The *Acacia acuminata* (Jam) group: an analysis of variation to aid Sandalwood (*Santalum spicatum*) plantation research

Table of Contents

Summary

This preliminary study has shown that most of the variation within *A. acuminata* and its close relatives, *A. burkittii* and *A. oldfieldii*, can be accommodated by seven taxa:

1. ***Acacia acuminata* (typical variant)**: widespread in the western part of wheatbelt from near Three Springs to Borden and Ravensthorpe; an outlier appears to occur at Peak Charles.
2. ***Acacia acuminata* (narrow phyllode variant)**: common in the northern, central and eastern wheatbelt and extending slightly into the adjacent Arid Zone, ranging from near Morawa to Balladonia; outlier populations near Ravensthorpe.
3. ***Acacia acuminata* (small seed variant)**: scattered in the northern wheatbelt and adjacent Arid Zone from near Kalannie to north of Yalgoo and east of Binnu; outlier populations occur in south coastal regions south of Ongerup.
4. ***Acacia burkittii***: widespread in the Arid Zone from near Yalgoo (W.A.) to S.A. and N.S.W.
5. ***Acacia oldfieldii***: restricted to two populations flanking the Murchison River near Ajana.
6. ***Acacia acuminata/burkittii* (variant 1)**: restricted to a small area in the northern wheatbelt and adjacent Arid Zone from near Mullewa to near Nerren Nerren Station.
7. ***Acacia acuminata/burkittii* (variant 2)**: restricted to a small area in the northern wheatbelt from Eradu to Ajana, common in the Northampton-Nabawa region.

- These taxa are separated by finely graded morphological differences (mainly phyllode and pod/seed features) and are broadly supported by chloroplast DNA and isozyme data. Each taxon is described, illustrated by line drawings and photographs and their distributions mapped. A key to the recognition of the taxa is provided.
- Further study is needed before these taxa can be formally described and their complex patterns of variation and evolutionary relationships fully understood.
- **The seven taxa nevertheless are "good" biological entities and they provide an appropriate base from which to conduct Sandalwood host trial research.**
- Isozyme and chloroplast DNA data both indicate that *A. oldfieldii* is very distinct from the other taxa, even though it is morphologically very similar to them.
- Isozyme, chloroplast DNA, morphological and geographical distribution data all suggest that *A. acuminata* (narrow phyllode variant) is an ancient hybrid between *A. acuminata* (typical variant) and *A. burkittii*.

Variation within the Geraldton region is extreme and has not been adequately resolved; many plants in this area appear to combine characters of both *A. acuminata* and *A. burkittii* (i.e. *A. acuminata/burkittii* variants 1 and 2). All seven taxa of the *A. acuminata* group occur within the general vicinity of Geraldton and it is suggested that this area may represent the centre of diversity for the entire group. **Care should be taken when using seed collected from this area.**

A total of 59 populations were examined and sampled during field studies conducted in November and December 1998. Despite it being a poor year for fruit-set, **24 populations yielded sufficient quantity of seed for use in family provenance trials involving Sandalwood and Jam**. This seed represents all the known variants within *A. acuminata, A. burkittii* and *A. oldfieldii*.

Bulk seed collections were acquired from a number of taxa considered worthy of testing as supplementary

Sandalwood hosts, namely, *A. anthochaera*, *A. coolgardiensis* subsp. *latior*, *A. jibberdingensis*, *A. lasiocalyx*, *A. microbotrya*, *A. neurophylla* subsp. *erugata*, *A. resinimarginea* and *A. stereophylla* subsp. *stereophylla*.

The results of this study provide the basis for the selection of known provenance material of *A. acuminata* and its close relatives for trialing as host plants for use in Sandalwood silviculture. It remains to be seen whether or not provenance differences in these host plants will lead to optimised growth performance of Sandalwood trees.

Aim

The aims of this study

- to examine the phylo-geographic patterns of variation in the *A. acuminata* group within Western Australia,
- to elucidate and delimit the taxonomic entities within this group and
- to make provenance seed collections of them for use in host-compatibility trials involving plantation-grown Sandalwood (*Santalum spicatum*).

The work was undertaken to facilitate the selection of known provenance material of *A. acuminata* and its relatives as host plants in Sandalwood silviculture. Additional to using host plants of known taxonomic status and provenance it is hoped that the results of this study will lead to an optimisation in growth performance of Sandalwood trees by determining the most suitable hosts.

Introduction

As defined here the *A. acuminata* group comprises three species, *A. acuminata, A. burkittii* and *A. oldfieldii*. The species *A. jibberdingensis, A. multispicata* and *A. sessilispica* are related to this group but are not dealt with in this report.

Taxonomic background

As traditionally defined *A. acuminata* is largely confined to the wheatbelt region of southwest Western Australia, extending from the Murchison River to near Ravensthorpe and Salmon Gums. However, the northern and eastern limits of its distribution were not easily defined because of difficulties in separating the species from its very close relative, *A. burkittii* (which extends across the southern Arid Zone from around Yalgoo in Western Australia to South Australia and New South Wales). The conventional view of the relationship between these two species was one of a gradual transition from trees with wide, flat phyllodes and reasonably long flower spikes occuring in the western woodland areas of the wheatbelt (*A. acuminata*) through shrub forms with narrow, flat phyllodes from further inland in the wheatbelt, to finally merge into a form with +/- terete phyllodes and short spikes (*A. burkittii*) in the Arid Zone (see Gardner 1944). Indeed, this relationship between the two taxa was embodied in a recent classification by Kodela & Tindale (1998) where they were treated as subspecies of *A. acuminata*, namely, subsp. *acuminata* and subsp. *burkittii*.

Acacia oldfieldii was originally described in 1863 but in the following year it was relegated to synonymy under *A. acuminata* where it remained until the early 1980's. *Acacia oldfieldii* is now recognized as a distinct species with a very restricted distribution flanking the Murchison River near Ajana.

Acacia acuminata, A. burkittii and A. oldfieldii share the following combination of morphological attributes:

- woody tall shrubs or small trees;
- bark grey, smooth except often longitudinally fissured towards base of main stems;
- branchlets (mature) glabrous;
- new shoots normally invested with appressed golden hairs;

- phyllodes elongated, finely multistriate (minor nerves not anastomosing), green, glabrous except margins and tips fringed with minute, white hairs (glabrous in *A. oldfieldii*), the apices narrowed to fine, curved, acuminate to caudate points;
- flowers 4-merous;
- spikes oblong or cylindrical and sessile or (*A. oldfieldii*) very shortly pedunculate;
- pods long and linear, brown, raised over and normally constricted between the seeds to some degree, firmly chartaceous to thinly coriaceous-crustaceous;
- seeds dark brown to black, shiny to sub-shiny; aril white or creamy white.

Past examination of collections housed at the Western Australian Herbarium had revealed that *A. acuminata* and *A. burkittii* were not convincingly delimited. Furthermore, within material ascribed to these two taxa there existed a considerable range of morphological variation. The region from about Paynes Find to Ajana was particularly troublesome because many specimens from here appeared to combine characters of both species. The characters that were most effective in helping to separate *A. acuminata* and *A. burkittii* were phyllode width, spike length and pod and seed morphology. However, because very few fruiting specimens had been collected there were often problems in sorting the material, understanding the morphological variation, reliably circumscribing the taxa, and accurately applying names to the specimens. Unlike specimens of *A. acuminata* and *A. burkittii*, those ascribed to *A. oldfieldii* appeared to be quite invariate.

