Australian Low Rainfall Tree Improvement Group: Compendium of Hardwood Breeding Strategies

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Foreword

Growing interest in farm forestry on crop and grazing land in the 400–600 mm rainfall region of southern Australia has prompted a cooperative national effort to select and breed better trees. Tree planting can help control dryland salinity — a result of rising water tables — and reduce soil erosion. Rates of planting are likely to increase if farmers can choose trees that will also provide a worthwhile economic return. Selection and breeding will boost the benefits of tree planting by increasing yields of high quality timber or leaf oils.

This report is a compendium of the tree breeding strategies developed by the Australian Low Rainfall Tree Improvement Group (ALRTIG). The group is supported by the Joint Venture Agroforestry Program and the Natural Heritage Trust and is a collaborative undertaking involving researchers from State agencies and CSIRO. ALRTIG aims at speeding the improvement process of tree improvement by coordinating efforts across Australia.

This project was partially funded by three R&D Corporations — RIRDC, LWA and FWPRDC, which 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; Department of Conservation and Land Management, WA; Department of Natural Resources and Environment, Victoria; ForestrySA; Primary Industries and Resources SA and; State Forests of NSW.

This report, a new addition to RIRDC's diverse range of over 700 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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Executive Summary

The Australian Low Rainfall Tree Improvement Group (ALRTIG) is a cooperative of State and Commonwealth Government research organisation partners, whose aim is to produce and provide high quality genetic resources for selected hardwoods, softwoods and oil yielding mallee eucalypts suited to the 400-600 mm rainfall zone of southern Australia.

The focus is on species that can produce valuable forest products. Commercial viability is seen to be the key to widespread adoption of farm forestry, and achievement of the environmental benefits that it can provide. ALRTIG has selected nine of the many species adapted to low rainfall environments in southern Australia, on the basis of their good performance across a wide range of sites, and their ability to produce a commercial product (timber or leaf oil). ALRTIG's three working modules cover hardwoods, softwoods and short-rotation woody crops.

ALRTIG have recently completed a series of breeding strategies for a number of hardwood and softwood species. The focus of this compendium is on hardwood species. It includes the following parts:

1. Overview of species selection process and tree improvement strategies
2. Genetic improvement strategy for *Eucalyptus camaldulensis*
3. Genetic improvement strategy for *Eucalyptus cladocalyx*
4. Genetic improvement strategy for *Eucalyptus occidentalis*
5. Genetic improvement strategy for *Eucalyptus tricarpa*
6. Genetic improvement strategy for spotted gum

The overview part provides background information on all of the ALRTIG species, and explains how a group of nine 'key species' were selected for intensive tree improvement work in the 400-600 mm rainfall zone of southern Australia. It also provides general information on the mission, composition, scope and aims of ALRTIG.

The other parts in this compendium, dealing with the five individual hardwood 'key species', provide detailed information on the genetic resources and improvement strategies for each.

Each part is self-contained, and will be used by ALRTIG as a working document for the tree improvement programs. As such, it is expected that the strategies will be updated periodically as the tree improvement programs progress, and the ALRTIG Hardwoods Technical Committee reviews the strategies.

Part 1 : Overview of Species Selection Process and Tree Improvement Strategies

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1. Summary

1.1. Target Planting Zone

The Australian Low Rainfall Tree Improvement Group is a cooperative organisation that will produce improved germplasm for a selection of 'key species' of trees suited to low rainfall environments. The targeted low rainfall plantation zone is defined as those areas that receive 400–600 mm per year of winter or uniform rainfall within the southern States: NSW, South Australia, Tasmania, Victoria and Western Australia. Significant areas of cleared farmland, suitable for plantation establishment, exist within this zone.

1.2. Species Selection Process

Initially, ALRTIG considered a wide range of species, both Australian natives and overseas 'exotics' for inclusion in the project. The 'key species' were selected on the basis of their proven hardiness, growth rate and capacity to grow on a wide range of sites within the planting zone. The final list also took into consideration the need to fulfil other requirements. These include: short and long rotation lengths; market demand for both softwood and hardwood products and; alternatives for diverse site types, ranging from difficult sites - those exposed to cold, salinity, waterlogging and alkalinity - to sites with favourable soils and microclimate.

1.3. Hardwoods Species and Strategy

The key hardwood species selected for attention by ALRTIG are:

- Red ironbark - *Eucalyptus tricarpa* and *E. sideroxylon*
- River red gum - *E. camaldulensis*
- Spotted gum - *Corymbia maculata*, *C. variegata* and *C. henryi*
- Sugar gum - *E. cladocalyx*
- Swamp yate - *E. occidentalis*

These species are all proven to be hardy enough to survive in the target planting zone, and all have demonstrated good growth capacity. They are also complementary in their ability to grow on diverse site types. Two of the species, swamp yate and river red gum, are tolerant of seasonal waterlogging and saline conditions. Sugar gum and red ironbark are both tolerant of very droughty conditions, and have already demonstrated their good sawn timber properties. Spotted gum has very good natural form, and produces an excellent timber on better quality low rainfall sites.

The breeding objectives for the hardwoods are similar for all species. The main aim is to produce small logs suitable for sawn timber production. Selection in the first generation will be for traits including good stem form, growth rates, branching properties and apparent disease resistance. Selections based on wood properties may be incorporated into later generations. Breeding for straight stem will also increase pulp and firewood yields, as this property makes transport and handling more efficient.

The individual tree improvement strategies selected for each of the hardwoods 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**, which will be progressively thinned to **seedling seed orchards**, for production of high quality seed. Some may be retained longer for collection of progeny data, while others may be thinned more rapidly, to meet demand for improved seed.
4. Establishment of **clone banks** and **clonal seed orchards**. Selections will be taken from elite trees in existing trials and supplemented by later infusions from the seedling seed orchards.

The combination of options selected for each species depends on a number of factors including: perceived demand for the species; the amount of improvement needed to produce acceptable sawlogs; existing resources and; the need to meet short and long-term demand for seed.

1.4. Softwoods Species and Strategies

Two softwood key species were selected:

- Brutian pine - *Pinus brutia*
- Maritime pine - *P. pinaster*

Brutian pine is an extremely hardy species capable of withstanding harsh soil and climatic conditions. It has been planted extensively in the Mediterranean where it is used for production of timber and other products. ALRTIG has produced a breeding strategy for this species with objectives very similar to those described for the hardwoods key species. The main components of the strategy are the creation of seed stands and seed production areas for short-term seed production, and a nucleus breeding strategy, which will be used to provide substantial genetic gains in future.

Maritime pine is a tree species with properties broadly similar to radiata pine. However, it can tolerate significantly drier conditions, and is well suited to sites receiving above 400 mm of rainfall per year. The species has already undergone dramatic genetic improvement in Western Australia, where it is routinely planted on low rainfall sites. The objective of the ALRTIG program is to trial the Western Australian material throughout southern Australia on site types representative of the target planting zone. Such a genetic-by-environment study will help gauge the species’ suitability for broad-scale forestry.

1.5. Short Rotation Woody Crop Species and Strategy

Two species were selected to provide a short-rotation plantation option. These were:

- Blue mallee - *E. polybractea*
- Oil mallee - *Eucalyptus horistes*

Both mallee species produce high concentrations of cineole-rich leaf oil, and can be harvested on a 2-3 year coppice rotation system. These species have been tried on a commercial basis in Western Australia and NSW, but have not been extensively tested over a wide range of sites in the eastern States. The aim of the ALRTIG program will be to test individual families of these species on a range of sites in the target planting zone throughout southern Australia.

2. Introduction

The Australian Low Rainfall Tree Improvement Group (ALRTIG) was formed as a result of a resolution made at the National Low Rainfall Tree Improvement Workshop held during 1998 in Adelaide. This workshop brought together twenty major stakeholders in low rainfall farm forestry and tree improvement. Workshop sessions were devoted to presentation of low rainfall tree improvement progress papers, identification of research priorities and identification of information gaps. Participants were in general agreement that cooperative research is the path to rapid and efficient development of Australia's low rainfall tree genetic resources, and a model for a low rainfall tree improvement cooperative was developed.

Subsequent to the workshop, a partnership consisting of State agencies and CSIRO Forestry and Forest Products put a research proposal to the Joint Venture Agroforestry Program for support. The proposal outlined a strategy for tree improvement and the promotion of the use of genetically improved stock for low rainfall farm forestry. A number of *key species* were identified, and strategies for rapid development of their genetic resources were outlined. The ALRTIG cooperative proposal was supported, and the group commenced activity in August 1999.

The purpose of this paper is to provide information on the ALRTIG key species, reasons for their inclusion in ALRTIG programs and their potential for commercial low rainfall forestry. An overview of the breeding strategies and trial objectives for the key species is also provided.

3. Southern Low Rainfall Zone – Definition

ALRTIG's 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*. For the purposes of the project, the *southern low rainfall zone* is defined as those areas below approximately 29^{0}S (the northern NSW border), which receive average yearly precipitation of between 400 and 600 mm. These areas are shown in Figures 1-5.

The project does not address tree improvement in low rainfall areas of Queensland, the Northern Territory and northern Western Australia, which are climatically distinct with summer rainfall maxima and warmer temperatures, and would require a different suite of tree species.

Whilst the project's target planting area is defined in terms of rainfall, it should be remembered that this is only one of many variables that govern a site's ability to support growth of a given species. Temperature, insolation, wind, soil physical properties and depth, local topography, and subterranean water accessibility interact with rainfall to determine moisture availability at any given site.

Pan evaporation is a useful indicator of rainfall effectiveness. The annual moisture deficit (precipitation – evaporation) is far greater at Esperance, WA than at Oatlands, Tasmania, although Esperance receives more annual rainfall (Table 1).

Table 1. Climates of population centres in the southern low rainfall zone

State	Town	Annual rainfall (mm)	Mean daily temperature (^{0}C)	Annual pan evaporation (mm)	Mean annual rainfall deficit (mm)	Days/ year colder than 0^0C (minimum)
ACT	Canberra	631.6	12.9	1679	-1048	61.4
NSW	Deniliquin	408.7	16.5	1789	-1380	8.2
NSW	Temora	536.4	15.4	1606	-1070	31.7
SA	Bundaleer	555.6	16.0	1606	-1050	10.4
SA	Naracoorte	566.4	13.2	1387	-821	4.3
TAS	Oatlands	555.8	10.2	1022	-466	41.3
TAS	Campbell Town	561.6	10.7	1095	-533	62.9
VIC	Tatura	496.3	14.7	1387	-891	18.6
VIC	Stawell	581.2	14.1	1497	-916	5.9
WA	Esperance	612.7	16.9	1716	-1103	0
WA	Moora	461.7	18.3	2300	-1838	0.7

When considering rainfall effectiveness, dividing sites into those having high (annual pan evaporation of 1500 mm or more) or low evaporation potential is a useful first step that has helped explain the performance of bluegum plantations in SW WA (Harper et al. 1999).

4. Potentially Available Land

The aim of the ALRTIG project is to facilitate plantation expansion down to the 400 mm annum^{-1} rainfall isohyet by developing improved planting stock suited to low rainfall environments. The majority of Australia's plantations are established on sites receiving over 600 mm. The 400 – 600 mm rainfall zone is a logical target for the following reasons:

- Rainfall is high enough on average and reliable enough to support selected commercial tree species
- This is a traditional pastoral and agricultural zone, which will benefit from farm diversification
- Significant areas within the zone would benefit from increased tree planting for control of rising saline ground water by reducing groundwater recharge or increasing water use in discharge areas
- Parts of the zone have sufficient population, markets, infrastructure and access to export facilities to make production of specific forest products viable

The 400 – 600 mm rainfall zone in southern Australia has typically been used for purposes such as cropping (particularly grain production) and grazing. Widespread clearance of deep-rooted native vegetation to make way for shallow rooted pastures has been identified as one possible cause of rising water tables and salinisation of surface soils. Farmers are now seeking to diversify their farming interests and combat the rising water table problem, by planting trees that produce timber or other products.

So far, plantation potential studies in the southern States have concentrated on higher rainfall areas. For example, the recent series of studies produced by the Bureau of Rural Sciences as part of the supporting documentation for the Comprehensive Regional Assessment process has focused on regions in Victoria, NSW and Tasmania that contain significant areas of commercial native forests.

These studies have typically used a process of identifying *suitable*[1] areas of cleared, private land, and superimposing *capability* classes for a range of commercial species, such as *Eucalyptus globulus* and *Pinus radiata*. Typically, a lower rainfall threshold of 550-600 mm was used to define a lower capability class for these species.

However, formal plantation potential analysis has not been carried out for most of the southern low rainfall zone. Despite the lack of quantitative data, it is reasonable to assume that significant areas of plantation will be established for the following reasons:

- There is impetus from farmers and Government to control salinity within much of the zone by planting deep rooted vegetation (eg Bartle et al. 1999)
- There is a perceived need to diversify agricultural income due to falling prices of traditional commodities sourced from the zone, such as wool (eg Bartle et al. 1999)
- The Pacific Rim and global demand for sawn timber and forest products is predicted to rise (eg Neufeld 1997)
- There is significant, privately owned, cleared land in the zone

The following sections summarise the likely future extent and development of low rainfall farm forestry in each southern State.

4.1. NSW

The two main areas of interest in NSW are the Monaro Tablelands (zone A in Figure 1) and a large band extending west from Moree to Bourke in the north, and from Wagga to Deniliquin in the south.

Figure 1. 400-600 mm annual rainfall zone (30 year average) for NSW
Source data: Bureau of Meteorology

Both of these regions have substantial areas of cleared pastoral land that would be suited to low rainfall farm forestry. Moreover, interest in tree planting to control salinity problems is increasing in both regions, especially in the Murray Darling Basin. For example, a project to change the vegetation

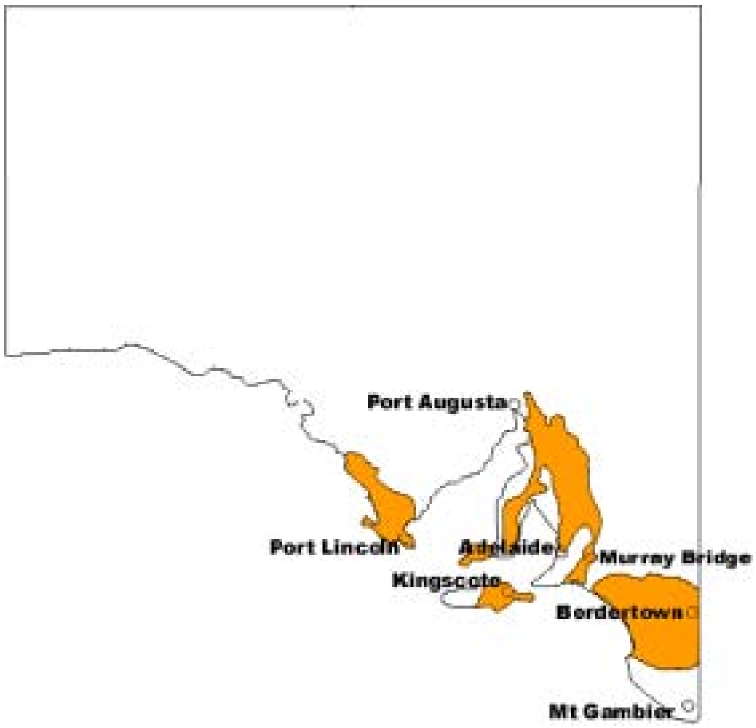
[1] **Suitable** areas are defined as those that are available for plantation establishment, taking into consideration factors such as economic viability, legal availability and social impacts. **Capable** areas are those areas which have the biophysical attributes necessary to support a commercial plantation of a given species.

structure of whole sub-catchments in southern NSW (and northern Victoria) is currently being planned. One significant difference between the Monaro Tablelands and the western slopes of NSW is temperature regime. The Monaro Tablelands are particularly cold in winter, and this may limit species selection to some extent.

4.2. South Australia

The low rainfall areas of South Australia are shown in Figure 2. Bulman and Fairlamb (1998) have identified 24 'regional site-types' within four main planting zones (mallee, mid north, Adelaide Hills and south east) in SA. These site type descriptions can be used in the context of the ALRTIG project to match key species to soil and climate types (at a broad scale) within the State, though the extent of area potentially available for plantations has not been quantified. However, there is a large amount of interest in farm forestry in the upper SE, the district north of the Green Triangle. In the area north of Mt Gambier, there is significant private ownership of cleared pastoral and agricultural land. The expansion of blue gum plantations in the Green Triangle is already encroaching on this area, despite the marginal productivity and questionable sustainability of this species in the sub 600 mm rainfall zone. It is envisaged that this area, together with the contiguous western Victoria region, will be a significant low rainfall farm forestry catchment. There are already a number of trials and plantations established, and active interest in low rainfall farm forestry.

Figure 2. 400-600 mm annual rainfall zone (30 year average) for South Australia
Source data: Bureau of Meteorology



4.3. Tasmania

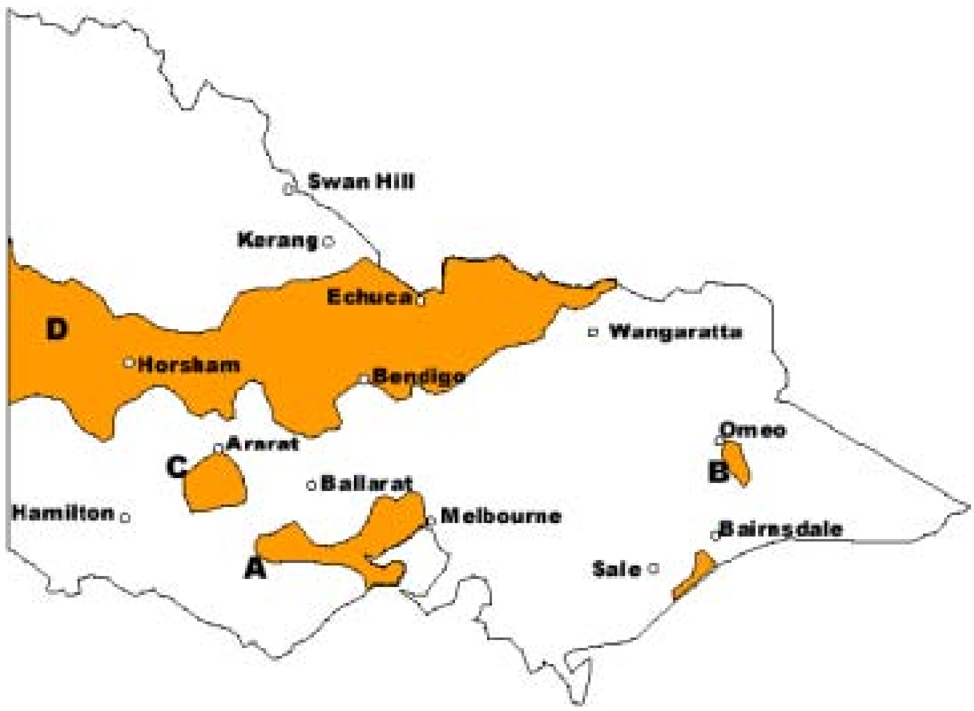
A large part of the Tasmanian low rainfall zone is the Midlands, situated east of the Central Plateau, traversed by the Midland Highway, extending south from Campbell Town to Oatlands, west to Bothwell and to the area to the north east of Hobart (Figure 3). The Tasmanian low rainfall zone is significantly cooler than areas in mainland Australia, with relatively cool summers and cold winters (see Table 1). This area has traditionally been used for grazing of sheep, and contains significant areas of cleared, privately owned land.

Figure 3. 400-600 mm annual rainfall zone (30 year average) for Tasmania
Source data: Bureau of Meteorology

4.4. Victoria

In the Central Highlands of Victoria, Bush et al. (1998) identified around 140 000 ha of potentially available land that would be suited to ALRTIG species in the low rainfall zone (zone A in Figure 4). Similarly, Tickle (2000) identified around 150 000 ha in Gippsland (Zone B in Figure 4).

Figure 4. 400-600 mm annual rainfall zone (30 year average) for Victoria
Source data: Bureau of Meteorology



However, the main 400-600 mm rainfall areas in Victoria (Zones C and D in Figure 4) have had no broad-scale plantation potential studies conducted within them. These zones are likely to provide a large source of land potentially available for low rainfall species plantations. The Victorian and Commonwealth Governments are actively promoting afforestation in this area through programs such as *Greening the Wimmera*, the *Glenelg Farm Forestry Program* and the *DPIE Small Scale Farm Forestry Project* (Hajek 1999).

4.5. Western Australia

The south-west of WA is a very large agricultural zone, totalling over 25 million ha (Bartle et al. 1999). Approximately 82% of this is privately owned, and 72% is cleared (under agriculture). Main industries are winter-growing annuals, cereal and pulse crops in rotation with sub-clover pastures (Bartle et al. 1999). A substantial part of the Western Australian wheat belt falls within the southern 400-600 mm rainfall zone (Figure 5). According to the Western Australian Salinity Action Plan (1998), the south-western agricultural zone already has 1.8 million ha of salt affected land, a figure projected to rise to 6 million ha if no remedial action is taken (Bartle 1999). The Western Australia Government is taking steps to correct regional water balance by a number of means.

Figure 5. 400-600 mm annual rainfall zone (30 year average) for Western Australia.
Source data: Bureau of Meteorology

One critical part of the plan is to plant significant areas (an estimated 3 million ha) of deep-rooted perennial crops. The Government aims to establish 150 000 ha of maritime pine plantations in the region, to create an industry base which may eventually draw on a plantation estate as large as 500 000 ha (Butcher & Hopkins 1999). There is also a substantial amount of land suited to short-rotation oil mallee species. The oil mallees are particularly well suited to the lower rainfall sites, possibly well below 400 mm/ annum (Bartle 1999).

5. Criteria for Species Selection for the ALRTIG Program

The species selections were made on the basis of the following criteria:

- Drought hardiness
- Tolerance of other environmental stresses such as salinity, alkalinity, and frost
- Ability to produce valuable forest products within the southern low rainfall zone
- Suitability for plantations across a substantial area within the southern low rainfall zone
- Complementarity with other species selected: the species together provide options for planting across a range of common site types within the zone
- Availability of information and access to the genetic resources required to rapidly generate improved germplasm

Other factors considered include:
- Status of existing improvement programs for species under consideration
- Size and scale of improvement program required
- Resources available to ALRTIG
- Known difficulties with plantation establishment and/or tree breeding for species under consideration

6. Potential Species List

A list of species for consideration (Appendix 1) was assembled using a variety of reference sources. Papers in the proceedings of the Low Rainfall Tree Improvement Workshop were used as a starting point; they give an up-to date summary of low rainfall tree improvement research in the southern States. Some papers (eg Bulman & Fairlamb 1999) give a comprehensive list of species suited to very low (sub 400 mm); low (400-650 mm) and high (600 mm plus) rainfall zones, with notes on survival, potential and productivity. This paper also identifies and characterises the physical aspects of target planting zones in SA. Similarly for SW Victoria, Bird et al. (1996) give a comprehensive description of land zones and list species appropriate to particular land units within each zone. Bird et al. also provide a table giving key parameters for each species, such as tolerance of salinity, alkalinity, frost etc.

For softwood species, Spencer (1999) and Boomsma (1999) give a comprehensive list of species suited to low rainfall areas. Butcher & Hopkins (1999) give an account of the improvement program and applicability of maritime pine to low rainfall sites in Australia and abroad.

Bartle et al. (1999) give an overview of mallee eucalypt species suited to Western Australia. The success of blue mallee as a low rainfall plantation species in Victoria and NSW is documented in James (1991).

7. Short-List of ALRTIG 'Key Species'

The species listed in Appendix 1 were carefully considered in terms of the criteria given in Section 5. It was relatively easy to form a short-list, due to the lack of information and/or biological resources available for many of the species. However, much consideration was given to the number of species required for the ALRTIG program, and the final choice of species. The key species were also considered in terms of their relative importance within the program. This is discussed further in later sections.

The adaptability of the selected key species to a range of environmental factors within the southern Australian low rainfall zone is indicated in Table 2. The species range covers the majority of site and climatic types likely to be targeted for farm forestry in the southern Australian low rainfall zone. Included are species suited to 'difficult' environments, such as waterlogged, saline and alkaline sites; droughty sites where moisture availability is low for protracted periods and; species capable of relatively high productivity, suited to sites where moisture and soils are relatively good.

Growth rates for the selected key species are lower (Table 3) than those expected from Australian high rainfall (>700 mm/year) plantations, which are typically capable of producing volume mean annual increments in the range 12-25 m^3/ha/year. This is to be expected, as water is a basic input requirement for rapid growth, and the physiological mechanisms that allow the more hardy species to survive in dry soil conditions by limiting transpiration preclude very high growth rates. Nevertheless, all of the selected key species have been grown successfully in plantation situations overseas.

One apparent exception to the trend towards low growth rates, is the red gum – flooded gum hybrid growing in southern Africa. However, the site from which the data were collected had quite high summer rainfall, and may not be representative. Early growth data (to three years) from trials in South Australia show that red gum hybrids grow rapidly, though it is too early to predict long-term MAI.

Table 2. Summary of environmental adaptability of ALRTIG key species

Environmental parameters	Swamp yate	Sugar gum	Red ironbark	Spotted gum	River red gum	River red –flooded gum hybrid	Maritime pine	Brutian pine	Oil mallee	Blue mallee
Annual rainfall[a]										
Where pan evaporation < 1500 mm/yr	350+	350+	400+	500+	400+	500+	400+	350+	350+	350+
Where pan evaporation > 1500 mm/yr	450+	450+	500+	600+	500+	600+	500+	400+	350+	350+
Other environmental factors [b]										
Frost	✓✓✓	✓✓	✓✓✓	✓	✓✓✓	✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓
Insect attack	✓✓	✓✓	✓✓	✓✓	✓	✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓
Cracking clay	✓✓✓	✓✓	✓✓	✖	✓✓	✓✓	✖	✓✓✓	✓	✓
Salinity EC_e dS m^{-1} [c]	0-10	0-5	0-5	0-5	0-8	0-5	?	?	?	?
Soil sodicity	✓✓✓	✓✓✓	✓	✓	✓✓	✓✓	?	?	?	?
Waterlogging	✓✓✓	✖	✖	✖	✓✓✓	✓✓	✖	✖	✓	✓
Alkalinity (pH >7.5)	✓✓✓	✓✓✓	✓	✓	✓✓	✓✓	✓✓	✓✓✓	✓	✓
Shallow soils	✓✓	✓✓	✓✓✓	✓✓	✓	✓	✓✓	✓✓✓	✓✓	✓✓

[a] Mean annual rainfall required for satisfactory growth
[b] Key: ✖ Unsuited ✓ Moderate ✓✓ Good ✓✓✓ Outstanding ? Unknown
[c] Salinity EC_e dS m^{-1} above which growth is reduced

Table 3. Indicative growth rates for ALRTIG key species

Species	MAI (m^3/ha/yr)[a]	Stand location	Notes	Reference
Swamp yate	1.5 - 6 @ 12-15 years	Calabria, Italy	From large plantations, range 560-1030 mm rainfall annum. Planted 600-900 sph[b]	Ciancio & Hermanin (1976)
Sugar gum	7.1 & 17.8 @ 6 years	Rhodesia, High Syringa and Hippo Valley	Rainfall at H.S. 530 mm/year; at H.V 356-432 mm/year. Stocking at H.S. 1537 sph; H.V. 976 sph	Poynton (1979)
Red ironbark	5-7 @ circa 30 years	Mamora (near Rabat), Morocco	Rainfall at Rabat is circa 500 mm/ year. Stocking 300-1000 sph	Knockaert (1984)
Spotted gum	1.6 - 3.2 @ 13 years	SW of Darkan, WA	Rainfall mean 680 mm/ year	Mazanec (1999b)
River red gum	(a) 2.5 – 11 @ 16 years (b) 3.3 @ 9 years	(a) Mamora (near Rabat), Morocco (b) sw WA	Rainfall at Rabat is circa 500 mm/ year. Stocking 800 sph Rainfall in sw WA is 700 mm. Mildly saline site.	(a) FAO (1981) (b) Mazanec (1999)
Red gum hybrids	16.8 @ 6 years	Ixopo, KwaZulu-Natal	Rainfall circa 800 mm/year. *E. grandis* x camaldulensis hybrids	Darrow (1995)
Maritime pine	6.8 @11 years	Gnangara, WA	Rainfall 810 mm/year	Butcher & Hopkins (1993)
Brutian pine	(a) 1.0 - 7.5 @ 10 years (b) 7 @ 24 years (c) 3.9-5.9 @ 70 years	(a) 3 sites in Israel (b) Lower Galilee, Israel (c) Turkey	a) Rainfall 440-560 mm/ year (b) 530 mm/ year. Stocking reduced 1800 → 150 sph (c) From a range of sites in Turkey	(a) Weinstein (1988) (b) Heth & Spetter (1993) (c) Allegri (1973)

[a] MAI is assumed to be stem volume MAI
[b] Stems per hectare

While it is expected that ALRTIG's tree breeding programs will be able to significantly improve growth rates of species such as *P. brutia* and *E. occidentalis*, it must be accepted that growth rates will still be relatively low. This implies that longer rotations will be needed; *P. brutia* is grown on a rotation of between 35 and 110 years in the eastern Mediterranean (Allegri 1973).

A more detailed account of each key species is given in the following sections.

