

# Achievements in forest tree genetic improvement in Australia and New Zealand

## 4: Tree improvement for low-rainfall farm forestry

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Revised manuscript received 8 September 2006

### Summary

The challenge for low-rainfall plantation forestry is to develop financially viable plantations using hardy species that produce commercial products as well as delivering environmental benefits. Since 1999, forest research agencies have co-operated on tree improvement for dryland southern Australia through the Australian Low Rainfall Tree Improvement Group (ALRTIG). A small number of key species, including hardwoods (tree-sized eucalypt species), softwoods (*Pinus brutia*, *P. pinaster* and *P. radiata*) and two mallee eucalypt species yielding foliar essential oils were selected for genetic evaluation and improvement. Selection was based on their adaptability, growth rates, yields of potential commercial products, and availability of reliable information and genetic resources.

Improvement for the hardwood and softwood species aims to develop breeds that will maximise the net present value (stumpage value less growing costs) of logs produced on rotations of 20–40 y. Breeding will be based on recurrent selection for general combining ability, primarily in open-pollinated breeding populations based on selections from the best natural provenances and planted stands. A total of 29 provenance-progeny trials of the key species have been established across a range of dryland sites. These trials are now yielding information on the genetic control of growth, stem form and branching traits. This will enable production of genetically-improved planting stock through later conversion of some trials to seedling seed orchards and development of clonal seed orchards. Interim seed production areas based on planted stands of known best provenances have been developed for short-term production of somewhat-improved seed, and genetic gain trials to compare these seed sources with unimproved material have been established.

**Keywords:** plantations; semiarid zones; farm forestry; seed sources; seed output; genetic improvement; seed orchards; *Eucalyptus*; *Pinus*; mallees

### Introduction

In recent decades there has been a growing awareness of wide-scale environmental problems such as dryland salinity, and the need to ameliorate this by planting deep-rooted perennial vegetation in the low-rainfall regions of southern Australia (Stirzaker *et al.* 2002). The aim of so-called commercial environmental forestry plantations is to generate two income streams for growers: an income imputed to the environmental benefits of plantations through, for example, salinity or carbon credits for trees that control dryland salinity and/or sequester carbon, and a commercial return from the sale of timber or other forest products (Nambiar and Ferguson 2005). Genetic improvement is expected to enhance commercial product yield and quality, bringing plantations closer to overall financial viability. In addition to genetic improvement, improved silviculture, environmental service payments, and optimised harvesting, transport and processing will all be needed for low-rainfall plantations to approach profitability and attract investment (Harwood *et al.* 2005).

The main plantation species in southern Australia, *Eucalyptus globulus* and *Pinus radiata*, grow poorly and are at risk of death from drought in environments receiving less than about 600 mm mean annual rainfall. Evaluation of tree species suited to Australia's dryland (400–600 mm mean annual rainfall) sheep-wheat belt has been on-going for many years in a number of State and Commonwealth organisations, but genetic improvement programs have been initiated for only a few such species. In South Australia and Victoria, *E. cladocalyx* has been planted widely as a low-rainfall farm tree species from the 1870s, while in Western Australia *P. pinaster* was identified as a suitable low-rainfall species and a genetic improvement program commenced in the 1940s (Butcher 2006).

## ALRTIG genetic improvement strategies

A multi-agency cooperative program, the Australian Low Rainfall Tree Improvement Group (ALRTIG), was established in 1999. The mission of ALRTIG is: *to produce genetically improved planting material for farm forestry in the low-rainfall areas of southern Australia, and inform tree growers of its availability.* ALRTIG pooled pre-existing biological and scientific resources belonging to its core partners (state forestry agencies from NSW, South Australia, Victoria and Western Australia, and Ensis) in order to maximise impact through nationally-coordinated research and development. Further details on ALRTIG's organisation and *modus operandi* are provided by Bush *et al.* (2007).

ALRTIG has coordinated genetic improvement of three groups of species: hardwoods, softwoods and short-rotation woody crops. Candidate species for improvement in these three groups were reviewed in 1998–1999 and a small number of key species on which to concentrate was selected using criteria of growth rates, potential commercial products, availability of reliable information on performance and availability of genetic resources.

