Increasing species diversity on landscapes impacted by coal mining in NSW, Australia

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Abstract

Interest in the establishment of self-sustaining, low maintenance native plant communities on post-mined land has emphasised the need for information on a more diverse suite of species suitable for rehabilitation. Research involving laboratory, glasshouse and field experimentation has been undertaken on native species local to areas that are affected by coal mining activities throughout New South Wales (NSW). Studies have ranged from investigations on seed biology through to methodologies for establishment on specific mine media.

Seed biology information is of vital importance for revegetation programs using direct seeding methods. Laboratory studies on germination, viability and dormancy have been used to identify the potential germination responses of seed from more than 100 species. This information assists the selection of appropriate species and the seeding rates necessary for broad-scale field application, but further provides valuable background for correct interpretation of field trial outcomes. Subsequent glasshouse trials provided a valuable tool for screening species for their suitability in the spectrum of growth media available at the mines. These trials also allowed the opportunity to assess characteristics of the media that may be limiting to plant growth, thus identifying the necessity for, and level of, management inputs required to produce a satisfactory level of field success. Given the often unreliable and erratic climatic conditions encountered in the field, a major focus of the project was the collection of long-term data through the monitoring of trials set up at each of nine mines. Data on emergence, establishment and persistence over the first four years has resulted in recommended species lists for each site.

Project outcomes have provided the coal mining industry in the region with the opportunity to increase the diversity and hence the robustness and sustainability of those areas where the end land use is targeting a native ecosystem. In addition, the trials have demonstrated how appropriate seedbed preparation is critical, and that some alteration to current rehabilitation preparatory practices may be required to maximise native species success. The sequential and cost-effective research approach to identifying and testing species suitability, identifying and modifying media to maximise success, and the monitoring and analysis of longer-term trials, are all features of this project that can be broadly applied to support the decision-making processes behind planning a rehabilitation program.

Introduction

Australian laws require mining companies to undertake rehabilitation to create a stable landscape and to ensure further land-use options after the life of the mine. Past minesite rehabilitation has focussed on rapid and economic plant establishment on hostile media (Bellairs, 1998; Bradshaw, 1998) to improve the characteristics of the substrate. Such revegetation has predominantly consisted of the use of exotic pasture species and a relatively narrow selection of native tree species from few taxonomic families, such as the Mimosaceae, Myrtaceae and Casuarinaceae (Ryan, 1995; Burns, 1999). These revegetated areas can have high management requirements (Marschke *et al.,* 1994). For at least five years post-establishment, maintenance can include the application of high rates of fertiliser, livestock grazing, the establishment of fenced tree plots throughout areas of pasture, repair of any erosion damage and weed control (Hannan and Gordon, 1996).

Interest in the type of rehabilitation undertaken in NSW has increased and resulted in a desire for native tree establishment. Trees were found to improve the physical and chemical characteristics of the spoil, as well as the hydrology and geotechnical aspects of slopes (NSW DMR, 1999). In addition to aesthetic improvements, they were found to require less maintenance than pasture, were more drought tolerant, provided shade and created habitat for fauna. The inclusion and success of native trees has lead to increased interest in the establishment of native species from a range of strata (lower, mid and upper canopy species) which better represent a native community.

Benefits of native communities

Establishing a species rich native plant community contributes to the conservation of Australia's biodiversity and the newly created system can become a source of local seed. Including a diverse range of native species increases the aesthetic value of the plant community and, where adjacent areas support undisturbed vegetation, the rehabilitated land can provide necessary migratory corridors for native fauna (Majer, 1990). Australian native plant communities play an essential role in supporting our native vertebrate fauna, through the provision of both food and shelter. Associated invertebrates and micro-organisms inhabiting these communities are essential for nutrient cycling.

Roles are also played in assisting erosion control, helping maintain soil structure and improving hydrological aspects of the substrate. In addition, adequate cover with native species can inhibit weed invasion through the efficient use of resources (space, light, nutrients and water).

Since seed is the most efficient and cost effective means for revegetating large areas of degraded land with a diverse range of species, an understanding of availability, seed quality, germination and dormancy factors is crucial (Dixon and Meney, 1994).