Acacia acuminata as a Sandalwood host

Santalum spicatum (Sandalwood) commonly grows in association with *Acacia acuminata* in the MidWest, Goldfields and Wheatbelt regions of southwest Western Australia. *Acacia acuminata* is a suitable host for *S. spicatum* (Herbert, 1925; Loneragan, 1990) and a mineral nutrition study by Struthers *et al.* (1986) indicated that K, Ca, N and Cu were transferred from the *A. acuminata* host roots to the parasite. Presently a number of trials have been established in the wheatbelt by CALM using unknown provenances of *A. acuminata* as hosts to *S. spicatum*.

Using isozymes and chloroplast DNA to assess patterns of genetic variation in *A. acuminata*

The study of patterns of genetic variation using different types of molecular markers, such as isozymes and chloroplast DNA, provide a strong basis for determining evolutionary (phylogenetic) relationships between populations and taxa. Combined with morphological and biogeographic data this approach can be used to identify historically and evolutionary independent groups of populations and taxa that correspond to distinct biological entities. Patterns of genetic variation within and between populations are related to gene flow and historical relationships such as common ancestry. The amount and extent of gene flow (either as seed or pollen dispersal) will effect the similarity or differentiation of populations. The effects of gene flow, or isolation of populations, can be assessed through the analysis of the nuclear markers such as isozymes whereas historical associations can be identified through analysis of chloroplast DNA. This study will use

data from both isozyme and chloroplast DNA analyses to elucidate the genetic and evolutionary relationships between populations and taxa of the *A. acuminata* group.

Methods

To effectively analyse the variation within and between members of the *A. acuminata* group it was considered necessary to first undertake field studies. The material collected would be used for chloroplast DNA and isozyme analyses and taxonomic study; additionally, provenance collections of seed would be made available for use in Sandalwood plantation research. Collecting sites for this field work were determined following a preliminary sort and examination of collections attributed to *A. acuminata, A. burkittii* and *A. oldfieldii* which were housed at the Western Australian Herbarium.

Field study and seed collection

The primary target species were *A. acuminata, A. burkittii* and *A. oldfieldii*, however, a few other acacias which were deemed potentially suitable for testing as Sandalwood hosts were also targeted.

The main field survey was conducted between 30 November and 12 December 1998 where sites throughout the wheatbelt and adjacent Arid Zone from Murchison River - Southern Cross - Borden were sampled. On this trip the first author was accompanied by Maurice McDonald (Australian Tree Seed Centre, Canberra) and Mark Dalton plus Alan Prosser (CALM's Manjimup Seed Centre). Other field studies undertaken for this project included work conducted in the Sandstone - Goongarrie area (Peter Jones, November 1998), Yalgoo - Wiluna area and north of Murchison River (Maurice McDonald, November 1998), Williams and Borden (Mark Dalton, January 1999) and Bolgart - Williams area (the first author, 29-30 December).

All forms of *A. acuminata, A. burkittii* and *A. oldfieldii* that had been identified in the preliminary herbarium survey were targeted during these surveys, and in most cases range-wide collections of each form was undertaken. In most cases seed and foliage samples were taken from 5-10 plants within each population. All materials from each plant received a unique collecting number linked to a herbarium voucher specimen. The samples collected were intended for use in the isozyme analysis (seed), silviculture research (seed), chloroplast DNA analysis (phyllodes) and taxonomic studies (all plant parts). The phyllodes destined for use in the chloroplast DNA analyses were stored in a refrigerator (not frozen) immediately following collection; they were freighted to Perth about 5 days following collection. Bulk seed collections were made by Dalton and Prosser from a number of the populations: this seed was vouchered by a Maslin collection number.

For ease of reference each seed provenance for each taxon that was intended for use in the family trials was given a unique provenance name.

Seed cleaning was undertaken at the CALM Seed Centre by Alan Prosser.

Taxonomic study

In October 1998 the collections ascribed to *A. acuminata, A. burkittii* and *A. oldfieldii* at the Western Australian Herbarium were critically examined and sorted into what was considered to be natural groups (taxa). This preliminary investigation revealed

that the most informative taxonomic characters were:

- phyllode width
- spike length
- pod width
- seed length, width and thickness

Most specimens were scored for these characters. These groups were subsequently used as the basis for selecting sites to be visited during the November - December field surveys.

The taxa that had been recognized in October were reassessed in the light of fruiting specimens collected in November - December. The additional material was used to score the taxonomically informative characters. Brief descriptions were then prepared for each taxon that was finally recognized, illustrations prepared and their geographic distributions mapped. These morphologically-defined taxa were then assessed against the results of the isozyme and DNA analyses.

Isozyme analysis

Seeds (1-5) collected from 5 to 10 individuals from each of 25 population, covering each of the seven taxa comprising *A. acuminata* group, were germinated and assayed for isozyme variation. Twelve enzyme systems were resolved and 16 loci scored. All loci were polymorphic. Single locus diversity measures were estimated for each population.

Population phylogenetic analyses, to determine evolutionary relationships between populations and taxa, were based on both genetic distance and gene frequency data. Distance methods involved UPGMA and Wagner analyses. The continuous character Maximum Likelihood method CONTML (PHYLIP) was used to analyse gene frequency data. A modified Wagner method (FREQPAR) which applies the principal of parsimony to gene frequency data was then used to evaluate the best tree topology produced by the previous three methods.

Chloroplast DNA analysis

Total DNA was extracted from phyllode samples of five individuals from each of 25 populations in the *A. acuminata* group. Variation in chloroplast DNA was assayed using probes specific to chloroplast sequences. This assay identifies changes to the length of fragments of DNA that is caused by mutation. The presence and absence of mutations was analysed to determine genetic relationships between individuals and populations.

Results

Field studies and seed collection

A total of 55 populations of the primary target species, *A. acuminata. burkittii* and *A. oldfieldii* and 4 populations of the supplementary species, *A. anthochaera, A. microbotrya* and *A. resinimarginea,* were examined and sampled. Voucher specimens of all collections were deposited at the Western Australian Herbarium. The collection sites for members of the *A. acuminata* group, showing what material was gathered from each, are shown in Figure 1.

Many of the plants examined in December were either completely sterile or alternatively, their pods contained large numbers of aborted seed. This meant that range-wide seed was not collected from *A. acuminata* (both the Typical and Narrow phyllode variants). Also, because in 1998 *A. burkittii* seed matured in the latter half of November (a couple of weeks prior

to *A. acuminata* and *A. oldfieldii*) and because this species grows in rather remote regions, relatively few seed collections of this species were collected; seed collected from this species was from the western part of its geographic range.

Seed and phyllodes intended for use in the isozyme and chloroplast DNA analyses were collected from 29 populations (see Figure 1 and Appendix 2). Appendix 2 also includes a summary of seed collected for provenance trials and which is presented in greater detail in Appendix 3.

24 populations yielded sufficient quantity of seed for use in family provenance trials involving the primary target species (see Figure 1 and Appendix 3). This seed represents all the known variants within *A. acuminata, A. burkittii* and *A. oldfieldii*. Additional bulk seed samples (for use in Sandalwood host species trials) were acquired for the supplementary species *A. anthochaera, A. coolgardiensis* subsp. *coolgardiensis* and subsp. *latior, A. jibberdingensis, A. lasiocalyx, A. microbotrya, A. neurophylla* subsp. *erugata, A. resinimarginea* and *A. stereophylla* subsp. *stereophylla*, and for primary target species *A. acuminata* and *A. burkittii* (see Appendix 4).