### Improvement objectives

The following general improvement objective was developed for the hardwood species: *To develop breeds that will maximise the net present value (stumpage value less growing costs) of logs produced on rotations of 20–40 years, on a per-hectare basis. Focus will be on production of a low-cost, high-value final crop which can be used for solid wood applications including sawlogs, veneer and engineered wood products.*

Leaf area index, stand water use and susceptibility of the plantation to drought can be manipulated by thinning and pruning so that available site resources are directed to an optimum number of trees per hectare (White *et al.* 2003). The aim of genetic improvement programs will be to breed for improved profitability, taking into account likely silvicultural regimes. In addition to improving growth rates, breeding will therefore aim to improve branching and stem form so as to reduce the silvicultural inputs and attendant costs required to produce valuable logs on the retained trees. Wood density, hardness and stiffness of the selected hardwood species is sufficiently high for likely wood products (Blakemore *et al.* 2002). At this stage there is insufficient market information to identify wood properties requiring improvement. Survival, growth (height and diameter at breast height), stem form (apical dominance and stem straightness) and branching (light branching and tendency for self-pruning) have been identified as selection traits, but economic weights for these traits have not yet been determined. Improvement objectives for the softwood species are broadly similar, and more straightforward because markets for wood products from radiata pine and maritime pine are already well established. For the mallee species, essential oil yield and quality will be major traits for improvement.

### Hardwoods

*Eucalyptus camaldulensis* (river red gum), *E. cladocalyx* (sugar gum), *E. occidentalis* (swamp yate), *E. tricarpa* and *E. sideroxylon* (red ironbarks) and *Corymbia maculata* and *C. citriodora* subsp. *variegata* (spotted gums) were selected for genetic improvement.

These species were judged sufficiently hardy for at least part of the target planting area and capable of producing sawlogs or other commercial wood products. Strategies were developed to secure short-term supplies of somewhat-improved seed, and to commence improvement programs to deliver ongoing genetic gains. The strategies are based primarily on recurrent selection for general combining ability in open-pollinated breeding populations (Harwood *et al.* 2001). Some important elements of the strategies for these hardwood species have already been implemented:

- analysis of partners' pre-existing field trials to make recommendations on best-bet interim seed sources, including best natural provenances and planted stands
- conversion of some existing plantings into seed production areas by selective thinning to meet short-term demand for improved seed
- for each key species, establishment of provenance/progeny trials testing a common set of 80–100 or so open-pollinated progenies from known superior provenances and planted seed sources, across a range of dryland environments in southern Australia
- establishment of genetic gain trials to test the performance of recommended interim improved seed sources against unimproved natural-provenance controls
- research into vegetative propagation as a deployment option.

Harwood *et al.* (2005) reviewed progress achieved to that date and presented additional biological information obtained on the species, but made no major recommendations for changes in the improvement strategy or methods for improvement.

### Softwoods

Two key species were chosen initially. ALRTIG's involvement with *P. pinaster* (maritime pine) is restricted to planting a series of yield trials that compare the performance of various categories of improved and unimproved genetic stock produced by the Western Australian breeding program (Butcher 2007). *Pinus brutia*, native to the eastern Mediterranean and western Asia, has potential for very dry sites, including those with alkaline and/or shallow soils. It is amongst the most drought-resistant *Pinus* species. A genetic improvement strategy was prepared and commenced for *P. brutia* (Spencer and Boardman 2002). ALRTIG created two seed stands by thinning existing plantations for short-term seed production. These will supplement seed available from a pre-existing clonal seed orchard in Western Australia. A survey of all known Australian *P. brutia* stands was undertaken, and a list of 161 candidate plus trees compiled. The top 39 of these trees were grafted into clonal seed orchards in the ACT, South Australia and Western Australia in 2003. Three progeny trials testing open-pollinated seedlots collected from 70 of the candidate plus trees were established in 2002. New collections have been made from the species' natural range to expand the genetic base.

In 2002, the potential for creating a low-rainfall breed of *P. radiata*, distinct from the Australian breeds developed for higher-rainfall environments, was examined. A strategy was devised for creating a new breed, incorporating selections from the southern natural provenances (two Mexican islands and

Cambria, USA), which may display greater drought tolerance. The strategy (Matheson *et al.* 2007) has a number of components:

- preliminary screening in field trials of selected material from provenance stands including Cambria, Guadalupe and Cedros for genetic variation in drought resistance
- establishment of longer-term field trials of candidate material on target site types
- formation of a breeding population using stored seed and controlled crosses in existing stands of the Mexican and Cambria provenances of interest
- possible integration of additional drought resistance through interspecific hybridisation with closely related species such as *P. attenuata*, *P. oocarpa* or other pines if breeding barriers can be identified and overcome.

Work under the strategy, including establishment of field trials and controlled crossing programs, commenced in 2003–2004.

### Short-rotation woody crops

Two mallee eucalypt species, *E. polybractea* (blue mallee) and *E. horistes* (oil mallee), have been selected for a series of genotype  $\times$  environment trials in each of the southern mainland states. Both of these species have high yields of cineole-rich leaf oils, and are grown on three-year coppice rotations. In Western Australia it was already known that *E. horistes* was suited to relatively drier sites and *E. polybractea* relatively wetter ones, though their performance on eastern Australian site types was unknown. The study aims to determine (1) the relative suitability of each species on target site types in eastern Australia, and (2) whether single national breeding populations for each species

will suffice or whether genotype  $\times$  environment interaction across the different regions is sufficient to warrant separate breeding populations. Seedling-based trials testing common sets of 24 open-pollinated families of each species on a total of five sites (two sites in Western Australia and one each in NSW, South Australia and Victoria) have been established.