Seed biology of Australian native species

Even with a sufficient supply of seed and favourable field conditions, some native species are still difficult to establish. Australian native species have developed unique adaptive strategies as a result of their highly endemic nature (Dixon and Meney, 1994). More specifically, Australia's variable environmental conditions have caused the development of a wide range of germination responses to ensure survival of the resulting seedling (Bell, 1999). For example, fire has played an important role in the selection of reproductive strategies, and as a result, the germination requirements of many native Australian plants (Bell *et al.,* 1987).

The major factors affecting the germination of seeds include seed quality, viability, the presence of basic germination requirements and seed dormancy. According to Bell (1994), approximately one-third of Australian species possess dormancy mechanisms, a further third have non-dormant seeds, and the remainder are often difficult to establish from seed due to factors such as low viability.

Seed viability and dormancy are important to rehabilitation programs for a number of reasons. Knowing the viability of seed will assist in determining seeding rates, since more seed will be required to achieve a given level of germination if the viability is low (Dixon, 1997). This will assist in estimating the cost of seed and the relative cost of sowing different species. Undertaking viability tests can also determine whether, for example, certain harvesting, cleaning or storage conditions are detrimental to the viability of the seeds, or whether a given seed lot should be discarded rather than sown. In addition, viability tests can indicate whether poor germination is due to the presence of dormancy mechanisms or a result of low seed viability.

There has been limited research into the suitability of many of our native Australian plant species for mined land rehabilitation. The identification of seed dormancy mechanisms, and the effective means to overcome them, can allow the selection of a larger number of species for establishment at a given site (Richards and Beardsell, 1987). As well as increasing species richness, this could ensure that certain, possibly key species, are not omitted from a revegetated area (Dixon, 1997). Applying dormancy breaking treatments can also assist rehabilitation projects where uniform and timely seedling establishment is required (Adkins and Bellairs, 1995). In addition, information about the extent of dormancy will indicate whether the application of dormancy breaking treatments is feasible and assist in the interpretation of field results, thus improving the success of rehabilitation programs.

Field environment

Once appropriate species have been selected for revegetation, environmental conditions associated with post-mined land need to be taken into consideration when predicting success. Landscape attributes (topography, hydrology, soil stability, flora and fauna) are significantly altered through disturbance by open-cut coal mining (Bell, 1996[a]). Substrate materials from depth are often exposed on the surface presenting both physical and chemical conditions unfavourable for many plants. Even where surface soils are returned to the surface, the soil handling *per se* can have a major impact on soil structure and organic matter content and distribution. In addition, rainfall is not always reliable, contributing to difficulties associated with emergence, establishment and survival in problematic substrates. For vegetative growth to occur in a substrate, the root zone must have a suitable water holding capacity and aeration, be physically unrestrictive to emergence and root growth, have a sufficient supply of plant nutrients and be minimally impacted by factors such as salinity, sodicity, metal toxicities, acidity and alkalinity (Bell, 1996[b]; Hannan and Gordon, 1996).

The initial establishment of seedlings, and even long-term persistence, is affected by aspects such as seedbed preparation and planting methods, soil variation, species used and seed origin (Montalvo *et al.,* 2002). Site preparation prior to seeding varies between mines, although some basic procedures are undertaken at most sites. Since reshaping of overburden usually results in compaction, cultivation is required to improve seedbed conditions. Surface cultivation can provide micro-site conditions that are optimum for both seed germination and establishment and provide a more favourable environment when climatic conditions are inadequate (Bradshaw, 1998; Clarke and Davison, 2001). Other amelioration techniques to improve the seedbed on post-mined land include rock raking, deep ripping and mulching (Burns, 1999). Fertiliser addition, both at establishment and post-establishment is another rehabilitation practice common to most sites, particularly where pasture species are sown.

Project aim and objectives

A research program was undertaken to provide practical information for use by mine environmental practitioners to overcome various establishment difficulties for a group of native groundcover and mid-canopy species.

The overall aim of this study was to assess the establishment success of a range of native species on post-mined land in NSW, and to determine key factors affecting establishment. To enable the fulfilment of this broad aim, three separate studies were undertaken, each with specific objectives.