7.1. Hardwoods

7.1.1. Sugar gum - *Eucalyptus cladocalyx*

Sugar gum is suited to a large proportion of the 400–600+ mm zones of southern Australia, in soils that are relatively well drained and have adequate soil moisture holding capacity. The species was selected because of its hardiness and tolerance of a wide range of conditions, and would be suited to well structured, freely draining soils throughout the southern low rainfall zone. The species' moderate frost resistant enables use in all bar severely frost prone areas. *Eucalyptus cladocalyx* displays moderate tolerance of salinity. It will tolerate salinities up to around 5 dS m^{-1} EC_e without reduction in growth. Salinities over 10 dS m^{-1} EC_e are injurious to the species (Marcar et al. 1995).

A further reason for selection of this species is the relatively good plantation resources, provenance information from planted trials across a range of sites, and demonstrated usefulness of the species within the target planting zone. Some 1000 ha is planted in the region around Colac, Western Victoria, most of this having been established as windbreaks by direct seeding in the late 19th and early 20th centuries. These farm plantings are providing the resource for a developing firewood industry and some small-scale milling operations. Substantial areas of plantations also exist near Majorca and the You Yangs, around Wail, western Victoria and South Australia. There are large areas of plantations near Wanilla on Eyre Peninsula, in the Adelaide Hills and near Wirrabara. Extensive smaller scale rural plantings in SA are largely a legacy of a 'free-tree scheme' in the late 19^{th} century.

There is currently strong demand for seed of *E. cladocalyx*, but much of this is being used for direct seeding of windbreak plantings. This application does not require highly improved seed, and its practitioners cannot afford to pay premium prices. The current annual production of *E. cladocalyx* seedlings by nurseries across southern Australia is estimated to be around 300 000 plants, sufficient for about 300 ha of plantations. This planting rate would require about 5 kg of seed annually.

7.1.2. Swamp yate - *Eucalyptus occidentalis*

Swamp yate grows especially well on waterlogged and heavy soils, and in salinity-affected or threatened country, of which substantial areas occur in the southern low rainfall zone. It is typically planted in lower parts of the landscape on heavy soils, and will tolerate salinities up to around 10 dS m^{-1} EC_e without reduction in growth. Salinity over 15 dS m^{-1} EC_e is injurious to the species (Marcar et al. 1995). The species is also very drought tolerant, and would be suited to sites receiving upwards of 350 mm winter/uniform rainfall. Because of its good salinity tolerance, it may find application in discharge zones where rainfall exceeds 600 mm. Growth rates are moderate, but stem form of most provenances is poor. However, clear provenance differences in stem form suggest that this trait is under genetic control, so the prospect of breeding for improved stem straightness and reduced forking together with the species' inherent hardiness make it an important species in the ALRTIG program.

While swamp yate timber has not commonly been utilised in Australia, it is known to be of high density. It is likely to be a useful timber for heavy construction, of at least moderate durability. Its sawing properties are being investigated at present. It is also known to produce a useful pulp. It has been used for this purpose overseas.

7.1.3. Red ironbark - *Eucalyptus sideroxylon* and *E. tricarpa*

E. tricarpa, a species native to central and coastal Victoria, and south coastal NSW, has been extensively harvested from natural stands within this range. It has been tested in many arid zones of the world as part of species introduction trials, notably in Israel, and Chile, where it is considered a candidate for afforestation in 200-400 mm zones.

Its wood is hard, durable and has long been used as posts, poles, and for heavy construction. Its use in finer construction such as furniture and craft wood is well known from the cottage industry. The ability of 15 to 40-year-old plantation trees of the closely related *E. sideroxylon* was found to be satisfactory, with outputs of quality product found to be improved by quality sawing and drying practices (Washusen et al. 1998). This study also indicated that the proportion of highest grade timber would possibly be readily increased by early form pruning. The timber of *E. tricarpa* is expected to be very similar in quality.

Eucalyptus tricarpa has been planted widely as a farm forestry species, but not yet on a large scale, in drier parts of southern Australia. It grows well on siltstone-derived soils of drier hills, and is not suited to areas subject to seasonal waterlogging or salinity. It often performs very well on sites better than usual for the natural stands, and may be useful for planting in areas where more demanding eucalypts have failed. This could include sites where *E. globulus* has proven to be insufficiently hardy to survive periodic droughts.

Within Victoria there are extensive possibilities in the 500 to 800 mm per annum rainfall zone, on mudstone bedrock/sedimentary undulating terrain, in both inland and coastal districts. There is a possibility of use in country where species such as *E. globulus* have been tested for groundwater control, such as break of slope country in north-east Victoria. Perhaps the greatest potential lies on the inland slopes of the Campaspe, Loddon and Avoca river headwaters, where former ironbark country was cleared for light pasture. Note that in the former natural distribution of *E. tricarpa*, deployment of exotic provenances might be considered inappropriate due to concerns about pollution of remnant natural genetic resources.

In South Australia and Western Australia, there is a substantial area of land that might be appropriate to grow the species. *E. tricarpa* is of great interest for the drier areas with less than 650 mm annual rainfall. In WA, it requires good, relatively deep soil and does not perform well when planted in periodically waterlogged soils. For this reason the species might be planted upslope in a complementary arrangement with river red gum or swamp yate in the low-lying areas.

7.1.4. River red gum - *Eucalyptus camaldulensis*

River red gum is a versatile species that is frequently planted in amenity/conservation plantings. It is tolerant of waterlogging and moderate salinity, and is often planted in lower parts of the landscape. In this regard it is similar to swamp yate. However, plantations in Australia often suffer heavy defoliation from insects, and this together with its generally poor stem form precludes the use of *E. camaldulensis* for widespread plantation establishment in the southern low rainfall zone.

The main use of *E. camaldulensis* in Australian low rainfall forestry may be as a parent species for the production of interspecific hybrids. This is the primary reason for selection of river red gum in the ALRTIG program. Hybrids between *E. camaldulensis* and *E. grandis* have been used extensively in South Africa and Brazil, in climatic zones too dry for pure *E. grandis*. These hybrids generally have better survival on marginal sites than *E. grandis*, and better growth rate, form and pulp properties than *E. camaldulensis* (Arnold & Vercoe 1999). Interspecific hybrid combinations between *E. camaldulensis* and other species such as *E. globulus* and *E. saligna* also show promise. ALRTIG partners are presently assessing a variety of river red gum hybrids in field trials.

Sites that are likely to be suitable for river red gum hybrids include those receiving 500 mm + rainfall per year. The hybrids are likely to be less drought hardy than red ironbark, swamp yate and sugar gum, but will grow faster than these species. They are also likely to be much more tolerant of frost and waterlogging than sugar gum and spotted gum. They may be ideally suited to sites marginal for *E. globulus* on the edge of the 600 mm rainfall isohyet.

River red gum is considered to be a species of secondary importance in the ALRTIG program. Activity will be limited to exchange of superior clones and a single new provenance-progeny trial of the known best provenances, to be used as a resource for future breeding work.

7.1.5. Spotted gums - *Corymbia maculata; C. variegata*

Spotted gum was selected for the ALRTIG program because of its widely demonstrated growth, form and sawn timber properties in many low rainfall farm forestry plantations in southern Australia.

Relative to the other ALRTIG key hardwood species, spotted gum has the advantage of producing trees of superior stem form, even in open grown situations or at low stocking densities. Its timber properties are excellent, and it is among the best Australian hardwoods in terms of sawn timber recovery. Its growth rates are very good on appropriate sites receiving greater than 500-600 mm annual rainfall. However, it is the least hardy of the key species, and is not suited to waterlogged, saline or very dry sites. It is also frost sensitive, though this trait is under genetic control and frost hardiness could be improved by breeding. Spotted gums occur naturally in areas of eastern Australia receiving highly variable rainfall, and can tolerate prolonged drought by the adaptive mechanism of leaf-shedding of up to 90% of the canopy, followed by rapid resprouting from epicormic buds on the branches once the drought ends (Pook 1985).

Consideration of the limiting factors of drought, salinity, waterlogging and frost, supported by practical experience, suggests that spotted gum plantations in western Victoria are best restricted to mid and upper hill slopes receiving over 500 mm mean annual rainfall, with free air drainage. Valley-bottom, frost-prone sites, which are also more likely to have salinity and waterlogging problems, should be avoided (R Bird, pers. comm. 2000). CSIRO's irrigated provenance-progeny trials planted on three non-saline, level sites around Deniliquin, SW NSW, receive annual rainfall of around 500 mm and 300-400 mm supplementary irrigation water. Frost damage has not been a serious problem in these plantings. Much better growth (twice the height growth, at age three years) has been obtained on red loamy earths than on heavy grey-brown clays. Because the ALRTIG target zone spans the lower limits of the acceptable rainfall for the species, it will be prudent to restrict plantings to soils which allow unimpeded root access to a soil profile at least 2 m deep, enabling substantial 'buffering' during drought years by stored soil water.

Within ALRTIG's zone of responsibility, the two spotted gum species may be suited to different geographic regions. Evidence to hand (Mazanec 1999) suggests that *C. maculata* is the preferred species for SW WA, although *C. maculata* from Casino provenance in northern NSW may also be useful. In western Victoria and inland southern NSW, *C. maculata* also outperforms *C. variegata* (CSIRO unpublished; Tibbitts 1999; Bird et al. 2000). However, on the basis of the two species' natural distributions, *C. variegata* might well outperform *C. maculata* in northern NSW on dry sites west of the Great Dividing Range, at latitudes where the former species replaces the latter in natural forests to the east of the ALRTIG target zone.

7.2. Softwoods

7.2.1. Brutian pine - *Pinus brutia*

Pinus brutia is an extremely hardy species, originating from the eastern Mediterranean. It is closely related to *P. eldarica* (which is sometimes considered as a sub-species) and *P. halepensis* (Aleppo pine). The species was selected for genetic improvement under the ALRTIG program because of its extreme hardiness and good form in select provenances. Australian Aleppo pine introductions have demonstrated very poor form, and for this reason they have not been included in the ALRTIG program. *Pinus brutia* is suited to sites receiving as little as 350 mm mean annual rainfall. While it grows more slowly than *P. pinaster*, it can tolerate shallow, heavy clay and highly alkaline soils. It complements *P. pinaster*, being suitable for planting at the lower end of the rainfall spectrum, and on shallow soils. Pests and diseases have not been a problem for *P. brutia* in Australia.

7.2.2. Maritime pine - *Pinus pinaster*

Maritime pine is a hardy conifer of Mediterranean origin. CALM WA has managed a long-term tree breeding program for this species in WA, where it is planted in significant areas. CALM WA aim to use this species extensively in the 400-600 mm rainfall zone, to help control salinity problems on agricultural land (though not on land already salt-affected), and to diversify farm income. It produces a useful sawn timber, which can be processed in sawmills designed for *P. radiata*, and its wood can also be used for pulp. Because of its demonstrated usefulness and high degree of genetic improvement, ALRTIG selected the species for testing throughout southern Australia. While it has been planted to a limited extent in the eastern States (especially SA on low nutrition sites, otherwise suited to *P. radiata*), detailed information on the performance of CALM's improved breeds throughout much of the low rainfall zone is lacking.

7.3. Short Rotation Woody Crops

Short-rotation woody crops may be a particularly attractive farm forestry option where mean annual rainfalls are around 400 mm or lower, and replanting of perennial vegetation is needed to control rising water tables. In Western Australia, a suite of mallee eucalypts has been successfully tested in field trials for the production of biomass and leaf oils. Species tested include: *E. angustissima, E. horistes, E. kochii ssp. kochii, E. kochii ssp. plenissima, E. loxophleba ssp. lissophloia* and *E. polybractea.*

Results obtained by CALM WA indicate that all these species produce high concentrations of the desirable cineole oil fraction, and that the different species prefer different habitats. However, with the exception of *E. polybractea*, which is established as a commercial crop in part of its natural range at West Wyalong, NSW, the species have not been extensively trialled except in WA. ALRTIG has selected *E. polybractea* and *E. horistes* for a series of trials throughout the southern States. The objective of these trials is to determine the degree of genotype-by-environment interaction at the species and family level, which will help breeders decide whether material that is genetically improved by CALM WA and ANU/GR David Pty Ltd (of West Wyalong, NSW) by can be deployed with good results in the eastern States.

8. Overview of Tree Improvement Strategies

ALRTIG has developed genetic improvement strategies for five hardwood species and one softwood species. In addition, oil mallee species intended for short rotation oil production and already improved maritime pine are being tested on a range of sites throughout southern Australia's low rainfall zone. This section explains the rationale for site selection for the ALRTIG program, and the approach to tree improvement that is being taken for each species.

8.1 Hardwoods

The ALRTIG Hardwoods Technical Committee has developed genetic improvement strategies for five species groups, namely *Eucalyptus camaldulensis* (river red gum), *E. cladocalyx* (sugar gum), *E. occidentalis* (swamp yate), *E. tricarpa/sideroxylon* (red ironbarks) and *Corymbia maculata/variegata* (spotted gums). Strategies for each of these species groups are set out in individual documents. This paper provides a brief overview of the decisions that have been made, and why different strategies have been developed for the different species, affecting the number and types of breeding trials and seed orchards that will be established.

The quality of planting stock that could be produced by the ALRTIG improvement programs can be ranked in terms of increasing levels of genetic improvement (Table 4). The rankings are based on general arguments and calculations of the type developed by Shelbourne (1992).

Table 4. Ranking of different categories of genetic materials that could be produced by ALRTIG in the first generation of improvement

	Category of material	Ranking	Comments
1.	Seed collected from phenotypically superior trees in best natural	Baseline standard for ALRTIG	For some species, large gains over use of inferior provenances

	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 *E. cladocalyx,* 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 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

Some of the options shown in Table 4 may not be available for some of the species. For example, spotted gums are very difficult to propagate by stem cuttings so the option of clonal forestry is ruled out. ALRTIG will assess the cutting propagation of red ironbarks, sugar gum and swamp yate during year 2000. Grafted clonal seed orchards have been successfully developed for spotted gums and *E. camaldulensis*, but not yet for the other ALRTIG species, although no problems are envisaged.

Some of the partner agencies will not be able to devote the staff and resources to develop activities 5 to 8 for the ALRTIG hardwood species (clonal seed orchards, controlled pollination to produce control-crossed families, and development of tested clones for clonal forestry). CALM and CSIRO have a well-developed capacity and facilities to undertake this work, so the ALRTIG program incorporates work on categories 5-8 by these agencies. Other agencies would be able to participate in these activities should they so wish. The distribution of germplasm production facilities is given in Table 5.

Table 5. Distribution of hardwood breeding trials and seed orchards among project partners

Species	VIC	SA	NSW	WA	CSIRO
E. occidentalis	1 PT-SSO[a]	1 PT-SSO	1 PT-SSO	1 PT-CSO[b]	Clone bank-CSO[c]
E. cladocalyx	1 PT-SSO	1 PT-SSO	1 PT-SSO	1 PT-CSO	-
E. camaldulensis	-	-	-	1 PT-CSO	Clone bank[d]
C. maculata	1 PT-SSO	-	-	1 PT-CSO	Clone bank-CSO

C. variegata	-	-	1 PT-SSO	-	-
E. sideroxylon	-	-	1 PT-SSO	-	-
E. tricarpa	1 PT-SSO	-	1 PT-SSO	1 PT-CSO	-

[a]PT-SSO = provenance-family trial aggressively developed into seedling seed orchard by heavy, early selective thinning, yielding large quantities of somewhat-improved seed within 6-8 years.

[b]PT-CSO = provenance-family trial with mild thinning, which will produce small quantities of seed but will provide higher-quality information on the performance of provenances, families and individual trees, and from which outstanding trees selected from age 8 years or so onwards could be grafted into a clonal seed orchard to give highly improved seed.

[c]Clone bank-CSO = clone bank of selections from already-established trials, developed into grafted clonal seed orchard.

[d]Clone bank = clone bank of grafts of outstanding individual trees from already-established trials accessible to ALRTIG. Controlled pollination within the clone bank could produce elite pure-species and interspecific hybrid progenies.

The SSO route involves heavy, early thinning of a provenance-progeny trial. It will rapidly (within 6-8 years) deliver large quantities of improved seed, when SSOs are developed from a broad and appropriate base (many families from known best provenances) on sites both representative of target planting environments and conducive to early, heavy flowering. This situation clearly applies to *E. cladocalyx* in parts of western Victoria and SE South Australia where the Wirrabara provenance has been successfully grown in plantations for over 100 years and produces good seed crops. The amount and quality of genetic information provided from the SSO is only modest, because the heavy selective thinning variably affects competition between trees and hence their relative performance. SSOs are also expensive to maintain because opening the stand results in vigorous weed growth, which must be controlled.

In a regional environment where a species is less well-tested, provenance rankings are more uncertain, and there is not an urgent demand for large quantities of seed, the option of maintaining progeny trial with only light thinning for at least 8-10 years, and then grafting out the best individuals into a CSO, is considered appropriate. This applies, for example, to *E. cladocalyx* in Western Australia.

In practice, the PT-SSO and unthinned PT-CSO routes to improved seed production can be thought of as the two extremes of the way in which any ALRTIG provenance-progeny trial could be managed, with management adjusted according to circumstances. For example, if interim seed production areas produced high quality seed that successfully met the demand for improved *E. cladocalyx* seed over the period 2001-2006, the first thinning of ALRTIG *E. cladocalyx* SSOs could be delayed at least until 2006 so as to improve the quality of genetic information obtained and make more accurate selections for the next generation of the breeding population and for grafting into CSOs. The quantity of seed produced by the SSOs, would, however be reduced, and the onset of seed production delayed.

8.2. Softwoods

The ALRTIG Softwoods Technical Committee has developed tree improvement programs for two softwood species, *P. pinaster* and *P. brutia*. Genetically improved *P. pinaster* material produced by CALM WA will be deployed to ten sites throughout southern Australia. *P. brutia* selections will be grafted to rootstocks and established in three clonal seed orchards (Table 6).

Table 6. Distribution of softwoods trial sites and CSOs among project partners

Species	Tasmania	Victoria	SA	NSW	WA	CSIRO
P. pinaster	2 trial sites	2 trial sites	2 trial sites	2 trial sites	2 trial sites	-
P. brutia	-	-	1 CSO	1 CSO	1CSO	-

The *P. pinaster* sites were selected to represent potential plantation catchment areas within each State. Full details of site selection and the ALRTIG *P. pinaster* program are given in Butcher (In Press).

The three Brutian pine sites will be selected on the basis of good chance of flowering and cone set. For this reason they will probably be sited in a maritime climate, as this has been shown to increase flowering. Full details of the *P. brutia* program and site selections are given in Spencer & Boardman (In Press).

8.3. Short Rotation Woody Crops

The ALRTIG Short Rotation Woody Crops Technical Committee originally developed plans to tests clonal selections of two species, *E. horistes* and *E. polybractea* at five sites throughout southern Australia. However, this plan has been postponed due to difficulties in propagating rooted cuttings of some selections. An alternative plan will now be pursued, involving a series of tests of seedling families of *E. polybractea* and *E. horistes* in the southern States. Seed for the trials will be sourced from CALM WA's existing resources and the Australian National University/GR. Davis *E. polybractea* seed orchard at West Wyalong, NSW.

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Appendix 1. List of candidate species for ALRTIG program

Species	Common name	Study	Growth rate	Product	Comment	Class
Hardwoods						
Acacia mearnsii	late black wattle	5,9,10	High		Short, insect-prone life in 400-600 mm zone	SS
A. dealbata	silver wattle	9	High		Commercial stems only in 900 mm plus rainfall zone	US
A. falciformis	hickory wattle	9	Unknown			
A. melanoxylon	blackwood	9	Medium	ST	Good soil, high rainfall and shelter for good form	US
Allocasuarina luehmannii	bull-oak	9	Low	ST	Very attractive appearance timber, v. slow growth	SS
A. verticillata	drooping she-oak	9,10	Medium		Poor form common	
Casuarina cunninghamiana	river she-oak	2,5,9	Medium	ST	Waterlogged or riverine soils	US
C. glauca	grey she-oak	4,5,9	Medium	ST	Suited to waterlogged and alkaline sites	
C. obesa	swamp she-oak	4	Medium	ST	Suited to waterlogged and alkaline sites	
Corymbia maculata	spotted gum	1,2,5,6,9,10	med. High	ST	Excellent form, frost sensitive	VS
C. variegata	spotted gum	1,2,5,6	med. High	ST	Excellent form, frost sensitive	VS
C. henryi	spotted gum	1,2	med. High	ST	Excellent form, frost sensitive	VS
C. citriodora	lemon scented gum	6	med. High	ST,O	Prefers northern sites, higher rainfall	SS
E. astringens	brown mallet	2,9	Low		Slow growth a problem, good drought tolerance	S
E. baxteri	brown stringybark	9	Medium		Suited to sandy coastal soils	SS
E. benthamii	Camden white gum	1,10	med-High	ST	Requires higher rainfall	US
E. botryoides	southern mahogany	5,6,9	med-High	ST	Requires higher rainfall	
E. bosistoana	Gippsland grey box	9	Medium	ST	Maybe quite site specific; lack of available information	S
E. brookerana		5			Requires higher rainfall	US
E. camaldulensis	river red gum	2,4,5,9,10	Medium	ST,O	Good salt and waterlog tolerance. Good hybrid parent	VS
E. cladocalyx	sugar gum	2,5,6,9,10	Medium	ST	Good form & drought tolerance; some frost sensitivity	VS
E. cornuta	yate	9	Medium		Tough, grows well but form a problem	
E. cypellocarpa	mountain grey gum	9	Med.-High	ST	Requires higher rainfall. Timber defect common problem	SS

Key to Class codes: US= Unsuitable; SS= Somewhat suitable; S= Suitable; VS= Very Suitable. Study reference key at end of table.

Species	Common name	Study	Growth rate	Product	Comment	Class
E. dunnii	Dunn's white gum	6	High-v. high		Probably better suited to northern regions	SS
E. fastigata	brown barrel	9	High	ST	Requires higher rainfall for good growth	US
E. globulus subsp globulus	Tasmanian blue gum	4,5,6,9,10	V. high	ST,O	Better suited to higher (600+mm) rainfall	US
E. globulus subsp bicostata	southern blue gum	2,4,6,9	V. high	ST	Better suited to higher (600+mm) rainfall	US
E. gomphocephala	tuart	9	High		Good drought tolerance	SS
E. grandis	flooded gum	2,4,5,6,9	V. high	ST,P	Exc. Form. Prefers higher rainfall. Hybrid more hardy w/ good form	VS
E. largiflorens	black box	2	Low		Poor form, poor commercial prospects	SS
E. leucoxylon/leucoxylon	SA bluegum/ yellow gum	2,9,10	Med.-high		Good form & drought tolerance; best subspecies	S
E. leucoxylon/megalocarpa	red flowering yellow gum	2	Medium		Inferior to subsp. *leucoxylon*	SS
E. leucoxylon/pauperita	SA bluegum/ yellow gum	2	Low-medium		Inferior to subsp. *leucoxylon*	SS
E. leucoxylon/pruinosa	SA bluegum/ yellow gum	2	Low-medium		Inferior to subsp. *leucoxylon*	SS
E. macrorhyncha	red stringybark	6,9	Medium		Prefers dry, well drained soils	SS
E. melliodora	yellow box	9	Medium	F	Form is fair only; can be good on light soils	SS
E. microcarpa	grey box	9	Medium		Suited to intermediate flats, 500-700 mm rainfall	SS
E. muelleriana	yellow stringybark	9	Med.-high		Requires higher rainfall	US
E. nitens	shining gum	9	V. high	P	Drought tolerance fair at best. Needs good water availability	US
E. obliqua	messmate stringybark	9	High	ST	Needs good water availability. Suited to higher rainfall	SS
E. occidentalis	swamp yate	2,5,9,10	Med.-high	ST,P	Tolerates drought, salt and waterlogging. Form varies w/ provenance	VS
E. ovata	swamp gum	2,9	Medium		Requires plenty of non-saline water	US
E. paniculata	grey ironbark	9	Medium	ST	Good heavy timber, suited to higher rainfall	SS
E. polyanthemos	red box	9	Medium			
E. porosa	black mallee box	2	Medium			
E. punctata	grey gum	2	Medium			
E. saligna	Sydney blue gum	2,4,6,9	High	ST	Good form, growth rate and reasonable hardiness	S
E. sideroxylon subsp. sideroxylon	red ironbark	2,5,6,9,10	Medium		Performs well on loam/ sands and sedimentary derived soils	VS
E. sideroxylon subsp. tricarpa	red ironbark	2,5,6,9,10	Medium		Performs well on loam/ sands and sedimentary derived soils	VS
E. tereticornis	forest red gum	2,9	High		Northern close relative of *E. camal.*, which is probably better	SS
E. viminalis	manna gum	2,4,5,9	High	ST	Poor form in low rainfall provenances	SS

Key to Class codes: US= Unsuitable; SS= Somewhat suitable; S= Suitable; VS= Very Suitable. Study reference key at end of table.

Species	Common name	Study	Growth rate	Product	Comment	Class
Grevillea robusta	silky oak	2	Low	ST	Better suited to northern areas	US
Melaleuca uncinata	broom honey-myrtle	2	Medium			
Melia azaderach	white cedar	2	Low			
Paulownia tomentosa	royal paulownia	2	High	ST	Prefers much higher rainfall/ very good water availability	US
Populus alba	white poplar	12	High	ST	Needs reasonable water availability, tolerates flooding	SS
P. euphratica	Euphrates poplar	12	Medium	ST	Good salinity tolerance, tolerates flooding	SS
Quercus ilex	oak	12	Low	ST	Poor apical dominance and stem form	SS
Q. suber	cork oak	12	Low	Cork	Bark is stripped for production of cork	SS
Robinia pseudoacacia	black locust	2	Medium		Used for fodder, soil nitrification	SS
Softwoods						
Abies grandis	grand fir	8	Low	ST	Low rainfall provenances exist, but not extensively tested	SS
Callitris glaucophylla	white cypress pine	3,9	Low	ST	Excellent timber properties; very drought tolerant	SS
C. preissii	Murray pine	9	Low	ST	Excellent timber properties; very drought tolerant	SS
C. gracilis		10	Low	ST	Excellent timber properties; very drought tolerant	SS
Cupressus arizonica	Arizona cypress	3			Very hardy, form good, limited testing in Australia	SS
C. atlantica	Atlas cypress	3			Likely very drought tolerant. Little information	SS
C. dupreziana	Saharan cypress	3	Low		Likely very drought tolerant. Little information	SS
C. libani	Lebanese cedar	3			Likely very drought tolerant. Little information	SS
C. lusitanica	Mexican cypress	2,4	Medium	ST	Sap problems in low rainfall; better than *C. macrocarpa*	S
C. macrocarpa	Monterey cypress	2,4	Medium	ST	Sap problems in low rainfall; good sawn timber properties	S
Larix occidentalis	western larch	8			Low rainfall provenances exist, but not extensively tested	SS

Key to Class codes: US= Unsuitable; SS= Somewhat suitable; S= Suitable; VS= Very Suitable. Study reference key at end of table.

Species	Common name	Study	Growth rate	Product	Comment	Class
Pinus albicaulis	whitebark pine	8			Low rainfall provenances exist. Largely untested	SS
P. attenuata	knobcone pine	8			Low rainfall/ cold tolerant hybrid when crossed with *P. radiata*	SS
P. arizonica	Arizona cypress	8			Mexican low rainfall sp. Largely untested	SS
P. brutia	Brutian pine	3	Medium	ST	alkaline soil tolerant, very plastic. Good drought, cold tolerance, form.	VS
P. canariensis	Canary Island pine	3	Low-med.	ST	fire resistant, generally good form	S
P. cembroides	Mexican nut pine	3		F	Short tree (7 m) produces edible nuts	SS
P. contorta	lodgepole pine	8			Tree improvement program in USA. Largely untested in Australia	SS
P. coulteri	Coulter pine	8			Low rainfall provenances exist. Largely untested	SS
P. eldarica	Eldar pine	3	Medium	ST	alkaline soil tolerant, very plastic. Good drought, cold tolerance, form.	VS
P. edulis	pinyon pine	3	Low	F	Tree to 15 m. Produces edible nuts	SS
P. engelmannii	Apache pine	8			Mexican low rainfall sp. Largely untested	SS
P. flexilis	limber pine	8			Low rainfall provenances exist. Largely untested	SS
P. greggii	Gregg pine	8			Interest as radiata hybrid. STBA planning some plantings	S
P. halepensis	Aleppo pine	3,9	Medium		Form of Australian population very poor. Very hardy	SS
P. jeffreyi	Jeffrey pine	8			Related P. ponderosa (hybrids?). Largely untested	SS
P. leiophylla var. chihuahua	Chihuahua pine	8			Mexican low rainfall sp. Largely untested	SS
P. lumholtzii	Lumholtz pine	8			Mexican low rainfall sp. Largely untested	SS
P. monticola	white pine	8			Tree improvement program in USA. Largely untested in Australia	SS
P. pinaster	maritime pine	3,7	High	ST,P	CALM WA has bred and tested extensively; very good all-round	VS
P. pinea	stone pine	3			good drought tolerance and shade	SS
P. ponderosa	ponderosa pine	8			Tree improvement program in USA. Largely untested in Australia	SS
P. radiata	Monterey pine	4,6,9	V. high	ST,P	V. plastic sp; better above 600 mm. Other orgs. breeding for high rainfall applications	S
P. roxburghii	chir pine	3			Generally good form	SS
P. sabiniana	digger pine	8			Low rainfall provenances exist. Largely untested	SS
P. torreyana	Torrey pine	3,8			Low rainfall provenances exist. Largely untested	SS
Pseudotsuga menziesii	Douglas fir	8	Medium		Low rainfall provenances exist. Improved in USA	SS
Short rotation woody crops						

Key to Class codes: US= Unsuitable; SS= Somewhat suitable; S= Suitable; VS= Very Suitable. Study reference key at end of table.