In all, 29 progeny trials of hardwood species, ten yield trials of *P. pinaster*, three progeny trials and three clonal seed orchards of *P. brutia* and five mallee genetic trials have been planted by ALRTIG partners over the period 2000–2002: a total of over 50 ha of genetic trials.

## Progress to date

### *Eucalyptus cladocalyx* progeny trials

Early results obtained from ALRTIG trials of one of the key hardwood species, *E. cladocalyx*, illustrate the progress already made in genetic evaluation and the potential for genetic improvement. Assessment data are presented from one of the *E. cladocalyx* progeny trials near Bordertown, South Australia, managed by PIRSA Forestry. Height and diameter at breast height (dbh) were measured and stem forking assessed 28 months after planting. Forking was scored as: 1 = a fork at ground level, 2 = a fork in the first quarter of the stem, 3 = a fork in the second quarter ... through to 6 = no forks. Seed source means for height, dbh and forking score are shown in Table 1. Each seedlot mean represents the mean of five or more open-pollinated progenies from that seedlot. Narrow-sense, individual tree, within-provenance heritabilities for each trait were calculated using a coefficient of relationship of 0.4 within open-pollinated families.

**Table 1.** Twenty-eighth-month growth and stem form of seedlots in *Eucalyptus cladocalyx* progeny trial at Bordertown, South Australia

Region and seedlot	Stem form (1–6 fork score)	Diameter bh (mm)	Height (dm)
Kangaroo Island			
Flinders Chase NP	3.3	37.8	40.5
American River	3.3	34.4	38.9
Flinders Chase	3.6	42.3	43.5
Cygnets River	3.6	39.2	42.9
Planted stands			
Mt Burr	4.7	45.9	41.6
Kersbrook SPA*	5.0	43.7	41.0
Majorca	5.2	48.9	43.2
Wail	5.2	47.2	41.3
Lismore	5.3	41.6	39.6
Southern Flinders			
S. Wilmington	5.0	37.6	35.0
Wilmington	5.0	36.6	34.9
Wirrabara S.F.	5.1	41.1	38.7
Mt Remarkable	5.0	35.4	34.4
Average s.e.d. <sup>†</sup>	0.6	2.2	3.1
Heritability (s.e.)	0.21 (0.05)	0.21 (0.06)	0.25 (0.06)

\*Kersbrook seed production area

<sup>†</sup>s.e.d. = standard error of difference of seedlot means

The Southern Flinders natural provenances have significantly better stem form (less forking) than those from Kangaroo Island. Conversely, the Kangaroo Island provenances are more vigorous than those from the Southern Flinders. The planted/improved seed sources (progeny from phenotypically superior mother trees selected from land race plantations originally derived from Southern Flinders provenance, except for Kersbrook SPA, which is a mixture of Southern Flinders and Kangaroo Island provenances) combine vigour equivalent to Kangaroo Island with the superior stem form of Southern Flinders. Within-seed source individual-tree heritabilities for height, dbh and stem form were moderate (0.21–0.25) for the three traits.

This result corroborates information on natural provenance rankings derived from Partners' earlier trials, supports ALRTIG's recommendation to use material derived from the identified seed stands and seed production areas, and demonstrates the potential for further genetic improvement. With a total of nine provenance/progeny trials of *E. cladocalyx* established across dryland southern Australia in 2001, breeders now have excellent genetic resources available. Outstanding selections could be grafted into clonal seed orchards, and some trials converted to seedling seed orchards via selective thinning.

#### Outcrossing rates in interim seed production areas

It is well known that selfing will reduce the performance of progeny in many *Eucalyptus* species (Eldridge *et al.* 1993). Outcrossing rates were determined in two of the interim seed production areas to see whether high levels of selfing might be a problem (Bush *et al.* 2007). A multi-provenance *E. occidentalis* seed production area in South Australia was studied by examining genetic variability of progeny from ten trees using microsatellite markers. Mean estimated outcrossing rates of the ten parents ranged from 0.69 to 1, with a mean of 0.92 (i.e. 92% outcrossing rate). Allozyme markers on progeny of ten trees were similarly used to determine outcrossing rates in a *C. maculata* seed production area developed from a provenance–progeny trial of *C. maculata* which also included *C. citriodora* subsp. *variegata* and *C. henryi* progenies. Outcrossing rates for individual trees ranged from 0.50 to 1, and the mean multi-locus outcrossing rate was 0.76. These results suggest that inbreeding is unlikely to be a major problem in *E. occidentalis* seed orchards, but should be

kept under study in *C. maculata* seed orchards as it may affect progeny performance.