The first series of experiments aimed to determine for which species seed biology limits establishment. Seed viability, germination and dormancy were studied on a select group of native species. In the second phase of the project, a range of coal mine media were selected from each of nine open-cut coal mines for further experimentation under glasshouse conditions, to determine whether, and for which species, the mine media limits emergence under well-watered conditions. Finally, field trials were established to determine for which species field conditions would limit emergence and survival over time.

Methodology

Site descriptions

The coal mines that were the focus of this study (Figure 1) occur within four separate coalfields in NSW, Australia and these are the Hunter, Newcastle, Western and Southern coalfields (NSW DMR, 2002). In addition to coal mining, the Hunter Valley region, in which the Hunter Coalfield is situated, has a long history of agricultural land use including cattle grazing, cropping and vineyards. The Newcastle Coalfield incorporates the city of Newcastle and extends along the central coast of NSW and west to the Hunter Valley. High levels of population growth have occurred in the Newcastle region over the past few decades. The Western Coalfield extends from the Blue Mountains near Lithgow. The majority of undeveloped coal resources in the Lithgow region have been incorporated into National Parks, although the region has a long history of coal mining in addition to cattle grazing. Part of the Southern coalfield is being encroached upon by urban development, predominantly from the Sydney metropolitan region (one of the most rapidly growing regions in the state). In addition, the Royal, Heathcote and Nattai National Parks overlie part of the area.

Species selection

A large range of species to be used for the study were identified from species lists from minesite Environmental Impact Statements, a review of related literature and local surveys. Once the total species list had been collated, exotic species, grasses, sedges and upper canopy trees were excluded, leaving the native 'understorey' species local to the areas of interest. The final selection of species was based on availability from commercial seed suppliers and relative cost, which was dependent upon the amount of seed required and/or seed weight. A total of 104 species were identified and are listed in Appendix 1.

Laboratory trials

Seed germination experiments were undertaken on all species in laboratories at The University of Queensland. Seeds of each species were placed in Petri dishes on moist filter paper treated with a fungicide solution. The Petri dishes were placed in an incubator at 20°C with exposure to continuous white light for 12 weeks and monitored in a laminar flow unit to minimise fungal spread.

Species selection for viability testing was based on germination result (<80%), seed availability and ease of application of the method in relation to seed size and type. Tetrazolium chloride tests were conducted on 41 species which were scarified and soaked in distilled water overnight to soften the seed coat. The seeds were placed in 0.1% tetrazolium chloride solution and left overnight in the dark at ambient temperature. Seeds were then scored as viable (when the seed, including the embryo, were stained red), possibly viable (if the seed was partly stained or pink), or inviable (if the seed was empty, damaged, unstained, discoloured or contents were shrivelled or powdery).

Germination and viability results have enabled the identification of species likely to have a type of dormancy in place. Those species that had germination results of 10% or less and higher viability were selected for dormancy testing. The dormancy breaking treatments selected for use were gibberellic acid (50 and 500 mg/L), 10% 'Seed Starter' smoke water (Kings Park and Botanic Gardens), heat (80°C water for 1 minute), heat and smoke water, boiling for 1 minute, 5% NaOCl and leaching. After treatment, seeds were germination tested according to the above method.

Media characterisation and glasshouse trial

Selection of the media was based upon those materials that were being used or were to be used for rehabilitation purposes at each site and consisted of forest and agricultural topsoils, subsoil materials, spoils and coarse coal rejects. Chemical and physical characterisation of these media was undertaken to assist with the interpretation of emergence, establishment and growth responses in both glasshouse and field experiments.

The glasshouse trials were run at The University of Queensland's glasshouses using bulk material from the participating minesites. The media were sieved to 1 cm to remove large debris and to make the material appropriate for potting. Watering occurred daily and watering to field capacity occurred weekly to ensure that moisture availability did not become a variable. In total, 560 pots were kept under glasshouse conditions for 12 weeks and new emergents were marked and recorded over this period.