The field survey also provided valuable information and specimen material that was subsequently used for the taxonomic assessment of variation within the *A. acuminata* group.

Taxonomy

Morphological criteria enable five main taxa to be defined, based primarily on finely graded differences in phyllode and pod/seed features, and the length of the flowering spikes.

1. *Acacia acuminata* (typical variant)
2. *Acacia acuminata* (narrow phyllode variant)
3. *Acacia acuminata* (small seed variant)
4. *Acacia burkittii*
5. *Acacia oldfieldii*

Specimens from the Geraldton region (i.e. Mingenew north to Nerren Nerren and east to Mullewa) and some from near Paynes Find do not fit comfortably into any of these taxa. These plants share, in various combinations, characters of both *A. acuminata* and *A. burkittii* and are referred to here as *A. acuminata/burkittii* (Variant 1 and Variant 2). A few populations appeared to be intermediate between Variants 1 and 2. A map of the Geraldton region and surrounds is presented in Figure 2 which shows that all of the above-mentioned taxa occur there, not just the putative intermediate forms.

The above-mentioned seven taxa together comprise the *A. acuminata* group; their principal morphological differences are summarized in Table 1 and a map showing their combined distributions is given in Figure 3. A key to these taxa, together with a description, map, illustration and photographs of each, is presented in Appendix 1. Locality details for all the specimens of *A. acuminata, A. burkittii* and *A. oldfieldii* used in this study can be obtained from the W.A. Herbarium WAHERB database. The names applied to these specimens are the same as those used in this report. This information can be used to recollect taxa from particular areas should the need arise.

Isozyme Analysis

A complex pattern of allele frequency variation was found across the *A. acuminata* group. There were some allele frequency differences between the taxa, but except for *A. oldfieldii*, the differences provided no clear separation. Significant allele frequency differences between *A. oldfieldii* and other taxa were observed at six loci.

Apart from *A. oldfieldii* genetic diversity within populations of the taxa was high compared with most other plant species investigated within and outside Australia. *Acacia oldfieldii* which is geographically restricted showed significantly lower levels of genetic diversity (*H*e) and heterozygosity (*H*o) than the other taxa (Table 2).

The Distance Wagner method (Figure 4) gave the best phylogenetic tree when evaluated by FREQPARS. The grouping of populations generally followed the recognised taxonomic entities. *Acacia burkittii* and *A. oldfieldii* formed two distinct population groups. The *A. acuminata* (small seed variant) populations clustered together and were associatedwith the *A. acuminata* (typical variant) populations. Only the *A. acuminata* (narrow phyllode variant) did not form any clear population group. Populations of *A. burkittii/acuminata* (variants 1 & 2), concentrated in the Geraldton area, were distributed throughout the phylogenetic tree although most tended to fall between the *A. acuminata* and *A. burkittii* groups.

Chloroplast DNA analysis

The data showed a high level of genetic variation within the *A. acuminata* group. There were 88 mutations detected. These mutations are analysed so that individuals with the same set of mutations can be identified. A group of shared mutations is called a haplotype and similarities between haplotypes can be determined and are shown in Figure 5. There were 39 haplotypes in the *A. acuminata* group. *Acacia anfractuosa* and *A. ephedroides* were used as unrelated species in order to orient the mutations. *Acacia oldfieldii* clade A is clearly distinct and characterised by haplotypes that are quite different to those in the rest of the group. Apart from *A. oldfieldii*, the haplotype groups are not generally specific to particular taxa, although *A. acuminata* (narrow phyllode variant) shares similar haplotyes to the southern most *A. burkittii* individuals. The haplotype group shared by *A. acuminata* (narrow phyllode variant) and southern *A. burkittii* (clade B) is the most distinctive within the *A. acuminata/burkittii* group. The presence of most of the haplotypes in the Geraldton area suggests that this may be the centre of origin of this group.

The relationships between populations based on frequency of chloroplast mutations is shown in Figure 6. *Acacia oldfieldii* is clearly different from the other taxa, which cluster into two groups. *Acacia burkittii* (except population 22) and *A. acuminata* (narrow phyllode variant) cluster together in one group, and *A. acuminata* (typical variant) (except populations 2 and 5), *A. acuminata* (small seed variant) and *A. acuminata/burkittii* (variant 1) cluster together in the other group.

Table 1. Main distinguishing morphological features of taxa comprising the *A. acuminata* group**.**

Table 2. Average population single locus diversity measures for each taxon based on 16 isozyme loci.

Figure 1. Collection sites for members of the *A. acuminata* group showing what material was collected from each population for isozyme and chloroplast analyses, and for plantation research trials. Provenance names are given in quotes, e.g. "Murchison'. Population numbers refer to those listed in Appendices 2 and 3. Abbreviations for collectors: BRM - B.R. Maslin, MM - M. McDonald and P. Butcher, PJ - P. Jones, ATSC - Australian Tree Seed Centre. The supplementary species *A. anthochaera, A. jibberdingensis, A. lasiocalyx, A. microbotrya* and *A. resinimarginea* listed in Appendix 4 are not shown here**.**

Figure 2. Map of Geraldton area showing locations of members of *A. acuminata* group within the region (based on vouchered herbarium records).

Figure 3. Map showing the distribution of taxa comprising the *A. acuminata* group. Note: The two *A. acuminata/burkittii* variants from around Geraldton are not mapped separately here (see Figure 2 for location details of these populations).

Figure 5. Relationships between haplotypes identified by chloroplast DNA analysis. The numbers on the branches represent mutations. The main clades A, B, and C are indicated. The numbers to the right of the haplotype number are population numbers with number of individuals of each haplotype given in paretheses.

Figure 6. Relationships between populations of the *A. acuminata* complex based on chloroplast DNA analysis. The numbers on the end of branches are population numbers.

Discussion

Taxonomy and phylogeny

This preliminary study has shown that most of the variation within the *A. acuminata* group can be accommodated by seven taxa, namely, *A. acuminata* (Typical, Narrow phyllode and Small seed variants), *A. burkittii*, *A. oldfieldii* and the two *A. acuminata/burkittii* variants from the Geraldton region. These seven taxa are separated by finely graded morphological differences and are broadly supported by chloroplast DNA and isozyme data. However, further study would be required to better-define these taxa and better-understand their complex variation patterns and phylogenetic relationships. These taxa, nevertheless, appear to be "good" biological entities and are appropriate for use in Sandalwood host trials. While more field and laboratory studies would undoubtedly yield worthwhile taxonomic information, such expenditure of time and money would not seem justifiable at this stage. The need to undertake such work should be assessed following the results of the host and provenance trials.

The isozyme and chloroplast DNA data both confirm that *A. oldfieldii* is distinct from the other taxa. The degree of distinctness indicated by the genetic data is much greater than the differences observed in the morphological characters. Furthermore, the chloroplast DNA data indicates that *A. oldfieldii* is monophyletic, that is, it is a natural taxon arising from the same ancestor. In contrast *A. acuminata* and *A. burkittii* are polyphyletic, that is, they are comprised of members that arise from different ancestral populations.

Acacia acuminata (narrow phyllode variant) is geographically located between *A. acuminata* (typical variant) and *A. burkittii*. This taxon has the general pod and seed morphology of *A. acuminata* but has narrow phyllodes like *A. burkttii*. The isozyme data also placed this taxon intermediate between *A. acuminata* (typical variant) and *A. burkittii*. The chloroplast DNA data clearly identified the narrow phyllode variant of *A. acuminata* as having historical affinities with *A. burkittii*. The combination of this information suggests that *A. acuminata* (narrow phyllode variant) may be an ancient hybrid derivative arising from *A. acuminata* (typical variant) and *A. burkittii* or their ancestors.