#### Genetic gain trials

In 2003 a total of 20 genetic gain trials of four of the key hardwood species were established by collaborating tree-growing companies. These trials will enable the performance of recommended interim 'best bet' seed sources to be compared with non-improved benchmarks on collaborators own sites using their preferred silvicultural regime. These trials used large plots and at least five replicates to obtain accurate rankings of seedlot performance. Early results (Bush *et al.* 2007) from the *C. maculata* genetic gain trials indicate superior growth of the seed orchard material under test, relative to natural provenances.

#### Planting rates and capacity to supply improved seed

Planting rates have fluctuated in recent years (Table 2). From surveys of major nurseries, the total annual plantings for the ALRTIG key species were about 1300 ha (hardwood species), 1600 ha (softwood species) and 600 ha (mallee species) in 2004.

The interim seed production areas of the key hardwood species have typically produced about 2 kg of seed ha<sup>-1</sup> y<sup>-1</sup>. Assuming typical seed numbers per kilogram of seed, nursery efficiencies and stocking rates, and thinning provenance/progeny trials to convert them into seedling seed orchards, annual plantings of 2000 ha for sugar gum and swamp yate, 1000 ha for spotted gum and somewhat less than 1000 ha for red ironbarks could be supported. This capacity could be supplemented by clonal seed orchards established from selections from the provenance/progeny trials. Private-sector firms have established other seedling seed orchards of *C. citriodora* subsp. *variegata*, *C. maculata*, *E. camaldulensis* and *E. cladocalyx*. The WA Forest Products Commission has independently developed seedling seed orchards of the two oil mallee species. The seed supply capacity of *P. brutia* in the thinned seed stands and clonal seed orchards is yet to be established.

Clonal propagation is another option for deploying improved germplasm. *E. camaldulensis* clones are already commercially available. *Eucalyptus cladocalyx*, *E. occidentalis* and red

**Table 2.** Plantation establishment rates for ALRTIG key species

Species	Number of seedlings (× 1000) raised in major nurseries		Estimate of area planted (ha) <sup>1</sup>	
	2001	2004	2001	2004
Sugar gum	402	989	400	1000
Swamp yate	108	10	100	100
Red ironbark	102	84	100	100
River red gum	325	141	300	100
Mallee	3695	1596	1400	600
Spotted gum	523	253	500	300
Maritime pine	9200	2367	6200	1600
Brutian pine	4	9	4	9

<sup>1</sup>Assuming stocking rates of 2600 trees ha<sup>-1</sup> (oil mallees), 1500 trees ha<sup>-1</sup> (maritime pine) and 1000 trees ha<sup>-1</sup> (other species)

ironbarks can be propagated readily from stem cuttings taken from seedling hedge plants, indicating that family forestry is technically feasible (C. Harwood, unpublished data).

In summary, progress has been made towards remedying a serious impediment to adoption of plantation forestry in low-rainfall southern Australia: making available germplasm that can yield a commercial product in addition to an environmental benefit. Improved planting material of the chosen key species will be available to support the development of sizeable plantation estates. In 1999, when the ALRTIG key species were selected, it was thought that new information might effect changes to the key species. Thus far, the original key species have remained among the 'best bets' for low-rainfall forestry (Nambiar and Ferguson 2005).

### Extension and communication

ALRTIG has communicated information and promoted the use of genetically improved germplasm through written publications for scientific and general audiences (Harwood and Bush 2002), presentations to the media, conferences and workshops, contributions to training courses for forestry and agroforestry practitioners, and a website (<http://www.ffp.csiro.au/alrtig/>) containing information on the key species and available best-bet seed sources. Communication among geographically-spread partners from different organisations, and leadership of ALRTIG, were significant challenges. The role of a National Coordinator in the first four years of the program was found to be essential.

### The future of low-rainfall tree improvement

Over the next 1–2 y the ALRTIG genetic trials will be assessed and data assembled for across-site statistical analysis. The extent of further investment in tree improvement will depend on the future demand for improved seed. The ALRTIG trials will also be of use for studies in a wide range of disciplines including population genetics, growth and yield modelling, hydrology and wood quality studies.

### Acknowledgements

We wish to acknowledge the strong contributions of former members of the ALRTIG National Steering Committee, particularly Ms Sharon Davis, Ms Deborah O'Connell, Dr Hans Porada, Mr Des Stackpole and Mr Mick Underdown. Financial support for the program from the Joint Venture Agroforestry Program, the Department of Agriculture, Fisheries and Forestry, and the partner agencies including Ensis, Forests NSW, Primary Industries and Resources, South Australia – Forestry, the Victorian Department of Primary Industries and the Forest Products Commission of Western Australia is gratefully acknowledged.

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