Long-term field trials

A series of three field trials were established for the field component of the project. The Spring 1996 and Autumn 1997 trials tested 27 species across 13 media and 18 species across nine media, respectively, at a seeding rate of 625 seeds/m^2. The Spring 1997 trial tested 52 species across 11 media and the seeding rates varied depending upon the seed size of each species. Larger-seeded species were sown in each quadrat at 78 seeds/m^2 whereas the smaller-seeded species (such as Asteraceae and Myrtaceae species) were sown at 2500/m^2. Species with medium sized seeds were sown at 625 seeds/m^2. Seed was broadcast by hand onto 4m^2 quadrats. Individual emergents were marked and recorded using coloured tags to allow survival to be determined for up to 3.5 years. Where available, rainfall data was obtained from on-site records, and compared to regional climate data.

<u>Results and Discussion</u>

Laboratory trials

In general, *Acacia* species had the highest germination (>80%), although several other species also had high germination results, namely *Brachychiton populneus*, *Hardenbergia violacea*, *Hibbertia scandens, Pultenaea villosa* and several Proteaceae species. Germination results were used as an indication of germination potential and, when associated with viability testing, showed whether germination was restricted by viability. Species results could be divided into three categories: low viability (and hence low germination potential); similar viability and germination percentages; and high viability but low germination under controlled laboratory conditions. This enabled the identification of species that had germination restricted by dormancy (Figure 2).

Germination under laboratory conditions was significantly improved, and dormancy was therefore broken, for some pretreated species. Species positively influenced by heat pretreatments included the majority of the hard-seeded legumes and *Dodonaea triquetra* (Figure 3). *Geijera parviflora* had increased germination with complete removal of the seed coat and *Leptospermum trinervium* had increased germination with the smoke water treatment (Figure 4).

Knowledge of the quality and germination requirements of seed, in addition to factors such as appropriate seed storage, are essential components of successful rehabilitation as they can indicate and influence the revegetation potential for a particular species. Viability testing can identify those species with zero viability (as was the case for *Clematis aristata*, *Pandorea pandorana* and *Philotheca salsolifolia* in this study), and ensure only seed with reasonable quality is used. Testing for dormancy can identify those species with improved germination after seed treatment, which if practical, can be administered to improve field success.

Glasshouse trial

Results from the glasshouse studies showed all media to support some emergence under non-water limiting conditions, although the extent of species success varied. *Acacia* species generally had the highest emergence, and topsoils supported highest emergence across species, most likely due to the greater water holding capacity and more favourable chemical and physical characteristics. Media analysis showed the spoil materials to be highly sodic, although in the presence of sufficient water, this did not appear to prevent seedling emergence. Glasshouse testing enabled the selection of species appropriate for field experimentation at each site.

Field trials

Although field trial results varied greatly depending on medium, rainfall and species sown, some general results are presented below. The families in which the most successful species occurred included Casuarinaceae, Fabaceae, Meliaceae, Mimosaceae, Myrtaceae, Proteaceae and Sterculiaceae. Of the 51 species sown in the field trials, eight (from four families) had greater than 5% survival recorded at trial completion in one or more media. These were *Acacia cultriformis*, *A. salicina*, *Banksia ericifolia*, *B. spinulosa*, *Brachychiton populneus*, *Hardenbergia violacea*, *Kennedia rubicunda* and *Lambertia formosa*. *Banksia ericifolia* had the highest number of remaining seedlings (>22%) of all species recorded at West Cliff Colliery in autumn 1997. In general, Spring 1996 trial results were higher, both in terms of emergence and survival, than the Autumn and Spring 1997 trials, mainly as a result of greater rainfall. Examples of results presented in this paper are for spring 1996.

Hunter Valley topsoils were far less successful as substrates than the spoil and coal reject materials. This was due to intense competition from exotic pastures and weeds which occurred in the soil seed bank and germinated rapidly post cultivation. The Hunter Valley's long agricultural history has contributed to the large pasture seed loads in the topsoils of this region. Dicotyledenous weed species have also contributed to competition, particularly in topsoils, although spoil, coal reject and subsoil materials also suffered from weed inundation. Without specific management strategies regarding the control of exotic pasture species and weeds, topsoil materials are less favourable as substrates for establishing native understorey species. The results from Mount Owen Mine (Figure 5) are the exception to this, however, due to the less disturbed origin of the topsoil at this site. Emergence results for *Acacia cultriformis* in the forest topsoil were equivalent to 550 000 seedlings per hectare.