The variation in the Geraldton region (Mingenew to Nerren Nerren) has not been adequately resolved. Populations from here show a complex and high degree of morphological variation and the plants appear to combine characters of both *A. acuminata* and *A. burkittii*. Nevertheless, most (but not all) plants from here can be accommodated within two variants, namely, *A. acuminata/burkittii* variants 1 and 2.

Within the broader region surrounding Geraldton can be found *all* taxa of the *A. acuminata* group and also all of the chloroplast haplotype groups. This suggests that the Geraldton region may be the centre of diversity for this complex.

Although Kodela & Tindale (1998) treated *A. acuminata* and *A. burkittii* as subspecies of *A. acuminata* it is here considered best, *pro tem* at least, not to adopt this classification. However, judging from our results it is likely that five or six taxa will ultimately need to be recognized to accommodate the

variation within these two species. The rank applied to these taxa will need to be assessed in the light of further taxonomic study.

Silviculture implications

The most obvious and important result from this preliminary study of the *A. acuminata* group is that the use of known provenances of host plants is essential, at least in the first phase of Sandalwood plantation research. The seed supplied as part of this project will serve this purpose.

The seven taxa comprising the *A. acuminata* group all have the same general facies in the field and are distinguished be relatively minor morphological characters. Therefore care should be taken not to confuse them, particularly in the Geraldton region where all the taxa occur. The recommended re-collection strategy for the taxa/provenances should involve use of the WAHERB database as a guide to site selection. Alternatively, the maps and locality data provided in this report will enable provenances from known areas of occurrence to be re-collected (it is advised to avoid the limits of the geographic ranges where taxa abut).

If the natural conditions under which taxa grow can be taken as an indication of their likely requirements under cultivation, then the following main trends are evident:

- *A. acuminata* (all three variants) and *A. acuminata/burkittii* (variants 1 & 2) favour loamy clay or sandy loam (pH5.5-7) but should perform suitably on more sandy sites so long as water is not limiting.
- *A. burkittii* will tolerate more alkaline soils than any of the other taxa.
- *A. oldfieldii* is the only taxon in the group that occurs on deep yellow sand.

Under natural conditions all the taxa display growth form differences depending upon the age of the plants and how far apart they grow. Young plants tend to be multistemmed and have a rounded growth form. Mature plants growing in open sites away from competition have more spreading crowns than those occurring closer together in dense populations. This growth form variation was most evident in *A. oldfieldii*. In cultivation it may be possible to develop a form of host plant that best suits Sandalwood growth requirements by varying the spacing of the hosts.

Trialing of other potential hosts (apart from Jam), using seed supplied by this project, could lead to a broadening of the genetic base of hosts in Sandalwood silviculture.

1998 was not a good year for seed production in *Acacia*. Many of the plants observed in December were either completely sterile or alternatively, their pods contained large numbers of aborted seed. This applied not only to *A. acuminata* (which is known to be variable with regard to pod-set) but to most other *Acacia* species throughout the northern and central agricultural zone. It is suspected that a severe frost which affected much of southern Australia in August 1998 may have been responsible for this reduced seed production by deleteriously affecting the flowers. It remains to be seen whether or not there will be a subsequent reduction in germination from seed collected during this study.

Future studies

Further taxonomic work on the seven entities recognized in this preliminary study will need to be undertaken in due course. This work should lead to the formalizing of a classification for members of this group. The amount and complexity of variation within the Geraldton region had not generally been appreciated until now; this area requires particular attention. For example, are *A. acuminata/burkittii* variants 1 & 2 hybrids involving *A. acuminata* and *A. burkittii* or do they simply represent extremes of variation within one or both these taxa. If any of the *A. acuminata/burkittii* plants are subsequently shown to be superior Sandalwood hosts then further taxonomic studies should be undertaken ahead of their widespread use.

Detailed field studies will need to be conducted in conjunction with further taxonomic work. This applies particularly to the zones of geographic contact between *A. acuminata* (narrow phyllode variant) and both *A. burkittii* and *A. acuminata* (typical variant). Also, further sampling of the eastern part of the range of *A. burkittii* and *A. acuminata* (narrow phyllode variant) and the northern part of the range of *A. acuminata* (typical variant) are likely to yield taxonomically informative information. Further sampling of the outlying populations that occur in all three variants of *A. acuminata* would be useful, especially from the point of view of acquiring material for further chloroplast and isozyme analyses. The more important of these outliers include:

A. acuminata (small seed variant): south coastal populations.
A. acuminata (typical variant): Peak Charles.
A. acuminata (narrow phyllode variant): near Ravensthorpe.
A. ? *acuminata*/*burkittii* (variant 2): northwest of Paynes Find.

Field studies would be best conducted when plants are in fruit because pods and seeds appear to provide more useful information than do flowers. A problem in preparing the maps included in this report was that much of the herbarium material used was in flower, therefore the boundaries in many cases must be regarded as provisional.

Acknowledgements

We are especially indebted to Peter Jones, Manager of the Sandalwood Business Unit, for providing financial support to this project. Maurice McDonald of the Australian Tree Seed Centre (CSIRO) is thanked for assistance with the field work and for offering much useful advice on seed collection techniques. Mark Dalton, Manager of the Manjimup Seed Centre and Allan Prosser are thanked for participating in the field work and for processing the seed samples collected. John Maslin and Margaret Pieroni are gratefully acknowledged for their fine graphics which are reproduced here, namely, maps and line drawings respectively. Jon Brand is thanked for advice regarding Sandalwood silviculture. The work was conducted at the Western Australian Herbarium within the Biodiversity Conservation Group of CALMScience.

References

Gardner, C.A. (1944). The vegetation of Western Australia with special reference to the climate and soils. Presidential Address, 1942. J. Roy. Soc. W. Australia 28: xi-lxxxvii.

Herbert, D.A. (1925). The Root Parasitism of Western Australian Santalaceae. *Journal and Proceedings of the Royal Society of W.A.*, **11**: 127-149.

Kodela, P.G. and Tindale, M.D. (1998). The reduction of *Acacia burkittii* to *Acacia acuminata* subsp. *burkittii* (Acacia sect Juliflorae: Fabaceae, Mimosoideae). *Telopea* 7(4): 415-417.

Loneragan, O.W. (1990). Historical Review of Sandalwood (*Santalum spicatum*) Research in Western Australia. Research Bulletin No. 4. Department of Conservation and Land Management, Western Australia.

Struthers, R., Lamont, B.B., Fox, J.E.D., Wijesuriya, S. and Crossland, T. (1986). Mineral nutrition of Sandalwood (*Santalum spicatum*). *Journal of Experimental Botany* 37: 1274-1284.

Appendix 1: Taxa of the *A. acuminata* group

Key to taxa

Taxa of the *A. acuminata* group are often difficult to distinguish because the characters separating them are variable and rather cryptic. Taxa can often only be reliably identified by using a combination of characters; a knowledge of where the plants were collected from will also help ensure a correct identification (see Figure 2, 3, 8, 11, 15, 16, 22 & 25). Table 1 contains most of the same information that is presented in this key and therefore provides an alternative way of identifying specimens.

Tips for using this key: It is best to use fruiting material; hairs along the phyllode margins are best observed at x10 magnification or higher; measure phyllode, pods and seed dimensions very accurately (a millimeter difference may not seem significant, however, on small organs like seeds or narrow phyllodes and pods it may represent a substantial proportion of their total size).