Species	Common name	Study	Growth rate	Product	Comment	Class
E. angustissima		11	V. good oil producer		Commercial plantation and breeding in WA	VS
E. horistes	oil mallee	11	V. good oil producer		Commercial plantation and breeding in WA	VS
E. kochii ssp kochii		11	V. good oil producer		Commercial plantation and breeding in WA	VS
E. kochii ssp plenissima		11	V. good oil producer		Commercial plantation and breeding in WA	VS
E. loxophleba ssp. lissophloia		11	V. good oil producer		Commercial plantation and breeding in WA	VS
E. polybractea	blue mallee	11	V. good oil producer		Commercial plantation and breeding in NSW and WA	VS

Key to Author codes in Appendix I

Code	Reference
1	Arnold & Vercoe (1999)
2	Bulman & Fairlamb (1999)
3	Spencer (1999)
4	Bush (1999)
5	Stackpole & Hamlet (1999)
6	Washusen & Waugh
7	Butcher (1999)
8	Boomsma (1999)
9	Bird et al. (1996b)
10	Hajek (1999)
11	Bartle et al. (1999)
12	Goor & Barney (1976)

Key to Product codes in Appendix I

Code	Product category
ST	Sawn timber
P	Pulp
F	Food

Key to Class codes: US= Unsuitable; SS= Somewhat suitable; S= Suitable; VS= Very Suitable. Study reference key at end of table.

PART 2: *EUCALYPTUS CAMALDULENSIS*

GENETIC IMPROVEMENT STRATEGY IN SOUTHERN AUSTRALIA

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1. Summary

Eucalyptus camaldulensis is one of the eucalypt species selected for a collaborative genetic improvement program by ALRTIG (the Australian Low Rainfall Tree Improvement Group). The species is of some interest for planting in its own right, but generally displays slow growth, poor stem form and susceptibility to attack by a range of insect pests. It is considered to have greater potential as a parent in interspecific hybrid combinations with *E. grandis*, *E. globulus* and other eucalypt species, which would be deployed via tested elite clones.

Superior natural provenances of the species (Lake Albacutya and surrounds, and Laura, SA) displaying rapid growth and above-average stem form, have already been identified from the results of provenance trials in Western Australia, Victoria and southern NSW.

ALRTIG partners have already established a wealth of planted genetic resources of *E. camaldulensis* in many provenance and provenance-progeny trials across dryland southern Australia, although many of these are less than 5 years old. A **comprehensive review of performance data** from existing trials will be conducted to provide information on the best provenances of *E. camaldulensis* for planting in different geographic regions across the ALRTIG target zone, and the extent of genotype-by-environment at the provenance and family level. The review will be completed by December 2000.

It is not considered appropriate for ALRTIG to establish a new series of provenance-progeny trials. **Some of the existing trials will be selectively thinned to convert them to seedling seed orchards**, and CALM has already developed a grafted clonal seed orchard from selections made in its WA provenance trial. Together, these seed orchards should be able to meet the demand for genetically improved *E. camaldulensis* seed within 5 years.

Only **one new ALRTIG provenance-progeny trial will be planted by CALM**, to expand the planted genetic base of the Laura and Lake Albacutya provenances. This trial will incorporate a total of at least 100 families from these known better provenances. The trial will supply data on variation in growth and estimates of genetic parameters, and outstanding individual trees from the trial will be grafted out into clone banks for advanced breeding and exchange among ALRTIG partners.

ALRTIG will **select outstanding individual trees** from a number of their existing trials. Criteria for identifying these selections will be outstanding volume production, single straight stem, and tolerance to pests, diseases and salinity. The selections will be **grafted into clone banks**, and the partners then may **exchange clones** so that individual partners can develop ***E. camaldulensis*** **clonal seed orchards** and/or clone banks for **control-pollinated production of interspecific hybrids** *of E. camaldulensis* as they see fit. Grafting of at least 30 outstanding trees of superior provenances, selected from existing trials, will be undertaken during years 2000 and 2001, and exchange of clones will take place after 2001. Pollen will also be collected from these selections, where feasible, and exchanged between interested partners.

CSIRO will produce, in 2001, a set of *E. grandis* x *E. camaldulensis* hybrid progenies by controlled crossing, using superior *E. camaldulensis* pollens and selected *E. grandis* parents. Seed from these crosses will be shared among interested agencies for planting and evaluation, providing the opportunity to develop outstanding hybrid clones. Actual development of hybrid clones is outside the scope of the ALRTIG program.

2. Background

Eucalyptus camaldulensis is the most widely distributed of all eucalypts. It occurs in temperate climates of southern Australia and in the tropical north and grows in rainfall zones ranging from 150 mm to 1250 mm (Boland et al. 1984). Towards the lower extremes of this rainfall range it is confined to low-lying environments along watercourses where its deep rooting system can access soil water reserves. Because of its adaptation to arid and semi arid environments *E. camaldulensis* has been planted extensively around the world (Midgely et al. 1989). Major uses include posts, poles, firewood, pulpwood and to a lesser extent sawn timber (Eldridge et al. 1993). Timber from natural stands in southern Australia has been used widely for railway sleepers, heavy construction and furniture. These uses continue, although harvesting rates are now low, owing to exhaustion of resources and protection of most of the remnant forests and woodlands. Pulp yield from *E. camaldulensis* wood is low, and pulp produced from *E. camaldulensis* is regarded as being of poor quality and unlikely to be economically attractive in Australia (Clark & Rawlins 1999; Clark et al. 1999).

Within Australia *E. camaldulensis* has been planted widely as a farm species, used in small block plantings and in the reclamation of salt affected land (Sands 1981). It is not generally considered a commercial species because of its poor stem form and slow long-term growth rate.

The species is of considerable interest for hybridisation. In South Africa, Brazil and several other countries it is hybridised with species such as *E. grandis* to extend the range of commercial pulpwood plantations into lower rainfall areas not plantable to the other parent species. Strong interest in interspecific hybrids involving *E. camaldulensis* is developing in Australia, and initial trials of hybrid seedlings and clones are under way within the ALRTIG region (Dale et al. 2000; McComb et al. 2000).

Eucalyptus camaldulensis is one of the eucalypt species selected for a collaborative genetic improvement program by the ALRTIG's partners (Table 1).

Table 1. ALRTIG partners and collaborators

Partner/ collaborator organisation	State	Current involvement
State Forests of New South Wales	NSW	All programs
ForestrySA	SA	All programs
Primary Industries & Resources SA	SA	All programs
Private Forests Tasmania	TAS	Softwoods program only
Department of Natural Resources and Environment (Includes Centre for Forest Tree Technology and Hamilton Pastoral and Veterinary Institute)	VIC	All programs
Department of Conservation and Land Management	WA	All programs
ANU Department of Forestry	National	Mallees (short-rotation crops) program only
CSIRO Forestry & Forest Products	National	All programs

3. Basic Elements of Planning Tree Improvement

3.1. Need for a Well Defined Strategy and Plan

Tree improvement programs aim to develop new plantations superior to their predecessors in one or several key economic traits. Programs start with a carefully chosen improvement strategy implemented through a dependent improvement plan. These key components of tree breeding are defined as follows (after Eldridge et al. 1993):

Improvement strategy (a conceptual plan) **-** the framework of ideas, the conceptual overview, or philosophy of the management of genetic improvement of a tree species used in plantations. Its essential elements are

(a) population improvement by a combination of a particular type of **selection** and a particular type of **mating**, starting with a well adapted broad genetic base, and

(b) an efficient system for **mass propagation** of outstanding selected individuals either as seed or cuttings.

Improvement plan - having decided which Breeding Strategy (particular combination of selection and mating) will provide the greatest genetic gain per decade at an acceptable cost for a particular plantation program, and appropriate methods of mass propagation, the tree breeder can prepare a detailed Improvement Plan to implement the Strategy. Typically the plan includes a set of objectives and a flow chart of what is to be done each month for several years ahead and is subject to regular revision, every 2-5 years (Eldridge et al. 1993).

3.2. Clear Objectives

Tree improvement projects should have a clear set of objectives defining the improvements required and identifying the traits for which to select.

3.3. Hierarchy of Populations in a Breeding Strategy

As an ongoing recurrent process, a breeding strategy accumulates benefits over successive generations of a cycle of testing, selection and mating (Figure 1). Every effective breeding strategy involves the maintenance of a hierarchy of three major types of population which can continue to meet the demand for genetically improved planting stock for a fourth population, the wood-producing plantations. These four populations are:

Base population - The base or gene resource population consists of the natural forests of *E. camaldulensis* and some plantations in which selection can be carried out; these broadly-based reserves will continue to be a source of a wide range of genetic variation to meet future needs.

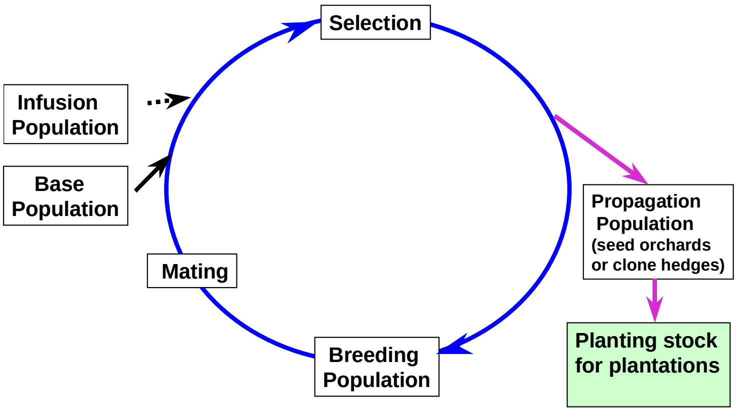
Breeding population - The selected trees and their progeny in a series of progeny trials and possibly clonal archives in which the breeding cycle of selection and mating will be repeated over many generations. This is the tree breeder’s main area of work.

Propagation population - The intensively selected trees (commonly fewer than 100 selected trees) propagated in seed orchards or cuttings multiplication areas where the combinations of genes selected in the breeding population are mass produced as genetically improved planting stock.

Production population - The major plantation areas established using the improved germplasm.

A fifth type of population, the infusion population, describes additional material brought into the breeding population in the second and later generations from the base population and other sources.

Figure 1. Activity cycle for tree improvement



Infusion of new material maintains adequate genetic diversity and provides additional superior genetic material.

3.4. Selection and Mating

Selection and mating are key activities in breeding. They accumulate genes, which influence yield and adaptation, increasing over successive generations the frequency of superior trees. Every successful breeding strategy, therefore, requires efficient methods of selecting superior material including the progeny tests in which the selection is carried out, appropriate measurement techniques and selection technology (e.g. selection indices). Mating can be done by open pollination or controlled pollination, carefully minimising the potential of inbreeding, which has been shown to be strongly deleterious in eucalypts.

In pursuing its principal functions of efficient selection and mating, a strategy should aim to assess the variation within a species, generate genetic information about it and see that genetic resources for future selection are conserved.

3.5. Personnel and Funding

Availability of technical expertise and institutional support as well as an appropriate level of funding over the longer term are key elements in determining the type of breeding strategy adopted.

4. Determinants of the ALRTIG Genetic Improvement Strategy for *E. camaldulensis* in Southern Australia

4.1. Improvement Objectives

The ALRTIG improvement objective for *E. camaldulensis* as a pure species is to maximise the value (per hectare per year) of logs produced by plantations of the species in the target planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles, and posts.

At the same time, ALRTIG will initiate the production of interspecific hybrids of *E. camaldulensis* potentially well-adapted to the target planting zone. Partners will select outstanding individual trees from existing trials, and graft these selections into clone banks. This will facilitate controlled pollination with other species such as *E. grandis* and *E. globulus* to produce interspecific hybrids. Hybrid seed will be produced and distributed to ALRTIG partners for testing in field trials. Development and testing of hybrid clones is outside the scope of the ALRTIG project.
The main products from plantations of interspecific hybrids are expected to be small sawlogs, poles, posts and pulpwood. Collaboration will be sought with other parties already involved in the production or importation and testing of *E. camaldulensis* hybrids, to make effective use of ALRTIG genetic resources and avoid duplication of effort.

Water use is an important consideration for plantings that aim to maximise water use so as to combat rising water tables. However, water use is difficult and expensive to measure directly, and selection and breeding for increased water use *per se* is not considered a feasible breeding objective, although water use of individual trees is strongly correlated with crown size and cross-sectional area of sapwood (Benyon et al. 1999).

4.2. Target Planting Areas and Anticipated Scale of Planting

The target planting areas may be defined in general terms as suitable site types for the species in the 400-650 mm winter/uniform rainfall zone in southern Australia. Temperature, site topography, local hydrology and soil type interact with rainfall to determine available moisture, so the rainfall range is only a general guide. Some provenances of *E. camaldulensis* are known to be relatively salt tolerant, although less so than *E. occidentalis* (Marcar et al. 1995; Benyon et al. 1999). The species is also able to tolerate a greater exposure to waterlogging than most other eucalypts. It is typically planted in lower parts of the landscape and in areas prone to inundation.

The current planting rate in Southern Australia is low (probably no more than 100 ha per year) owing to the poor commercial viability of the species. The anticipated future scale of planting of pure *E. camaldulensis* is hard to predict. Of the five eucalypt species selected by ALRTIG for genetic improvement, it is expected to be the least planted, because of its poor performance in terms of growth rate and/or stem form relative to the other species.

Interspecific hybrids with *E. grandis* and *E. globulus* are currently attracting considerable interest, and a number of seedling and clone trials of such hybrids are already underway within ALRTIG's target zone (Dale et al. 2000; McComb et al. 2000). It is hoped that such hybrids will combine complementary characteristics such as the drought, waterlogging and salinity tolerance of *E. camaldulensis* and the superior growth, stem form and wood quality of the other parent species. Effective deployment of such hybrids could be via clonal forestry using field-tested, elite clones.

4.3. Selection Criteria and Traits for Selection

The ideal *E. camaldulensis* tree for farm forestry plantations would be: well-adapted to target planting environments (displaying excellent survival and health, tolerance of salinity, seasonal waterlogging and drought, and resistance to attack by pests and diseases); have good vigour, as expressed by rapid stem volume growth; a straight single bole and; light lower branches that self-prune.

The selection traits for the first generation are usable stem volume (to top diameter over bark of 10 cm, estimated from height and dbh), absence of forking, a straight stem, and resistance to pests and diseases, drought tolerance and tolerance of soil salinity. For selection to be effective and lead to genetic gain, these traits must be heritable in the breeding population.

Standard guidelines for assessing stem form and branching in *E. camaldulensis* will be developed.

4.4. Institutional Setting, Personnel and Available Funding

The participating agencies in ALRTIG have existing scientific and technical staff experienced in eucalypt breeding and propagation who will implement the improvement strategy for *E. camaldulensis*. They will be assisted until December 2001 by ALRTIG's National Coordinator, who will coordinate activities, oversee expenditure, and help to ensure that milestones and deadlines are met.

Short-term funding to support ALRTIG's collaborative activities has been provided by RIRDC via the Joint Venture Agroforestry Program. Fewer funds will be allocated to *E. camaldulensis* than to the other eucalypt species being developed under ALRTIG's Hardwoods component, because (i) partner agencies have already established extensive planted genetic resources of the species which will be developed into seed orchards, and (ii) it is considered to be of lower priority. Funds allocated for work on *E. camaldulensis* total about $20 000, to be spent over the period June 1999 to December 2001, at which time this funding will cease. The RIRDC funding will be used to cover the direct salary costs of days worked by scientists and technicians on *E. camaldulensis*, and other direct costs such as travel, trial assessment, scion and pollen collection, nursery operations and trial establishment and management.

The participating agencies will make matching funding contributions to meet the balance of staff salaries and organisational overheads. They also bring to the project considerable intellectual property and established genetic resources of the species (seed collections and field trials). They will provide the land required for genetic trials and seed orchards, or negotiate secure tenure for these plantings with other landholders.

The agencies will carry on the improvement program after June 2001, under collaborative or individual-agency management arrangements yet to be determined. Sales of seed or tested clones will generate revenues to support the collaborative project.

4.5. Information on the Species

A comprehensive literature review for the species has been produced (Doran 1998). This reference is an invaluable resource for those with a further interest.

4.5.1. Taxonomic variation

A northern and southern form of *E. camaldulensis* have long been recognised (e.g. Pryor & Byrne 1969). *E. camaldulensis* variety *camaldulensis* is widespread in south eastern Australia and distinguished by its strongly beaked (rostrate) operculum. *E. camaldulensis* variety *obtusa* is widespread in inland and northern Australia, extending southwards in Western Australia to around latitude 30^{o}C, and has a rounded or obtuse operculum (Brooker & Kleinig 1990).

4.5.2. Pollination and breeding system

By analogy with other *Eucalyptus* species with flowers of similar size, we may anticipate that insects (primarily flies and bees) are the main pollinators with nectarivorous birds and small bats (in the tropics) perhaps playing a minor role. *E. camaldulensis* flowers are morphologically bisexual. Individual flowers are protandrous, meaning pollen is shed before the stigma is receptive and thus self-pollination is avoided at that level. However, in *E. camaldulensis*, as in many other eucalypt species, individual trees produce many flowers over a long period in any given flowering season. Therefore, there is ample opportunity for selfing within the crown as flowers on individual trees develop at different times. Most *Eucalyptus* species investigated to date have a mixed mating system, with open-pollinated seed comprising a mix of outcrossed and inbred seed, the latter including both selfed seed and that arising between matings between close relatives. A study on the breeding system of *E. camaldulensis* from Lake Albacutya found that average rates of outcrossing in this provenance were quite high ($t = 0.86$) (McDonald et al. 1995).

4.5.3. Inbreeding depression

Isolated trees, stands where only a few trees flower, or stands that have a very narrow genetic base of only one or a few parents, can be expected to produce inbred seed. Plants raised from this seed will be of poor quality, have lower survival, slow growth and poor stem form, because inbreeding depression is strong in all *Eucalyptus* species investigated to date (Eldridge et al. 1993).Inbreeding depression has been demonstrated experimentally for *E. camaldulensis* (Doran 1992).

4.5.4. Flowering and seeding

Eucalyptus camaldulensis first flowers at around 4-7 years after planting. Many trees in the CSIRO provenance-progeny trial at Deniliquin, NSW, carried heavy bud crops at age 4 years. In CALM trials, the time from bud initiation to anthesis has been observed to be around 12 months. Anthesis occurs in the summer months in southern provenances of the species. Time from anthesis to seed maturity in WA is about 4 months (Oddie & McComb 1998).

The average seed yield from control-pollination is high, in the range 45-55 viable seeds per capsule (Oddie & McComb 1998). Yields per capsule from open pollination are lower, with one estimate of 15 viable seeds per capsule (Doran 1998).

Depending on site and silviculture, *Eucalyptus camaldulensis* seedling seed orchards may be expected to yield at least moderate seed crops from age 5-6 years. Based on CALM's experience, grafted seed orchards may be expected to produce heavy seed crops within 4-5 years of grafting.

4.5.5. Controlled pollination

Methods of controlled pollination in eucalypts have been outlined by Moncur (1995). Basic methodology for *E. camaldulensis* is well known (Oddie & McComb 1998), and has been practiced by CALM and several other organisations for several years.

4.5.6. Vegetative propagation

Mass vegetative propagation by rooted cuttings is feasible for *E. camaldulensis* and its hybrids, which have been developed for clonal forestry in a number of countries such as Morocco, Africa, Brazil, USA and India as well as in Australia (e.g. Arnold et al. 1999). Clones can be developed either from seedlings, or from basal coppice resulting from felling or girdling selection-aged trees.

CALM experience in establishing clonal seed orchards of *E. camaldulensis* has shown that grafting of scions from selected superior trees onto seedling root stocks and deployment in a clonal seed orchard is readily achievable.

4.5.7. Genetic variation

Provenance trials have been conducted in many countries. Substantial provenance variation has been reported by many authors and results of trials are reviewed by Eldridge (1975) and Eldridge et al. (1993). One of the most outstanding provenances in Mediterranean climates has proved to be Lake Albacutya. Mazanec (1999) found good growth for trees from Victorian provenances including Lake Albacutya, in a trial of 20 provenances in the Wellington catchment of south western WA. Despite having the fastest growth in the trial, trees from Lake Albacutya had relatively poor form. Another

provenance from the Laura area in SA yielded comparable volumes in this trial, with significantly better stem form.

4.5.8. Estimates of genetic parameters

- *Heritabilities.* Significant provenance differences show that growth and form traits are under some degree of genetic control. Estimates of heritabilities for these are not yet published for Australian trials of *E. camaldulensis*. Based on experience with other eucalypts, it might be anticipated that within-provenance, narrow-sense heritabilities will be low (0.1-0.2) for growth traits, moderate (0.3-0.5) for stem form and branching traits, and high (> 0.5) for wood properties such as density (Eldridge et al. 1993).

- *Genotype-by-Environment Interaction* – Eldridge et al. (1993) note that provenance by environment was extreme between Mediterranean and tropical environments but not within these two zones. More detailed testing may however reveal some differences. Genotype-by-environment interaction at the family and clonal levels has not yet been studied in Australia. Assessment of the provenance-progeny trials established by CSIRO in 1996 will provide estimates of genotype-by-environment interaction at the family level, as most of the families are in common across the different sites.

4.6. Available Genetic Resources

Planted genetic resources available to ALRTIG are listed in Table 4. Material in the form of cuttings and pollen may be swapped on a reciprocal basis for the purpose of hybridisation work.

Four of the progeny trials, managed by CSIRO, or CSIRO and SFNSW, have been established with the aim of developing them into seedling seed orchards. These trials include families predominantly from the western Victorian provenances (Lake Albacutya and nearby areas) which have generally proved superior within the ALRTIG target zone. CSIRO and SFNSW will develop these orchards with their own resources and market the seed, but will make available research quantities of seed, and clonal selections, for use by ALRTIG. The other trials listed in Table 2 can be used by ALRTIG to provide genetic information and also for selections of outstanding individual trees to supply pollen, seed and scion material for use in future breeding.

In addition to the above genetic resources, CALM has established a grafted clonal seed orchard of 38 clones, comprising phenotypic selections from their provenance trial (Mazanec 1999) and other selections. This CSO is not a contribution to ALRTIG, but some seed from the orchard is being marketed commercially by CALM and can be purchased by growers.

Locally selected or imported clones of *E. camaldulensis* are being tested in a number of clone trials. These have been developed by agencies such as CFTT, CALM and CSIRO, and by other organizations or consortia such as Xylonova. Some of the clones are ‘encumbered’ in the sense that other parties involved in their development have shares in intellectual property or would require royalties for their propagation.

Table 2. Planted genetic resources of E. camaldulensis *available to ALRTIG*

Organisation and location	Year planted	Number of provenances	Sites	Families	Irrigated/ rain-fed	Total trees	Last measure
CALM							
Wellington, WA	1985	20	1	-	Rain-fed	3000	1994
Huntley	1985	25	1	-	Rain-fed	3000	-
Jarrahdale	1985	-	1	-	Rain-fed	3000	-
CFTT							
Kyabram	1978	15	Thinned	-	Rain-fed	400	1997
TFP	1993	7	4	-	Irrigated	700	1997
TFP	1993	18	1	-	Irrigated	720	1997
TFP	1993	-	1	15 clones	Irrigated	300	1997
Whitehead's	1988	-	1	20 clones	Rain-fed	500	1998
CSIRO+ others[a]							
Deniliquin, NSW	1996	30	1	99	Rain-fed	2000	1999
Wellington, NSW	1996	30	1	99	Rain-fed	2000	1999
Ex Simpson, USA	19 clones in glass house and two field trials in southern NSW						-
Dubbo, NSW	1995	Albacutya area	1	28	Irrigated	1000	2000
CSIRO+ SFNSW							
Albury, NSW	1998	29	1	108	Irrigated	3000	-
Albury, NSW	1998	72	1	-	Irrigated	2000	-
DNRE Hamilton							
Various, w. Victoria	1989	8 or 9	6	Some clones	Rain-fed	3000	1991
Various, w. Victoria	1985	4	4	-	Rain-fed	600	1999
PIRSA							
Various, SA	1992	20	6	-	Rain-fed	848	1997
Grand total of trees						*26000+*	

[a] To be selectively thinned for conversion to seedling seed orchards.

5. Proposed ALRTIG Improvement Strategy for *E. camaldulensis* and Summary of Improvement Plan

5.1. Outline of Proposed Improvement Strategy

In the short term, to 2002, superior seed of *E. camaldulensis* can only be provided from superior trees in the best natural provenances, and from CALM's clonal seed orchard if sufficient seed is produced. These sources should be considerably superior to unselected seed from 'average' natural stands. There is also a possibility of growers using selected clones of *E. camaldulensis*. ALRTIG will review the data from already-established clone trials so as to advise growers of the performance of available clones, relative to seedlings.

ALRTIG have already established substantial planted genetic resources of *E. camaldulensis* in many provenance and provenance-progeny trials across dryland southern Australia (Table 2). A **comprehensive review of performance data** from existing trials will be conducted to provide information on the best provenances of *E. camaldulensis* for planting in different geographic regions across the ALRTIG target zone, and the extent of genotype-by-environment interaction at the provenance and family level. CSIRO Entomology's data on *E. camaldulensis* insect browsing susceptibility will be incorporated into the review. The review will be completed by December 2000. This will enable ALRTIG to better advise growers on the best provenances for particular geographic areas, and the range of performance that can be expected.

It is not considered appropriate for ALRTIG to establish a new round of provenance-progeny trials. **Up to four of the existing CSIRO and CSIRO + SFNSW provenance-progeny trials will be selectively thinned to convert them to seedling seed orchards**, and these, together with CALM's clonal seed orchard, should be able to meet the demand for genetically improved *E. camaldulensis* seed within 3 years.

One new provenance-progeny trial will be planted in WA by CALM, to expand the planted base of the Laura and Lake Albacutya provenances, which have performed well in WA. This trial will incorporate a total of at least 100 families from the known better provenances. The trial will supply data on variation in growth and estimates of genetic parameters. This information will be used to select further outstanding trees which will be grafted into a clone bank by CALM to add to the genetic resources available for control-crossed breeding and development of clonal seed orchards.

ALRTIG will **select outstanding individual trees** from a number of their existing trials. Criteria for making these selections will be outstanding volume production, single straight stem, and tolerance to pests, diseases and salinity. The selections will be **grafted into clone archives**, and the partners then may **exchange clones** so that individual partners can develop ***E. camaldulensis* clonal seed orchards** and/or **clone banks for control-pollinated production of interspecific hybrids of *E. camaldulensis*** as they see fit. Grafting of at least 30 outstanding trees of superior provenances, selected from existing trials, will be undertaken during years 2000 and 2001, and exchange of clones will take place by the end of year 2002. Pollen will also be collected from these selections, where feasible, and exchanged between interested partners.

One or more open-pollinated **clonal seed orchards** incorporating 20 or more outstanding selections, and doubling as a small elite breeding population regenerated by controlled pollination, could be established at relatively low cost, to provide more rapid genetic gains within *E. camaldulensis*. The priority to do this is not high, given that CALM has already established one such CSO. A decision on whether to do this will be made in year 2002 after grafting of the initial round of selections is completed.

During 2001, controlled crossing will produce a set of *E. grandis x E. camaldulensis* hybrid progenies. Further development of hybrid clones may be undertaken by the agencies, but is outside the scope of the ALRTIG program.

Vegetative propagation of outstanding clones would deliver the highest level of genetic gain within any one generation (Shelbourne 1992). At this stage, there is no plan to develop and test additional *E. camaldulensis* clones within the ALRTIG program.

5.2. Expected Genetic Gains

A significant proportion of the gains to be achieved in the first cycle will be due to releases from ‘neighbourhood inbreeding’. Natural stand eucalypt seed has a degree of inbreeding due to neighbourhood inbreeding effects (Eldridge et al. 1993; Burgess et al. 1996). Experience from other eucalypt breeding programs indicates that usable volume gains of up to 20% per generation can be anticipated from seed produced by the seedling seed orchards, over and above those from provenance selection, with substantial improvement in form traits as well (Meskimen 1983). The actual magnitudes of gains to be achieved will depend on heritabilities and genetic variances of the traits of interest. These gains result from genetic selection during the selective thinning of the orchards (assuming that good flowering and high levels of outcrossing are achieved).

Selection in some of the seedling seed orchards developed from existing provenance-progeny trials is planned to be carried out at young ages (3 to 6 years). To validate the worth and durability of such selections, studies of age-age correlations may be carried out on unthinned progeny trials such as the new ALRTIG trial to be established by CALM. Even if correlations of performance between the early selection ages and full rotation ages are only moderate, substantial gains will still be provided by the rapid generation turnovers which will be achieved.

Gains beyond the first cycle will depend on accuracy in selecting the best genotypes and management of inbreeding in both the breeding and propagation populations.

Gains from deployment of tested interspecific hybrid clones are expected to be greater than those from breeding within *E. camaldulensis*. Substantial improvements in wood properties and stem form, as well as volume, are anticipated for some site types.

5.3. Interim Seed Sources for Years 2000-2007

5.3.1. Natural-provenance seed

CSIRO’s Australian Tree Seed Centre is the best-placed agency to collect seed from outstanding phenotypes in known superior provenances such as Lake Albacutya, and has many existing seedlots in store from this and other sources.

5.3.2. Seedling seed orchards

Up to four provenance-progeny trials established by CSIRO and SFNSW over the period 1996-1998 (Table 2) will be developed into seedling seed orchards by selective thinning.

