins, flavanoids, wax, ether, terpenes and preparative GLC. There were no cyanogenic glucosides in the leaves, little or no saponin was present and flavanoids occurred in varying amounts. Definite differences occur in the chemical constituents of the leaf types sampled and differences within a type with age. Younger plants of *A aneura* and *A coolgardiensis* are less palatable than older (larger) ones. Flavanoids are more evident in younger samples of both species while the broad leaf mulga had much greater saponin and a higher proportion of ether extract than other edible mulga types examined. Of the tests undertaken that for terpenes shows most promise in terms of delineating possible varieties. The proportion of wax appears most variable within a particular plant.

Recher HF, Majer JD, Gowing G and Sarti NL (1993). Canopy invertebrate communities in woodlands - a comparison of morning and afternoon samples by chemical knockdown. *Mulga Research Centre Journal* **11**, 27-30.
Chemical knockdown procedures were used to sample invertebrate communities during the morning and afternoon on four species of eucalypts (*Eucalyptus capillosa, E loxophleba, E erythronema* and *E yilgarnensis*) and Jam Wattle (*Acacia acuminata*) in the wheatbelt of Western Australia. There were differences between morning and afternoon samples on the wattle and bulked *Eucalyptus* trees for individual taxa of invertebrates. Some taxa were significantly more abundant in morning samples (Collembola- and Coleoptera-larvae) whilst others were significantly more abundant in those taken during the afternoon (Araneae, Hemiptera-others, Thysanoptera, Coleoptera-adults, Diptera-adults and Hymenoptera-others). The importance of standardising sampling to set times of day is shown, and temperature, wind speed and cloud cover conditions should be as similar as possible on each sampling occasion.

Shea SR, Bartle JR and Richmond PC (1978). Preliminary studies of water relations of some tree species at Yeelirrie. *Mulga Research Centre Annual Report* no. **2**, 59-62.
Several of the tree species (*Eucalyptus trivalva, E clelandii*, and *Casuarina custata*) growing on the Yeelirrie lease were found to be using water stored at depth in the soil profile ('water spenders') and will thus probably be adversely affected by a drop in the water table. *Acacia aneura*, a drought evader, was not using stored water and its ability to survive would probably not be affected by a reduction of the water table.

Titze JF, Craig G and Lamont BB (1979). Vesicular-arbuscular mycorrhizae in jarrah forest - a preliminary note. *Mulga Research Centre Annual Report* no. **3**, 29-33.
Vesicular-arbuscular mycorrhizae (VA) in understorey and ground flora plants of the jarrah forest were studied. VA was found on a range of species and appears to be more frequent in some plants than others. For example, species of Dilleniaceae had more than those of Proteaceae. Infection was independent of plant age. In an area infected with jarrah dieback (*Phytophthera cinnamomi*), resistant plants appear to associated with more VA.

Turner JM, Fox JED and Lamont BB (1985). Notes on *Eucalyptus todiana* F. Muell. *Mulga Research Centre Journal* **8**, 101-111.
Apparent selective growth of some species under *Eucalyptus todiana* at Eneabba, Western Australia, whilst other nearby heathland species are absent, was examined. Species lists are given. No one mechanism emerged to be a main contributor to species suppression or enhancement under *E todiana* but soil moisture,

depth of litter and levels of some nutrients (including P) were significantly higher under the clumps than in the adjacent heath. No significant differences were detected in pH, soil texture and percent organic matter. Environmental factors were more favourable in the clumps. Allelopathy was not adequately determined as a causative mechanism in suppression. The presence of some elements at higher levels under clumps compared with in the heath, could act to disadvantage the suppressed species. In contrast higher moisture content and litter depth may be favourable to those species associated with the clumps.

Twigg LE (1990). The sensitivity of some Western Australian caterpillars to fluoroacetate. *Mulga Research Centre Journal* **10**, 14-18.
The sensitivity to fluoro acetate (1080) of three species of lepidopteran and one species of hymenopteran larvae, which co-exist with fluoroacetate-bearing vegetation in Western Australia, was determined. Larvae of *Perga dorsalis* (hymenopteran) and *Mnesamplea privata* feed mainly on eucalypts and were very sensitive to the toxin with LD_{50} values of 1.05 and 3.88 mg 1080 kg^{-1} respectively. *Spilosoma* sp. has a catholic diet and was moderately tolerant of fluoroacetate (LD_{50} 42.73 mg 1080 kg^{-1}). However, larvae of *Ochrogaster lunifer*, which when collected were feeding on fluoroacetate-bearing *Gastrolobium microcarpum*, were extremely tolerant to the toxin (LD_{50} *c.* 150 mg 1080 kg^{-1}). This suggests that co-evolution has occurred between the tolerant insects and the toxic plants.

