



An Australian Government Initiative



Australian Low Rainfall Tree Improvement Group (ALRTIG)

Update of hardwood breeding strategies

**A report for the RIRDC/Land & Water
Australia/FWPRDC/MDBC
Joint Venture Agroforestry Program**

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Foreword

Growing interest in farm forestry on crop and grazing land in the sheep-wheat belt of southern Australia has prompted a cooperative national effort to select and breed trees suited to ‘commercial environmental forestry’ (CEF). CEF aims to simultaneously return growers an income imputed to the environmental benefits of plantations (e.g. salinity or carbon credits for trees that control dryland salinity and/or sequester carbon), and a commercial return from timber or other products. Selection and breeding is expected to improve the commercial returns by increasing yield and product quality.

The Australian Low Rainfall Tree Improvement Group (ALRTIG) is a collaborative undertaking involving researchers from State agencies and CSIRO. ALRTIG aims to speed the process of tree improvement by coordinating effort across Australia.

This report provides an update to the Australian Low Rainfall Tree Improvement Group (ALRTIG) Compendium of Hardwood Breeding Strategies originally published in 2001 (RIRDC publication No. 01/100). The update should be read with reference to the earlier publication. It includes new information that has come to light since ALRTIG formed in 1999, and discusses the implications of this on the tree improvement strategies.

This project was funded by the Natural Heritage Trust and the Joint Venture Agroforestry Program (JVAP). The JVAP is supported by three R&D Corporations — Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia, and Forest and Wood Products Research and Development Corporation (FWPRDC), together with the Murray-Darling Basin Commission (MDBC). These agencies are funded principally by the Federal Government. Significant financial and in-kind contributions were also made by the project partners: CSIRO Forestry and Forest Products; Forest Products Commission, WA; Department of Sustainability and Environment, Victoria; ForestrySA and State Forests of NSW.

This report, a new addition to RIRDC’s diverse range of over 1200 research publications, forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems.

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Tony Byrne

Acting Managing Director

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Abbreviations

ALRTIG	Australian Low Rainfall Tree Improvement Group
CEF	Commercial Environmental Forestry
CFTT	Centre for Forest Tree Technology
CSIRO	Commonwealth Scientific Industrial Research Organisation
CSO	Clonal Seed Orchard
DBH	Diameter at breast height
DNRE	Department of Natural Resources and Energy
FFP	Forestry and Forest Products
FPC	Forest Products Commission (Western Australia)
JVAP	Joint Venture Agroforestry Program
PVI	Pastoral and Veterinary Institute
RIRDC	Rural Industries Research and Development Corporation
SFNSW	State Forests of New South Wales (now DPI&T, Forests NSW)
SPA	Seed Production Area
SSO	Seedling Seed Orchard

Executive summary

This report updates RIRDC publication No. 01/100 “Compendium of Hardwood Breeding Strategies” (Harwood *et al.* 2001). The original breeding strategies adopted for the ALRTIG key eucalypt species *Eucalyptus camaldulensis*, *E. cladocalyx*, *E. occidentalis*, *E. sideroxylon* / *E. tricarpa* and *C. maculata* / *C. citriodora* subsp. *variegata* are proceeding largely according to plan.

The breeding objectives, breeding objective traits and selection traits have been tentatively defined. The breeding objective is to maximise the net value (stumpage value – plantation costs) of logs destined for solid-wood and engineered-wood products produced on rotations of 20-40 years, on a per-hectare basis. The core breeding objective traits to achieve this breeding objective are survival, log volume, stem form and branching characteristics. Incorporation of wood quality traits into the breeding objective may be required as information on processing accumulates. Selection traits follow the breeding objective traits. Survival, height and diameter at breast height have been chosen to maximise volume productivity per hectare. Stem form and branching have been chosen to both minimise the amount of silvicultural cost and effort in thinning and pruning required to manage the stands, and to maximise the production of high value product (i.e. knot-free timber).

A total of 33 progeny trials have been established over the period 2000-2002, enabling a flexible approach to be taken. Planting targets and anticipated demand for improved seed of each key species can be reviewed each year, and the number of progeny trials required for early conversion to seedling seed orchards can be determined. It should be relatively straightforward to meet the demand for seed to support an annual plantation establishment rate of 1000 ha per species by years 2008-2010.

Progeny trials not required for conversion to seedling seed orchards will be left to grow on without thinning to deliver more accurate genetic information from later-age selection. Clonal seed orchards (CSO) can be developed by grafting selections from these trials, delivering seed from around 2010 to 2104, depending on species. Excellent results with cutting propagation achieved for *E. occidentalis* open up the possibility of clonal forestry with this species.

A full revision of the ALRTIG eucalypt breeding strategies would be appropriate in mid-2005, by which time 3-year data should have been collected and analysed from the progeny trials of all of the key species, with the exception of *E. sideroxylon*.

Introduction

The Australian Low Rainfall Tree Improvement Group (ALRTIG) is a cooperative of State and Commonwealth Government agencies whose mission 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 commenced operations in mid-1999 and is part-funded by the Natural Heritage Trust and the Joint Venture Agroforestry Program (JVAP), with matching funds and other inputs provided by the participating agencies.

This report updates the breeding strategies for key eucalypt species subject to ALRTIG’s genetic improvement programs. RIRDC publication No. 01/100 “Compendium of Hardwood Breeding Strategies” (Harwood *et al.* 2001) presented genetic improvement strategies for a number of key eucalypt species for the low rainfall zone of southern Australia (400-600 mm mean annual rainfall). An overview of tree breeding for the low rainfall zone was provided, and strategies were presented for *Corymbia maculata*, *Eucalyptus camaldulensis*, *E. cladocalyx*, *E. occidentalis* and *E. tricarpa*. A summary article “Breeding trees for the low rainfall regions of southern Australia” (Harwood and Bush 2002) was published to provide a simple overview of ALRTIG’s progress to that date.