Westside Mine had good results from the hard-seeded legumes, particularly in the spoil material, although up to 150 000 seedlings per hectare were calculated for the topsoil for *Kennedia rubicunda* and *Banksia spinulosa* (Figure 6). This site is surrounded by relatively undisturbed forest and does not have the long agricultural history characteristic of the upper Hunter region.

Clarence Colliery field results for the Spring 1996 trial were significantly greater for *Banksia ericifolia* in the topsoil (equivalent to 800 000 seedlings per hectare) (Figure 7). The topsoil utilised for rehabilitation purposes at this site had a high sand content which proved favourable for the Proteaceae species. Any unsown species recorded in this material were non-competitive natives which had colonised from the adjacent National Park.

Germination and viability data can aid interpretation of results obtained in the field. Some species, such as *Swainsona galegifolia*, *Geijera parviflora*, *Philotheca salsolifolia* and *Pandorea pandorana,* had low or no field emergence, likely to be a result of their low viability. Some of the hard-seeded species, for example *Acacia brownii*, *A. filicifolia*, *Daviesia leptophylla* and *Jacksonia scoparia,* were shown to have greater viability than initial germination responses would suggest, and may therefore have increased field success given a pretreatment.

Conclusions

Emergence success on post-mined land is largely dependent upon seed quality, appropriate seedbed preparation and adequate rainfall. It has been shown in this study that several native species can establish in various mine media under field conditions, and as a result, some of the minesites involved in this study have begun to include a more species-rich seed mix in their rehabilitation programs. It should be noted, however, that the species selected for these field trials are only a subset of the potential species for use in rehabilitation of post-mined land. Recommendations for further study would thus include methods to improve the seedbed, and investigation into a broader range of native species.

Acknowledgements

This paper comprises work undertaken as part of an Australian Coal Association Research Program (ACARP) funded project entitled 'Native Understorey Species Regeneration Project at NSW Coal Mines' (C4009 and C7010) (Gillespie *et al*., 1998; 2001). Additional financial support was provided by the NSW Minerals Council.

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Figure 1 Location of the nine open-cut coal mines involved in the study

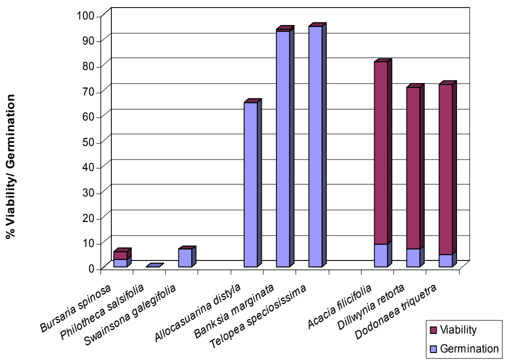

Figure 2 Viability and germination results for nine species tested in laboratory conditions

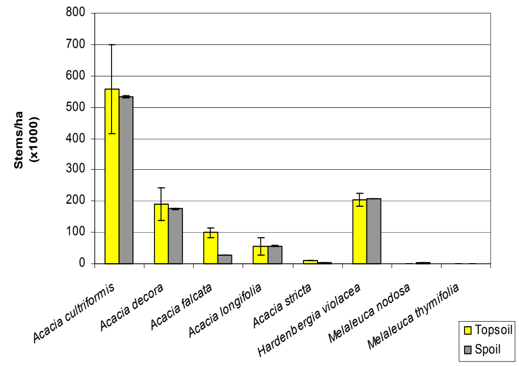

Figure 5 Spring 1996 field trial results in Mount Owen Mine topsoil and spoil (Hunter Coalfield)

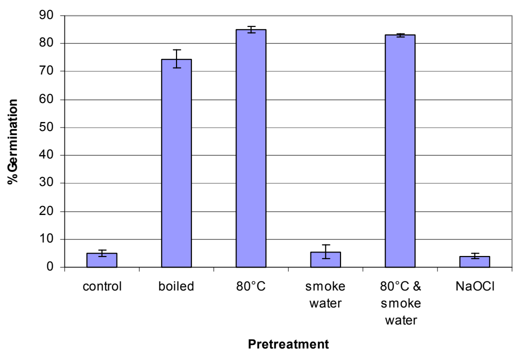

Figure 3 Germination results for *Dodonaea triquetra* seeds with various pretreatments