1 Phyllode margins glabrous; phyllodes 3-5 mm wide; pods 2-4 mm wide; seeds compressed, elliptic (Murchison River) **A. oldfieldii**

1: Phyllode margins fringed with short, white hairs (hairs sometimes confined to upper 1/4 of phyllodes, or just the tips)

2 Phyllodes terete to flat, 0.7-2 mm wide AND seeds clearly turgid (often globose); flowering spikes 5-10(-20) mm (Arid Zone) **A. burkittii**

2: Phyllodes flat, more than 2 mm wide OR if 2 mm or narrower then seeds laterally compressed; flowering spikes 10-30 mm long

3 Pods 2.5-3 mm wide; seeds 2-3 mm long, <2 mm wide; compressed (1-1.5 mm thick); phyllodes (5-)7-10 cm long, 3-6 mm wide, straight (Kalannie - near Yalgoo) **A. acuminata (small seed variant)**

3: Pods 3-7 mm wide; seeds larger than above; phyllodes often >10 cm long

4 Phyllodes mostly 2-3 mm wide and straight to shallowly incurved; pods 3-5 mm wide

5 Seeds 3-4 mm long, 1.8-2.5 mm wide, compressed (1-1.5 mm thick) (Morawa SE to Balladonia) **A. acuminata (narrow phyllode variant)**

5: Seeds slightly larger and more turgid than above (4-5 mm long, 2.5-3 mm wide, 1.5-2.5 mm thick) (Mullewa N to north of Murchison River) **A. acuminata/burkittii (Variant 1)**

4: Phyllodes mostly 4-8 mm wide and +/- straight to recurved; pods 4-7 mm wide

6 Seeds 2.3-3 mm wide, mostly compressed (1.8-2.5 mm thick) (Mingenew S to Borden & Ravensthorpe area) **A. acuminata (typical variant)**

6: Seeds broader than above and clearly turgid (3.5-4 mm wide, 3-3.5 mm thick), globose (Eradu to Northampton and Ajana) **A. acuminata/burkittii (Variant 2)**

The taxa

Acacia acuminata (typical variant)

Description. Tall obconic *shrubs* or *trees* 3-7(-10) m tall, branchlets ascending to erect, sometimes pendulous to sub-pendulous, few-branched at ground level or with a single, straight to sub-straight bole 0.3-1.5(-2) m long and 10-30(-45) cm DBH; crowns dense, rounded to sub-rounded and up to 7-8(-10) across. *Phyllodes* flat, (6-)8-15(-18) cm long, (3-)4-8(-10) mm wide, normally +/- straight to shallowly recurved, infrequently shallowly incurved, often spreading at various angles (patent to ascending), green, margins fringed with minute white hairs; apices curved-acuminate. New shoots yellow-hairy when first initiated. *Spikes* 15-30 mm long (when dry), golden. *Pods* 4-8 cm long, 4-7 mm wide, flat but variably raised over seeds and shallowly to deeply constricted between them, rarely straight-sided, firmly chartaceous to thinly coriaceous-crustaceous. *Seeds* mostly compressed, obloid or ellipsoid to ovoid, 3-4.5 mm long, 2.3-3 mm wide, 1.8-2.5 mm thick, black, shiny to slightly shiny.

Distribution. Western part of the wheatbelt from near Mingenew S to Borden and Ravensthorpe; an outlier appears to occur at Peak Charles, about 130 km due NE of Ravensthorpe (however, this is based on the identification of a flowering specimen - pods are needed to confirm the identity of this outlier). The western boundary of the geographic range is located close to Dandaragan, Toodyay and Williams; the eastern boundary is located close to Wongan Hills, Kellerberrin, Corrigin and Ongerup. In the absence of fruits and further field studies it is difficult to precisely map the eastern boundary of the range where it abuts that of *A. acuminata* (narrow phyllode variant); therefore, the description of this boundary given above and shown in Figures 3 and 8 (which was based to a large degree on flowering material) should be regarded as provisional.

Habitat. Most commonly occurs in brown loamy clay or sandy loam (pH5.5-7) in lower parts of the landscape (often near water courses) or in low hilly country, in low eucalypt Woodland. Soil colour varies from dark brown, red-brown, pink-brown to grey-brown. It has also been recorded from shallow white sand over laterite near Corrigin, from clays and from around granite outcrops. At the northern extremity of its range this variant may occur on low sandy rises associated with salt lakes.

Parasites. Plants sometimes show signs of light Gall Rust infection. A number of the plants from the Toodyay - York area in particular were heavily infected with the aerial parasite, *Amyema*.

Phenology. Flowers from September to October. Fruiting specimens with mature seeds have been collected mainly between mid-December and mid-January, infrequently in late November. This variant is somewhat variable in its fruiting. In some years pods may fail to develop completely, or only a proportion of the plants will set fruit.

Note. This is the variant which accords with the original type collection of the species, which is why it is called the Typical variant.

Variation. Specimens with broadest phyllodes occur mostly in the Toodyay - Katanning region; in areas to the north and east of here the phyllodes appear to become progressively narrower. Specimens with consistently narrow phyllodes occur in southern areas from Borden to Ravensthorpe. Few specimens with atypically narrow phyllodes (3 mm wide) occur scattered elsewhere throughout the range in

areas where normal broad phyllode individuals are found, e.g. Corrigin, Tambellup, New Norcia. It is often difficult, especially from herbarium material without pods, to distinguish typical *A. acuminata* from the narrow phyllode variant of the species (see below under Affinities).

The tallest plants observed occurred near Corrigin. These were old trees about 10 m high, they had 2-3 main trunks arising from ground level (each about 0.45 m DBH) and crowns measuring about 10 m across.

Plants growing in open sites away from competition tend to have wider and more rounded crowns (to about 8 m across) than on plants from within closely spaced (about 1-3 m apart), often monospecific, populations.

Within a single population one can encounter plants with single boles (commonly to about 1-1.5 m long) or with 2-6 main stems arising from ground level.

Pendulous forms of this variant are found scattered throughout the range. In most places these pendulous plants occur at a low frequency within populations of typical individuals (which have ascending to erect branchlets and variously spreading to ascending phyllodes).

Affinities. This variant is distinguished (somewhat arbitrarily) from the narrow phyllode variant of *A. acuminata* by its generally wider, often shallowly recurved and more spreading phyllodes, wider pods and often slightly wider and thicker seeds. *Acacia acuminata* (narrow phyllode variant) apparently only very occasionally develops a single bole (to about 1 m long). In the central and northern wheatbelt the geographic ranges of these two variants abut and further field and laboratory studies are needed here to more confidentally separate the two taxa. Areas where both variants appear to occur include the Kellerberrin - Merredin and Wongan Hills regions. Plants of *A. acuminata/burkittii* (Variant 2) from around Geraldton (see below) are very similar to *A. acuminata* (typical variant) except that they have clearly turgid, wider seeds.

1998 Collections. *B.R. Maslin* 7781-7783, 7845-7856

Figure 7. Illustrations of *A. acuminata* (typical variant). A- Flowering branchlet (note wide-spreading, shallowly recurved phyllodes). B - Phyllodes showing width variation (with detail showing cross-section: note margins are minutely hairy). C - Pod. D - Seed (plane view). E - Seed (side view). A from *N.N. Donner* 1404; B from *H. Demarz* 3917 (left hand phyllode) and *T.E.H. Aplin* 1038 (right hand phyllode); C - E from *B.R. Maslin* 7852. Drawings by M. Pieroni.