5.3.3. CALM clonal seed orchard

Seed from this orchard is commercially available

5.4. Main Breeding Population and First Seedling Seed Orchards

5.4.1. Composition of ALRTIG main breeding population

For a long-term breeding program running over several generations, it is desirable to have an initial breeding population of 200 or more unrelated families (Eldridge et al. 1993). The new ALRTIG breeding population in Western Australia will initially consist of approximately 100 families from western Victoria and from the Laura, SA region, planted in a single trial. The existing CSIRO and CSIRO/SFNSW provenance-progeny trials in southern NSW together comprise over 100 families of known superior natural provenances. These trials, which will be converted to SSOs, and other trials listed in Table 2, can contribute selections to a second-generation ALRTIG breeding population should the partners decide to proceed with this. Together, all of these plantings can contribute selections from a very broad genetic base of over 200 families of known superior provenances, if required.

5.4.2. Deployment of ALRTIG first-generation provenance-progeny trial

To complement existing trials, the ALRTIG Hardwood Technical Committee has decided to deploy a single provenance-progeny trial at one site in Western Australia. This trial will be maintained with only light selective thinning and will provide good genetic information including ranking of provenances and families, heritabilities and genetic correlations including age-age correlations. The best individuals in the trial, identified by index selection, will be grafted out into a clone bank and will be available for exchange among ALRTIG partner agencies.

The site will be selected according to the following criteria:

- Located within the general range of climates in which the species is planted (450-750 mm annual rainfall, winter or uniform rainfall).
- The site will be located on a semi-saline site with salinity levels which should enable discrimination between salt-tolerant and salt-sensitive genotypes of the species.
- Site assessment, involving coring or excavation to 2 m soil depth, to confirm that the site should support reasonable growth and seed production of *E. camaldulensis*. Site should be level or gently sloping with no large environmental gradients nor irregularities within the area to be planted.
- Land either owned/managed by a participating agency, or an agreement negotiated and signed with land owner, giving secure tenure and intellectual property rights to the trial for at least 10 years (it may be necessary to offer the land-owner a share of the seeds to be produced, to secure such agreements).
- Site conveniently accessible to CALM, the lead ALRTIG agency, for establishment and management of the planting, and seed collection.

Seedlings will be raised at a nursery in WA. The progenies will be given a set of field number codes, which will remain unchanged even if not all progenies are successfully raised.

5.4.3. Design of ALRTIG progeny trial

Assuming that there are no restrictions imposed by the shape of the planting area, the trial will use a latinised row column design with 5 replicates and one 5-tree line plot of each family in each replicate. Assuming there are 100 families, this equates to a total of 2500 trees (100 families x 25 trees) . A double row external perimeter planting increases the number of trees to about 3100 trees. The initial spacing will be 4 m between field rows and 2 m between trees along rows.

The total area required for the planting will be of the order of 2.5 ha. Fencing, site preparation, fertilising, weed management and other management issues will be covered in individual working plans drawn up by the relevant lead agency, CALM.

5.4.4. Scheduling of operations to develop ALRTIG and other seedling seed orchards

A brief description of operations for the first generation, together with a time scale for each stage, is presented below (see Box 1) and summarised diagrammatically in Figure 2. The time scale is approximate only. A decision will be made around year 2005 on whether to proceed to a second cycle of the main breeding population.

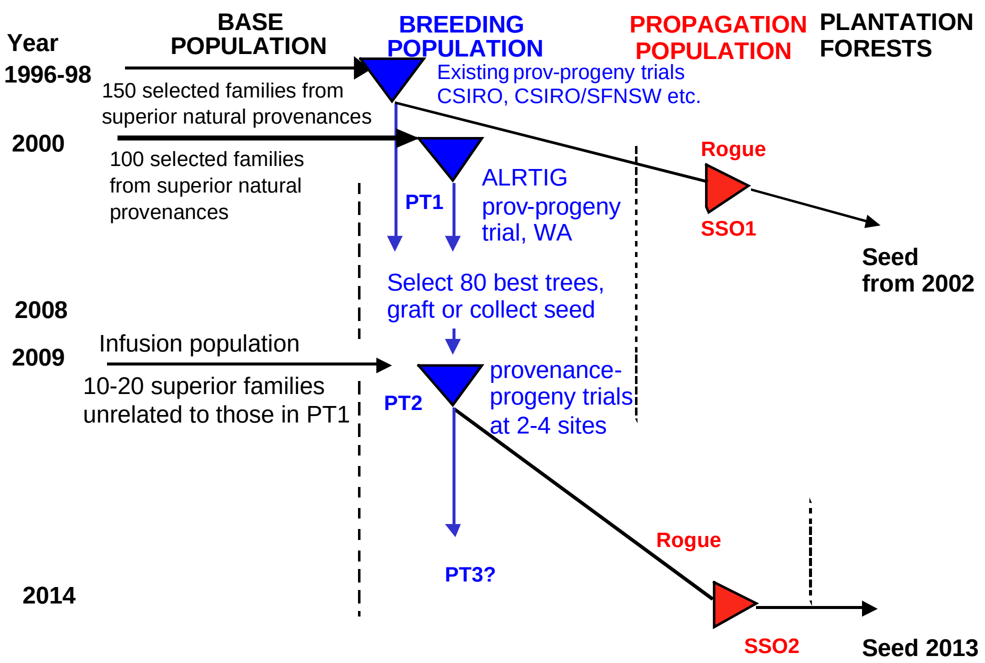
Note that it would be possible to further thin this trial, to enable production of genetically improved seed, but it is anticipated that already-established SSOs and CSOs will be able to meet anticipated demand for improved *E. camaldulensis* seed.

The details of the second cycle of the main breeding population will be determined after a review of the information obtained from the first cycle of breeding. One very important question that must be addressed is whether there is sufficient genotype-by-environment interaction to warrant two or more separate breeding populations in the second generation.

Box 1. Chronological summary of *E. camaldulensis* tree improvement activities

2000	*Establishment of ALRTIG progeny trial*
Purpose:	first cycle of breeding population, to obtain genetic information and make accurate selections of outstanding trees for clone bank and advanced breeding. Supplements already-established trials.
Material:	Approximately 100 open pollinated families from superior natural provenances. (Table 2).
Design:	Randomised latinised row-column design with 5 replicates. Each family will be represented a single 5-tree row plot in each replication. Surrounded by double row external perimeter planting of surplus stock. Spacing will initially be 4 m between rows and 2 m within rows.
2004	*First major assessment of progeny trial*
Age:	around 3-4 years (actual timing depends on development – ideally want crowns touching along rows, mean height about 6 m).
Purpose:	Assess height, dbh and proportion of trees that are forking/single-stemmed. First estimate of relative performances of different seed sources. Keep unthinned to allow for age –age correlations to be made.
2006	*Second assessment of progeny trial*
Age:	around 6 years - exact timing will depend on actual growth and development of trial.
Purpose:	Further assessment to compare families and allow estimation of age-age correlations and other genetic parameters. This assessment will provide performance data to assist selection of parents for the second cycle of breeding.
2008:	*First thinning of progeny trial*
Age:	8 years, after the second major assessment is completed (trees to be thinned can be marked by the assessment team).
Selection:	Remove worst tree in each 5-tree row plot, retain up to 4 best trees.
Purpose:	reduce stocking to maintain vigorous growth on retained trees.
2008	*Selection of outstanding individual trees for grafting into clone ba*nk
Age:	8 years
Selection:	Identify best 20 or so individual trees using multi-trait index selection.

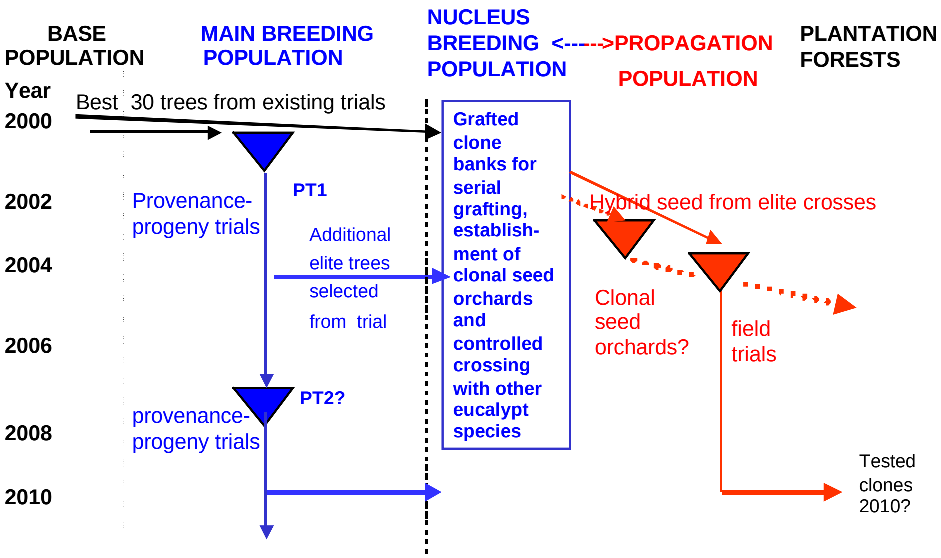
Figure 2. Improvement strategy for *E. camaldulensis*: main population



5.5. Clone Banks and Clonal Seed Orchards

Clone bank/clonal seed orchard (CSO) activities are summarised diagrammatically in Figure 3.

Figure 3. Improvement strategy for *E. camaldulensis*: clonal seed orchard and controlled crossing to produce hybrids



5.5.1. Selection of candidate trees for grafting into clone banks

Initial selections will be made in existing trials at least 5 years old, provided by ALRTIG (Table 2). Ideally, each outstanding tree should be from a stand of known superior provenance, and at least two standard deviations above the stand mean for the selection criteria (volume, absence of forking, stem straightness, resistance to insect attack, and salinity tolerance where appropriate). After selection during years 2000-2001, outstanding trees will be grafted into clone banks. Sufficient material will be raised for cuttings to be swapped between partners, as required. Rootstocks for grafting will, where possible, be raised from seed from the same open-pollinated family that yielded each selection, or open-pollinated seed collected from the ortet itself, prior to grafting.

5.5.2. Controlled crossing

The selections will be established in clone banks and seed orchards by CALM, CSIRO and possibly other agencies, and managed intensively so as to induce early flowering. They will then be available for controlled pollination. CSIRO will produce, in 2001, a set of *E. grandis* x *E. camaldulensis* hybrid progenies by controlled crossing, using superior *E. camaldulensis* pollens and CSIRO's selected *E. grandis* parents. Seed from these crosses will be shared among interested agencies for planting and evaluation.

5.6. Additional Components of the Improvement Strategy

5.6.1. Collaboration with other agencies and organizations working on *E. camaldulensis* and its hybrids

It will be important to maintain contact with Saltgrow (formerly Xylonova), Murdoch University/North Forests and other groups already testing *E. camaldulensis* hybrids, so as to minimise duplication of effort and enable ALRTIG to complement the work already undertaken. It may be noted that the genetic base of *E. camaldulensis* involved in current hybrid trials is relatively narrow, involving only a very few *E. camaldulensis* trees as parents (Dale et al. 2000; McComb et al. 2000).

5.6.2. Treatments to promote flowering and seed production

Recent studies on *E. nitens* in Tasmania indicate that high levels of nitrogen, applied as urea, can greatly increase flowering and seed production. Application of paclobutrazol, as a root drench of Cultar, may also stimulate flowering and seed production.

Experience with *E. camaldulensis, E. globulus* and *E. nitens* (Moncur et al. 1995) indicates that hives of honey bees located in seed orchards during flowering can increase the level of seed set and/or the outcrossing rate. This measure could be implemented at one of more of the seed orchards established from existing trials.

5.6.3. Provenance resource stands

ALRTIG will collaborate with individuals and organisations that are planting *E. camaldulensis*, to develop a number of provenance resource stands (block plantings of known provenance). Given the agreement of the plantation owners, these can provide several valuable functions in the ALRTIG improvement program, including a resource of candidate outstanding trees which could be grafted into the clone bank or supply seed, possible conversion of some stands to seed production areas by selective thinning, development of biomass equations, etc. ALRTIG will document the exact location, extent and provenance origin of potentially useful provenance resource stands, including those already established, in a database. ALRTIG may provide, or arrange provision, of seed of known superior seed sources for such plantings.

5.6.4. Genetic gain trials

Genetic gain trials are an important part of planning all tree improvement programs (Eldridge et al. 1993, p.180). If comparative trials are not planted it would never be known whether and by how much improvement has been achieved. Genetic gain trials, also known as yield trials, compare a small number of commercial varieties in well-designed replicated trials with large plots to allow for thinning and realistic measurement. As well as monitoring genetic gain, such trials can have high value for extension: showing farmers how much they can increase productivity with new varieties.

Such trials could be established by Regional Plantation Committees, Greening Australia and other agencies, with technical advice from ALRTIG and/or CSIRO’s Farm Forestry Seed and Information Support Program. Seed from the SSOs established in 1998 by CSIRO and CALM may be available for gain trials by year 2004 or 2005.

Later, gain trials should be established to compare the performance of the first commercial harvest of seed from the ALRTIG seedling seed orchards with seed production area seed and regular industry seedlots.

5.6.5. Genetic conservation

Although *E. camaldulensis* is widespread, some individual provenances could be lost through increasing salinisation of landscapes, or other unforeseeable circumstances. If known superior provenances are threatened in this way, it would be desirable for ALRTIG to support ex-situ conservation of these provenances. This could be achieved to some extent by long-term storage of seed from these provenances, and by well-documented provenance resource stands representing many parents from a particular provenance.

6. Program Reviews

An essential component of genetic improvement programs is regular in-depth review, analysis, evaluation and subsequent revision. The first of such reviews for this program has been tentatively scheduled for mid 2001, when experience and results from the first 18 months of the program have been obtained. Further reviews would be conducted at least once every 2 years. There is sufficient expertise within ALRTIG to carry out the reviews, but it would be desirable for an outside expert not involved in the group to participate in the major reviews.

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PART 3: *EUCALYPTUS CLADOCALYX*

GENETIC IMPROVEMENT STRATEGY IN SOUTHERN AUSTRALIA

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1. Summary

Eucalyptus cladocalyx is one of the eucalypt species selected for a collaborative genetic improvement program by the participating agencies in ALRTIG (the Australian Low Rainfall Tree Improvement Group). A strategy for the improvement of *E. cladocalyx* by ALRTIG partner agencies, combining elements from several successful eucalypt improvement programs in Australia and elsewhere, is recommended and described.

The **improvement objective** is to maximise the value of logs produced by plantations in the target planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles and posts. The initial selection criteria are improved volume production, single straight stem, and resistance to pests and diseases. Selection and breeding for improved wood properties may be also be appropriate, once market prospects for different wood products become clearer, enabling important wood quality traits to be identified.

Superior natural provenances of the species (Wirrabara and Flinders Chase, Kangaroo Island) displaying rapid growth and good stem form, have already been identified from the results of provenance trials at six sites in South Australia. Further seed collections are being made from outstanding trees in these provenances as an interim source of superior seed. Seed from a multi-provenance seed production area established in South Australia in 1992, is now available. A 30-year-old second-generation plantation at Wail, western Victoria, established from superior trees of first-generation plantations at Wail derived from the Wirrabara provenance, will be developed into another interim seed production area by selective thinning and should yield seed by December 2001. A seedling seed orchard planted in 1998 at Benalla in Victoria should commence seed production by year 2004-2005.

ALRTIG partners will establish a new **main breeding population** in four new provenance-progeny trials at carefully selected sites in NSW, SA,VIC and WA. These trials will incorporate at least 100 families from (i) superior mother trees from good provenances and (ii) superior trees in field trials and planted stands of these provenances. The trials will serve the dual purposes of supplying data on variation in growth and estimates of genetic parameters, and supplying genetically improved seed.

Three of the sites will be converted by selective thinning to seedling seed orchards (SSOs) which will supply genetically-improved seed for plantations and for the next generation of the main breeding population. These trials are termed progeny trial – seedling seed orchards (**PT-SSOs**). One site (in WA) will be left unthinned for longer, and may be used for selection of scions for a clonal seed orchard (depending on demand for seed). This stand is referred to as a **PT-CSO**, as it will serve as progeny trial that will supply material for clonal seed orchard establishment.

Vegetative propagation of seedlings of elite families, via rooted stem cuttings, is a possible route towards clone trials and clonal forestry with outstanding field-tested clones. The feasibility of developing this option will be evaluated in year 2000 by propagation trials, using seedlings from the best currently available progenies.

2. Background

Eucalyptus cladocalyx is a medium to tall tree of potentially good form, moderately fast growth rate, and good coppicing ability. It has been widely used in shelterbelts and for shade and amenity. This species is a prime candidate for farm woodlot planting in semiarid areas with about 400-600 mm annual rainfall falling predominantly in winter. *E. cladocalyx* tolerates low to moderate salinity and a wide variety of infertile soils including calcareous soils, but is intolerant of waterlogging (Marcar et al. 1995) and very light sandy soils. The wood of *E. cladocalyx* is often used in the round for telephone poles, fence posts and firewood. It is also used in heavy and general construction and in cabinet making. It is a useful species for honey and charcoal production.

This species is endemic to South Australia where it occurs naturally in four disjunct areas. Best growth and form is in populations of the southern Flinders Ranges and towards the top of Spencer Gulf. Other localities are on the eastern side of Eyre Peninsula, around Cleve and south in the Koppiko Hills-Marble Range region, and in a number of small populations on Kangaroo Island (Boland et al. 1984; Nicolle 1997).

Typically, form of trees in natural provenances is fair to poor with about one-third of trees on better sites classified as being of good form. Stems may be clear to two-thirds of the tree height on the more favourable sites, while on poorer sites stems are clear for only one-third to one-half the total height and are often crooked.

Eucalyptus cladocalyx has been planted widely as a farm forestry species in drier parts of southern Australia. It was recognised very early as a eucalypt species that would perform well in plantations in country too dry for faster-growing species such as *E. globulus*. In South Australia, plantations were also established near the natural stands at Wirrabara and at Bundaleer. There are extensive shelterbelts in western Victoria, established by direct seeding in the late 19th century (Hamilton 1999). There are at least 1000 ha in the region around Colac (DNRE survey 1999 – Hamilton pers. comm. 2000). Many of these windbreaks are now being managed sustainably for firewood production on a coppicing rotation. Further west at Wail, conventional seedling-based plantations were established, commencing in 1911. The Wail and other nearby plantations were managed for many years for large post and pole production, and a preservative treatment plant was operated at Wail. The best logs from the western Victorian plantings are starting to be sawn in Victorian mills for sawn timber for furniture making and droppers and posts for fencing. Good quality sawlogs are fetching prices of up to \$100 m^{-3} delivered to the mill gate (Andrew Lang, pers. comm. 2000).

A RIRDC-funded report on the silviculture and productivity of the Wail plantations has been prepared (Stewart et al. 2000). Large block plantations were also established at Majorca near Maryborough (over 100 ha) and in the You Yangs. Smaller scale plantings – windbreaks and roadside plantings – are common throughout the drier parts of Victoria and South Australia.

E. cladocalyx is one of the eucalypt species selected for a collaborative genetic improvement program by the following participating agencies in ALRTIG (the Australian Low Rainfall Tree Improvement Group). Table 1 gives details of ALRTIG's partners.

Table 1. ALRTIG partners and collaborators

Partner/ collaborator Organisation	State	Current involvement
State Forests New South Wales	NSW	All programs
ForestrySA	SA	All programs
Primary Industries & Resources SA	SA	All programs
Private Forests Tasmania	TAS	Softwoods program only
Department of Natural Resources and Environment (Includes Centre for Forest Tree Technology and Hamilton Pastoral and Veterinary Institute)	VIC	All programs
Department of Conservation and Land Management	WA	All programs
Australian National University Department of Forestry	National	Mallees (short-rotation crops) program only
CSIRO Forestry & Forest Products	National	All programs

3. Basic Elements Of Planning Tree Improvement

3.1. Need for a Well Defined Strategy and Plan

Tree improvement programs aim to develop new plantations superior to their predecessors in one or several important economic traits. Programs start with a carefully chosen improvement strategy implemented through a dependent improvement plan. These key components of tree breeding are defined as follows (after Eldridge et al. 1993) -

Improvement strategy (a conceptual plan) - the framework of ideas, the conceptual overview, or philosophy of the management of genetic improvement of a tree species used in plantations. Its essential elements are:

(a) Population improvement by a combination of a particular type of **selection** and a particular type of **mating**, starting with a well adapted broad genetic base, and

(b) An efficient system for **mass propagation** of outstanding selected individuals either as seed or cuttings.

Improvement plan - having decided which Breeding Strategy (particular combination of selection and mating) will provide the greatest genetic gain per decade at an acceptable cost for a particular plantation program, and appropriate methods of mass propagation, the tree breeder can prepare a detailed Improvement Plan to implement the Strategy. Typically, the plan includes a set of objectives and a flow chart of what is to be done each month for several years ahead and is subject to regular revision, every 2-5 years (Eldridge et al. 1993).

3.2. Clear Objectives

Tree improvement projects should have a clear set of objectives defining the improvements required and identifying the traits for which to select.

3.3. Hierarchy of Populations in a Breeding Strategy

As an ongoing recurrent process, a breeding strategy accumulates benefits over successive generations of a cycle of testing, selection and mating (Figure 1). Every effective breeding strategy involves the maintenance of a hierarchy of three major types of population which can continue to meet the demand for genetically improved planting stock for a fourth population, the wood-producing plantations. The four populations are summarised as follows:

Base population - The base or gene resource population consists of the natural forests of *E. cladocalyx* and some plantations in which selection can be carried out; these broadly-based reserves will continue to be a source of a wide range of genetic variation to meet future needs.

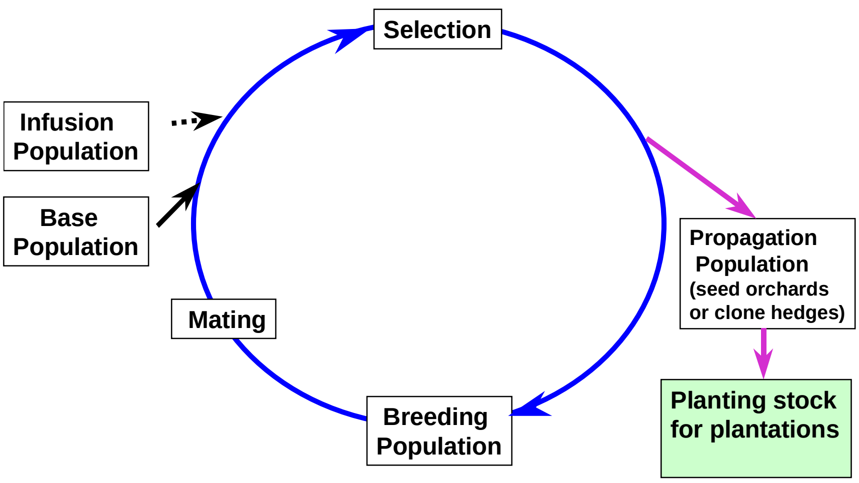
Breeding population - The selected trees and their progeny in a series of progeny trials and possibly clonal archives in which the breeding cycle of selection and mating will be repeated over many generations. This is the tree breeder's main area of work.

Propagation population - The intensively selected trees (commonly fewer than 100 selected trees) propagated in seed orchards or cuttings multiplication areas where the combinations of genes selected in the breeding population are mass produced as genetically improved planting stock.

Production population - The major plantation areas established using the improved germplasm.

A fifth type of population, the infusion population, describes additional material from the base population brought into the breeding population in the second and later generations to maintain adequate genetic diversity and provide additional superior genetic material.

Figure 1. Activity cycle for tree improvement



3.4. Selection and Mating

Selection and mating are key activities in breeding. They accumulate genes, which influence yield and adaption, increasing over successive generations the frequency of superior trees. Every successful breeding strategy, therefore, requires efficient methods of selecting superior material including the progeny tests in which the selection is carried out, appropriate measurement techniques and selection technology (e.g. selection indices). Mating can be done by open pollination or controlled pollination, carefully minimising the potential of inbreeding, which has been shown to be strongly deleterious in eucalypts.

In pursuing its principal functions of efficient selection and mating, a strategy should aim to assess the variation within a species, generate genetic information about it, and see that genetic resources for future selection are conserved.

3.5. Personnel and Funding

Availability of technical expertise and institutional support as well as an appropriate level of funding over the longer term are essential elements in determining the type of breeding strategy adopted.

4. Determinants of the ALRTIG Genetic Improvement Strategy for *E. cladocalyx* in Southern Australia

4.1. Improvement Objective

The ALRTIG improvement objective for *E. cladocalyx* is to maximise the value (per hectare per year) of logs produced by plantations in the target planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles, and posts. The initial selection criteria are improved volume production, a single straight stem with light branching, and resistance to pests, and diseases. Sufficient high-quality germplasm to meet anticipated planting demand for the species across southern Australia must be produced, as soon as possible. Efforts may be made to improve wood properties, once market prospects for the wood products become clearer, enabling important wood quality traits to be identified.

Water use, an important consideration for plantings that aim to maximise water use to combat rising water tables, will be related closely to wood volume production. Water use of individual trees is strongly correlated with crown size and cross-sectional area of sapwood (Benyon et al. 1999). Water use is difficult and expensive to measure directly, and selection and breeding for increased water use *per se* is not considered a feasible breeding objective.

4.2. Target Planting Areas and Anticipated Scale of Planting

The target planting areas may be defined in general terms as suitable site types in the 400-600 mm winter/uniform rainfall zone in southern Australia. Temperature, site topography, local hydrology and soil type interact with rainfall to determine available moisture, so the rainfall range is only a general guide. *Eucalyptus cladocalyx* displays moderate tolerance of salinity; up to around 5 dS m^{-1} EC_e will not reduce growth. Salinities over 10 dS m^{-1} EC_e are injurious to the species (Marcar et al. 1995). Sugar gum is suited to a large proportion of the 400–600+ mm zones of southern Australia, in soils that are both relatively well drained and have adequate soil moisture holding capacity (particularly in the lower rainfall zones). The species' moderate frost resistant enables its use in all bar severely frost prone areas.

There is already a large area of planted forests of *E. cladocalyx* within the ALRTIG target planting area. Some 1000 ha is planted in the region around Colac, western Victoria, most of this having been established as windbreaks by direct seeding in the late 19^{th} and early 20^{th} centuries. These farm plantings are providing the resource for a developing firewood industry and some small-scale milling operations. Substantial areas of plantations also exist near Majorca and the You Yangs, around Wail, western Victoria and South Australia. There are large areas of plantations near Wanilla on Eyre Peninsula, in the Adelaide Hills and near Wirrabara. Extensive smaller scale rural plantings in SA are largely a legacy of a 'free-tree scheme' in the early years of the twentieth century.

In SW Victoria alone, there are some 1.4 M ha identified as being potentially suitable for growing *E. globulus*, receiving over 600 mm annual rainfall and within 150 km of a port. (Private Forestry Council 1998). A good portion of this land in the 600-650 mm range, where *E. globulus* is vulnerable to drought, would be a target area for *E. cladocalyx* plantations. The zone in western Victoria to the north, receiving 450-600 mm represents a further potentially large area (perhaps 1 million ha). However, most of this is cropping land, and some heavy clay soils exist that are unsuitable; perhaps 10% could be suitable. That still leaves around 100,000 ha (an estimate) in the 450-650 mm rainfall area of western Victoria that would be suitable if there were a market for the product. A good deal of the eroded hilly country from Ararat through the Central Highlands, much of it recharge area for the region, could be ideal. It would serve an additional purpose of salinity control for the croplands and grazing country (R. Bird, DNRE, pers. comm. 2000).

There is currently strong demand for seed of *E. cladocalyx,* but much of this is being used for direct seeding of windbreak plantings. This application does not require highly improved seed, and its practitioners cannot afford to pay premium prices. The current annual production of *E. cladocalyx* seedlings by plant nurseries across southern Australia is estimated to be around 300,000, sufficient for afforesting about 300 ha. This annual planting rate would require about 5-10 kg of seed.

The anticipated future scale of planting is hard to predict, but will almost certainly increase substantially. It will be determined to some extent by the levels of government and investor support to farm forestry through tax concessions, grants, subsidies, carbon and salinity credits, and direct investment. It will also be partly dependent on the success of the ALRTIG improvement program. Availability of adaptable, fast-growing, straight stemmed varieties providing a more valuable commercial timber harvest should make planting more economically attractive, leading to greater uptake.

4.3. Selection Criteria and Traits for Selection

The ideal *E. cladocalyx* tree for farm forestry plantations would be well-adapted to target planting environments (displaying excellent survival and health, drought tolerance, and resistant to attack by pests and diseases) have good vigour, as expressed by rapid stem volume growth, a straight single bole, and light lower branches that self-prune.

The selection traits for the first generation are usable stem volume (to top diameter of 10 cm, estimated from height and dbh), absence of forking, a straight stem, and resistance to pests and diseases. For selection to be effective and lead to genetic gain, these traits must be heritable in the breeding population.

Standard guidelines for assessing stem form and branching in *E. cladocalyx* will be developed for use across all of the ALRTIG trials.

4.4. Institutional Setting, Personnel and Available Funding

The participating agencies in ALRTIG have existing scientific and technical staff experienced in eucalypt breeding and propagation, who will implement the improvement strategy for *E. cladocalyx*. They will be assisted until December 2001 by ALRTIG's National Coordinator, who will coordinate activities, oversee expenditure, and help to ensure that milestones and deadlines are met.

Short-term funding to support ALRTIG's collaborative activities has been provided by RIRDC via the Joint Venture Agroforestry Program. Funds available to ALRTIG for work on *E. cladocalyx* total about $50,000, to be spent over the period June 1999 to June 2001 (extended to December 2001 because of the late start of the project), at which time this funding will cease. The RIRDC funding will be used to cover the direct salary costs of days worked by scientists and technicians on *E. cladocalyx,* and other direct costs such as travel, seed collection, nursery operations and trial establishment and management.