Twigg LE, Majer JD and Kotula R (1982). The influence of fluoroacetate producing plants upon seed selection by seed harvesting ants. *Mulga Research Centre Annual Report* no. **6**, 75-80.
The response of ants to seed containing fluoroacetate, which were placed in artificial depots in a *Eucalyptus wandoo* open woodland, suggested that the presence of this substance has very little influence upon the seed selection of harvesting ants. Of the total seed offered, 44.3% was removed in 24 hours. The principal ant species observed taking seed were *Camponotus* sp. JDM 183; *Melophorus* sp. JDM 117; *Meranoplus* sp. JDM 400; *Monomorium* sp. 1(ANIC) and *Rhytidoponera* sp. JDM 121. Small numbers of *Gastrolobium microcarpum* seed were removed from two of five extracted ant nests.

Unsworth P (1984). Sewage nutrient extraction with *Lemna minor* and *Myriophyllum aquaticum*. *Mulga Research Centre Annual Report* no. **7**, 35-42.
Nitrogen content and productivity of *Lemna minor* and *Myriophyllum aquaticum* grown in a dilution range of nutrient concentrations from Westfield Wastewater Plant secondary effluent were determined. Increased growth tended to be associated with increased P levels for both species. Both species took up luxury amounts of N although only in *L minor* was N concentration in the tissues significantly related to growth.

Van Leeuwen SJ and Fox JED (1985). An account of edaphic factors in relation to the distribution of perennial woody species in a tropical mulga community. *Mulga Research Centre Journal* **8**, 1-12.
The study investigated whether edaphic factors could be responsible for some differences in the structure, floristics and density of *Acacia aneura* associations. Height, stem and crown dimensions of *A aneura*, and edaphic properties of two sets of sites, one down a steep hillside, the other representing a number of valley locations, were assessed. In both areas *A aneura* was the main dominant. Hill slopes provide a harsher environment in that surfaces tend to be stonier, soil moisture content is lower and the depth of soil is variable. However, valley sites tended to have lower proportions of the main plant nutrients N, P and K. This may be a reflection of higher standing woody biomass in valley sites where there were twice as many *A aneura* trees, with taller maximum heights than on the hill sites. Mean values for height, crown size and stem diameter were similar in hillside and valley locations. Moisture availability is likely to be the main influence on woody perennial biomass development. *A aneura* is more abundant on acidic soils. Soil nutrient and pH analyses suggest that soil chemical composition has some effect on species distribution and, possibly, also on density and size of perennial species. Patches of high Mg overlying dolomite on the hillside were characterised by mallee *Eucalyptus, A bivenosa and Triodia wiseana*. In the Hamersley Ranges *A aneura* tended to form compact stands on south facing slopes (which may have more moisture).

Ward D and Fox JED (1982). Ecological notes on *Acacia* species 1. *Acacia urophylla. Mulga Research Centre Annual Report* no. **6**, 41-48.
An account is given of the ecology of *Acacia urophylla* (under-storey of jarrah and karri forests of south western Western Australia) under headings of habitat; communities; response to biotic factors (burning, animal feeders, parasites, diseases); performance; adaptive features; phenology and life history.

Wijesuriya SR and Fox JED (1985). Growth and nutrient concentration of sandalwood seedlings grown in different potting mixtures. *Mulga Research Centre Journal* **8**, 33-40.
Growth of *Santalum album* seeds in five different soil mixes was compared. Germination rate was not affected by soil treatment. Shoot and root lengths, dry weights and nutrient (N, P, K, Ca, Mg, and Na) analyses were made at intervals up to 15 months from germination. Fertilising soil mixes increased plant growth in terms of height and dry matter production. 'Native mix 2' potting mix was able to support plants beyond 12 months; other mixes tested were not. It appears that fertilisers may improve the growth rate of seedlings and may support them in the field for some time prior to attachment to hosts.