Since the eucalypt breeding strategies were prepared in mid-2000, the role of plantation forestry in low-rainfall southern Australia has received detailed consideration. Tree plantations are being established with the expectation of both environmental and commercial outcomes. The reader is referred to the following important publications for further information: Australian Greenhouse Office (2001), Nambiar and Brown (2001), Stirzaker *et al.* (2002) and van Bueren *et al.* (2002).

State Government agencies, farmers and private companies are increasing the planting rates of ALRTIG’s key eucalypt species. Surveys of major nurseries revealed that planting rates of the key species selected by ALRTIG have increased substantially, compared with previous years, albeit from a low base. Based on the numbers of seedlings produced, establishment of the key species probably totalled about 1500 ha in 2001. As discussed below, planting rates in the future will depend to a considerable extent on the emerging markets for environmental services (van Bueren *et al.* 2002). The combination of environmental service payments together with commercial returns from timber products could make plantations in some low rainfall areas financially attractive, leading to a large expansion in planting rates, and increased demand for genetically improved planting stock.

This review of the ALRTIG breeding strategies indicates that only minor modifications to the strategies are required. Progress to date and recommended modifications are presented as an update to Harwood *et al.* (2001), which should be read in conjunction with this document.

Refinement of breeding objectives and selection traits

Breeding objectives

Any tree improvement program is directed towards a **breeding (or genetic improvement) objective**, which can be thought of as the goal of breeding, or a specification of the ideal tree genotype that we are trying to develop by breeding. The breeding objective is fundamentally an economic objective determined by the users who require low-cost forest products with specified characteristics that will support profitable end-use applications. It is critically important for any breeding program that an appropriate breeding objective is chosen, as the breeding objective drives the direction of genetic change achieved by breeding.

Modern tree breeding programs for commercial wood-producing plantations typically have a clearly-defined breeding objective expressed in economic terms such as “a breed of tree that will yield pulpwood that minimises the wood cost of producing a tonne of pulp, per hectare and per year”. Appropriate breeding objective traits and selection traits are then determined; in the above example we might choose volume production, wood density and pulp yield at rotation age as breeding objective traits, and diameter at breast height, and density and pulp yield estimated from an increment core at half rotation age, as selection traits. Economic weights for the objective traits are then determined based on their relative importance in achieving the breeding objective, and correlations between the objective and selection traits determined or assumed. A genetic improvement strategy is then developed with the aim of progressing quickly and cost-effectively towards the breeding objective by some combination of selection and crossing followed by mass-propagation of genetically improved planting stock (Eldridge *et al.* 1993). Depending on genetic correlations between traits, it is generally not feasible to incorporate more than 3-4 selection traits in a breeding objective, as including more traits does not facilitate progress towards the breeding objective.

Wood products and markets for ALRTIG key species

ALRTIG was set up to breed trees to meet an anticipated demand for an emerging, expanding low-rainfall plantation industry. Large-scale end use of the key eucalypt species grown in low-rainfall plantations is not yet firmly established. However, enough is known of wood properties from use of these species worldwide (references in Harwood *et al.* 2001) and in Australia (e.g. Blakemore *et al.* 2002), to determine the most likely end uses and hence infer desirable log and wood properties, formulate tentative breeding objectives and identify appropriate traits for selection.

ALRTIG’s target eucalypt species are generally unsuitable for pulp production, because of their high wood density. Commercial timber products from these species’ plantations may include sawlogs (Blakemore *et al.* 2002), poles and posts. There may also be opportunities for producing engineered products such as laminated veneer lumber from logs. Depending on the location of plantations, thinnings and sawmill residues may be marketable as firewood or for charcoal production, and potentially as a feedstock for composite products. The development of regional plantation estates sufficient to supply local processing industries such as sawmills will be vital for the commercial success of low rainfall plantation forestry, but is outside the scope of this report.

Because of slow growth, long-rotation eucalypt plantation forestry for solid wood products is financially unattractive to investors where mean annual rainfalls are much below 600 mm, if revenue from timber sales is the only return to the grower. However, if breeding can lift the value of timber produced, this will bring the plantation closer to profitability.

Figure 1 illustrates the potential contribution to the economics of low-rainfall plantation forestry that can be made by tree breeding and other technical interventions. The relationships are only notional to illustrate the general principles. The benefits arising from improvements in different parts of the value chain for production forestry: improved silviculture, improved planting stock, improved harvesting and processing, and so on, are generally additive in their effects. Technical improvements across the value chain, including genetic improvement, will bring plantations closer to being a profitable business in mid-to-low rainfall environments.