The participating agencies will match funds to meet the balance of staff salaries and organisational overheads. They also bring to the project considerable intellectual property and established genetic resources (seed collections and field trials). They will provide the land required for genetic trials and seed orchards, or negotiate secure tenure for these plantings with other landholders.

The agencies will carry on the improvement program after June 2001, under collaborative or individual-agency management arrangements yet to be determined. Sales of seed or tested clones will generate revenues to support the collaborative project.

4.5. Information on the Species

A review of information on *E. cladocalyx* has been prepared recently (Doran 2000). Key factors influencing the choice of improvement strategy are summarised below.

4.5.1. Taxonomic variation and hybrids

Pryor and Johnson (1971), in their informal classification of the eucalypts, placed *E. cladocalyx* in the Subgenus Symphyomyrtus, section Bisectaria, series Cladocalyces, with one other species, *E. brockwayi*. However, these two species have few features in common. In *E. cladocalyx* the cotyledons are bilobed rather than bisected as in *E. brockwayi*. *E. cladocalyx* does not appear to have close affinities to any other species in the genus (Boland et al. 1984). In a more recent classification, Chippendale (1988) places *E. cladocalyx* on its own in series Microcorythae of the subgenus Symphyomyrtus.

Eucalyptus cladocalyx var. *nana* Hort. is a smaller more spreading tree, which grows to 15 m in height. It originates from Eyre Peninsular and has been developed as a horticultural variety (Nicolle 1997). It has a much bushier habit and hence is more suitable for shelterbelts and garden plantings than for timber production.

One record of a natural hybrid between *E. cladocalyx* and *E. camaldulensis* appears in the summary list of reported hybrids compiled by Griffin et al. (1988).

4.5.2. Pollination and breeding system

Aspects of the breeding system, floral morphology and pistil (gynaecium) cytology were studied in three trees of *E. cladocalyx* by Ellis and Sedgley (1992). The individual trees ranged from self-compatible to self-incompatible. The authors discuss the implications of floral structure and of the location and extent of outcrossing control in relation to seed genotypes and seed output.

By analogy with other *Eucalyptus* species with flowers of similar size, we may anticipate that insects (primarily flies and bees) are the main pollinators with nectarivorous birds perhaps playing a supplementary role. *E. cladocalyx* flowers are morphologically bisexual. Individual flowers are protandrous, meaning pollen is shed before the stigma is receptive and thus self-pollination is avoided. In *E. cladocalyx*, as in many other eucalypt species, individual trees produce many flowers over a long period in any given flowering season. Therefore, there is ample opportunity for selfing within the crown as flowers on individual trees develop at different times. Most *Eucalyptus* species investigated to date have a mixed mating system, with open-pollinated seed comprising a mix of outcrossed and inbred seed, the latter including both selfed seed and that arising between matings between close relatives. The proportion of outcrossed and inbred seed in natural provenances of *E. cladocalyx* is not known.

4.5.3. Inbreeding depression

Isolated trees, stands where only a few trees flower, or stands that have a very narrow genetic base of only one or a few parents, can be expected to produce inbred seed that will produce plants that are poor in quality, with lower survival, slow growth and poor stem form, because inbreeding depression is strong in all *Eucalyptus* species investigated to date (Eldridge et al. 1993).

4.5.4. Flowering and seeding

Flowering occurs January to April (Boland et al. 1984), with mature seed available for collection about 12 months later. Seed collections may be undertaken throughout the year, as seed crops may be retained on the tree for 3 to 4 years (Bonney 1994).

There are approximately 120,000 viable seed per kilogram of seed and chaff mix (Turnbull and Doran 1987). Seed of this species is orthodox in its storage behaviour and will keep in good condition for several years if air-dried and placed in a refrigerator (3°–5°) in an airtight container.

Depending on site and silviculture, *Eucalyptus cladocalyx* seedling seed orchards may be expected to yield at least moderate seed crops from age 5-6 years.

4.5.5. Controlled pollination

Methods of controlled pollination in eucalypts have been outlined by Moncur (1995). No basic problems are anticipated for *E. cladocalyx*, but some testing will be needed to determine the number of days to peak receptivity after anthesis, and whether more efficient ‘one stop pollination’ techniques such as those recently developed for *E. globulus* (Harbard et al. 1999) can be used.

4.5.6. Vegetative propagation

Efforts to develop cost-effective methods of mass propagating rooted cuttings in Australia are worth pursuing, as vegetative propagation of elite, field tested clones will capture much more genetic gain than seed from open-pollinated seed orchards (Shelbourne 1992). Usually, seedlings are easier to propagate by rooted stem cuttings than are selection-aged trees, even if the latter are cut to produce basal coppice shoots. Clonal propagation of seedlings produced by controlled crosses between elite trees, followed by clonal testing to identify the best clones, and maintenance of juvenile hedge plants by repeated hedging, might therefore be the best route to operational clonal forestry.

Grafting of scions from selected superior trees onto seedling rootstocks is expected to be feasible, as with most eucalypts investigated to date. This would enable the development of clone banks for controlled pollination between selections, and clonal seed orchards.

4.5.7. Pests and diseases

Properly managed *Eucalyptus cladocalyx* plantations in Australia are relatively free from widespread, serious diseases and pests. Plantations in this country have required no special pest control measures, and are relatively easy to manage in this regard. However, a number of occurrences of pests and diseases have been recorded both in Australia and overseas.

In the Transvaal of South Africa, Poynton (1979) reported that a stand of *E. cladocalyx* was completely destroyed by the fungus *Polyporus baudonii*. Attack by the leafspot fungi, *Mycosphaerella* spp. has also been reported on this species in South Africa (Poynton 1979).

In Australia, gumtree scale (*Eriococcus confusus*) can affect *E. cladocalyx* (Carne and Taylor 1984), especially young and pollarded trees, those growing on unfavourable sites or which have been weakened by defoliating, sap-sucking or wood-boring insects. Dense colonies of white or brown scales occur along stems and leaves producing a sticky honeydew covered with sooty mould (Farrow 1996). This can cause branches to die back. Small saplings are the most susceptible, and can be killed by the direct effects of sap-removal and indirectly by the build-up of sooty mould, which inhibits photosynthesis. Infestations spread outwards into surrounding trees, leading to patches of dying and dead trees in plantations. Adult scale are attacked by a range of parasitic wasps and flies; predatory larvae of moths (*Catoblemma* and *Stathmopoda* spp.); lacewing larvae (*Chrysopa* spp.); hoverfly larvae (Syrphidae) and; the adults and larvae of several ladybirds, including *Rhizobius ventralis* (grey adult) and *Coccinella transversalis* (yellow and black). Ants interfere with natural enemy control as they defend the scale to ensure a supply of honeydew. Removal of ants generally causes outbreaks to quickly collapse. There is a tendency for scale numbers to build up in spring and early summer and for predators to catch up and reduce the scale numbers to very low levels by the end of the autumn.

Eucalyptus cladocalyx is one of the preferred hosts of Christmas beetle, *Anoplognathus* sp. (Farrow 1996). It is moderately susceptible to leaf blister sawfly (*Phylacteophaga froggatti*) (Farrow 1996). Usually only juvenile foliage of young trees or young adult leaves near the ground are attacked. Massive outbreaks can occur in young plantations due to the sawfly's high capacity for increase, which enables them to escape from the control exerted by their parasites. Defoliation can be severe in young plantations and can cause tree death if several defoliation cycles occur in succession during the course of a season.

In South Africa, Morocco and USA, trees weakened by drought are occasionally attacked by the stem borer, *Phoracantha semipunctata* (Poynton 1979; Montoya-Oliver et al. 1983; Paine et al. 1990; Hanks et al. 1993; Hanks et al. 1995). Chemical insecticides are ineffective against borers so removal of infected trees and prevention of drought stress through appropriate plantation management are the only recourse currently available to tree-growers (El-Yousfi 1989; Farrow 1996).

4.5.8. Genetic variation

Despite the long-time use of the species as a farm and plantation tree in many parts of the world, it is only recently that systematic seed collections from individual trees from all known natural occurrences of the species have been undertaken.

PIRSA established a series of small-scale provenance trials of *E. cladocalyx* as part of its Farm Tree Improvement Project (Fairlamb & Bulman 1994). Recent assessments for ALRTIG have been made at 3.4 to 5.4 years after planting (Bulman et al. 2000). A clear and consistent pattern of provenance variation was established in these trials, which covered six different sites in south-eastern South Australia with mean annual rainfalls ranging from 400 to 850 mm and a range of soil types. The pattern of provenance ranking for height and diameter was consistent across the six sites, with Flinders Chase National Park, Kangaroo Island, the best performer, followed closely by Wirrabara. Wilmington provenance was intermediate, while Wanilla, and a seed source collected by 'Trees for Life' from Kangaroo Island were poorest. There were no clear differences in survival, which was greater than 70% overall at all sites. Similar provenance rankings have been observed in two DNRE trials near Colac in western Victoria (Sue Harris, pers. comm. 2000).

Superior performance of a derived seed source from Lismore (western Victoria), relative to all natural provenances, was indicated in the two DNRE Colac trials. The Lismore seed source is believed to be a mix of seed from superior trees in an *E. cladocalyx* windbreak which was a first-generation direct-seeded planting, derived from a mix of seed from superior trees in the Wirrabara provenance, collected by SA Woods and Forests Department in the late 19th century. The DNRE results will be published in April.

The Port Lincoln provenance of *E. cladocalyx* in South Australia has proved most drought tolerant in Western Australian plantings (Turnbull & Pryor 1984).

In Chile, Jayawickrama et al. (1993) advise that a clonal orchard of *E. cladocalyx* was planned based on material in the species introduction trials of the 1960s.
The interspecific hybrid, *E. camaldulensis* x *E. cladocalyx*, was manipulated and tested in Morocco but was the slowest growing of the range of hybrids tested (Mesbah 1995)

4.5.9. Wood and sawing properties

Washusen et al. (1998) made a preliminary study of the timber sawing and seasoning properties of *E. cladocalyx* and several other species growing in plantations in Victoria's 580-750 mm rainfall zone. This study demonstrated 35-37% recovery of acceptable grades, and 17-19% recovery of select grades, of sawn wood products from *E. cladocalyx* logs averaging 33 cm in diameter. Basic density of the timber was around 800 kg m^{-3}. Surface checking was a minor source of defect in boards. The wood is also suitable for poles and posts. For many years sugar gum provided the resource for production of CCA treated poles and posts on Eyre Peninsula in SA and at Wail in western Victoria. CSIRO Forestry and Forest Products is now planning studies of natural durability of posts of *E. cladocalyx* and other dry-zone eucalypt species. Information obtained from this and other studies should provide further information on the economic potential of *E. cladocalyx* wood, and identify any problem areas that might be addressed through genetic improvement. The wood is considered too dense to be suitable for pulp production.

4.5.10. Estimates of genetic parameters

Heritabilities: No direct information on heritabilities of economic traits in *E. cladocalyx* is available. Clear differences between provenances in growth and form traits suggest that these traits will be heritable in breeding populations. Experience with other eucalypts, suggests that within-provenance, narrow-sense heritabilities will be low (0.1-0.2) for growth traits, moderate (0.3-0.5) for stem form and branching traits, and high (> 0.5) for wood properties such as density (Eldridge et al. 1993).

Genotype-by-Environment Interaction: In six trials across a range of sites in SA, provenance-by-site interactions for height and dbh were both non-significant and very small relative to the provenance differences (mean squares for interaction less than 5% of those for provenance difference, in both cases). The pattern of provenance performance in height and diameter growth was very clear and consistent – Flinders Chase NP (Kangaroo Island) was the fastest-growing provenance at all six sites, generally followed by Wirrabara CSIRO 15019, and then Wilmington and Wirrabara, with Wanilla markedly inferior. Little is known of the extent of genotype-by-environment interaction in *E. cladocalyx* at the family level as progeny trials across a range of sites have yet to be established.

4.6. Available Genetic Resources

CSIRO made individual-tree collections from superior trees in natural stands in 1999 and 2000 (Larmour & Whitfeld 1999; CSIRO unpubl.). Together with previous holdings, this has brought the number of individual families from superior natural provenances to over 100 (see also Table 2).

Table 2. Available genetic resources of E. cladocalyx *in planted stands in southern Australia* (prepared by ALRTIG Hardwoods Technical Committee, October 1999)

Organisation and location	Planting year	Number of provenances	Number of families	Number of sites	Total trees	Last measure
CSIRO						
Benalla	1998	8	64	1	2000	-
DNRE						
Colac	1996?	5		2	1000	1999
Horsham: Wail, Barrett, etc.	1911 on	1		Several	20,000	-
Maryborough: Majorca	1900			1	20,000	-
Hamilton	1985	11834[a] (4 trees ex -Gilgandra)		3	144	-
Echuca arboretum	Old			1	1	-
CFTT						
Shepparton	Unknown	Unknown		1	20	-
You Yangs	1950?	Unknown		1	10,000?	-

Shepparton	1993?	Unknown		1	2000	-
ForestrySA						
Mt Gambier	?	Unknown		1	2000	-
PIRSA						
Murray Bridge	1992	5	SPA	1	400	-
Kersbrook	1992	5	SPA	1	455	-
Private						
Direct seeded belts (hundreds of km in w. Victoria). Probably ex-Wirrabara				Many		-
Total trees					*50000+*	

[a] CSIRO seedlot number

ALRTIG is coordinating seed collections from around 25 outstanding trees in planted stands in western Victoria and South Australia, in February-June 2000. Most of these selections have been made in extensive stands believed to originate from the Wirrabara provenance. Given a relatively high selection intensity, these families should be somewhat superior in performance to natural-stand families. Table 2 summarises the known planted genetic resources of the species.

It will be feasible to assess the 1998 CSIRO provenance-progeny trial of 90 ATSC family seedlots in December 2000, at age around 2.3 years. This trials test 90 families, including some from previously untested provenances. Trees in this trial should average 3 m tall at time of this assessment, large enough to detect differences in vigour and forking. Any families displaying outstanding performance could be included in the new ALRTIG breeding population. CSIRO has reserved 5 g of seed from most of the families in these trials for this eventuality (some families, however, are already exhausted).

5. Proposed ALRTIG Improvement Strategy for *E. cladocalyx* and Summary of Improvement Plan

5.1. Outline of Proposed Improvement Strategy

In the short term, to year 2005, superior seed of *E. cladocalyx* can only be provided from superior trees in the best natural provenances (Flinders Chase and Wirrabara) and from already-established seed production areas. These sources should be considerably superior to unselected seed from the poorer provenances (Wanilla, Wilmington). It is considered likely that the PIRSA seed production area at Kersbrook, and a seed production area that is being developed at Wail, western Victoria would produce seed of the best genetic quality during this period. Seed collected from trees of superior phenotype in windbreaks around Colac and Lismore, western Victoria, may also be genetically superior to natural-provenance seed. The CSIRO seed orchard at Benalla, Victoria, should also make a useful contribution by around year 2005.

ALRTIG will establish four large, family-identified progeny trials that will be progressively thinned to become seedling seed orchards. The timing of thinning can be varied from site to site, to meet the dual objectives of early seed production and collection of progeny information. One of three sites designated as PT-SSOs (progeny trial –seedling seed orchards) can be thinned early, for rapid seed production purposes. The remaining two PT-SSOs can be flexibly managed and either left unthinned for a longer period, to provide genetic data, or thinned early should demand for seed be very high. The PT-CSO (progeny trial – clonal seed orchard) site in WA will be left unthinned for as long as practical, and thereafter lightly thinned, to provide data such as age-age correlations. Scion material can be collected from this site should the need for clonal seed orchards arise.

The breeding strategy in the main population can be defined as recurrent selection for general combining ability with open pollination in single populations keeping family identity (Eldridge et al. 1993). Details of the strategy and plan are given below, and in diagrammatic form in Figure 2.

This PT-SSOs combine the breeding and propagation populations in a single plantation on each site for each generation. These plantations serve sequentially as progeny tests of trees selected in the previous generation, as a basis for selection and breeding for the next generation, and finally as commercial seed orchards. They also function as both progeny and provenance trials to identify planted stands and areas in the natural range of interest for future seed collection, and provide estimates of genetic parameters (heritabilities, genotype by environment interactions, age-age correlations) for *E. cladocalyx*. Regeneration of the main ALRTIG breeding population is based on open pollination.

The option of clonal seed orchards, and an elite nucleus breeding population, regenerated by controlled pollination to provide more rapid genetic gains has been considered. However, in view of the expected good genetic merit of the seed from the interim seed production areas at Kersbrook and Wail (based on the good performance of second-generation plantings at Wail and in the DNRE Colac trials), this option is not considered appropriate at this stage, given ALRTIG's limited resources. However, should the demand for seed from first generation SSOs exceed their production capacity, ALRTIG may choose to establish CSOs.

The option of vegetative propagation of elite genotypes, leading to clonal forestry with field-tested clones of *E. cladocalyx*, would be the quickest way of mass-producing highly superior planting material, and will be evaluated by cutting propagation trials during year 2000.

5.2. Expected Genetic Gains

Experience from other eucalypt breeding programs indicates that usable volume gains of up to 20% can be anticipated from seed produced by the seedling seed orchards, over and above those from provenance selection, with substantial improvement in form traits as well. The actual magnitudes of gains to be achieved will depend on heritabilities and genetic variances of the traits of interest. These gains result from genetic selection during the selective thinning of the orchards, and reduced levels of inbreeding relative to that in natural stands (assuming that good flowering and high levels of outcrossing are achieved). A significant proportion of the gains to be achieved in the first cycle will be due to releases from ‘neighbourhood inbreeding’. Natural stand eucalypt seed has a degree of inbreeding due to neighbourhood inbreeding effects (Eldridge et al. 1993).

Selection in the first cycle of this program is planned to be carried out at young ages (3 to 6 years). To validate the worth and durability of such selections, studies of age-age correlations will be carried out. Even if correlations of performance between the early selection ages and full rotation ages are only moderate, substantial gains will still be provided by the rapid generation turnovers which will be achieved.

Clonal seed orchards which are developed with high selection intensities and rogueing based on progeny tests would offer significant additional gain relative to the open-pollinated seedling seed orchards. Vegetative propagation of outstanding clones, if feasible, would deliver the highest level of genetic gain within any one generation (Shelbourne 1992).

Gains beyond the first cycle will depend on accuracy in selecting the best genotypes and management of inbreeding in both the breeding and propagation populations. Gains in the first and all subsequent cycles will be cumulative. If agricultural experience and even that from other eucalypt programs can be taken as guides, then 3 to 5 generations of breeding *E. cladocalyx* should provide wood-production populations with an average performance, in terms of the improvement objective, exceeding that of the best trees propagated from natural stand seed (Namkoong et al. 1980; Meskimen et al. 1983).

5.3. Interim Seed Sources for Years 2000-2007

5.3.1. Natural-provenance seed

Small amounts of seed have been collected from superior trees in known superior natural provenances such as Wirrabara and Flinders Chase. CSIRO has undertaken such collections in 1999 and 2000, to obtain individual-tree seedlots for the ALRTIG seed orchards. Seed surplus to ALRTIG requirements can be bulked and sold by CSIRO. ALRTIG can promote the use of such seed.

5.3.2. PIRSA seed production area

The PIRSA multi-provenance SPA at Kersbrook established in 1992 was thinned in January 2000. Seed produced from flowering after this thinning will be suitable for collection and sale as a somewhat-improved seed source, from mid 2001.

5.3.3. Seed production area at Wail

Second-generation plantations at Wail, western Victoria, are ideal for conversion to seed production areas. These plantations were established in the early 1970s using a mix of seed collected from several trees of superior phenotype selected in first-generation plantations at Wail, which were in turn derived from seed collections made from superior trees in the Wirrabara natural provenance made by ForestrySA (formerly the South Australian Woods and Forests Department). The plantations have been well-maintained and thinned to a density of around 400 sph, and display a high proportion of straight, vigorous trees. Further selective thinning to around 200 sph, and fertiliser application, should promote heavy flowering and seed production. DNRE Horsham will manage one of the stands in this way.

5.3.4. Other planted seed production areas

Seed collected from trees of superior phenotype in windbreaks around Colac and Lismore, western Victoria, may also be genetically superior to natural-provenance seed (Harris 2000). Some of these windbreaks are being felled for firewood, enabling easy seed collection from felled trees.

5.3.5. CSIRO SSO planted in 1998

The SSOs established in 1998 by CSIRO partners at Benalla, Victoria should, if properly developed by selective thinning, commence commercial seed production in around year 2005.

5.4. Main Breeding Population and First Seedling Seed Orchards

5.4.1. Composition of ALRTIG main breeding population

For a long-term breeding program running over several generations, it is desirable to have an initial breeding population of 100 or more unrelated families. Following the March 2000 collection, CSIRO currently holds over 100 families from the best natural provenances, Wirrabara and Flinders Chase. A further 25 or so families from trees of superior phenotype in planted stands of known provenance origin (mainly Wirrabara) will be obtained by ALRTIG during year 2000.

A final review of the families to be included will be made by the ALRTIG Hardwoods Technical Committee in January 2001. Taking into account the year 2000 collections from natural and planted stands, selecting the best families from among the above seed sources should give a total of at least 100 families for inclusion in the ALRTIG main breeding population. Seed (10 g) from each family used in the ALRTIG trials will be reserved and kept in long-term (20 year) storage at CSIRO FFP.

5.4.2. Deployment of main breeding population

The ALRTIG Hardwood Technical Committee has decided to deploy the first cycle of the main breeding population in progeny trials at four sites: one each in South Australia, Western Australia, Victoria and NSW. Following assessment of early performance, three of the trials (in SA, VIC and NSW) will be developed by selective thinning into seedling seed orchards (SSOs). The site in WA will be left unthinned for longer, and can optionally be used as a scion collection resource. This stand is referred to as a PT-CSO.

The sites will be selected according to the following criteria:

- Located within the general range of climates in which the species is planted (350-600 mm annual rainfall, winter or uniform rainfall).
- Detailed site assessment, involving coring or excavation to 3 m soil depth, to confirm that the site should support reasonable growth and seed production of *E. cladocalyx*. At least one of the five sites will be judged capable of supporting heavy, early flowering and seed production. One site, nominally in South Australia, may be located on a slightly-saline site with salinity levels of around 5-8 dS m^{-1} EC_e that would enable discrimination between salt-tolerant and salt-sensitive genotypes of the species.
- Sites should be level or gently sloping with no large environmental gradients nor irregularities within the area to be planted.
- Land either owned/managed by a participating agency, or an agreement negotiated and signed with land owner, giving secure tenure and intellectual property rights to the trial for at least 10 years (it may be necessary to offer the land-owner a share of the seeds to be produced, to secure such agreements).
- Site conveniently accessible to the relevant lead ALRTIG agency, for establishment and management of the planting, and seed collection.
- Isolated by at least 200 m from other stands of *E. cladocalyx* to avoid contamination with unselected pollen.

Seedlings for all four plantings may be raised in different nurseries but will be given a common set of field number codes for raising in the nurseries, which will remain unchanged even if not all progenies are successfully raised or planted at all sites.

5.4.3. Standard design of ALRTIG progeny trials with adjacent block planting

Assuming that there are no restrictions imposed by the shape of the planting area, the three PT-SSO plantings will use an identical layout and design. A different treatment randomisation will be used at each site. The standard will be a latinised row column design with 4 replicates and one 5-tree line plot of each family in each replicate. Assuming there are 100 families, this equates to a total of 100 x 20 = 2000 trees. Two external perimeter rows increases the number of trees to about 2400 trees. The initial spacing will be 4 m between field rows and 2 m between trees along rows. This planting density has been selected as optimum for the PT-SSOs. While lower initial stocking may delay the onset of thinning and reduce competition on the sites, problems with weed control and heavy branching may result. Though heavy lower branching can be managed by pruning, this is undesirable in a genetic trial.

The PT-CSO, to be planted in WA will differ from the PT-SSOs only in the initial spacing. The PT-CSO will be thinned later and will have an initial spacing of 4 m between rows and wider spacing, 2.5 m, between trees.

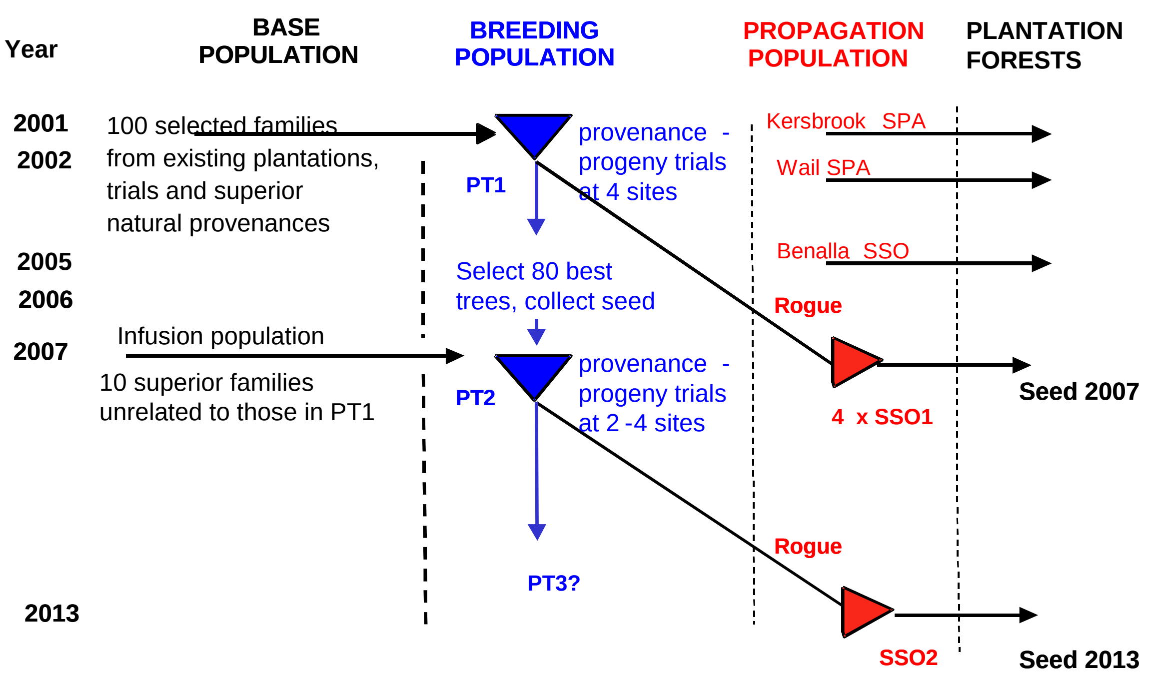
If needed, additional block of 144 trees (12 x 12) will be planted at one side of each trial, at the same spacing. This block will incorporate 12 trees from 12 families of the best performing seed sources. It will be left unthinned for at least 6 years, to demonstrate the stand performance of the best available seed sources of *E. cladocalyx* in a block planting, under the climate and soil conditions prevailing at each site. These blocks will be valuable for further studies not directly related to breeding, for example water use, silvicultural thinning, pruning, nutrition, effect of trees on soil, etc. The close spacing of the trees should reduce flowering and any associated pollen contamination of the adjacent orchard. In some cases, these blocks may be unnecessary, due to the close proximity of nearby resource plantings. It is likely that resource plantings will be established and managed by ALRTIG agencies as plantation and silviculture trials using the same seed sources as the PT-SSOs.

The total area required for each planting will be of the order of two hectares. Fencing, site preparation, fertilising, weed management and other management issues will be covered in individual working plans drawn up by the relevant lead agency for each site.

5.4.4. Scheduling of operations to rapidly develop seedling seed orchards

A detailed description of operations for the first generation, together with a time scale for each stage, is presented below (see Box 1) and summarised diagrammatically in Figure 2. This time scale applies to those sites that are selected for early conversion to SSOs. At least one site (in WA) will be left unthinned for longer, as a progeny trial. The time scale is approximate only. Different trials will probably grow at different rates, so the scheduling of operations may diverge at the different sites.

Figure 2. Improvement strategy for *E. cladocalyx*: interim seed sources and main breeding population



The details of the second cycle of the main breeding population will be determined after a review of the information obtained from the first cycle of breeding. One very important question that must be addressed is whether there is sufficient genotype-by-environment interaction to warrant two or more separate breeding populations in the second generation.

Box 1. Summary of *E. cladocalyx* tree breeding activities

2001	*Establishment of four ALRTIG progeny trials*
Purpose:	First cycle of breeding population, later to be converted by selective thinning to first-cycle seedling seed orchards.
Material:	Approximately 100 open pollinated families from superior natural provenances and planted stands of these provenances (Table 1).
Design:	Randomised latinised row-column design with 4 replicates. Each family will be represented a single 5-tree row plot in each replication. Surrounded by external perimeter row of surplus stock. Spacing will initially be 4 m between rows and 2 m within rows in the PT-SSOs; 4m between and 2.5 m within for the PT-CSO. Adjacent block planting of 144 (12 x 12 trees) to be left unthinned and planted at same spacing as adjacent stand.
2004	*First major assessment of progeny trials*
Age:	Around 3-4 years (crowns touching along rows, mean tree height about 5-6 m).
Purpose:	Assess height, dbh and proportion of trees that are forking/single-stemmed. First estimate of relative performances of different seed sources (natural provenances planted stands, and individual families.
2004	*First thinning of PT-SSOs*
Age:	3+ years, after the first major assessment is completed (trees to be thinned can be marked by the assessment team).
Selection:	Remove up to worst 2 trees in each 4-tree row plot, retain 2 best trees. PT-CSO left unthinned.
Purpose:	Reduce stocking to maintain vigorous growth and deep crowns on the best trees within each family.
2006	*Second assessment of progeny trials*
Age:	5+ years - exact timing will depend on actual growth and development at individual sites. Mean tree height about 7 m.
Purpose:	Further assessment to compare families and allow estimation of age-age correlations and other genetic parameters. This assessment will provide performance data to assist selection of parents for the second cycle.
2006	*Second thinning of PT-SSOs to develop orchard function*
Age:	Immediately following second assessment and analysis of assessment data
Selection:	Remove the worse of the two trees in each PT-SSO plot to leave the single best tree per family row plot, reducing stand density to around 312 stems/ha. Also, completely remove the worst 20% of plots of the inferior families, to reduce stand density to around 250 stems per hectare. Thinning to achieve this final density will be conducted using selection based on a multi-trait selection index (Cotterill & Dean 1990). Initial development of the orchard's seed production capacity will be achieved by this second thinning, as neighbouring trees will be unrelated enabling open pollinated matings to produced highly out-crossed seed. Thinning of the PT-CSO site may be necessary at this stage to maintain stand vigour.
2007	*Selection of seed parents for the second cycle*
Age:	6+ years
Selection:	Selection method to be determined based on analysis of assessment data. Extent of genotype-by-environment interaction will determine whether single or multiple breeding population is appropriate for second cycle.