Figure 8. Map showing distribution of *A. acuminata* (typical variant) (based on vouchered herbarium records: see text for discussion of boundaries).

Figure 9. *A. acuminata* (typical variant). Clockwise from top left: A. Inflorescence (photographer: M. McDonald). B. Habit, near Katanning, W.A. (photographer: M. McDonald). C. Pods (photographer: B.R. Maslin). D. Habit, near Borden, W.A. (photographer: B.R. Maslin).

***Acacia acuminata* (narrow phyllode variant)**

Description. Obconic or rounded *shrubs* or small obconic *trees* commonly 2-5 m tall and 1.5-4 m wide, sometimes (e.g. around granite rocks) trees 6-7 m tall and spreading to about 7 m across, plants in open sites away from competition tend to have more rounded crowns than those in dense populations; with 2-6 main stems arising from ground level, sometimes with a single bole up to 0.5 m long (very occasionally to 1 m, e.g. *B.R. Maslin 7841*), the main stems rather straight, slender and ascending to erect; crowns dense to mid-dense, rounded to sub-rounded, spreading and occupying 20-40% of the total plant height. New shoots yellow-hairy. *Phyllodes* flat, 7-14 cm long, (1.5-)2-4 mm wide, ascending to erect, straight to very shallowly curved, green, margins fringed with minute white hairs, apices narrowed to curved-acuminate tips. *Spikes* (7-)10-15(-20) mm long (when dry), golden. *Pods* (2-)3-8 cm long, 3-4(-5) mm wide, variously raised over the seeds and shallowly or sometimes moderately constricted between them, firmly chartaceous to thinly coriaceous-crustaceous. *Seeds* compressed, elliptic to oblong-elliptic, oblong-ovate or ovate, 3-4 mm long, 1.8-2.5(-3) mm wide, 1-1.5(-2) mm thick, shiny to sub-shiny, dark brown to black; aril white or creamy white.

Distribution. Northern, central and eastern wheatbelt region and extending just into the adjacent Arid Zone, from near Morawa SE to Balladonia; outlier populations appear to occur at Carracarrup Pool and on the Phillips River near Ravensthorpe. The northern boundary of the geographic range runs west of Wubin, and close to Beacon, Southern Cross and Kalgoorlie. The southern boundary runs close to Wubin, Kellerberrin, north of Hyden and south of Norseman. In the absence of fruits and more field studies it is difficult to precisely map the northern boundary where it abuts that of *A. burkittii* and the western boundary where it abuts and narrowly overlaps that of *A. acuminata* (typical variant) - see discussions under these two taxa (see also Figures 3 and 11).

Habitat. This variant is commonly found on brown or red-brown loam or clay-loam flats (pH 6-7) in tall shrubland or open eucalypt woodland. It is also commonly found on sandy loam associated with granite rocks and commonly forms dense fringing communities around the base of these outcrops. It has also been recorded from low sand rises associated with salt lakes and appears slightly to moderately salt tolerant.

Parasites. Plants sometimes show signs of light Gall Rust infection.

Phenology. Flowers from late July to September, sometimes extending to October. Pods with mature seed have been collected mainly in late November and December. Not all trees in a population necessarily produce fruit and those that do commonly display considerable differences with regard to the amount of fruit set. It is not known what factors cause this variation but it is likely that the timing and/or intensity of rainfall events play a role.

Variation. Specimens with the widest pods (to 5 mm) and widest seeds (to 3 mm wide) often occur in well-watered sites such as the base of granite rocks (e.g. Petradur Rocks west of Kalannie, Wongan Hills); these plants are often taller than those elsewhere. Also, plants from low sand rises between saline depressions in the Lake Cowcowing have pods to 5 mm wide (see *G. Craig 1620*).

Phyllodes can vary from 2-4 mm wide between plants within a single population.

Affinities. This variant is most closely related to *A. acuminata* (typical variant) and indeed, as noted above it

is difficult to separate the two in the areas where their geographic ranges overlap. The isozyme analysis suggests affinities with *A. burkittii* and, as discussed under *A. burkittii*, the two are easily confused unless in fruit.

1998 Collections. *B.R. Maslin 7817-7829, 7831, 7833, 7835, 7837, 7839, 7841, 7843*.

Figure 10. Illustrations of *A. acuminata* (narrow phyllode variant). A- Flowering branchlet (note straight to shallowly incurved phyllodes). B - Single phyllode (with detail showing cross-section: note margins are minutely hairy). C - Seed (plane view). D- Seed (side view: note seed is laterally compressed). E - Pod. A from *C.A. Gardner* s.n. (PERTH 00462500); B-E from *B.R. Maslin* 7822. Drawings by M. Pieroni.

Figure 11. Map showing distribution of *A. acuminata* (narrow phyllode variant) (based on vouchered herbarium records: see text for discussion of boundaries).

Figure 12. *A. acuminata* (narrow phyllode variant). Clockwise from top left: **A**. Pods. **B**. Habit, E of Kalannie, W.A. **C**. Detail of multistemmed habit, Buntine Rock, W.A. **D**. Population fringing Moorine Rock, W.A. (Photographer: B.R. Maslin).

Acacia acuminata (small seed variant)

Description. Rounded *shrubs* or small *trees* (2-)3-5 m tall, multi-stemmed with 3-6 main stems arising from ground level, sometimes (when a tree) with a short bole to about 1 m long, main branches and branchlets erect; crowns neat and compact, 2.5-6 m across. New shoots golden hairy. *Phyllodes* flat, (5-)7-10 cm long, 3-6 mm wide, straight, ascending to erect, bright mid- to dark-green, margins fringed with minute white hairs; apices narrowed to a curved, delicate, acuminate to caudate point. *Spikes* 1 or 2 per axil, 10-20 mm long (when dry), golden. *Pods* 4-8 cm long, 2.5-3 mm wide, light brown, pendulous, straight to shallowly curved, flat but prominently raised over seeds, scarcely constricted between seeds, firmly chartaceous to thinly crustaceous. *Seeds* compressed, obloid-ellipsoid to obloid or (when very short) almost square, 2-3 mm long, 1.5-1.8 mm wide, 1-1.5 mm thick, glossy, black; aril white, membraneous, extending 1/3-1/2 way down one side of the seed.

Distribution. The main area of occurrence is the northern wheatbelt and adjacent Arid Zone from about 50 km NE of Kalannie north to Jingemarra Station (N of Yalgoo) and east of Binnu. Somewhat surprisingly herbarium collections show that it also occurs in a small area along the south coast (S of Ongerup): these southern populations have not yet been examined in the field. Relatively few collections of this variant have been made to date but it is suspected that future sampling within the areas indicated above will show it to be more common than current collections indicate. See Figures 3 and 15.

Habitat. The northern populations appear to occur in higher parts of the landscape in sometimes rocky, reddish or greyish brown fine loam (pH 5.5-6) or sandy clay, in open scrub or shrubland. The southern populations occur in granitic sandy loam in *Eucalyptus* woodland on gently undulating plains.

Phenology. Flowers in August - September. Fruits with mature seeds occur from mid-November to mid-December.

Affinities. This variant is distinguished from all other variants of *A. acuminata* by a combination of its narrow pods with small seeds and its broad phyllodes.

Rank. It is likely that this variant will ultimately be afforded formal subspecific rank within *A. acuminata*.