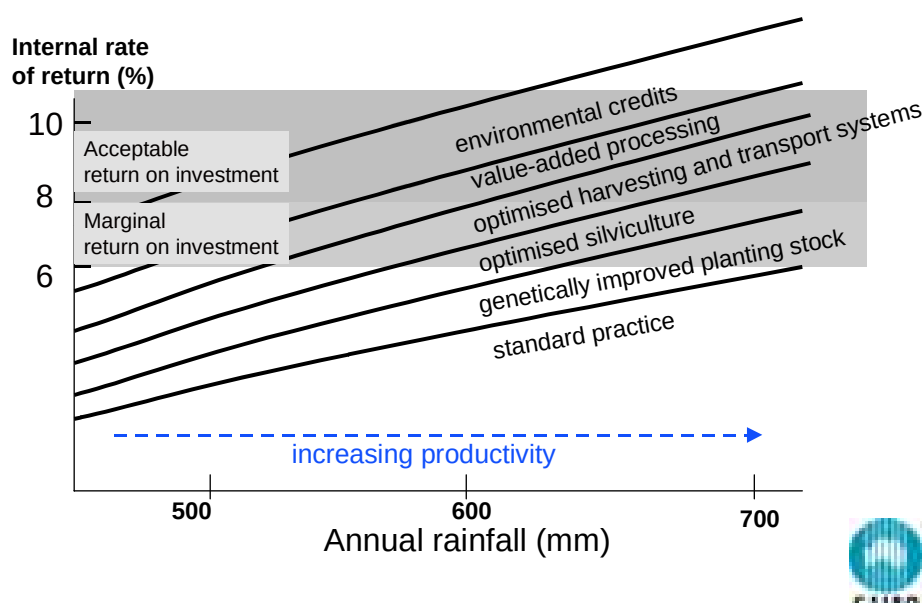


Figure 1. A conceptual model to illustrate how improvements in commercial forestry and environmental credits can together create profitable plantation investments in lower-rainfall environments

Role of environmental service payments

Payment for environmental services provided by plantations may secure the financial attractiveness of a plantation investment, even if the combined effects of all the technical improvements on wood production fail to achieve profitability from timber sales alone (Figure 1).

To date, the most significant environmental service to become a commercial reality is the provision of “transpiration” or “salinity” services. Tree plantations established on cleared land can increase evapotranspiration and minimise “leakage” of soil water down the soil profile to salt-bearing lower soil horizons. This reduces the problem of rising saline water tables and resulting salinization of landscapes and watercourses (Stirzaker *et al.* 2002).

Evapotranspiration from a tree plantation is primarily a function of leaf area index of the stand, which in turn is closely related to growth rate. Any successful plantation which can sustainably maintain a leaf area index appropriate to the local climate conditions will provide this environmental service (Stirzaker *et al.* 2002). Therefore, ALRTIG is not incorporating high water use *per se* as a selection trait in its breeding objectives. Unimproved planting stock of a well-adapted species and provenance can in fact be planted, if provision of transpiration services is the sole purpose of the plantation.

Another emerging environmental service is carbon sequestration. However, as with transpiration services, there is no strong case for incorporating carbon sequestration *per se* as a direct selection

trait in breeding objectives. Any breeding objective for profitable commercial wood production will lead to relatively high levels of carbon sequestration.

Some plantations in the low-rainfall zone provide additional on-farm benefits including shelter for livestock, windbreaks for stock and crops, and enhanced biodiversity. The on-farm benefits may be important drivers for adoption of farm forestry and may determine species choice (Bird 2000). However, they are not readily marketable (except in that tree plantations may increase the value of a farm) and their incorporation into a breeding objective would be very difficult.

In summary, ALRTIG is not incorporating selection traits linked directly to the provision of environmental services (hydrological services, carbon sequestration and other on-farm environmental services) in its breeding objectives. Breeds developed for commercial wood production will adequately provide these environmental services as a by-product, given appropriate species-site matching and silviculture.

Developing breeding objectives for key ALRTIG eucalypt species

Low rainfall environments impose certain constraints in the determination of breeding objectives. The scope for increasing total wood production (on a per-hectare, per-year basis) through breeding is limited, because water availability fundamentally limits plantation productivity in low-rainfall southern Australia. The yield of high-value timber can, however, be increased by focussing the limited biomass production capacity of the site into merchantable stems, which is analogous to improving the harvest index in food crops. This can be done through a combination of genetic improvement and optimised silvicultural systems (establishment, spacing, thinning and pruning). Using unimproved stock, the ALRTIG key species have poor to moderate stem form, with a low proportion of “final crop” trees. This means the proportion of high-value sawlogs in the final crop would be low, despite selective thinning and pruning.

Breeding can reduce the costs of growing trees as well as increasing their stumpage value. Net, rather than gross, financial returns determine plantation profitability. For low rainfall plantations receiving credit payments for environmental services, net financial returns can be expressed as:

Net present value of	timber stumpage
	+ environmental service payments
	+ residual wood products (where markets exist)
	+ on-farm benefits (where applicable)
	- costs of growing the plantation

Breeding focuses on developing varieties that will both increase the stumpage value (the price paid to the grower for the standing timber), and reduce the cost of plantation establishment and management.

With genetically improved planting stock, we can grow uniform plantations where more of the trees are potentially “final crop” trees. This will reduce the costs of thinning and pruning (very important components of the plantation cost for sawlog production). For example, trees could be planted at a wider initial spacing if apical dominance was strong and branching light, with a strong tendency to self-pruning. Thinning could be systematic (“out-row” thinning) rather than selective, reducing the cost of the thinning operations. Uniform tree size and good stem form also reduces harvesting and processing costs. This potentially increases the stumpage value.

Taking all of the above considerations into account, the following general breeding objective has been developed for the ALRTIG key species:

To develop breeds that will maximise the net present value (stumpage value – 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.

It is anticipated that where there are markets for firewood and poles, thinnings may be funded through sales of these products. As the breeding objective encompasses the reduction of costs, incurred early in the rotation, and increasing revenues, accrued at the end of the rotation, the discount rate used will affect outcomes, and requires attention.

Further study is required to refine the above breeding objective and to determine relevant breeding objective traits. It appears clear that the following must be accepted as breeding objective traits:

Survival	good survival is important for successful uniform plantations
Growth	log volume determines returns to the grower
Stem form	(apical dominance and stem straightness to maximise log value)
Branching	(light branching and a tendency for self-pruning to minimise pruning costs)

ALRTIG selection traits

Taking into account the above breeding objective traits and the likely wood products, the core selection traits for the ALRTIG key species are:

Survival	
Growth	(height and diameter, which can be combined into volume)
Stem form	(apical dominance and stem straightness)
Branching	(light branching and tendency for self-pruning)

Trees superior for the above traits can be grown with appropriate silviculture to produce straight logs, free from major wood defects. Exceptions to this generalisation arise if trees are susceptible to defect or biological attack, such as attack by stem-boring insects, that lowers the value of logs.