2007	*Promotion of heavy flowering*
Age:	6+ years
Method:	Heavy fertilisation of PT-SSOs may be appropriate, to improve flowering and seed set. The application of a flowering promoter such as paclobutrazol could also be considered. Hives of bees may be introduced to the SSOs to promote cross-pollination if there are few pollinators on site (Moncur et al. 1995).
2008	*Seed collection for second cycle*
Age:	7+ years. Seed should be collected from capsules resulting from flowering **after** the second thinning. Adequate flowering and seed set required (at least 60% of retained trees flowering, and most of selections producing seed).
Method:	Seed will need to be collected and kept identified by individual parent tree.
2008	*Final thinning of C-1 seedling seed orchards*
Age:	72+ months.
Purpose:	Upgrade the genetic quality of seed to be produced and promote abundant flowering.
Method:	The ideal final stocking for abundant seed production is probably around 200 trees per ha (average spacing between trees around 7-8 m). A lower density would run the risk of higher levels of selfing, because increasing inter-crown distances reduce movement of pollinators between crowns. Thinning to achieve this final density will be conducted using selection based on a multi-trait selection index (Cotterill & Dean 1990).

5.5. Additional Components of the Improvement Strategy

5.5.1. Treatments to promote flowering and seed production

Recent studies on *E. nitens* in Tasmania indicate that high levels of nitrogen, applied as urea, can greatly increase flowering and seed production. Application of paclobutrazol, as a root drench of Cultar, may also stimulate flowering and seed production. It is recommended that a small scale replicated trial of these treatments be implemented in part of the PIRSA SPA in mid-2000, to see whether seed production on superior trees can be improved.

Experience with *E. camaldulensis, E. globulus* and *E. nitens* (Moncur et al. 1995) indicates that hives of honey bees located in seed orchards during flowering can increase the level of seed set and/or the outcrossing rate. This measure could be implemented at one of more of the seed orchards.

5.5.2. Clonal seed orchards and nucleus breeding

Abundant seed of good genetic quality produced by selectively thinned SPAs derived from the best natural provenances should be available from the Kersbrook (PIRSA) and Wail (Victoria DNRE) SPAs, from year 2001-2002. Based on the performance of the Wail second-generation plantations, this seed should be of sufficient quality to yield vigorous plantations in which the majority of trees can be developed into final crop (sawlog) trees with minimum silvicultural effort. The extra effort required to establish clonal seed orchards and nucleus breeding populations in the first generation of breeding therefore seems unwarranted. If demand for seed exceeds supply, ALRTIG may choose to establish one or more CSOs based on selections from the PT-CSO, and other genetic resources including the PT-SSOs.

5.5.3. Vegetative propagation study

As part of the ALRTIG strategy, CSIRO will conduct a small-scale study of the feasibility of propagating rooted stem cuttings of seedlings, during year 2000. This will determine whether mass-production of selected genotypes for clonal forestry is a realistic option for *E. cladocalyx*.

5.5.4. Provenance resource stands

ALRTIG will collaborate with individuals and organisations who are planting *E. cladocalyx*, to develop a number of provenance resource stands (block plantings of known provenance). Given the agreement of the plantation owners, these can provide several valuable functions in the ALRTIG improvement program, including a resource of candidate outstanding trees which could be grafting into the clone bank or supply seed, possible conversion of some stands to seed production areas by selective thinning, development of biomass equations, etc. ALRTIG will document the exact location, extent and provenance origin of potentially useful provenance resource stands, including those already established, in a database. ALRTIG may provide, or arrange provision, of seed of known superior seed sources for such plantings. Some of these stands could be based on seed collections from planted seed production areas such as Kerslake and Wail.

5.5.5. Genetic gain trials

Genetic gain trials are an important part of planning all tree improvement programs (Eldridge et al. 1993, p.180). If comparative trials are not planted it would never be known whether and by how much improvement has been achieved. Genetic gain trials, also known as yield trials, compare a small number of commercial varieties in well-designed replicated trials with large plots to allow for thinning and realistic measurement. As well as monitoring genetic gain, such trials can have a high value for extension: showing farmers how much they can increase productivity with new varieties.

Seed from the existing PIRSA seed production area, superior trees at Wail, and from the collections of superior natural provenances recently made by CSIRO, could be compared with ‘routine’ collections from natural provenance and planted stands in gain trials from year 2001. Such trials could be established by Regional Plantation Committees, Greening Australia and other agencies, with technical advice from ALRTIG and/or CSIRO’s Farm Forestry Seed and Information Support Program.

Later, gain trials should be established to compare the performance of the first commercial harvest of seed from the ALRTIG seedling seed orchards with seed production area seed and other commercially available seedlots.

5.5.6. Genetic conservation

Bonney (1994) describes the conservation status of *E. cladocalyx* in South Australia as good. Many of the natural provenances are located in National Parks and State Forests. There seems to be no pressing requirement for ex-situ genetic conservation.

5.5.7. Population genetics studies

Little is known about the provenance origin of most of the many woodlots and shelterbelts in southern Australia, limiting the usefulness of these secondary centres of diversity. A study of population genetics with molecular markers would be valuable in this regard. It would also be useful to establish the degree of outcrossing in natural and planted stands. ALRTIG would not carry out such studies with its own resources, but should provide support and family seedlots to agencies doing the studies.

6. Program Reviews

An essential component of genetic improvement programs is regular in-depth review, analysis, evaluation and subsequent revision. The first of such reviews for this program has been tentatively scheduled for mid 2001, when experience and results from the first 18 months of the program have been obtained. Further reviews would be conducted at least once every 2 years. There is sufficient expertise within ALRTIG to carry out the reviews, but it would be desirable for an outside expert not involved in the group to participate in the major reviews.

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PART 4: *EUCALYPTUS OCCIDENTALIS*

GENETIC IMPROVEMENT STRATEGY IN SOUTHERN AUSTRALIA

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1. Summary

Eucalyptus occidentalis is one of the eucalypt species selected for a collaborative genetic improvement program by ALRTIG (the Australian Low Rainfall Tree Improvement Group). A strategy for the improvement of *E. occidentalis*, combining elements from several successful eucalypt improvement programs in Australia and elsewhere, is recommended and described.

The **improvement objective** is to maximise the value of logs per hectare per year produced by plantations in the target planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles, posts and possibly pulpwood. The initial selection criteria are improved volume production, single straight stem, and tolerance to pests, diseases and salinity. Selection and breeding for improved wood properties may be appropriate from the second generation, once market prospects for different wood products become clearer, enabling important wood quality traits to be identified.

Superior natural provenances of the species (Grass Patch/Swan Lagoon, and Ravensthorpe) displaying rapid growth and good stem form, have already been identified from the results of provenance trials in South Australia. Further seed collections are being made from outstanding trees in these provenances, as an interim source of superior seed. Seed from two multi-provenance seed production areas established in South Australia in 1992 is now available, and four seedling seed orchards planted in 1998 (one in Victoria, one in NSW and two in Western Australia) should commence seed production by around 2004-2005.

ALRTIG will establish a new **main breeding population** in four new provenance-progeny trials at carefully selected sites, one in each participating State. These trials will incorporate a total of at least 70 families from (i) superior mother trees in the known better provenances and (ii) superior trees in field trials and planted stands of these provenances.

Three of the sites will be converted by selective thinning to seedling seed orchards (SSOs) which will supply genetically-improved seed for plantations and for the next generation of the main breeding population. These trials are termed progeny trial–seedling seed orchards (**PT-SSOs**). One site (in WA) will be left unthinned for longer, and may be used for selection of scions for a clonal seed orchard (depending on demand for seed). This stand is referred to as a **PT-CSO**, as it will serve as a progeny trial, which will supply material for clonal seed orchard establishment.

Grafting of 15 or so outstanding trees of superior provenances, selected from existing field trials and other planted stands, will be undertaken during 2000, to form a **nucleus breeding population** to produce highly-improved seed. The grafted clones will be maintained in clone banks for controlled pollination between elite trees, and one or more small-scale **grafted clonal seed orchards** incorporating these clones may be established. The nucleus population will be progressively upgraded with further outstanding trees from the newer trials as they reach selection age.

Vegetative propagation of seedlings of elite families, via rooted stem cuttings, is a possible route towards clone trials and clonal forestry with outstanding field-tested clones. The feasibility of developing this option will be evaluated in year 2000 by propagation trials, using seedlings from the best currently available families.

2. Background

Eucalyptus occidentalis, a species native to south-western Western Australia, has been extensively planted in many semi-arid and arid temperate regions around the world. Planting is mostly for firewood, shade, windbreaks and catchment afforestation rather than for industrial wood production, and is nowhere on a very large scale. Italy has the greatest area of plantations, with a total of over 10,000 ha in Calabria and Sicily.

Eucalyptus occidentalis has been planted widely as a farm forestry species, but not yet on a very large scale, in drier parts of southern Australia. It displays good growth on heavy soils subject to seasonal waterlogging and moderate salinity, making it ideal for plantings on salt-affected lands with rising water tables. The species is reported to be susceptible to damage by lerps (*Cardiaspina* spp.), gumleaf skeletonizer (*Uraba lugens*), sawflies (Pergidae) and termites in its natural range in Western Australia. Minor damage from leaf-eating beetles has been reported in New South Wales (Marcar et al. 1995). Prolonged outbreaks of lerp attack on *E. occidentalis* in its natural range were attributed to a newly described species of lerp, *Cardia jerramungae*, (Taylor 1992).

Eucalyptus occidentalis is one of the eucalypt species selected for a collaborative genetic improvement program by the Australian Low Rainfall Tree Improvement Group (ALRTIG), whose partners are given in Table 1.

Table 1. ALRTIG partners and collaborators

Partner/ collaborator organisation	State	Current involvement
State Forests New South Wales	NSW	All programs
ForestrySA	SA	All programs
Primary Industries & Resources SA	SA	All programs
Private Forests Tasmania	TAS	Softwoods program only
Department of Natural Resources and Environment (Includes Centre for Forest Tree Technology and Hamilton Pastoral and Veterinary Institute)	VIC	All programs
Department of Conservation and Land Management	WA	All programs
ANU Department of Forestry	National	Mallees (short-rotation crops) program only
CSIRO Forestry and Forest Products	National	All programs

3. Basic Elements of Planning Tree Improvement

3.1. Need for a Well Defined Strategy and Plan

Tree improvement programs aim to develop new plantations superior to their predecessors in one or several key economic traits. Programs start with a carefully chosen improvement strategy implemented through a dependent improvement plan. The key components of tree breeding are defined as follows (after Eldridge et al. 1993) -

Improvement strategy (a conceptual plan) - the framework of ideas, the conceptual overview, or philosophy of the management of genetic improvement of a tree species used in plantations. Its essential elements are

(a) population improvement by a combination of a particular type of **selection** and a particular type of **mating**, starting with a well adapted broad genetic base, and

(b) an efficient system for **mass propagation** of outstanding selected individuals either as seed or cuttings.

Improvement plan - having decided which Breeding Strategy (particular combination of selection and mating) will provide the greatest genetic gain per decade at an acceptable cost for a particular plantation program, and appropriate methods of mass propagation, the tree breeder can prepare a detailed Improvement Plan to implement the Strategy. Typically the plan includes a set of objectives and a flow chart of activity for each month for several years ahead and is subject to regular revision, every 2-5 years (Eldridge et al. 1993).

3.2. Clear Objectives

Tree improvement projects should have a clear set of objectives, defining the improvements required and identifying the traits for which to select.

3.3. Hierarchy of Populations in a Breeding Strategy

As an ongoing recurrent process, a breeding strategy accumulates benefits over successive generations of a cycle of testing, selection and mating (Figure 1). Every effective breeding strategy involves the maintenance of a hierarchy of four major types of population which can continue to meet the demand for genetically improved planting stock for a fourth population, the wood-producing plantations. The four populations are summarised as follows:

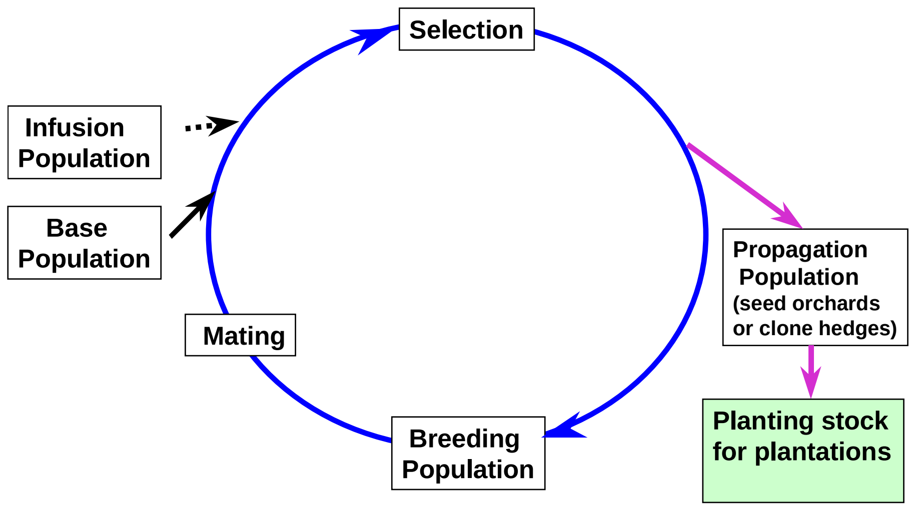
Base population - The base or gene resource population consists of the natural forests of *E. occidentalis* and some plantations in which selection can be carried out; these broadly-based reserves will continue to be a source of a wide range of genetic variation to meet future needs.

Breeding population - The selected trees and their progeny in a series of progeny trials and possibly clonal archives in which the breeding cycle of selection and mating will be repeated over many generations. This is the tree breeder’s main area of work.

Propagation population - The intensively selected trees (commonly fewer than 100 selected trees) propagated in seed orchards or cuttings multiplication areas where the combinations of genes selected in the breeding population are mass produced as genetically improved planting stock.

Production population - The major plantation areas established using the improved germplasm.

Figure 1. Activity cycle for tree improvement



A fifth type of population, the **infusion population**, describes additional material from the base population brought into the breeding population in the second and later generations to maintain adequate genetic diversity and provide additional superior genetic material.

3.4. Selection and Mating

Selection and mating are key activities in breeding. They accumulate genes, which influence yield and adaptation, increasing over successive generations the frequency of superior trees. Every successful breeding strategy, therefore, requires efficient methods of selecting superior material including the progeny tests in which the selection is carried out, appropriate measurement techniques and selection technology (e.g. selection indices). Mating can be done by open pollination or controlled pollination, carefully minimising the potential of inbreeding, which has been shown to be strongly deleterious in eucalypts.

In pursuing its principal functions of efficient selection and mating, a strategy should aim to assess the variation within a species, generate genetic information about it and see that genetic resources for future selection are conserved.

3.5. Personnel and Funding

Availability of technical expertise and institutional support as well as an appropriate level of funding over the longer term are key elements in determining the type of breeding strategy adopted.

4. Determinants of the ALRTIG Genetic Improvement Strategy for *E. occidentalis* in Southern Australia

4.1. Improvement Objective

The ALRTIG improvement objective for *E. occidentalis* is to maximise the value of logs (per hectare per year) produced by plantations in the target planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles, posts and possibly pulpwood. The initial selection criteria are improved volume production, a single straight stem with light branching, and resistance to pests, diseases and salinity. Sufficient high-quality germplasm to meet anticipated planting demand for the species across southern Australia must be produced, as soon as possible. Efforts may be made to improve wood properties, once market prospects for the wood products become clearer, enabling important wood quality traits to be identified.

Water use, an important consideration for plantings that aim to maximise water use so as to combat rising water tables, will be related closely to wood volume production. Water use of individual trees is strongly correlated with crown size and cross-sectional area of sapwood (Benyon et al. 1999). Water use is difficult and expensive to measure directly, and selection and breeding for increased water use *per se* is not considered a feasible breeding objective.

4.2. Target Planting Areas and Anticipated Scale of Planting

The target planting areas may be defined in general terms as suitable site types in the 350-750 mm winter/uniform rainfall zone in southern Australia. Temperature, site topography, local hydrology and soil type interact with rainfall to determine available moisture, so the rainfall range is only a general guide. *Eucalyptus occidentalis* displays better tolerance of salinity than the other hardwood species selected for improvement by ALRTIG. It is typically planted in lower parts of the landscape on heavy soils, and will tolerate salinities up to around 10 dS m^{-1} EC_e without reduction in growth. Salinities over 15 dS m^{-1} EC_e are injurious to the species (Marcar et al. 1995).

Seed sales by CALM and CSIRO seed centres alone of around 4 kg per year, and reports of seedling production in large nurseries in southern Australia, suggest the current planting rate is probably at least 300 ha per year.

The anticipated future scale of planting is hard to predict but will almost certainly increase substantially. It will be determined to some extent by the levels of government and investor support to farm forestry through tax concessions, grants, subsidies, carbon and salinity credits, and direct investment. It will also be partly dependent on the success of the ALRTIG improvement program. Availability of adaptable, fast-growing, straight stemmed varieties providing a more valuable commercial timber harvest should make planting more economically attractive, leading to greater uptake.

4.3. Selection Criteria and Traits for Selection

The ideal *E. occidentalis* tree for farm forestry plantations would be well-adapted to target planting environments (displaying excellent survival and health, tolerant of salinity, seasonal waterlogging and drought, and resistant to attack by pests and diseases) have good vigour, as expressed by rapid stem volume growth, a straight single bole, and light lower branches that self-prune.

The selection traits for the first generation are:
- usable stem volume (to top diameter over bark of 10 cm, estimated from height and dbh)
- stem straightness
- absence of forking
- resistance to pests and diseases
- tolerance of soil salinity for trials planted on saline sites.

For selection to be effective and lead to genetic gain, these traits must be heritable in the breeding population.

Standard guidelines for assessing stem form and branching in *E. occidentalis* will be developed for use across all of the ALRTIG trials.

4.4. Institutional Setting, Personnel and Available Funding

The participating agencies in ALRTIG have existing scientific and technical staff experienced in eucalypt breeding and propagation, who will implement the improvement strategy for *E. occidentalis*. They will be assisted until December 2001 by ALRTIG's National Coordinator, who will coordinate activities, oversee expenditure, and help to ensure that milestones and deadlines are met.

Short-term funding to support ALRTIG's collaborative activities has been provided by RIRDC via the Joint Venture Agroforestry Program. Funds available to ALRTIG for work on *E. occidentalis* total about $50,000, to be spent over the period June 1999 to June 2001 (extended to December 2001 because of the late start of the project), at which time this funding will cease. The RIRDC funding will be used to cover the direct salary costs of days worked by scientists and technicians on *E. occidentalis*, and other direct costs such as travel, seed collection, nursery operations and trial establishment and management.

The participating agencies will make matching funding contributions to meet the balance of staff salaries and organisational overheads. They also bring to the project considerable intellectual property and established genetic resources of the species (seed collections and field trials). They will provide the land required for genetic trials and seed orchards, or negotiate secure tenure for these plantings with other landholders.

The agencies will carry on the improvement program after June 2001, under collaborative or individual-agency management arrangements yet to be determined. Sales of seed or tested clones will generate revenues to support the collaborative project.

4.5. Information on the Species

A review of information on *E. occidentalis* has been prepared recently (Harwood 2000). Key factors influencing the choice of improvement strategy are summarised below.

4.5.1. Wood properties

Wood of *E. occidentalis* has been used to produce paper pulp on an industrial scale in Italy (G Mughini, pers. comm. 1999). Its wood is reported to be hard and durable, and suited for use as posts, poles, and for heavy construction (Hall et al. 1972). Detailed information on wood properties of ten-year-old plantation-grown trees in Italy is available (Ferrari 1991). Studies on wood from six-year-old plantations in Australia show it to have generally good pulping properties (Clark et al. 1999). In planted stands the species commonly displays poor stem form (low forking and heavy branching) reducing the production of economically usable wood. CSIRO and Melbourne University are currently conducting sawing studies on logs of *E. occidentalis* cut from 45-year-old plantations from the Barrett Reserve, western Victoria (P. Blakemore, pers. comm. 2000) and CSIRO plans to study the natural durability of *E. occidentalis* posts.

4.5.2. Taxonomic variation and hybrids

Eucalyptus occidentalis is related to a multi-stemmed shrub formerly described as *E. occidentalis* var. *stenantha* Diels ex Maiden, which has recently been given specific status and renamed *E. aspratilis* Johnson and Hill (Hill and Johnson 1992). *Eucalyptus aspratilis* differs from *E. occidentalis* in having persistent bark on the upper stem and limbs and a fruit shape that is cupular to cylindrical, rather than bell-shaped. *Eucalyptus astringens* has very similar buds, fruits and leaves to *E. occidentalis* but differs in having smooth bark to ground level and in preferring well-drained, hilly habitats (Boland et al. 1984). Natural hybrids with *E. rudis* have been observed (S. Hopper, pers. comm. 1999). In Morocco, promising results have been obtained from hybrids of *E. gomphocephala* with *E. occidentalis* (FAO 1981).

4.5.3. Pollination and breeding system

Studies on pollination and the breeding system of *E. occidentalis* have not been reported. By analogy with other *Eucalyptus* species with flowers of similar size, we may anticipate that insects (primarily flies and bees) are the main pollinators with nectarivorous birds also playing a significant role. *E. occidentalis* flowers are morphologically bisexual. Individual flowers are protandrous, meaning pollen is shed before the stigma is receptive and thus self-pollination is avoided at this level. In *E. occidentalis*, as in many other eucalypt species, individual trees produce many flowers over a long period in any given flowering season. Therefore, there is ample opportunity for selfing within the crown as flowers on individual trees develop at different times. Most *Eucalyptus* species investigated to date have a mixed mating system, with open-pollinated seed comprising a mix of outcrossed and inbred seed, the latter including both selfed seed and that arising between matings between close relatives. The proportions of outcrossed and inbred seed in natural provenances of *E. occidentalis* are not known.

4.5.4. Inbreeding depression

Isolated trees, stands where only a few trees flower, or stands that have a very narrow genetic base of only one or a few parents, can be expected to produce inbred seed that will produce plants that are poor in quality, with lower survival, slow growth and poor stem form, because inbreeding depression is strong in all *Eucalyptus* species investigated to date (Eldridge et al. 1993).

4.5.5. Flowering and seeding

Eucalyptus occidentalis flowers at a young age, buds and fruits being produced occasionally on seedlings in the nursery. Precocious flowering was obtained on seedlings less than one year old raised under a photoperiod of 16 hours per day (Bolotin 1975).

The time from bud initiation to anthesis is about 12 months in the natural range, and about 16 months in Israel (Zohar 1975). Anthesis occurs in the summer months in the natural range. Time from anthesis to seed maturity is believed to be about 12 months. Capsules on the tree retain mature seed for many months, unless the branches supporting them die. The number of viable seeds per kilogram of seed and chaff mixture is about 200,000. The average number of viable seeds per capsule is not known.

Depending on site and silviculture, *Eucalyptus occidentalis* seedling seed orchards may be expected to yield at least moderate seed crops from age 5-6 years. The PIRSA multi-provenance seed production areas at Red Hill and Bundaleer (South Australia) each yielded about 1 kg seed from 0.5 ha (= 2 kg/ha) from a bulk seed collection at age 7 years. A quick assessment made at the Red Hill seed production area in November 1998 by D. Bush, C. Harwood and R. Arnold indicated that about 30% of the trees were flowering at that time.

4.5.6. Controlled pollination

Methods of controlled pollination in eucalypts have been outlined by Moncur (1995). No basic problems are anticipated for *E. occidentalis*, but some testing will need to be done to determine the number of days to peak receptivity after anthesis, and whether more efficient ‘one stop pollination’ techniques such as those recently developed for *E. globulus* (Harbard et al. 1999) can be used.

4.5.7. Vegetative propagation

Mass vegetative propagation by rooted cuttings may be feasible for *E. occidentalis*. A high rooting percentage has been obtained in Israel, the species proving no more difficult than *E. camaldulensis* (Dr Yehiel Zohar, pers. comm. 2000). The latter species has proved suitable for clonal forestry. Efforts to develop cost-effective methods of mass propagating rooted cuttings in Australia are worth pursuing, as vegetative propagation of elite, field tested clones will capture much more genetic gain than seed from open-pollinated seed orchards (Shelbourne 1992). Usually, seedlings are easier to propagate by rooted stem cuttings than are selection-aged trees, even if the latter are cut to produce basal coppice shoots. Clonal propagation of seedlings produced by controlled crosses between elite trees, followed by clonal testing to identify the best clones, and maintenance of juvenile hedge plants by repeated hedging, may therefore be the best route to operational clonal forestry.

Grafting of scions from selected superior trees onto seedling rootstocks is expected to be feasible, as with most eucalypts investigated to date. This would enable the development of clone banks for controlled pollination between selections, and clonal seed orchards.

4.5.8. Genetic variation

Provenance trials have been conducted in several countries. Ten natural provenances were tested in small-scale provenance trials at five sites in South Australia, with mean annual rainfalls in the range 360 to 500 mm. The trials were assessed at age 3-5 years. Analysis of the results (Bulman et al. 1999) established that the Grass Patch (33°14 S, 121°43E) and Ravensthorpe (33°35 S, 120°02 E) provenances were consistently good performers in terms of height and diameter growth, and also had the highest proportion of single-stemmed trees. Three provenances (Rocky Gully, Thomas River and Esperance) were consistently slower-growing than the other seven. There was little provenance-by-site interaction in these trials. Unpublished 2-year and 4-year results of four provenance trials in Italy (two in Calabria and two in Sicily) indicate that Grass Patch, Ravensthorpe, Broomehill and Bremer Bay were the fastest-growing provenances of those tested, while the Peak Charles provenance (32°55S, 121°01E) performed very poorly (G. Mughini, pers. comm. 1999).

Five provenances of *E. occidentalis* were tested in a provenance trial on loess soil at Snaim in the northern Negev Desert of Israel. The best provenance, from a location 5 km east of Cape le Grande (33°56S, 122°18E) achieved a mean height of 7.7 m in 6 years, during which annual rainfall averaged 244 mm (Zohar & Moreshet 1987). The slowest-growing provenance, from 64 km north of Esperance (33°03S, 121°45E), had a height of only 4.07 m. The Cape le Grande provenance displayed significantly lower leaf-xylem water potential (down to as low as –5 Mpa) during the morning hours than the other provenances, and it was suggested that its greater capacity to transpire under low water potentials might explain its better performance at this arid site. It was also noticed that this provenance had some trees with straight trunks and produced fewer fruits than the other provenances. On saline sandy sites in the Gulf of Elat, Israel, the highest growth rate and resistance to salinity was displayed by a provenance collected north of Esperance (Zohar 1982).

The results from Israel are somewhat in contrast to those in Australia and Italy, in that the poorest provenance in Italy (64 km north of Esperance) is within 20 km of one of the best-performing provenances in the other trials, Grass Patch. More trials are required to determine the patterns of provenance variation in the species and the extent of provenance-by-environment interaction.

4.5.9. Estimates of genetic parameters

- *Heritabilities.* Significant provenance differences show that growth and form traits are under some degree of genetic control. Estimates of heritabilities for these, and other economically significant traits are not yet available for *E. occidentalis*, as progeny trials have not yet reached sufficient age for assessment. Based on experience with other eucalypts, it might be anticipated that within-provenance, narrow-sense heritabilities will be low (0.1-0.2) for growth traits, moderate (0.3-0.5) for stem form and branching traits, and high (> 0.5) for wood properties such as density (Eldridge et al. 1993). Progenies collected from superior trees in a provenance trial at Senaim, Israel, clearly outperformed a commercial control obtained from a local nursery when tested in a progeny trial (Zohar 1991).

- *Genotype-by-Environment Interaction* – Analysis of 3-5 year data from the five South Australian trials indicated that provenance-by-environment interactions were non-significant or small and of no practical importance for height, diameter and percentage of trees with single stems, there being consistently good and consistently poor provenances across the different sites. Genotype-by-environment interaction at the family and clonal levels has not yet been studied. Assessment of the provenance-progeny trials in Western Australia and Victoria planted by CALM and CSIRO in 1998 will provide estimates of genotype-by-environment interaction at the family level, as most of the families are in common across the different sites. Analysis of 3-year data should be available by 2002.