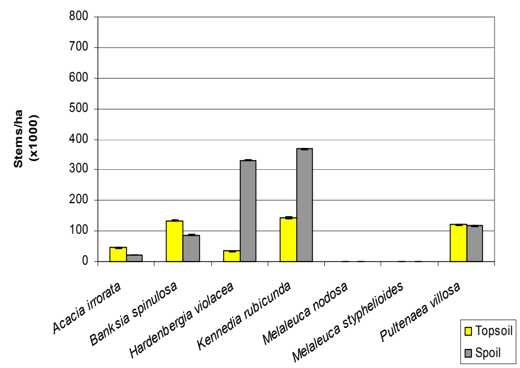

Figure 6 Spring 1996 field trial results in Westside Mine topsoil and spoil (Newcastle Coalfield)

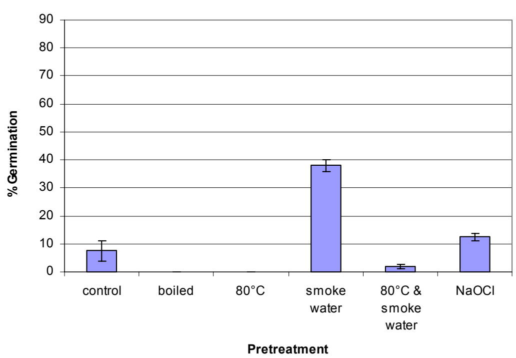

Figure 4 Germination results for *Leptospermum trinervium* seeds with various pretreatments

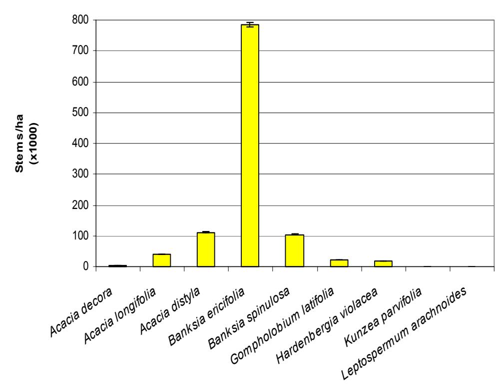

Figure 7 Spring 1996 field trial results for Clarence Colliery topsoil (Western Coalfield)

Appendix 1 Native species identified, sourced and tested for germination potential under controlled laboratory conditions