An important issue that must be considered is the age at which selection traits should be assessed. To date, we have little information on age-age correlations for these traits in the target species. It is likely that rotations will be at least 20 years. Genetic differences in survival and stem form are clearly evident from an early age, but differences in growth and branching may not correlate strongly with rotation-age values. Given the pressure to produce supplies of somewhat-improved seed over the next few years, there will be a compromise between selection age and accuracy of selection, and some of the ALRTIG progeny trials will be thinned at age 5 years or less for conversion to seedling seed orchards. Other progeny trials will be left to grow on un-thinned for a longer time before selections for breeding are made.

For some of the species it may be necessary to include additional traits in the breeding objective. For example, it would be desirable to improve the frost tolerance of spotted gums, and to increase the salinity tolerance of *E. occidentalis* and *E. camaldulensis*, which are likely to be planted at salinity-prone sites. Note, however, that survival, growth and stem form tend to integrate the effects of biological factors such as pests and diseases, and physical stresses such as drought, salinity and frost, so it may not be necessary to incorporate tolerance to individual factors as specific selection traits for breeding populations that are exposed to these biological and physical pressures.

At this stage, we consider that it is too early to specify wood property traits that would be included in the breeding objective for each species. All of the target species have wood of sufficient density and strength such that increases in wood density, stiffness and hardness are unlikely to increase the selling price of logs. Once log markets for these species are better developed and understood, it may well be that specific wood traits such as colour, or stability during processing and drying to minimise degrade, will be identified as important in determining log value (Blakemore *et al.* 2002). Provided that these wood traits vary in the ALRTIG breeding populations, and are heritable, it may be possible to select to improve these traits in the deployment populations (for example when selecting the individuals to go into clonal seed orchards or to be mass-propagated for clonal forestry).

Basic ALRTIG improvement strategies

The individual tree improvement strategies selected for each of the key ALRTIG species (Harwood *et al.* 2001) comprise various of the following elements:

1. Conversion of existing planted stands to **seed stands** by selective thinning for short-term production of somewhat improved seed.
2. Conversion of existing provenance trials to **seed production areas** by selective thinning for short-term production of improved seed.
3. Establishment of a series of **progeny trials**, some of which will be progressively thinned to **seedling seed orchards**, for production of high quality seed. Other progeny trials will be retained longer for collection of progeny data and accurate selection of superior trees.
4. Establishment of **clonal seed orchards**. Selections will be made from elite trees in existing trials and supplemented by selections from the progeny trials.
5. **Controlled pollination** between selected trees to develop outstanding families
6. Testing of clones for the development of **clonal forestry**

The strategies were designed to produce a range of genetically improved germplasm with varying levels of improvement as shown in Table 1 (from Harwood *et al.* 2001).

The combination of options selected for each species depended on a number of factors including the degree of improvement required, existing genetic resources, species biological characteristics, and the short- and long-term demand for improved seed.

The strategies for individual species (Harwood *et al.* 2001) set out the existing knowledge of the species, available genetic resources, and a detailed strategy with approximate timetables for action.

Table 1. Degrees of genetic improvement that could be produced by ALRTIG in the first generation

	Category of material	Ranking	Comments
1.	Seed collected from phenotypically superior trees in best natural provenances	Baseline standard for ALRTIG	For some species, large gains over use of inferior provenances
2.	Seed from interim seed production areas developed from planted stands of known best provenances	Modest improvement over 1	Gains depend on genetic base and degree of selective thinning. Genetic quality likely to be high for <i>E. cladocalyx</i> , at least.
3.	Seed from unthinned ALRTIG provenance-progeny trials	Modest improvement over 1?	Poor-quality pollen pool. Only small quantities of seed produced
4.	Seed from ALRTIG seedling seed orchards developed from provenance progeny trials	Significantly better than 2, in most cases	Provided SSO comprised predominantly from families from superior provenances. Large quantities of seed produced quickly.
5.	Seed from ALRTIG clonal seed orchards developed from outstanding trees in existing trials	Should be superior to 3 and 4, provided selection is done well, because selection intensity is higher than in SSOs	Genetic quality can be further improved by roguing inferior clones following progeny-testing. Can be scaled up to meet demand.
6.	Seed from ALRTIG clonal seed orchards developed from ALRTIG progeny trials	Higher quality than 5, for most species, because selecting from better genetic base	Would take at least 10 years to deliver any seed. Can be scaled up to meet demand. Long-term grafting success not confirmed for some species
7.	Seed families produced by controlled crossing between outstanding trees in ALRTIG breeding population	Higher quality than 1-6. Selfing eliminated	Expensive, limited quantity May be possible to produce operational quantities of seed, at acceptable cost if genetic gain is high Production of interspecific hybrid families possible
8.	Tested superior clones	Deliver highest levels of genetic improvement, assuming clones developed from best families are thoroughly tested in target environments, and best clones are deployed operationally	Development process lengthy and expensive, higher per-plant cost of stock relative to seedlings

Implementation of the breeding strategies, 2001-2003

Additional species information

Significant additional information that impacts on breeding strategies was obtained for several of the key species over the period 2001-2003.

Taxonomy and genetics

Interspecific hybrids involving *E. occidentalis* may be worthy of evaluation for their commercial potential. *Eucalyptus calyerup* appears to be a stabilised hybrid between *E. occidentalis* and *E. platypus*, occurring naturally in a small population near Jerramungup (McQuoid and Hopper 2002). It has been performing well in Landcare plantations around Jerramungup to age three years, showing resistance to attack by lerps, good vigour and straight stem form.