4.6. Available Genetic Resources

CALM has collected seed from 11 selected superior trees near Red Lake, close to the original Grass Patch collection. It will also collect an additional 10 or so trees from Swan Lagoon, the exact original location of the Grass Patch collection. It also has collections from 10 families at Jerramungup selected for resistance to the lerp *Cardia jerramungae.*

It is intended to collect seed from about 20 outstanding trees in planted stands in Victoria and South Australia, and from about 5 outstanding parents in planted stands in Western Australia during year 2000. These selections will be made in stands of known natural-provenance origin, where there has been a general flowering. Given a relatively high selection intensity, these families should be somewhat superior in performance to natural-stand families. Table 2 summarises the known planted genetic resources of the species.

It will be feasible to assess the 1998 CSIRO and CALM provenance-progeny trials of 90 ATSC family seedlots in December 2000, at age around 2.3 years. These trials test 90 families, including some from previously untested provenances. Trees in some of these trials should average 3 m tall at time of this assessment, large enough to detect differences in vigour and forking. Any families which display outstanding performance (assuming they are still available in the ATSC seed store) could be included in the new ALRTIG breeding population. CSIRO has reserved 10 g of seed from most of the families in these trials for this eventuality (some families, however, are already exhausted).

Table 2. Available genetic resources of E. occidentalis *in planted stands in southern Australia* (prepared by ALRTIG Hardwoods Working Group, October 1999)

Trial owner and location	Planting date	Provenance information	Number of families	Number of sites	Number of trees	Last measure
CSIRO and others						
Shelford, VIC	1998	Various (SSO)	90	1	2200	-
Wakool, NSW	1998	Various (SSO)	90	1	1800	-
CALM						
Wikkepin, WA	1998	Various (SSO)	100	1	2000	1999
Gingin, WA	1998	Various (SSO)	100	1	1000	1999?
PIRSA						
Various, SA	1993	Prov. trials	n.a.[a]	5	Unknown	1997-98
Bundaleer, SA	1992	8 bulk lots	n.a.	1 SPA	640 o.s.[b] (thinned to 50%)	1998
Red Hill, SA	1992	8 bulk lots	n.a.	1 SPA	706 o.s. (thinned to 33%)	1998
DNRE						
Hamilton	1985	Young River	Unknown	4	Unknown	1999
Hamilton	1989	Esperance	-	1	Unknown	1999
Barrett plantation 40km N. of Horsham, VIC	1940-1950	You Yangs[c]	-	1	>5000	-
Donald plantation 100km NE Horsham, VIC	1940-1950	You Yangs[c] Victoria	-	1	>5000	-
CFTT						
Timmering/ Tatura, VIC	1993	1 provenance	7	>1	Unknown	1997
Shepparton/ Nathalia, VIC	1993	3 provenances	-	>1	Unknown	1997
Timmering/ Tatura, VIC	1993	4 provenances	-	>1	Some candidate plus trees	1997
Kerang/ Girgarre, VIC	1993?	1 provenance	-	2	200	-
Lower Murray Water						
Mildura, VIC (sewerage irrigated)	1994	Katanning	-	1	ca. 5000	-

[a] Not applicable
[b] o.s. – original stocking
[c] Secondary seed source – original provenance unknown

5. Proposed Improvement Strategy for *E. occidentalis* and Summary of Improvement Plan

5.1. Outline of Proposed Improvement Strategy

In the short term, to year 2004, superior seed of *E. occidentalis* can only be provided from superior trees in the best natural provenances and from already-established seed production areas. These sources should be considerably superior to unselected seed from ‘average’ natural stands. By year 2004-5, seedling seed orchards established by CSIRO and CALM in 1998 should commence seed production.

ALRTIG will establish four large, family-identified progeny trials that will be progressively thinned to become seedling seed orchards. The timing of thinning can be varied from site to site, to meet the dual objectives of early seed production and collection of progeny information. One of three sites designated as PT-SSOs (progeny trial –seedling seed orchards) can be thinned early, for rapid seed production purposes. The remaining two PT-SSOs can be flexibly managed and either left unthinned for a longer period, to provide genetic data, or thinned early should demand for seed be very high. The PT-CSO (progeny trial – clonal seed orchard) site in WA will be left unthinned for as long as practical, and thereafter lightly thinned, to provide data such as age-age correlations. Scion material can be collected from this site as needed.

The breeding strategy in the main population can be defined as recurrent selection for general combining ability with open pollination in single populations keeping family identity (Eldridge et al. 1993). Details of the strategy and plan are given below, and in diagrammatic form in Figure 2.

The PT-SSOs combine the breeding and propagation populations in a single plantation on each site for each generation. These plantations serve sequentially as progeny tests of trees selected in the previous generation, as a basis for selection and breeding for the next generation, and finally as commercial seed orchards. They also function as both progeny and provenance trials to identify planted stands and areas in the natural range of interest for future seed collection, and provide estimates of genetic parameters (heritabilities, genotype by environment interactions, age-age correlations) for *E. occidentalis*. Regeneration of the main ALRTIG breeding population is based on open pollination.

Assuming grafting proves feasible, an open-pollinated clonal seed orchard, incorporating 20 or more outstanding selections from planted stands of the best provenances, and a small elite nucleus breeding population regenerated by controlled pollination, will be established at relatively low cost to provide more rapid genetic gains.

The option of vegetative propagation of elite genotypes, leading to clonal forestry with field-tested clones of *E. occidentalis*, would be the quickest way of mass-producing highly superior planting material, and will be evaluated.

There is a possibility that interspecific hybrid combinations with other eucalypt species might be highly productive; *E. occidentalis* x *E. gomphocephala* has been reported to be promising in Morocco (FAO 1981). Production of hybrids could be attempted by controlled pollination of trees in the nucleus population with pollen of other species, and any hybrid combinations produced evaluated in field trials. However, hybrid production with this species is of lower priority at this stage.

5.2. Expected Genetic Gains

A significant proportion of the gains to be achieved in the first cycle will be due to releases from 'neighbourhood inbreeding', found in natural stands of eucalypts (Eldridge et al. 1993; Burgess et al. 1996). Experience from other eucalypt breeding programs indicates that usable volume gains of up to 20% per generation can be anticipated from seed produced by the seedling seed orchards, over and above those from provenance selection, with substantial improvement in form traits as well. (Meskimen 1983). The actual magnitudes of gains to be achieved will depend on heritabilities and genetic variances of the traits of interest. These gains result from genetic selection during the selective thinning of the orchards (assuming that good flowering and high levels of outcrossing are achieved).

Selection in the first cycle of this program is to be carried out at young ages (3 to 6 years). To validate the worth and durability of such selections, studies of age-age correlations will be carried out. One site, the PT-CSO in WA, will be thinned later than the others (at around five years depending on stand development) and then only to reduce competition and to maintain stand vigour. Even if correlations of performance between the early selection ages and full rotation ages are only moderate, substantial gains will still be provided by the rapid generation turnovers which will be achieved.

Clonal seed orchards, which are developed with high selection intensities and rogueing based on progeny tests, would offer significant additional gain relative to the open-pollinated seedling seed orchards. Provided the ALRTIG grafting study establishes that grafting of this species is viable, this method of genetic improvement will be pursued concurrently to the seedling seed orchards. Vegetative propagation of outstanding clones, if feasible, would deliver the highest level of genetic gain within any one generation (Shelbourne 1992).

Gains beyond the first cycle will depend on accuracy in selecting the best genotypes and management of inbreeding in both the breeding and propagation populations. Gains in the first and all subsequent cycles will be cumulative. If agricultural experience and even that from other eucalypt programs can be taken as guides, then 3 to 5 generations of breeding *E. occidentalis* should provide wood-production populations with an average performance, in terms of the improvement objective, exceeding that of the best trees propagated from natural stand seed (Meskimen 1983; Namkoong et al. 1988).

5.3. Interim Seed Sources for Years 2000-2007

5.3.1. Natural-provenance seed

The CALM seed centre is best-placed to collect seed from outstanding phenotypes in known superior provenances such as Grass Patch and Ravensthorpe. This will be done as a standard CALM commercial operation, although ALRTIG will promote the use of such seed.

5.3.2. PIRSA seed production areas

The two PIRSA multi-provenance SPAs established in 1992 have already commenced seed production. These stands, based on the ten provenances tested in South Australia, have had about 50% of trees removed to date. In their present condition, it is considered unlikely that the seed which they produce is superior to that collected from the best natural provenances, as they incorporate some clearly inferior provenances (Rocky Gully, Thomas River, Esperance) of which many trees remain. A further 50% selective thinning of these stands is desirable, to increase the intensity of selection and the genetic quality of seed that they produce. This would lower stand density to about 275 stems per hectare, with average distance between trees about 6 m, not too distant for pollen transfer between trees by insects and birds. Collecting seed from only the better trees in these stands, rather than from all trees, would further lift the quality of seed collected, but reduce the quantity.

5.3.3.Other planted seed production areas

Field inspections of planted stands during year 2000 may identify some stands which could function as SPAs if selectively thinned.

5.3.4. CSIRO and CALM SSOs planted in 1998

The four SSOs established in 1998 by CSIRO and CALM should, if properly developed by selective thinning, commence commercial seed production in around year 2004-5.

5.4. Main Breeding Population and First Seedling Seed Orchards

5.4.1. Composition of ALRTIG main breeding population

For a long-term breeding program running over several generations, it is desirable to have an initial breeding population of 200 or more unrelated families (Eldridge et al. 1993). This is difficult in the case of *E. occidentalis*. Although the CSIRO and CALM seed centres currently hold over 100 families, provenance trial results indicate that some of these are from poorly-performing provenances and would not be appropriate for inclusion in the breeding population. Seed (10 g) from each family used in the ALRTIG trials will be reserved and kept in long-term (20 year) storage at CSIRO FFP.

A final review of the families to be included will be made by the ALRTIG Hardwoods Working Group in January 2001. Selecting the best families from among the above seed sources should give a total of at least 70, and perhaps as many as 80 families, for inclusion in the ALRTIG main breeding population. Infusion of additional unrelated families will be possible in subsequent generations.

5.4.2. Deployment of main breeding population

The ALRTIG Hardwood Technical Committee has decided to deploy the first cycle of the main breeding population in progeny trials at four sites: one each in South Australia and Western Australia, Victoria and NSW. Following assessment of early performance, these trials will be developed by selective thinning into seedling seed orchards (SSOs).

The sites will be selected according to the following criteria:

- Located within the general range of climates in which the species is planted (350-750 mm annual rainfall, winter or uniform rainfall).
- Detailed site assessment, involving coring or excavation to 3 m soil depth, to confirm that the site should support reasonable growth and seed production of *E. occidentalis*. At least one of the four sites will be judged capable of supporting heavy, early flowering and seed production. One site, nominally in South Australia, may be located on a semi-saline site with salinity levels which would enable discrimination between salt-tolerant and salt-sensitive genotypes of the species.
- Sites should be level or gently sloping with no large environmental gradients nor irregularities within the area to be planted.

- Land either owned/managed by a participating agency, or an agreement negotiated and signed with land owner, giving secure tenure and intellectual property rights to the trial for at least 10 years (it may be necessary to offer the land-owner a share of the seeds to be produced, to secure such agreements).
- Site conveniently accessible to the manager-partner, for establishment and management of the planting, and seed collection.
- Isolated by at least 200 m from other stands of *E. occidentalis* to avoid contamination with unselected pollen.

Seedlings for all four plantings will be raised at a single nursery, most probably in South Australia (convenient for distribution). The progenies will be given a common set of field number codes for raising in the nursery, which will remain unchanged even if not all progenies are successfully raised, or planted at all sites.

5.4.3. Standard design of ALRTIG progeny trials with adjacent block planting

Assuming that there are no restrictions imposed by the shape of the planting area, the three PT-SSO plantings will use an identical layout and design. A different treatment randomisation will be used at each site. The standard design will be a latinised row column design with 4 replicates and one 5-tree line plot of each family in each replicate. Assuming there are 70 families, this equates to a total of 70 x 20 = 1400 trees. One external perimeter row increases the number of trees to about 1550 trees. The initial spacing will be 4 m between field rows and 2 m between trees along rows. This planting density has been selected as optimum for the PT-SSOs. While lower initial stocking may delay the onset of thinning and reduce competition on the sites, problems with weed control and heavy branching may result. Though heavy lower branching can be managed by pruning, this is undesirable in a genetic trial.

The PT-CSO, to be planted in WA, will differ from the PT-SSOs only in the initial spacing. The PT-CSO will be thinned later and will have an initial spacing of 4 m between rows and wider spacing, 2.5 m, between trees.

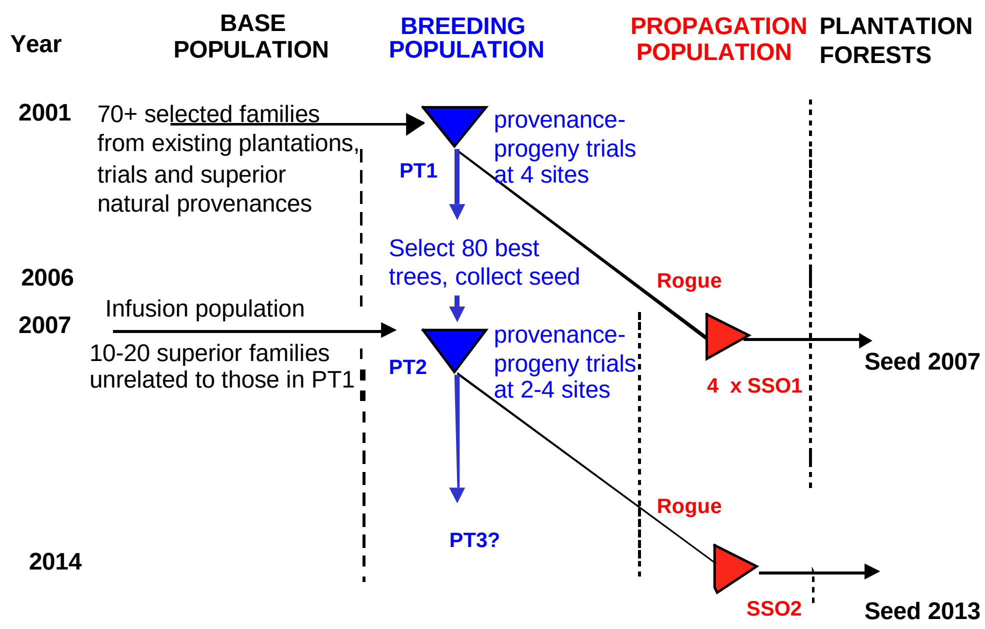
If needed, additional block of 144 trees (12 x 12) will be planted at one side of each trial, at the same spacing. Each block will incorporate 12 trees from 12 families of the best performing seed sources. It will be left unthinned for at least 6 years, to demonstrate the stand performance of the best available seed sources of *E. occidentalis* in a block planting, under the climate and soil conditions prevailing at each site. These blocks will be valuable for further studies not directly related to breeding, for example water use, silvicultural thinning, pruning, nutrition, effect of trees on soil, etc. The close spacing of the trees should reduce flowering and any associated pollen contamination of the adjacent orchard. In some cases, these blocks may be unnecessary, due to the close proximity of nearby resource plantings. It is likely that resource plantings will be established and managed by ALRTIG agencies as plantation and silviculture trials using the same seed sources as the PT-SSOs.

The total area required for each planting will be of the order of 1.3 ha. Fencing, site preparation, fertilizing, weed management and other management issues will be covered in working plans drawn up by the relevant lead agency for each site.

5.4.4. Scheduling of operations to develop seedling seed orchards

A detailed description of operations for the first generation, together with an approximate time scale for each stage, is presented in Box 1 below, and summarised diagrammatically in Figure 2. The trials will probably grow at different rates, so the scheduling of operations may diverge at the different sites.

Figure 2. Improvement strategy for *E. occidentalis* main breeding population



At least one of the PT-SSOs will be developed for improved seed production by heavy, early thinning. It will rapidly (within 6-8 years) deliver large quantities of improved seed. The SSOs will be developed from a broad and appropriate base (many families from known best provenances) on sites both representative of target planting environments and conducive to early, heavy flowering. However, the amount and quality of genetic information provided from the PT-SSO managed in this way will be modest, because the heavy selective thinning variably affects competition between trees and hence their relative performance.

In a regional environment where a species is less well-tested, provenance rankings are more uncertain, and there is not an urgent demand for large quantities of seed, the option of maintaining progeny trials with only light thinning, for at least 8-10 years, and then grafting out the best individuals into a CSO, is considered appropriate. The PT-CSO in WA will be managed in this way.

The early thinned PT-SSO and unthinned PT-CSO routes to improved seed production can be thought of as the two extremes of the way in which ALRTIG provenance-progeny trials of *E. occidentalis* could be managed. In practice, management can be adjusted according to circumstances. For example, if interim seed production areas produced high quality seed that successfully met the demand for improved *E. occidentalis* seed over the period 2001-2006, the first thinning of ALRTIG *E. occidentalis* SSOs could be delayed at least until 2006. This would improve the quality of genetic information obtained and make more accurate selections for the next generation of the breeding population and for grafting into CSOs. The quantity of seed produced by the SSOs, would, however be reduced, and the onset of seed production delayed.

The details of the second cycle of the main breeding population will be determined after a review of the information obtained from the first cycle of breeding. One very important question that must be addressed is whether there is sufficient genotype-by-environment interaction to warrant two or more separate breeding populations in the second generation.

Box 1. Summary of *E. occidentalis* tree breeding activity cycle

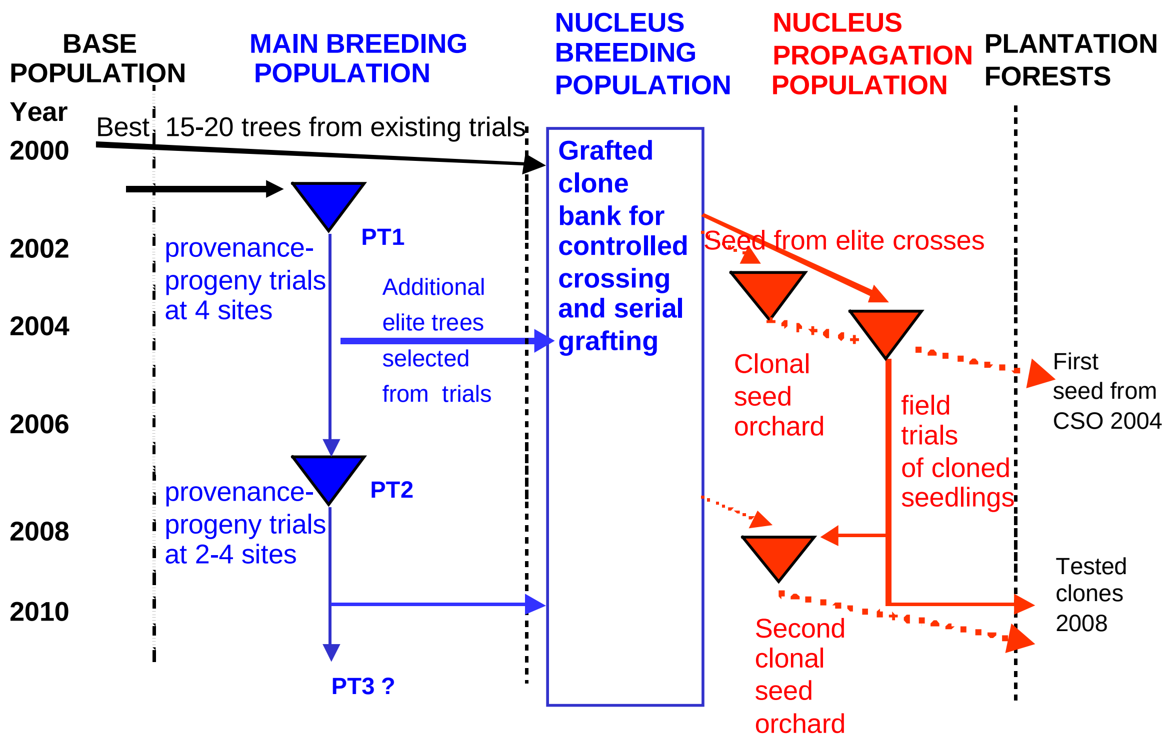
2001	*Establishment of four ALRTIG progeny trials*	
Purpose:	First cycle of breeding population; PT-SSOs to be converted later by selective thinning to first-cycle seedling seed orchards.	
Material:	Approximately 70 open pollinated families from superior natural provenances and planted stands of these provenances (Table 2).	
Design:	Randomised latinised row-column design with 4 replicates. Each family will be represented a single 5-tree row plot in each replication. Surrounded by external perimeter row of surplus stock. Spacing will initially be 4 m between rows and 2 m within rows in the PT-SSOs; 4m between and 2.5 m within for the PT-CSO. Adjacent block planting of 144 (12 x 12 trees) to be left unthinned and planted at same spacing as adjacent stand.	
2004	*First major assessment of progeny trials*	
Age:	Around 3 years (crowns touching along rows, mean tree height about 5 m).	
Purpose:	Assess height, dbh and proportion of trees that are forking/single-stemmed. First estimate of relative performances of different seed sources (natural provenances, planted stands, and individual families.	
2004	*First thinning of PT-SSOs*	
Age:	3+ years, after the first major assessment is completed (trees to be thinned can be marked by the assessment team).	
Selection:	Remove up to worst 2 trees in each 5-tree row plot, retain 3 best trees. PT-CSO left unthinned.	
Purpose:	Reduce stocking to maintain vigorous growth and deep crowns on the best trees within each family.	
2006	*Second assessment of progeny trials*	
Age:	Around 5 years - exact timing will depend on actual growth and development at individual sites. Mean tree height about 7 m.	
Purpose:	Further assessment to compare families and allow estimation of age-age correlations and other genetic parameters. This assessment will provide performance data to assist selection of parents for the second cycle.	
2006	*Second thinning to develop orchard function of PT-SSOs*	
Age:	Immediately following second assessment and analysis of assessment data	
Selection:	Remove the two worst of the three remaining trees in each PT-SSO plot to leave the single best one per family row plot. Also, completely remove the worst 10% of plots of the inferior families, so as to reduce stand density from around 250 to around 250 stems per hectare. Initial development of the orchard's seed production capacity will be achieved by this second thinning, as neighbouring trees will be unrelated enabling open pollinated matings to produced highly out-crossed seed. Thinning of the PT-CSO site may be necessary at this stage to maintain stand vigour.	
2006	*Selection of seed parents for the second cycle*	
Age:	5+ years	
Selection:	Selection method to be determined based on analysis of assessment data. Extent of genotype-by-environment interaction will determine whether single or multiple breeding population is appropriate for second cycle.	
2006	*Promotion of heavy flowering*	
Age:	5+ years	
Method:	Heavy fertilization of PT-SSOs may be appropriate to improve flowering and seed set. The application of a flowering promoter such as paclobutrazol could also be considered. It may be appropriate to introduce hives of bees to the SSOs to promote cross-pollination if there are few pollinators on site (Moncur et al. 1995).	
2006	*Seed collection for second cycle*	
Age:	6+ years Seed should be collected from capsules resulting from flowering **after** the second thinning. Adequate flowering and seed set required (at least 60% of retained trees flowering, and most of selections producing seed).	
Method:	Seed will need to be collected and kept identified by individual parent tree.	
2007	*Final thinning of C-1 seedling seed orchards*	

Age:	6+years
Purpose:	Upgrade the genetic quality of seed to be produced and promote abundant flowering.
Method:	The ideal final stocking for abundant seed production is probably around 200 trees per ha (average spacing between trees around 7-8 m). A lower density would run the risk of higher levels of selfing, because increasing inter-crown distances reduce movement of pollinators between crowns. Thinning to achieve this final density will be conducted using selection based on a multi-trait selection index, following a third assessment (Cotterill & Dean 1990).

5.5. Nucleus breeding population

Because of the great provenance variation revealed in the PIRSA provenance trials, and the need to substantially improve stem form to produce logs of acceptable quality for commercial use as sawlogs, poles and posts, it is considered worthwhile to establish a nucleus breeding population based on selections from the best natural provenances. This will provide accelerated genetic gain. Nucleus population activities are summarised diagrammatically in Figure 3.

Figure 3. Improvement strategy for E. occidentalis: clonal seed orchards, controlled crossing and clonal propagation



5.5.1. Selection of candidate trees for grafting into clone bank

During year 2000, existing trials and plantations of known provenance greater than 6 years old will be searched for outstanding phenotypes. Ideally, each outstanding tree should be from a stand of known superior provenance, and at least two standard deviations above the stand mean for the selection criteria (volume, absence of forking, and stem straightness) CFTT has already grafted 5 such selections from plantations near Shepparton. An additional 10 or so trees may be selected from other plantings in the eastern States and 5-10 in Western Australia. Overall, ALRTIG partners will aim to successfully graft a minimum of 4 ramets from at least 20 selected ortets, onto seedling root stocks, during year 2000.

Further selections for grafting into the clone bank could be made from the CSIRO and CALM progeny trials, from around year 2004. Later selections could be made from the PT-SSOs and PT-CSO.

5.5.2.Clonal seed orchards

Assuming grafting techniques for this species are successfully developed, an open-pollinated grafted clonal seed orchards (CSOs) will be developed in Canberra. Additional ramets for inclusion in the CSO could be propagated by serial grafting from the original grafts, or further collections of scion material from the ortets.

5.5.3. Controlled crossing in the clone banks

The grafts (Section 5.5.2.) will be raised in large pots at CSIRO (and perhaps other agencies), and managed intensively in clone banks so as to induce early flowering. They will then be available for controlled pollination. The agencies may exchange clones.

5.5.4. Deployment of control-crossed seed

Once grafts in the clone bank are flowering, a systematic set of controlled crosses can be made. Control-pollinated seed would be obtained from perhaps 30 crosses, with at least 10 individuals crossed to at least 3 others (experience with other species suggests that not all crosses will be successful). The progenies would be used for several purposes -

- field trials to establish the next generation of a nucleus breeding population in which genetic gain would be much faster than in the main breeding population of large open-pollinated progeny trials
- the field trials would rank the original selections for their general combining ability – this would assist the development of a grafted clonal seed orchard
- providing seedlings of superior quality to propagate as rooted cuttings which would be tested in field clone trials with a view to operational clonal forestry with field-tested clones (assuming that cutting propagation of *E. occidentalis* seedlings proves feasible)
- providing small amounts of high-quality seed for demonstration plantings to show the benefits of genetic improvement

Once control-pollinated seed is available in about 2003, seedling trials could be established in small field trials on at least 2 sites. With 30 families, 5-tree plots, 4 replicates and 4 x 2 m spacing, each trial would occupy 0.5 ha.

Clonal propagation of 5 seedlings from each of 30 crosses would aim to produce at least 16 ramets of each of the 150 seedling clones, sufficient for clone screening trials at 2 field sites, each trial consisting of 4 replicates of 2-tree plots of each clone, and occupying around 1 ha. Clonal tests, if successful and large enough, could also be converted to CSOs by removal of inferior clones.

5.6. Additional Components of the Improvement Strategy

5.6.1. Treatments to promote flowering and seed production

Recent studies on *E. nitens* in Tasmania indicate that high levels of nitrogen, applied as urea, can greatly increase flowering and seed production. Application of paclobutrazol, as a root drench of Cultar, may also stimulate flowering and seed production. It is recommended that a small scale replicated trial of these treatments be implemented in part of one of the PIRSA SPAs in mid-2000, to see whether seed production on superior trees can be improved.

Experience with *E. camaldulensis, E. globulus* and *E. nitens* (Moncur et al. 1995) indicates that hives of honey bees located in seed orchards during flowering can increase the level of seed set and/or the outcrossing rate. This measure could be implemented at one of more of the seed orchards.

5.6.2. Vegetative propagation study

As part of the ALRTIG strategy, CSIRO will conduct a small-scale study of the feasibility of propagating rooted stem cuttings of seedlings, during year 2000. This will determine whether mass-production of selected genotypes for clonal forestry is a realistic option for *E. occidentalis*.

5.6.3. Studies of wood and sawing properties

ALRTIG will closely monitor the progress of studies currently being carried out by CSIRO Forestry and Forest Products and Melbourne University on wood properties, sawing and pulping of plantation-grown *E. occidentalis*. The studies should clarify the economic potential of *E. occidentalis* wood, and identify any problem areas that might be addressed through genetic improvement.

5.6.4. Provenance resource stands

ALRTIG will collaborate with others who are planting *E. occidentalis*, to develop a number of provenance resource stands (block plantings of known provenance). Such stands could provide several valuable functions, including resources of candidate outstanding trees for grafting into the clone bank, seed supply, conversion to seed production areas by selective thinning, and development of biomass equations. ALRTIG will document the exact location, extent and provenance origin of potentially useful provenance resource stands, including those already established, in a database. ALRTIG may provide, or arrange provision, of seed of known superior seed sources for such plantings.

5.6.5. Genetic gain trials

Genetic gain trials, also known as yield trials, are an important part of planning all tree improvement programs (Eldridge et al. 1993, p.180). Comparative trials show whether, and how much improvement has been achieved. Genetic gain trials compare a small number of commercial varieties in well-designed replicated experiments with large plots to allow for thinning and realistic measurement. As well as monitoring genetic gain, such trials can have a high value for extension: showing farmers how much they can increase productivity with new varieties.

Seed from the existing PIRSA seed production areas, and from the recent collections of superior natural provenances by CALM, could be compared with ‘routine’ natural provenance seed sources in gain trials from year 2001. Such trials could be established by Regional Plantation Committees, Greening Australia and other agencies, with technical advice from ALRTIG. Seed from the SSOs established in 1998 by CSIRO and CALM may be available for gain trials by year 2004 or 2005.