FAMILY	SPECIES	FAMILY	SPECIES
ASTERACEAE	*Bracteantha bracteata*	MIMOSACEAE	*Acacia terminalis*
ASTERACEAE	*Cassinia aculeata*	MIMOSACEAE	*Acacia ulicifolia*
ASTERACEAE	*Cassinia quinquefaria*	MIMOSACEAE	*Acacia uncinata*
ASTERACEAE	*Olearia elliptica*	MYOPORACEAE	*Myoporum montanum*
ASTERACEAE	*Ozothamnus diosmifolius*	MYRTACEAE	*Angophora floribunda*
BIGNONIACEAE	*Pandorea pandorana*	MYRTACEAE	*Baeckea densifolia*
CAESALPINIACEAE	*Senna artemisioides* subsp. *filifolia*	MYRTACEAE	*Baeckea linifolia*
CAESALPINIACEAE	*Senna odorata*	MYRTACEAE	*Callistemon citrinus*
CASUARINACEAE	*Allocasuarina distyla*	MYRTACEAE	*Callistemon linearis*
CASUARINACEAE	*Allocasuarina littoralis*	MYRTACEAE	*Callistemon salignus*
CASUARINACEAE	*Allocasuarina luehmannii*	MYRTACEAE	*Calytrix tetragona*
CASUARINACEAE	*Allocasuarina nana*	MYRTACEAE	*Kunzea ambigua*
CASUARINACEAE	*Allocasuarina verticillata*	MYRTACEAE	*Kunzea parvifolia*
CASUARINACEAE	*Allocasuarina torulosa*	MYRTACEAE	*Leptospermum arachnoides*
CASUARINACEAE	*Casuarina glauca*	MYRTACEAE	*Leptospermum brevipes*
DILLENIACEAE	*Hibbertia scandens*	MYRTACEAE	*Leptospermum grandifolium*
FABACEAE	*Bossiaea heterophylla*	MYRTACEAE	*Leptospermum juniperinum*
FABACEAE	*Daviesia genistifolia*	MYRTACEAE	*Leptospermum macrocarpum*
FABACEAE	*Daviesia latifolia*	MYRTACEAE	*Leptospermum obovatum*
FABACEAE	*Daviesia leptophylla*	MYRTACEAE	*Leptospermum polygalifolium*
FABACEAE	*Daviesia ulicifolia*	MYRTACEAE	*Leptospermum scoparium*
FABACEAE	*Dillwynia retorta*	MYRTACEAE	*Leptospermum trinervium*
FABACEAE	*Gompholobium latifolium*	MYRTACEAE	*Melaleuca armillaris*
FABACEAE	*Hardenbergia violacea*	MYRTACEAE	*Melaleuca decora*
FABACEAE	*Indigofera australis*	MYRTACEAE	*Melaleuca linariifolia*
FABACEAE	*Jacksonia scoparia*	MYRTACEAE	*Melaleuca nodosa*
FABACEAE	*Kennedia prostrata*	MYRTACEAE	*Melaleuca sieberi*
FABACEAE	*Kennedia rubicunda*	MYRTACEAE	*Melaleuca styphelioides*
FABACEAE	*Oxylobium ilicifolium*	MYRTACEAE	*Melaleuca thymifolia*
FABACEAE	*Pultenaea retusa*	PITTOSPORACEAE	*Bursaria spinosa*
FABACEAE	*Pultenaea villosa*	PITTOSPORACEAE	*Pittosporum undulatum*
FABACEAE	*Swainsona galegifolia*	PROTEACEAE	*Banksia collina*
MELIACEAE	*Melia azedarach*	PROTEACEAE	*Banksia ericifolia*
MIMOSACEAE	*Acacia brownii*	PROTEACEAE	*Banksia integrifolia*
MIMOSACEAE	*Acacia buxifolia*	PROTEACEAE	*Banksia marginata*
MIMOSACEAE	*Acacia cultriformis*	PROTEACEAE	*Banksia oblongifolia*
MIMOSACEAE	*Acacia dealbata*	PROTEACEAE	*Banksia serrata*
MIMOSACEAE	*Acacia deanei*	PROTEACEAE	*Banksia spinulosa*
MIMOSACEAE	*Acacia decora*	PROTEACEAE	*Hakea dactyloides*
MIMOSACEAE	*Acacia falcata*	PROTEACEAE	*Isopogon anemonifolius*
MIMOSACEAE	*Acacia falciformis*	PROTEACEAE	*Lambertia formosa*
MIMOSACEAE	*Acacia filicifolia*	PROTEACEAE	*Persoonia levis*
MIMOSACEAE	*Acacia implexa*	PROTEACEAE	*Persoonia linearis*
MIMOSACEAE	*Acacia irrorata*	PROTEACEAE	*Telopea speciosissima*
MIMOSACEAE	*Acacia kybeanensis*	RANUNCULACEAE	*Clematis aristata*
MIMOSACEAE	*Acacia longifolia*	RANUNCULACEAE	*Clematis glycinoides*
MIMOSACEAE	*Acacia mearnsii*	RUTACEAE	*Geijera parviflora*
MIMOSACEAE	*Acacia melanoxylon*	RUTACEAE	*Philotheca salsolifolia*
MIMOSACEAE	*Acacia myrtifolia*	RUTACEAE	*Philotheca salsolifolia*
MIMOSACEAE	*Acacia salicina*	SAPINDACEAE	*Dodonaea triquetra*
MIMOSACEAE	*Acacia stricta*	SAPINDACEAE	*Dodonaea viscosa*
MIMOSACEAE	*Acacia suaveolens*	STERCULIACEAE	*Brachychiton populneus*