Interspecific hybrids between *E. camaldulensis* and *E. grandis*, and *E. camaldulensis* and *E. globulus* have shown some potential on drier sites in Western Australia where they have outperformed *E. globulus* bluegum (Barbour 2004). Similarly, these two hybrids have showed promising initial performance on saline, waterlogged and low rainfall sites in the southern Murray-Darling Basin (Dale 2002). The performance of the hybrids generally seems to be better on winter-predominant low rainfall sites than in Queensland, where summer rainfall predominates. Insect attack and disease seem to be problematic in summer rainfall environments.

An isozyme survey of natural and cultivated populations of *E. cladocalyx* (McDonald *et al.* 2003) confirmed that there is clear genetic divergence between the three main regions of natural occurrence (southern Flinders Ranges, Kangaroo Island and Eyre Peninsula). Cultivated populations from western Victoria were genetically similar to the superior Wirrabara natural provenance from the southern Flinders Ranges, supporting historical records that indicate Wirrabara is the origin of the western Victorian populations. The two Kangaroo Island populations sampled contained less than half the allelic diversity of the Wirrabara provenance. Multi-locus estimates of outcrossing rates in four natural populations averaged 0.57, and single-locus estimates averaged 0.52, indicating that in natural provenances about 40% of viable seeds produced are the result of self-fertilization, with additional neighbourhood inbreeding. This must be taken into account when estimating genetic parameters from open-pollinated progeny trials. Assuming that inbreeding depression of growth is as strong in *E. cladocalyx* as in other eucalypts, achieving higher rates of outcrossing in seed orchards should improve the vigour of orchard-derived planting stock seed.

There has been a change in the taxonomy of spotted gums. Based on isozyme studies (McDonald *et al.* 2000) and morphological evidence, *Corymbia variegata* was relegated to sub-specific status as *C. citriodora* subsp. *variegata* by McDonald and Bean (2000). It is clear from this evidence that *C. maculata* and *C. citriodora* subsp. *variegata* are separate species and should be maintained in separate breeding populations, as has been done by ALRTIG.

Outcrossing rates were determined in a *C. maculata* seedling seed orchard at Deniliquin, New South Wales. The multi-locus outcrossing rate t_m for the ten parent trees studied averaged 0.76. While five of the parent trees assayed had very high out-crossing rates ($t = > 0.90$), the mean estimate for the stand was affected by significant levels of inbreeding in some of the trees, with two trees having t_m values of 0.50 and 0.53. The difference between single- and multi-locus outcrossing estimates ($t_m - t_s$), was not significant, indicating that inbreeding in the stand is due primarily to selfing rather than relative mating. Surveys of flowering phenology in the stand have shown major differences among

C. maculata trees in their time of peak flowering; this may have contributed to reduced out-crossing in some of the sampled trees.

There may be similar differences between provenances in their peak flowering times for the other ALRTIG key species; surveys of flowering phenology are a high priority once the first seedling seed orchards commence flowering.

Ranking of provenances

Three provenances of *E. sideroxylon* and seven provenances of *E. tricarpa* were tested in provenance trials at two sites in north-east Victoria (Noble and Arnold 2002). Survival to age 1.5 years averaged 90% and species mean growth rates were similar, with mean dbh at age 3 years averaging 6 cm at the Rutherglen site and 5.5 cm at the Indigo Valley site for *E. sideroxylon*, the corresponding figures for *E. tricarpa* being 5.1 and 5.0 cm. There were significant differences between provenances in their early growth. The three provenances of *E. sideroxylon* from the Chiltern and Wangaratta areas in north-east Victoria all grew well, as did an *E. tricarpa* provenance from Mt Raymond near Orbost in east Gippsland. An *E. tricarpa* provenance from Rushworth in Central Victoria was the poorest performer at both sites. While there was significant variation among the provenances for stem form and branch characteristics, stem form of the ironbarks was substantially inferior to that of *E. cladocalyx* planted adjacent to each trial. Later-age results from these trials will provide more reliable provenance rankings.

Wood properties

Important information on sawing and wood properties of *E. cladocalyx* and *E. occidentalis* has come from a recently published study by Blakemore *et al.* (2002). Small sawlogs were harvested from plantations of these species at sites receiving 400- 450 mm mean annual rainfall in western Victoria. The *E. cladocalyx* plantation was approximately 30 years old and *E. occidentalis* 42 years old. Three-metre butt logs ranging from 30 to 53 cm in diameter at breast height were harvested and back-sawn, and the recovery of different grades of boards was measured. The combined recovery of appearance and cover-grade boards was low (average 18% for *E. cladocalyx* and 14% for *E. occidentalis*). Decay from dead branch stubs was the most important defect leading to downgrading of boards, particularly for *E. occidentalis*, reflecting the need for good silviculture to produce high-value logs. Wane, green knots and pith were other major causes of product downgrade. Surface checking was another significant problem and careful drying schedules were required to prevent drying degrade. It should be noted that the sampled plantations had not been thinned, nor the logs pruned. This study concluded that it was important to improve stem form and branching characteristics of these species, through genetic improvement and appropriate silviculture, to improve the recovery of high-value products.

Interim seed production areas

The two interim seed production areas of *E. cladocalyx* that were created by selective thinning of second-generation plantations of the species at Wail State Forest in western Victoria appear unlikely to be a significant source of improved seed in the near future. In mid-2000, two 28-year-old plantation blocks each of about 1 ha in area were thinned by DNRE from a stand density of about 700 stems/ha to approximately 150 stems/ha, and the retained trees were fertilised to promote rapid crown growth and development of new seed crops. When inspected in October 2002 there has been very little growth of the crowns of the retained trees in the thinned stands, and no new bud crops had been set. It appears that heavily stocked mature stands of *E. cladocalyx* do not respond quickly to thinning.