1998 Collections. *B.R. Maslin 7796, 7830*; *M. McDonald* & *P. Butcher 2590-2599, 2616.*

Figure 13. *Acacia acuminata* (small seed variant). From left to right: **A**. Pods. **B**. Habit, E of Binnu, W.A. (Photographer: B.R. Maslin).

Figure 14. Illustrations of *A. acuminata* (small seed variant). A- Flowering branchlet. B - Single phyllode showing caudate tip (with detail showing cross-section: note margins are minutely hairy). C - Seed (plane view: note small seed). D- Seed (side view: note small seed which is laterally compressed). E - Pod. A from *G. Phillips* for *A.M. Ashby* 4865; B - E from *B.R. Maslin* 7521. Drawings by M. Pieroni.

Figure 15. Map showing distribution of *A. acuminata* (small seed variant) (based on vouchered herbarium records).

Acacia acuminata/burkittii complex

Specimens in the general region of Geraldton and a few from near Paynes Find cannot be comfortably accommodated within any of the formal variants of *A. burkittii* or *A. acuminata*. Indeed, plants from these areas appear to exhibit various combinations of morphological attributes that characterise *A. burkittii*, *A. acuminata* (typical variant) and *A. acuminata* (narrow phyllode variant). These putative intermediate forms are therefore called *A. acuminata/burkittii:* it is not known whether they are hybrids or simply represent extremes of variation within *A. acuminata* and/or *A. burkittii*. The *A. acuminata/burkittii* variants are concentrated in the area from Morawa north to Nerren Nerren Station and east to the latitude of about Mullewa; plants from granite rock areas just to the north of Paynes Find may also be referable to these variants. Although the patterns of variation are very complex there appears to be two main trends (described under variants 1 and 2 which follow). What appears to be intermediates between variants 1 and 2 occur near Mingenew (e.g. *B.R. Maslin* 7784), Yuna (*B.R. Maslin* 7799) and Ajana (*B.R. Maslin* 7794). Figure 2 shows the taxa of the *A. acuminata* group which are recorded from within the greater region surrounding Geraldton: this figure shows all taxa from the *A. acuminata* group, not only *A. acuminata/burkittii* variants 1 & 2, occur here.

A. acuminata/burkittii (Variant 1)

Phyllodes straight to shallowly incurved, occasionally shallowly recurved, narrow (2-3 mm wide), seeds fairly turgid but compressed to some degree, (3.5-)4-5 mm long, 2.5-3(-3.5) wide and 1.5-2.5 mm thick, and pods 4-5 mm wide and clearly rounded over the seeds. The phyllodes are very similar to those found on *A. acuminata* (narrow phyllode variant) while the seeds are similar to those found on *A. burkittii* except that they are more compressed, thus not as thick. These plants occur near Mullewa but most collections are from near Binnu north to near Nerren Nerren Station. In the absence of seeds it is often not possible to distinguish this variant from flat phyllode forms of *A. burkittii*, thus, in Figure 2 the sterile and flowering specimens from between Yalgoo (where typical *A. burkittii* occurs) and Mullewa have not been mapped. This variant is represented in the present study by the following 1998 collections: *M. McDonald & P. Butcher 2580-2589, 2617, 2618; B.R. Maslin 7788, 7789, 7795* and *7801*.

A. acuminata/burkittii (Variant 2)

Phyllodes +/- straight to moderately recurved, lax, (3-)4-8 mm wide, seeds large and turgid, 4-5 mm long, 3.5-4 mm wide, 3-3.5 mm thick, pods 4-6 mm wide and clearly rounded over the seeds. This variant differs from Variant 1 in having generally broader and thinner, often recurved phyllodes and wider, thicker seeds. Flowering specimens of Variant 2 can easily be mistaken for the more southerly distributed *A. acuminata* (typical variant); however, the broad phyllode form of *A. acuminata* has narrower, somewhat compressed seeds (i.e. 2.3-3 mm wide and 1.8-2.5 mm thick). These plants are common in the

Northampton-Nabawa area but they range south to Eradu (Greenough River) and Mt Fairfax, and north to near Ajana. Although this geographic range overlaps that of Variant 1 the two are not known to be sympatric. Variant 2 is represented in this study by the following 1998 collections: *B.R. Maslin 7786, 7800*.

It is possible that the specimens from granite rock areas 15-20 km N and NW of Paynes Find referred to under *A. burkittii* are referable to Variant 2, however, better fruiting material is needed to check this.

Figure 16. Map showing distribution of *A. acuminata/burkittii* (Variants 1 & 2). See Figure 2 for details of distribution of these variants within the Geraldton region.

Figure 17. Illustrations of *A. acuminata/burkittii* (Variant 1). A- Phyllode. B - Pod. C - Seed (plane view). D- Seed (side view: note seed is laterally compressed). All from *B.R. Maslin* 7788. Drawings by M. Pieroni.

Figure 18. *A. acuminata/burkittii* (Variant 1). **A**. Habit, near Nerren Nerren, W.A. **B**. Pods. (Photographer: B.R. Maslin).

Figure 19. Illustrations of *A. acuminata/burkittii* (Variant 2). A & B - Phyllodes showing width variation. C - Pod. D - Seed (plane view). E- Seed (side view: note seed is markedly turgid). A, C - E from *B.R. Maslin* 7786; B from *B.R. Maslin* 7785. Drawings by M. Pieroni.

Figure 20. *A. acuminata/burkittii* (Variant 2). **A**. Pods. **B**. Habit, E of Binnu, W.A. (Photographer: B.R. Maslin).

Acacia burkittii

Description. Multi-stemmed *shrubs* or small *trees* 1.5-5 m tall, sometimes trees 7-8 m tall with single bole (to about 1 m long) or sparingly branched at ground level; crowns dense to mid-dense, rounded and 3-6 m wide. *Phyllodes* terete, quadrangular, subterete or flat, (5-)6-13(-20) cm long, 0.7-1.5 mm wide or up to 2 mm wide when flat, straight to shallowly incurved, ascending to erect, margins fringed with minute white hairs but on terete phyllodes the hairs commonly confined to the apical region of the phyllodes (sometimes just the tips); apices narrowed to a delicate, curved-acuminate point. *Spikes* obloid to cylindrical, normally 5-10 mm long (when dry), occasionally to 20 mm long, golden. *Pods* 4-8 cm long, 4-5(6-7) mm wide, often moniliform to sub-moniliform, sometimes prominently rounded over seeds but only shallowly constricted between them, firmly chartaceous to thinly coriaceous-crustaceous. *Seeds* globose to ovoid or obloid-ellipsoid, 3.5-5(-6) mm long, 3-4.5 mm wide, clearly turgid (3-4.5 mm thick); aril white.

Distribution. Arid Zone from near Yalgoo eastwards through South Australia to New South Wales. In Western Australia the northern boundary of the geographic range runs just north of Meekatharra, Wiluna and Warburton. The southern boundary extends to the west of Wubin, just north or Kalgoorlie and just south of Forrest (on the Nullarbor Plain). In the absence of fruits it is difficult to precisely map the southern boundary *of A. burkittii* where it abuts that of *A. acuminata* (narrow phyllode variant); therefore, the description of this boundary given above and shown in Figures 3 and 22 (which were based to a large degree on flowering material) should be regarded as provisional.

Habitat. Commonly found on plains in red clay-loam or sandy loam (pH 5.5-8) over limestone or a hardpan, in mixed *Acacia* shrubland with Mulga (*A. aneura*) and/or Bowgada (*A. ramulosa*). It has also been recorded from coarse sand associated with granite outcrops, low rocky hills, and (especially in the eastern part of its range in W.A.) in open low Eucalyptus woodland.