These observations suggest that if progeny trials are left unthinned past the point where intense competition sets in, they may not be able to develop bud crops and function well as seedling seed

orchards, even if subsequent heavy thinning is carried out. By contrast, observations on CSIRO's progeny trial of *E. cladocalyx* at Benalla, Victoria, showed that at age 4.5 years after planting, 70% of the trees in the unthinned stand were flowering, with 50% flowering heavily. Similar heavy flowering was observed in the ForestrySA thinned seed production area at Kersbrook, South Australia at age 6-10 years.

Seed yields

Some quantitative information has been obtained on seed yields from interim SPAs, as shown in Table 2.

Table 2. Seed yields obtained from ALRTIG interim seed production areas managed by ForestrySA

Species	SPA	area (ha)	Year	Age of SPA (years)	Seed yield
<i>E. cladocalyx</i>	Kersbrook	0.5	2000	8	2000 g
<i>E. occidentalis</i>	Bundaleer	0.64	2000	8	440 g from 14 trees
			2001	9	1790 g from 11 trees
<i>E. occidentalis</i>	Red Hill	0.67	2000	9	500 g from 10 trees

It should be noted that the above yields are from collections of a small proportion of superior trees within the SPA, not from all seed-bearing trees. Comparable yields have been obtained from CSIRO's irrigated SPAs of spotted gum in the Deniliquin area. However, it has been noted that yields are not consistent from year to year, with poor seed crops in the year following a heavy collection. It is too early to categorise any of the species as strongly biennial in the size of their seed crops, a documented phenomenon for some eucalypt species in their natural environments, including *E. camaldulensis* (Boland *et al.* 1980).

Based on the experience with the interim SPAs, it is anticipated that seed yields of 5 kg per hectare will be obtained from well-sited and well-managed seed orchards every second year or so for *E. cladocalyx*, *E. occidentalis* and *C. maculata*, from age 7-8 years after planting (earlier in some cases). A seed yield of 2 kg per hectare per year, averaged across several years, would appear to be achievable on suitable sites. These yields can be translated into the capacity to provide planting stock and areas of plantations, as shown in Table 3.

Less information on seed yields is available for the other key ALRTIG species. It appears from observations made in provenance and progeny trials of *C. citriodora* subsp. *variegata* and red ironbark (*E. sideroxylon* and *E. tricarpa*) in dryland Victoria and southern New South Wales that these species are slower to attain general flowering than are the three species shown in Tables 2 and 3.

Table 3. Capacity of seed orchards to meet plantation establishment targets

Species	<i>E. cladocalyx</i>	<i>E. occidentalis</i>	<i>C. maculata</i>
Seed yield from orchards (kg/ha) ¹	2	2	2
Viable seeds/kg	150 000	200 000	100 000
Assumed recovery from nursery (% plantable seedlings) ²	70	70	70
Plantation stocking (trees/ha)	1000	1000	1000
Area of plantations per hectare of seed orchard	210	280	140

¹ Seed weight after cleaning by sieving

² Assuming sowing by machine in an efficient nursery, allows for losses during final cleaning of seed for machine sowing

Progeny trials

The most important assets developed by ALRTIG during the period 2000-2002 are progeny trials of each of the key species across dryland southern Australia. As discussed by Harwood *et al.* (2001) some of the progeny trials will be developed into seedling seed orchards by selective thinning to deliver improved seed, while other trials will be grown on without thinning for a longer period to enable more accurate ranking of families and individuals. Clonal seed orchards may be developed from selections made from these unthinned trials. A total of 33 progeny trials was planted over the period 2000-2002 (Table 4).

For each species, a common set of progenies, taken from family collections from the known best natural provenances and selected superior trees in planted stands of these provenances, has been tested in progeny trials across several sites. The number of trials established is considerably greater than that originally planned. For example, eight progeny trials of *E. cladocalyx* were established, compared with the four trials envisaged in the original plan. The additional trials, referred to as “parallel trials”, were established by ALRTIG partner agencies where cooperative landowners were prepared to plant them, and available resources permitted. Three trials of an additional species, *E. sideroxylon* (a sister species of *E. tricarpa*), were established in 2002 as part of the ALRTIG program for 2002-03. These additional trials are a very valuable asset to the ALRTIG breeding programs. Family performance will be evaluated across a wider range of sites than originally planned, and selection of outstanding individuals will be more accurate and from a larger breeding population.

Table 4. Progeny trials of key eucalypt species established by ALRTIG partners, 2000-2002

Species	State	Manager	Est. date	Location	# Families ¹	Area (ha)	Status ²
<i>Corymbia maculata</i>	VIC	DNRE-PVI	2001	Hensley Park	118	1.9	OK
<i>C. maculata</i>	VIC	DNRE-PVI	2001	Balmoral	105	1.7	OK
<i>C. maculata</i>	VIC	DNRE-PVI	2001	Buckleys Swamp	108	1.7	OK
<i>C. maculata</i>	VIC	DNRE-PVI	2001	Brynterion SF	54	0.9	OK
<i>C. maculata</i>	VIC	DNRE-PVI	2001	Cavendish	91	1.5	OK
<i>C. maculata</i>	WA	FPC	2002	Tenterden	68	1.1	OK
<i>C. citriodora</i> ssp <i>variegata</i>	NSW	SF-NSW	2001	Willow Tree	120	1.9	written off
<i>Euc. camaldulensis</i>	WA	FPC	2002	Tenterden	96	1.5	OK
<i>E. cladocalyx</i>	VIC	CFTT	2001	Lismore	120	1.9	OK
<i>E. cladocalyx</i>	NSW	CSIRO FFP	2001	Corowa	83	1.3	OK
<i>E. cladocalyx</i>	VIC	DNRE-PVI	2001	Buckleys Swamp	96	1.5	OK
<i>E. cladocalyx</i>	VIC	DNRE-PVI	2001	Kalkee	90	1.4	OK
<i>E. cladocalyx</i>	SA	FORESTRYSA	2001	Wirriga	138	2.2	OK
<i>E. cladocalyx</i>	SA	FORESTRYSA	2001	Marcollat	63	1.0	OK
<i>E. cladocalyx</i>	WA	FPC	2001	Esperance	60	1.0	OK
<i>E. cladocalyx</i>	WA	FPC	2001	Moora	120	1.9	OK
<i>E. cladocalyx</i>	NSW	SFNSW	2001	Bruceale	109	1.7	OK
<i>E. occidentalis</i>	VIC	CFTT	2001	Yando	119	1.9	OK
<i>E. occidentalis</i>	VIC	DNRE-PVI	2001	Dunkeld	114	1.8	OK
<i>E. occidentalis</i>	VIC	DNRE-PVI	2002	Brynterion SF	100	1.6	marginal
<i>E. occidentalis</i>	VIC	DNRE-PVI	2002	Rupanyup	63	1.0	marginal
<i>E. occidentalis</i>	SA	FORESTRYSA	2001	Avenue	117	1.9	OK
<i>E. occidentalis</i>	WA	FPC	2001	Esperance	120	1.9	OK
<i>E. occidentalis</i>	WA	FPC	2001	Moora	105	1.7	OK
<i>E. occidentalis</i>	NSW	SFNSW	2001	Narrandera	120	1.9	marginal
<i>E. sideroxylon</i>	NSW	CSIRO FFP	2002	Corowa	100	1.6	OK
<i>E. sideroxylon</i>	NSW	CSIRO FFP	2002	Holbrook	100	1.6	OK
<i>E. sideroxylon</i>	VIC	DNRE-PVI	2002	Melville Forest	64	1.0	OK
<i>E. tricarpa</i>	VIC	CFTT	2000	Huntly	112	1.8	OK
<i>E. tricarpa</i>	VIC	CFTT	2000	Lake Tyers	115	1.8	OK
<i>E. tricarpa</i>	WA	FPC	2001	Esperance	63	1.0	OK
<i>E. tricarpa</i>	NSW	SF-NSW	2000	Walla Walla	108	1.7	OK
<i>E. tricarpa</i>	WA	FPC	2001	Moora	70	1.1	OK

¹Number of families in progeny trial. Most progeny trials comprise 4 replicates each with one 5-tree row plot of each family planted, surrounded by one or more external buffer rows. Spacing used in most trials is 4 m between rows and 2 m between trees within rows.

²Status as of March 2003. Survival greater than 70% is considered satisfactory for genetic trials, 50-70% marginal, and less than 50% a write-off (although it may still be feasible to select some superior trees in written-off trials).

Assessment of progeny trials

As shown in Table 4, all but four of the progeny trials were established successfully, with survival of 70% or higher up to March 2003. Generally survival is expected to be in the range 85-95% at planting plus 36 months for the majority of trials. A core set of progeny trials will be assessed at age 36 months, prior to any thinning. This will be undertaken in ALRTIG Stage 3, currently under contract with JVAP. Inspection of a number of trials indicates that, depending on species and site, mean tree heights will be of the order of 4 m to 6 m at this age. The assessments should provide an excellent set of data for evaluating genetic differences in survival, early growth and stem form of the butt log across a range of environments. At 36 months of age, the trees will be too small to accurately determine branching characteristics.

Depending on anticipated demand for improved seed, and predicted flowering intensity at different sites, some progeny trials will be chosen for early selective thinning to convert them to SSOs.

Because the trials of each species have most of their families in common, family rankings from the across-site analyses will be used in the thinning of those progeny trials dedicated as SSOs. The assessment data may be made available to postgraduate students or other researchers for further investigation.

The challenge facing the ALRTIG partners is to maintain these progeny trials, carry out the 36-month assessments, collectively analyse the data obtained, and carry out selective thinnings to develop some of the trials into SSOs. It is envisaged that a significant proportion of the work will be done in 2005 as part of an extension to the ALRTIG project (ALRTIG stage 3).

Specific observations from progeny trials

The ALRTIG progeny trials have not yet received formal assessments (the first formal assessments will be carried out at age 3 years). However, some useful observations have already been made. Firstly, the trials have been established during a period of drier than average years across most of low-rainfall southern Australia. In particular, drought conditions prevailed for the second half of 2002 and early 2003. Despite this, most of the progeny trials have shown excellent survival. This good early performance of a total of over 50 ha of trials across the target planting zone has confirmed that the ALRTIG key species are generally well adapted to the southern low-rainfall environment.

The only progeny test/SSO planting of *C. citriodora* subsp. *variegata* was established near Willow Tree, central New South Wales. Very dry and hot conditions hampered establishment and growth from the outset, causing about 20% early mortality. The whole trial was devastated by repeated very heavy frosts in July 2002, which resulted in 100% leaf scorch on nearly all of the trees present. Only 194 (8%) trees of the original 2400 had partial scorch when inspected in September 2002, and of these only 26 trees showed nil or minor damage. These trees were in families originating from 10 provenances, both inland and coastal. Six of the trees were from the Paddys Land (New South Wales) provenance, a relatively high proportion compared with the overall representation in the trial; this supports previous findings that Paddys Land has high frost tolerance relative to other spotted gums. Many trees were re-shooting from the base when inspected in September, and by April 2003, about 30-35% of the original stocking had re-grown stems, some well-formed up to about 2.5m tall. However, there were still too few trees to form a viable trial, with many plots entirely missing. Twenty out of the 26 putatively frost-tolerant trees noted in the previous spring (those of acceptable size) were sampled by SF NSW for scions in April 2003, to be grafted. This small resource of grafted ramets may be useful in future as a source of clones to be tested for frost hardiness.