Phenology. Flowers from July to September. The peak fruiting period occurs from early October to mid-December, depending upon area and local conditions.

Variation. In Western Australia flat phyllode forms of *A. burkittii* tend to occur along the southern and western edge of its geographic range; elsewhere in W.A. the phyllodes are generally terete to sub-terete. In some areas, e.g. around Paynes Find, both phyllode forms occur. Along its southern border where *A. burkittii* and *A. acuminata* (narrow phyllode variant) meet, the two species may have a very similar facies in the field and both commonly have flat phyllodes 1-2 mm wide. Therefore, in the absence of fruits they cannot be reliably distinguished (seeds are clearly more turgid and normally wider in *A. burkittii* than in *A. acuminata*). This situation occurs principally in the area from Yalgoo to south of Paynes Find and eastward to around Kalgoorlie; in this region the two species are sometimes sympatric (see *B.R. Maslin* 7840 - *A. burkittii* and 7841- *A. acuminata*). In the area south of Paynes Find the plants with flat phyllodes commonly have non-moniliform pods (i.e. prominently rounded over the seeds and scarcely constricted between them); in more arid inland areas the pods are normally +/- moniliform. Specimens with flat

phyllodes to 2 mm wide are also occasionally encountered on plants from N.S.W. and S.A. (see Kodela and Tindale 1998).

Specimens with the largest seeds (to 6 mm long and 4.5 mm wide) occur around Paynes Find: there appears to be no taxonomic significance in this character.

Specimens with the longer spikes (up to 20 mm) are normally found on some plants with flat phyllodes in the Mt. Magnet - Meekatharra area.

Specimens from granite rock areas 15-20 km N and NW of Paynes Find are atypical in having especially broad phyllodes (see *B.R. Maslin* 7809-7812). It is possible that these might represent the same taxon discussed above as *A. acuminata/burkittii* (Variant 2), however, the fruiting material from the Paynes Find populations is too inadequate for a positive identification to be made at this stage.

On specimens with terete phyllodes the hairs are generally confined to extremities of the phyllodes, sometimes just the tips. On flat phyllodes, however, the marginal hairs generally extend much further down the blade (to near the middle of the phyllode).

Affinities. *Acacia burkittii* is most readily distinguished from the other members of the *A. acuminata* group by a combination of its narrow phyllodes and large, turgid seeds. Furthermore, this species occurs further inland than the other taxa and it commonly has shorter spikes. *Acacia burkittii* is the only member of the group with terete phyllodes. Difficulties in distinguishing this species from *A. acuminata* (narrow phyllode variant) are noted above under Variation.

1998 Collections. *P. Jones 1 & 5*; *B.R. Maslin 7815, 7838, 7840*; *M. McDonald & P. Butcher 2499-2507, 2600-2604, 2605-2615, 2621-2624*.

Figure 21. Illustrations of *A. burkittii*. A- Flowering branchlet. B - Terete phyllode (with detail showing cross-section: note margins are minutely hairy). C - Flat, narrow phyllode (with detail showing cross-section: note margins are minutely hairy). D - Pod. E - Seed (plane view). F - Seed (side view showing marked turgidity). A from *F.M. Bennett* 151; B from *K. Thomas* 1; C, E & F from *P. Jones* 5; D from *M. McDonald* 2600. Drawings by M. Pieroni.

Figure 22. Map showing distribution of *A. burkittii* (based on vouchered herbarium records: see text for discussion of boundaries).

Figure 23. *A. burkittii*. Clockwise from top left: **A**. Inflorescence (photographer: M. Fagg). **B-D**. Variation in habit **B**, near Wiluna, W.A. (photographer: M. McDonald); **C**, near Mootwingie, N.S.W. (photographer: M. Fagg); **D**, near Yalgoo, W.A. (photographer: M. McDonald).

Acacia oldfieldii

Description. Rounded or obconic, openly branched, spreading *shrubs* or small *trees* 2-4 m tall, multi-stemmed or sparingly branched at ground level, sometimes mature plants with a single bole c. 1 m long, main stems and branches somewhat crooked (straighter in *A. acuminata*); crowns up to 4 m across, on mature plants generally sparsely foliaged (not as bushy as those of *A. acuminata*), but can be dense in run-off areas and in open sites. *Phyllodes* flat, 7-13 cm long, 3-5 mm wide, straight to shallowly incurved, coriaceous, sub-rigid, dark green, glabrous (margins not fringed with minute hairs); apices narrowed to a curved, delicate, acuminate to caudate point. *Spikes* 30-35 mm long (when dry), golden, the flowers not densely arranged; receptacle glabrous or white-hairy. *Pods* moniliform to sub-moniliform, 8-13 cm long, 2-4 mm wide, thinly crustaceous, finely longitudinally wrinkled on the surface. *Seeds* ellipsoid to obloid-ellipsoid, 3-4 mm long, 1.5-2 mm wide, compressed (1-1.5 mm thick), black, shiny (sometimes minutely pitted at centre); aril cream, much-folded below the seed.

Distribution. Known from only two populations on the Murchison River, one at Hawkes Head Lookout and the other extending from about 7-12 km north of the Murchison River Bridge along North West Coastal Highway. The species is common in both areas. Detailed sampling of the yellow sand shrublands in the area north to Tamala Station (Shark Bay) may show *A. oldfieldii* to be more common than current collections indicate. See Figures 3 and 25.

Habitat. Deep yellow sand or shallow, yellow-brown sand over sandstone, pH 5.5-6; in sandplain scrub.

Phenology. Flowers in August (few flowering collections seen). Fruits with mature seeds occur from late November to early January.

Variation. Morphologically *A. oldfieldii* is quite invariate. However, plants in open sites away from competition tend to be more densely foliaged and have a lower, more spreading habit than those occurring closer together in communities.

Affinities. Morphological characters including phyllode nervation, 4-merous flowers and general seed attributes show this species related to *A. acuminata* from which it is most readily distinguished by its glabrous phyllodes (the margins not fringed with hairs as in *A. acuminata*), its less densely flowered spikes with short peduncles and a glabrous or white-hairy receptacle (spikes sessile and receptacle normally golden-hairy in *A. acuminata*) and its moniliform to sub-moniliform, narrow, thinly crustaceous pods.

1998 Collections. *B.R. Maslin* 7790-7792; *M. McDonald* & *P. Butcher* 2619.

Figure 24. Illustrations of *A. oldfieldii*. A- Flowering branchlet. B - Single phyllode (with detail showing cross-section: note margins are glabrous). C - Pod. D- Seed (plane view). E - Pod (side view). A from *A.M. Ashby* 4538; B - E from *B.R. Maslin* 7791. Drawings by M. Pieroni.

Figure 25. Map showing distribution of *A. oldfieldii* (based on vouchered herbarium records).

Figure 26. *Acacia oldfieldii*. Clockwise from top left: **A**. Pods. **B.** Dense, spreading shrub in open site (along roadverge). **C**. Mature, openly branched small tree in stand of natural vegetation. (Photographer: B.R. Maslin).

Appendix 2. Summary of all seed and phyllode material collected/supplied for chloroplast DNA and isozyme analyses and for plantation research.

Appendix 3. Provenance collections of *A. acuminata* and its allies for use in family trials: collecting localities and habitat details.

Appendix 4. Bulk seed collections for Sandalwood host species trials.

Appendix 5. Climatic information for provenance collection sites.