For spotted gums in winter rainfall climates of southern Australia, frost is a major issue, especially for establishment in inland areas. The first year or two is the main danger period. To be safe, spotted gum plantings should probably be restricted to upper slope or ridge sites with ample air drainage, out of range of most frosts. In Queensland's summer rainfall plantation zone, where frost is less of a problem, tree breeders are focussing on *Ramularia* shoot blight resistance (Dickinson et al. 2004) and growth traits (Lee et al. 2004).

Clonal seed orchards

E. occidentalis has proved relatively easy to graft, and an ALRTIG clonal seed orchard is being developed by CSIRO from selections made in ForestrySA, Forest Science Centre and CSIRO field trials. This clonal seed orchard was planted out near Corowa, New South Wales, in spring 2003.

C. maculata and *C. citriodora* subsp. *variegata* have also proved easy to graft. WA FPC and CSIRO (together with commercial partners) have both developed grafted clonal seed orchards of *C. maculata*, based on selections from their trials established prior to commencement of ALRTIG.

No information has been obtained yet by the ALRTIG partners on grafting success with *E. cladocalyx* or the red ironbarks *E. sideroxylon* and *E. tricarpa*.

Production of *E. camaldulensis* interspecific hybrids

As noted in the original breeding strategy, *E. camaldulensis* is of interest more for its role as a parent in interspecific hybrid combinations rather than as a pure species. Both FPC and CSIRO have grafted *E. camaldulensis* selections from progeny trials; FPC had established a clonal seed orchard prior to commencement of ALRTIG. CSIRO has collected pollen from selected trees in its *E. camaldulensis* progeny trials in southern New South Wales and produced a series of *E. grandis* x *E. camaldulensis* hybrid crosses, using selected *E. grandis* clones also grafted from its progeny trials. Hybrid seeds are now available for testing by ALRTIG partners.

Cutting propagation

CSIRO carried out a cutting propagation study for ALRTIG in 2000-2001 (Brammall and Harwood 2001). Using conventional two-node stem cuttings taken from seedling hedge-plants, excellent rooting percentages (over 80% across two trials) were obtained with *E. camaldulensis*. Of the other key dry-zone eucalypt species tested, *E. occidentalis* was the best with an overall percentage rooting of 31%. *E. cladocalyx* was poorest with only 4% of cuttings rooting on average. Subsequent trials using tip cuttings and careful control of hedge plant nutrient status have given much better rooting of *E. occidentalis* (80-90% rooting of cuttings from seedling hedge plants). This latter result confirms that *E. occidentalis* could easily be developed for clonal forestry. Further technical improvements will be required for *C. maculata*, *E. cladocalyx*, *E. sideroxylon* and *E. tricarpa* if clonal forestry with these species is to be viable.

Genetic gain trials

Twenty genetic gain trials for *E. camaldulensis*, *E. cladocalyx*, *E. occidentalis*, *C. maculata* and *C. citriodora* subsp. *variegata* were established in 2003. Each gain trial will compare the known best natural provenance of a species with seed from ALRTIG's interim seed production areas, and in some cases other commercially available seed sources. The genetic gain trials use a design with five replicates of large (49-tree or 64-tree) blocks of each seed source, to enable accurate ranking and long-term evaluation of the performance of the different seed sources.

Seven of the genetic gain trials are being carried out in collaboration with industry partners.

Summary of modifications to ALRTIG breeding strategies

The original breeding strategies adopted for the ALRTIG key species are proceeding largely according to plan.

Some important additional information has been obtained on the biology and utilisation of the key species, which has influenced the implementation of the improvement strategies.

The breeding objective, breeding objective traits and selection traits for the species have been tentatively defined. The breeding objective is to maximise the net value (stumpage value – plantation costs) of logs destined for solid-wood and engineered-wood products produced on rotations of 20-40 years, on a per-hectare basis. The core breeding objective traits, to achieve this breeding objective, are survival, log volume, stem form and branching characteristics. Study of growing and processing industries, as they develop, will enable refinement of the breeding objective and the breeding objective traits, and may require incorporation of wood quality traits into the breeding objective. Selection traits follow the breeding objective traits: survival, height, diameter at breast height, stem form and branching. There is a compromise in the age of selection, between selecting as early as 3-5 years to deliver improved germplasm as quickly as possible, and the reduced accuracy that such early selection entails.

The large number of progeny trials established (Table 4) enables a flexible approach to be taken. Planting targets and anticipated demand for improved seed of each key species can be reviewed each year, and using calculations of the type presented in Table 3, the number of progeny trials required for early conversion to seedling seed orchards can be determined. It should be relatively straightforward to meet the demand for seed to support an annual plantation establishment rate of 1000 ha per species by year 2008-2010 (depending on species, as the progeny trials were established at different times), the only exceptions being *E. camaldulensis* and *C. citriodora* subsp. *variegata*. Other seedling and clonal seed orchards outside of the ALRTIG program should deliver additional supplies of improved seed, in some cases as early as 2005.

Progeny trials not required for conversion to seedling seed orchards can be left to grow on without thinning to deliver more accurate genetic information from later-age selection. Clonal seed orchards can be developed by grafting selections from these unthinned trials. If selections were made in trials at age 6-8 years, seed from clonal orchards could be delivered from around 2010 to 2104, depending on species.

Excellent results with cutting propagation achieved for *E. occidentalis* open up the possibility of clonal forestry with this species. This would enable rapid capture and deployment of trees with outstanding stem form, for a species in which forking and heavy branching is a serious limitation.

A full revision of the ALRTIG eucalypt breeding strategies would be appropriate in mid-2005, by which time 3-year data should have been collected and analysed from the progeny trials of all of the key species with the exception of *E. sideroxylon*.

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