Later, gain trials should be established to compare the performance of the first commercial harvest of seed from the ALRTIG seedling seed orchards with seed production area seed and regular industry seedlots.

5.6.6. Genetic conservation

Many of the natural provenances of *E. occidentalis* are small in extent, and it is possible some individual provenances could be lost through increasing salinisation of landscapes resulting from rising water tables following widespread land clearing for agriculture, leading to death of trees and entire stands. If known superior provenances are threatened in this way, it would be desirable for ALRTIG to support ex-situ conservation of these provenances. This could be achieved to some extent by long-term storage of seed from these provenances, and by well-documented provenance resource stands representing many parents from a particular provenance.

6. Program Reviews

An essential component of genetic improvement programs is regular in-depth review, analysis, evaluation and subsequent revision. The first of such reviews for this program has been tentatively scheduled for mid 2001, when experience and results from the first 18 months of the program have been obtained. Further reviews would be conducted at least once every 2 years. There is sufficient expertise within ALRTIG to carry out the reviews, but it would be desirable for an outside expert not involved in the group to participate in the major reviews.

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PART 5: *EUCALYPTUS TRICARPA*

GENETIC IMPROVEMENT STRATEGY IN SOUTHERN AUSTRALIA

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1. Summary

Eucalyptus tricarpa is one of the eucalypt species selected for a collaborative genetic improvement program by ALRTIG (the Australian Low Rainfall Tree Improvement Group). A strategy for the improvement of *E. tricarpa*, combining elements from several successful eucalypt improvement programs in Australia and elsewhere, is recommended and described.

The **improvement objective** is to maximise the value of logs produced by plantations in the target planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles and posts. The initial selection criteria are improved volume production, single straight stem, and resistance to pests, diseases and salinity. Selection and breeding for improved wood properties may be appropriate from the second generation, once market prospects for different wood products become clearer, enabling important wood quality traits to be identified.

Many **natural provenances** of the species across its range display good stem form. Collections have already been made with a view to establishing initial **breeding populations**. Several of these collections can act as an interim source of superior seed for operational plantings. Seed from a family by provenance trial in West Australia is now available for collection, and three trials in Victoria containing five provenances of *E. tricarpa* should commence seed production by year 2004-2005.

ALRTIG will establish a new **main breeding population** in three new provenance-progeny trials at carefully selected sites, in Victoria, NSW and WA. These trials will incorporate at least 130 families, mainly from superior mother trees in 13 provenances across its range. At least one and perhaps two of the trials will be converted by early, selective thinning to a seedling seed orchard. These trials are referred to as progeny trial – seedling seed orchards (PT-SSOs). They will supply genetically improved seed for plantations and for the next generation of the main breeding population. The trial situated in WA will be retained as a progeny trial, (ie. not be thinned until later), and will be used to supply genetic information such as age-age correlations and possibly scions for a clonal seed orchard if necessary. This trial is therefore termed a progeny trial – clonal seed orchard (PT-CSO).

Given the lack of knowledge about inter or intra provenance variation for this species, the breeding populations provide the first stage in formal domestication of *E. tricarpa*. The genetic information these will provide will enable decisions to be made about the feasibility of establishing **grafted clonal seed orchards and nucleus breeding populations.**

Vegetative propagation of seedlings of elite families, via rooted stem cuttings, is a possible route towards clone trials and clonal forestry with outstanding field-tested clones. The feasibility of developing this option will be evaluated in year 2000 by propagation trials, using seedlings from the best currently available progenies.

The research program will gain considerable assistance from regional plantation development schemes.

2. Background

Eucalyptus tricarpa, a species native to central and coastal Victoria and south coastal NSW, has been extensively harvested from natural stands. It has been little planted due to its natural abundance. However, harvestable native stands may become less readily available in the future. Planting of the species in Victoria has been mostly for shade, shelter and habitat values, rather than for industrial wood, and nowhere on a very large scale. It has been tested in many arid zones of the world as part of species introduction trials, notably in Israel, and Chile, where it is considered a candidate for afforestation in 200-400 mm rainfall zones.

Its wood is hard, durable and has long been used as posts, poles, and for heavy construction. Its use in finer construction such as furniture and craft wood is well known from the cottage industry. The sawn timber properties of 15 to 40 year old plantation trees of the closely related *E. sideroxylon* were found to be satisfactory, with outputs of quality product found to be improved by quality sawing and drying practices (Washusen et al. 1998). This study also indicated that the proportion of highest grade timber may possibly be increased by silviculture aimed at removing lower limbs at an early growth stage. Presumably, timber of *E. tricarpa* would have similar qualities.

Eucalyptus tricarpa has been planted widely for farm forestry purposes in drier parts of southern Australia, but not yet on a large scale. It has good growth on siltstone-derived soils of drier hills, though is not suited to areas subject to seasonal waterlogging or salinity. It often performs very well on sites somewhat better in quality than its natural stands, and may be useful for planting in areas where eucalypts that are more demanding have failed. This could include sites where *E. globulus* has proven to be insufficiently hardy to survive on periodically droughty sites.

The species is considered a useful commercial tree species for many low rainfall applications. Genetic improvement of growth and stem form, to complement its excellent wood quality and drought resistance will increase its usefulness. It has therefore been selected as one of the target eucalypt species for a collaborative genetic improvement program by ALRTIG, the Australian Low Rainfall Tree Improvement Group (Bush et al 2000). ALRTIG's partners are listed in Table 1.

Table 1. ALRTIG partners and collaborators

Partner/ collaborator organisation	State	Current involvement
State Forests New South Wales	NSW	All programs
ForestrySA	SA	All programs
Primary Industries & Resources SA	SA	All programs
Private Forests Tasmania	TAS	Softwoods program only
Department of Natural Resources and Environment (Includes Centre for Forest Tree Technology and Hamilton Pastoral and Veterinary Institute)	VIC	All programs
Department of Conservation and Land Management	WA	All programs
ANU Department of Forestry	National	Mallees (short-rotation crops) program only
CSIRO Forestry & Forest Products	National	All programs

3. Basic Elements of Planning Tree Improvement

3.1. Need for a Well Defined Strategy and Plan

Tree improvement programs aim to develop new plantations superior to their predecessors in one or several important economic traits. Programs start with a carefully chosen improvement strategy implemented through a dependent improvement plan. These essential components of tree breeding are defined as follows (after Eldridge et al. 1993):

Improvement strategy (a conceptual plan) - the framework of ideas, the conceptual overview, or philosophy of the management of genetic improvement of a tree species used in plantations. Its essential elements are :

(a) Population improvement by a combination of a particular type of **selection** and a particular type of **mating**, starting with a well adapted broad genetic base, and

(b) An efficient system for **mass propagation** of outstanding selected individuals either as seed or cuttings.

Improvement plan - having decided which breeding strategy (particular combination of selection and mating) will provide the greatest genetic gain per decade at an acceptable cost for a particular plantation program, and appropriate methods of mass propagation, the tree breeder can prepare a detailed improvement plan to implement the strategy. Typically, the plan includes a set of objectives and a flow chart of what is to be done each month for several years ahead and is subject to regular revision, every 2-5 years (Eldridge et al. 1993).

3.2. Clear Objectives

Tree improvement projects should have a clear set of objectives defining the improvements required and identifying the traits for which to select.

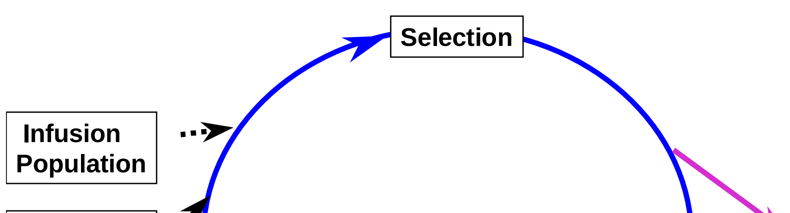
3.3. Hierarchy of Populations in a Breeding Strategy

As an ongoing recurrent process, a breeding strategy accumulates benefits over successive generations of a cycle of testing, selection and mating (Figure 1). Every effective breeding strategy involves the maintenance of a hierarchy of three major types of population which can continue to meet the demand for genetically improved planting stock for a fourth population, the wood-producing plantations. The four populations are summarised as follows:

1 Base population - The base or gene resource population consists of the natural forests of *E. tricarpa* and some plantations in which selection can be carried out. These broadly based reserves will continue to be a source of a wide range of genetic variation to meet future needs.

2 Breeding population - The selected trees and their progeny in a series of progeny trials and possibly clonal archives in which the breeding cycle of selection and mating will be repeated over many generations. This is the tree breeder's main area of work.

Figure 1. Activity cycle for tree improvement



3 Propagation population - The intensively selected trees (commonly fewer than 100 selected trees) propagated in seed orchards or cutting multiplication areas where the combinations of genes selected in the breeding population are mass produced as genetically improved planting stock.

4 Production population - The major plantation areas established using the improved germplasm.

A fifth type of population, the **infusion population**, describes additional material from the base population brought into the breeding population in the second and later generations to maintain adequate genetic diversity and provide additional superior genetic material.

3.4. Selection and Mating

Selection and mating are essential activities in breeding. They accumulate genes that influence yield and adaptation, increasing over successive generations the frequency of superior trees. Every successful breeding strategy, therefore, requires efficient methods of selecting superior material including the progeny tests in which the selection is carried out, appropriate measurement techniques and selection technology (e.g. selection indices). Mating can be done by open pollination or controlled pollination, carefully minimising the potential of inbreeding, which has been shown to be strongly deleterious in eucalypts.

In pursuing its principal functions of efficient selection and mating, a strategy should aim to assess the variation within a species, generate genetic information about it and see that genetic resources for future selection are conserved.

3.5. Personnel and Funding

Availability of technical expertise and institutional support as well as an appropriate level of funding over the longer term are important elements in determining the type of breeding strategy adopted.

4. Determinants of a Tree Improvement Strategy for *E. tricarpa* in Southern Australia

4.1. Breeding Objectives

For *E. tricarpa,* the following items comprise the initial objectives of a breeding program

1. Improved growth rate
2. Improved stem form

Drought resistance is not a breeding objective, as the breeding population is sought from within naturally drought resistant populations.

4.2. Target Planting Areas and Anticipated Scale of Planting

In Victoria, extensive possibilities exist in the 500 to 800 mm rainfall zone, on mudstone bedrock/sedimentary undulating terrain, in both inland and coastal districts. Country where species such as *E. globulus* have been tested for groundwater control, such as break of slope country in northeast Victoria may also have potential. Perhaps the greatest potential lies on the inland slopes of the Campaspe, Loddon and Avoca river headwaters, where former ironbark country was cleared for light pasture. Note that in the former natural distribution of *E. tricarpa*, deployment of exotic provenances might be considered inappropriate due to concerns about pollution of remnant natural genetic resources. This possibility suggests that in these areas improvement might be restricted to selection of a broad base of superior material within local provenances. This approach would result in a minimum of disruption to local genetic structure, in the event of cross pollination to natural stands.

In South Australia and Western Australia, there is a substantial area of land that might be appropriate to grow the species. *Eucalyptus tricarpa* is of great interest for farm forestry in the drier areas, with less than 650 mm annual rainfall. It has been suggested that *E. tricarpa*/*sideroxylon* is amongst the top four or five species for consideration in this area (Richard Moore, CALM Farm Forestry, pers. comm. 2000). In WA it requires good, relatively deep soil and does not perform at all well when planted in periodically waterlogged soils.

In NSW there is significant target plantation area. This species would be suited to replanting of recharge areas in low rainfall water catchments (in the NSW part of the Murray Darling Basin for example). Target regions with suitable soils and conditions would include the Riverina and the south west slopes.

Anticipated planting areas are very hard to forecast. There is little doubt that in the first instance improved *E. tricarpa* seed would be able to substitute for most *E. tricarpa* seed raised in extension nurseries, where the aim is primarily wood production or farm trees.

4.3. Selection Criteria and Traits for Selection

The ideal *E. tricarpa* tree for farm forestry plantations would be well adapted to target planting environments (displaying excellent survival and health, tolerance to dry conditions, and resistant to foliar grazing and wood boring insects). It would have good vigour, as expressed by reasonable stem growth, a straight single bole and light lower branches that self prune. Stem form and branching can also be manipulated to some extent by silvicultural practices such as close spacing and pruning.

The selection traits for the first generation are:

- Usable stem volume (to top diameter of 10 cm, and estimated from stem diameter and height)
- Absence of stem forking,
- A straight stem,
- Resistance to pests and diseases.

For selection to be effective and lead to genetic gain, these traits must be heritable in the breeding population.

Standard guidelines for assessing stem form and branching in *E. tricarpa* will be developed for use across all ALRTIG trials[1].

4.4. Institutional Setting, Personnel and Available Funding

The participating agencies in ALRTIG have existing scientific and technical staff, experienced in eucalypt breeding and propagation, who will implement the improvement strategy for *E. tricarpa*. They will be assisted at least until December 2001 by ALRTIG's National Coordinator, who will coordinate activities, oversee expenditure, and help to ensure that milestones and deadlines are met.

Short-term funding to support ALRTIG's collaborative activities has been provided by RIRDC via the Joint Venture Agroforestry Program. Funds available to ALRTIG for work on *E. tricarpa* total about $50,000, to be spent over the period June 1999 to June 2001 (extended to December 2001 because of the late start of the project), at which time this funding will cease. The RIRDC funding will be used to cover the direct salary costs of days worked by scientists and technicians on *E. tricarpa*, and other direct costs such as travel, seed collection, nursery operations and trial establishment and management.

The participating agencies will make matching funding contributions to meet the balance of staff salaries and organisational overheads. They also bring to the project intellectual property and established genetic resources of the species (seed collections and field trials). They will provide the land required for genetic trials and seed orchards, or negotiate secure tenure for these plantings with other landholders.

The agencies will carry on the improvement program after December 2001, under collaborative or individual-agency management arrangements yet to be determined. Sales of seed or tested clones will generate revenues to support the collaborative project.

4.5. Information on the Species

[1] Assessment scales will contain an even number of classes to which each tree's character is attributed. Stem form might be satisfactorily described by four or six categories ranging from excellent to poor. Branch scoring counts the number or classes of branches along a specified length of bole. Stem fork assessment can be best characterised by a binomial measure containing incidence, and a height above ground at which a fork occurs. Stem and branching characteristic scores can become complex and thus careful consideration of the traits to measure are required to ensure maximum inference from a minimum of measures.

A review of information on *E. tricarpa* is in process (Stackpole 2000). Key factors influencing the choice of improvement strategy are summarised below.

4.5.1. Taxonomic variation and hybrids

Eucalyptus tricarpa is related to *E. sideroxylon*, and until recently, both species were considered subspecies of *E. sideroxylon*.

4.5.2. Pollination and breeding system

Studies on pollination and the breeding system of *E. tricarpa* have not been reported. However, as a favourite species for apiary in natural habitats, considerable local knowledge of the flowering behaviour exists. Gloury (1998) found that flowering behaviour for *E. tricarpa* in central Victoria is influenced by site quality. He found that on the main site type, with relatively dry, shallow, yet fertile soils, flowering occurred in summer, prior to February in any given year. On the moister, and protected sites, trees tended towards winter flowering. The reason for this behaviour was not reported.

By analogy with other *Eucalyptus* species with flowers of similar size, we may anticipate that insects (primarily flies and bees) are the main pollinators with nectarivorous birds also playing a significant role. *E. tricarpa* flowers are morphologically bisexual. Individual flowers are protandrous, meaning that pollen is shed before the stigma is receptive and thus self-pollination of individual flowers is avoided. In *E. tricarpa*, as in many other eucalypt species, individual trees produce many flowers over a long period in any given flowering season. Therefore, many opportunities for selfing within the crown occur, as flowers on individual trees develop at different times. Most *Eucalyptus* species investigated to date have a mixed mating system, with open-pollinated seed comprising a mix of outcrossed and inbred seed, the latter including both selfed seed and that arising from matings between close relatives. The proportion of outcrossed and inbred seed in natural provenances of *E. tricarpa* is not known. This could be addressed by an isozyme study; ALRTIG will encourage such a study and could provide seedlots to support a researcher such as a university student.

4.5.3. Inbreeding depression

Isolated trees, stands where only a few trees flower, or stands that have a very narrow genetic base of only one or a few parents, can be expected to produce inbred seed. This seed will produce plants that are poor in quality, with lower survival, slow growth and poor stem form. This is because inbreeding depression is strong in all *Eucalyptus* species investigated to date (Eldridge et al. 1993).

4.5.4. Flowering and seeding

The age at which seed is first produced on *E. tricarpa* is not known. CALM's 14-year-old provenance-progeny trial in the Wellington catchment, WA did have seed crops from several seasons present, showing that seed production commenced no later than ten years of age. A small proportion of *E. tricarpa* trees in a DNRE provenance trial on a ridgetop site at the Saunders property north of Hamilton, Victoria planted in 1995 carried flower buds in February 2000. Depending on site and silviculture, *Eucalyptus tricarpa* seedling seed orchards may be expected to yield at least moderate seed crops from age 6-8 years.

The number of viable seeds per kilogram of seed and chaff mixture is about 220,000 (Boland et al. 1980). The average number of viable seeds per capsule is not known. However, seed extracted by CFTT in January 2000 appeared to bear at least five seeds per healthy capsule. The capsules can display persistent staminal rings upon seed maturity, which sometimes also carry the remains of the stamens. This forms a suitable cavity for occupation by spiders, which is often lined with web material. Both of these structures can obstruct the ready shedding of seed once dried, and can necessitate manual freeing of seed.

4.5.5. Controlled pollination

Methods of controlled pollination in eucalypts have been outlined by Moncur (1995). No basic problems are anticipated for *E. tricarpa*. Some testing will need to be done to determine the number of days to peak receptivity after anthesis, and whether more efficient ‘one stop pollination’ techniques such as those recently developed for *E. globulus* (Harbard et al. 1999) can be used.

4.5.6. Vegetative propagation

Vegetative propagation by rooted cuttings may be feasible for *E. tricarpa*. *In vitro* micro-propagation has been described for *E. sideroxylon* (Burger 1987). This species is of some interest for propagation by stem cuttings, as the propagation of *Eucalyptus sideroxylon* by this method has been reported, including a description of the influence of genetic variability on its success (Burger & Lee 1987). Efforts to develop cost-effective methods of mass propagating rooted cuttings in Australia are worth pursuing, as vegetative propagation of elite, field tested clones will capture much more genetic gain than seed from open-pollinated seed orchards (Shelbourne 1992). Usually, seedlings are easier to propagate by rooted stem cuttings than are selection-aged trees, even if the latter are cut to produce basal coppice shoots. Clonal propagation of seedlings produced by controlled crosses between elite trees, followed by clonal testing to identify the best clones, and maintenance of juvenile hedge plants by repeated hedging, may therefore be the best route to operational clonal forestry.

Grafting of scions from selected superior trees onto seedling rootstocks is expected to be feasible, as with most eucalypts investigated to date. This would enable the development of clone banks for controlled pollination between selections, and clonal seed orchards.

4.5.7. Genetic variation

Provenance trials have been conducted in Western Australia. Four natural provenances of *E. tricarpa* along with five provenances of *E. sideroxylon* were tested in a provenance-progeny trial at a site in the Wellington catchment east of Manjimup, with mean annual rainfall circa 650 mm. The trials were assessed at age 6 years. Analysis of the results (R. Mazanec 1999 unpublished) established that the Bodalla, Orbost and Bendigo provenances of *E. tricarpa* were consistently good performers in terms of height and diameter growth, and also had the highest proportion of single-stemmed trees. One provenance of *E. tricarpa* (Anglesea) was consistently slower growing and had much poorer form. All of these *E. tricarpa* provenances grew faster than the five provenances of *E. sideroxylon*, with Wangaratta (actually the Killawarra forest) the best of the latter species.

4.5.8. Estimates of genetic parameters

- *Heritabilities.* Significant provenance differences show that growth and form traits are under some degree of genetic control. Estimates of heritabilities for these and other economically significant traits are not yet available for *E. tricarpa*, as progeny trials have not yet reached assessment age. Based on experience with other eucalypts, it is anticipated that within-provenance, narrow-sense heritabilities will be low (0.1-0.2) for growth traits, moderate (0.3-0.5) for stem form and branching traits, and high (> 0.5) for wood properties such as density (Eldridge et al. 1993).

- *Genotype-by-Environment Interaction.* Assessment of provenance trials in Victoria planted by DNRE and CSIRO in 1998 will provide estimates of genotype-by-environment interaction at the provenance level, as the provenances are common across the different sites. As *E. tricarpa* occurs naturally across a wide range of rainfalls from over 1000 mm in coastal provenances such as Nowra, NSW to less than 500 mm in some western, inland Victorian provenances, some provenance-by-site interaction might well be expected. Analysis of 3-year data should be available by early 2002. It is possible that *E. sideroxylon* might perform better, relative to *E. tricarpa,* in central western NSW at latitudes north of about 34°S, north of the northernmost extent of the *E. tricarpa* natural distribution but within the natural distribution of *E. sideroxylon*. Genotype-by-environment interaction at the family and clonal levels has not yet been studied.

4.6. Available Genetic Resources

4.6.1. Family seedlots collected from natural provenances

CSIRO collections include 26 individual trees from three provenance locations: Narooma, Bodalla (both NSW), and Tarnagulla (Central Victoria). CFTT has collected seed from East Gippsland (3 provenances, 30 families), Heyfield (11 families) Christmas Hills (near Melbourne, 8 families), Clunes, Mt Bealiba, Whroo, Heathcote (10 families of each) and Lorne (10 families). See Stackpole & Tibbitts (2000) for details.

All these collections represent typical or above-average individuals in each stand, and are retained as individual family collections.

4.6.2. Planted stands of known provenance origin (Table 2).

Table 2. Available genetic resources of E. tricarpa *in planted stands in southern Australia* (prepared by ALRTIG Hardwoods Working Group, October 1999)

Manager	Location	Planting date	Provenances of *E. tricarpa*	Families	Sites	Trees	Last measure
CALM	Wellington catchment	1987	4	40	1	500+	1993
PVI	Hamilton	1995	2	-	4	768	
DNRE	Barnawatha	1998	5	-	1	?	2000
DNRE	Rutherglen	1998	5	-	1	?	2000
CFTT	Nathalia	1993	2	-	1	40	1997
CFTT	Shepparton	1994	2	-	1	200	1999

CALM WA has four provenances of *E. tricarpa*; each represented by ten individual parents, in a combined *E. tricarpa* and *E. sideroxylon* test in the Wellington catchment in WA. Seed crops were present on some of these in October 1999, and collections are planned for mid 2000.

Other stands of known *E. tricarpa* seedlots are planted in the CFTT managed Trees for Profit trials at Shepparton, although individual plot sizes are small, and no flowering activity has been observed. Two *E. tricarpa* seedlots are planted at four sites in the Hamilton District (Bird et al. 1996). These were planted with 24 trees for each provenance in each of four blocks, and may provide improved seeds.

If available, seed will be collected from outstanding trees in Victorian planted stands during 2000. These selections will be made in stands of known natural-provenance origin, where there has been a general flowering. Given a relatively high selection intensity, these families should be somewhat superior in performance to natural-stand families. Table 2 summarises the known planted genetic resources of the species.

It may be feasible to assess the 1998 DNRE/CSIRO provenance trials of five *E. tricarpa* provenances in March-June 2001 at age 3 years. These trials test five provenances. Trees in some of these trials should average 4 m tall at time of this assessment; large enough to detect differences in vigour and lower stem forking. Any provenances that display outstanding performance may be targeted for further collections in 2001, for inclusion in 2002 trials.

5. Breeding Strategy and Methods for Improvement of *E. tricarpa* in Southern Australia

5.1. Outline of Proposed Improvement Strategy

In the short term, to year 2004, superior seed of *E. tricarpa* can only be provided from superior trees in the best natural provenances and from already-established seed production areas. These sources may be considerably superior to unselected seed from ‘average’ natural stands. Untested natural forest collections collected by CFTT in 1999-2000 may form the basis of limited production planting. By year 2006-8, seedling seed orchards established by partner organisations in 2000-2001 should commence seed production.

ALRTIG will establish three large, family-identified progeny trials. Two of these will be progressively thinned to become seedling seed orchards (they are termed PT-SSOs). The other will be maintained as a progeny trial (it is termed a PT-CSO). The breeding strategy in the main population can be defined as recurrent selection for general combining ability with open pollination in single populations keeping family identity (Eldridge et al. 1993). Details of the strategy and plan are given below, and in diagrammatic form in Figure 2.

The PT-SSOs combine the breeding and propagation populations in a single plantation on each site for each generation. These plantations serve sequentially as progeny tests of trees selected in the previous generation, as a basis for selection and breeding for the next generation, and in the case of the PT-SSOs as commercial seed orchards. They also function as both progeny and provenance trials to identify planted stands and areas in the natural range of interest for future seed collection. Lastly, they provide estimates of genetic parameters (heritabilities, genotype by environment interactions, age-age correlations) for *E. tricarpa*. Regeneration of the main ALRTIG breeding population is based on open pollination.

A small elite nucleus breeding population, regenerated by controlled pollination, could be established at relatively low cost, if demand for seed warranted this. This would provide more rapid genetic gains. The option of vegetative propagation of elite genotypes, leading to clonal forestry with field-tested clones of *E. tricarpa*, would be the quickest way of mass-producing highly superior planting material, and will be evaluated once the first generation of the main breeding population has been assessed.

5.2. Expected Genetic Gains

Experience from other eucalypt breeding programs indicates that useable wood volume gains of up to 20% can be anticipated from seed produced by the seedling seed orchards. This gain is over and above those gains derived from provenance selection, with substantial improvement in form traits as well. The actual magnitudes of gains to be achieved will depend on heritabilities and genetic variances of the traits of interest. These gains result from genetic selection during the selective thinning of the orchards, and reduced levels of inbreeding relative to that in natural stands (if good flowering and high levels of outcrossing are achieved). A significant proportion of the gains to be achieved in the first cycle will be due to release from ‘neighbourhood inbreeding’. Eucalypt seed from natural stands has a degree of inbreeding due to neighbourhood inbreeding effects (Burgess et al. 1996, Eldridge et al. 1993).

Selection in the first cycle of this program is planned for young ages (3 to 6 years) in the PT-SSOs. To validate the worth and durability of such selections, studies of age-age correlations will be carried out. In addition to the PT-CSO, which will remain unthinned or only lightly thinned, re-assessment of CALM’s provenance-progeny trial in the Wellington catchment would enable correlations between 6-year and 16-year rankings of individual trees in an unthinned stand. Even if correlations of performance between the early selection ages and full rotation ages are only moderate, substantial gains will still be provided by the rapid generation turnovers that will be achieved from early selection.

Clonal seed orchards comprised of clones selected at high selection intensities, and subsequently rogued on the basis of progeny tests, would offer significant additional gain relative to the open-pollinated seedling seed orchards. Vegetative propagation of outstanding clones, if feasible, would deliver the highest level of genetic gain within any one generation (Shelbourne 1992). This option remains open if deemed necessary.

Gains beyond the first cycle will depend on accuracy in selecting the best genotypes and management of inbreeding in both the breeding and propagation populations. Gains in the first and all subsequent cycles will be cumulative. If agricultural experience and even that from other eucalypt programs can be taken as guides, then 3 to 5 generations of breeding *E. tricarpa* should provide wood-production populations with an average performance, in terms of the improvement objective, exceeding that of the best trees propagated from natural stand seed (Namkoong et al. 1988, Meskimen 1983).

5.3. Interim Seed Sources for Years 2000-2007

5.3.1. Natural-provenance seed

The CFTT genetics unit is equipped to collect seed from outstanding phenotypes in known superior Victorian provenances of *E. tricarpa*. This will be done as a standard CFTT commercial operation, although ALRTIG can promote the use of such seed. CSIRO’s ATSC may be the most appropriate organisation to arrange collections from coastal NSW populations if these prove useful.

5.3.2. CALM seed production areas

The CALM provenance-family trial in the Wellington catchment could be developed into a seed production area by selective thinning. This would be a relatively expensive operation, as the trees are now of substantial size (many exceeding 12 m in height) and several hundred trees would need to be felled and removed to enable access for seed collection. It would be desirable to completely eliminate the poorly performing Anglesea provenance of *E. tricarpa*, leaving the three provenances Narooma, Nowa Nowa and Bendigo which proved superior in this trial. The trial is laid out as a split plot design with families nested within provenance blocks, such that 100 trees of each provenance were planted in a 10 x 10 block in each of four replicates. Thinning to the best 20 trees per provenance block would yield good-quality thinned blocks, of reasonable size for seed production. It is possible that *E. tricarpa* might interbreed with *E. sideroxylon* in adjacent blocks, if flowering times overlap, and the performance of such inter-species hybrids is unknown.

5.3.3. Other planted seed production areas

Field inspections of planted stands during year 2000 may identify some stands that could function as seed production areas if selectively thinned.

5.4. Main Breeding Population and First Seedling Seed Orchards

5.4.1. Composition of ALRTIG main breeding population

For a long-term breeding program running over several generations, it is desirable to have an initial breeding population of 100 or more unrelated families.

CFTT and CSIRO currently hold over 140 families of this species. The relative value of these families is unknown, except that Anglesea (VIC) provenance proved particularly poor in CALM's trial. This leaves at least 130 families of largely unknown relative performance.

A final review of the families to be included in the first two trials will be made by the ALRTIG Hardwoods Technical Committee in April 2000. Selecting the best families from among the above seed sources should give at least 130 families for inclusion in the ALRTIG main breeding population. Seed reserves (10 g), of all families used in the ALRTIG PT-SSO/CSO trials will be placed in long-term (20 year) storage.

5.4.2. Deployment of main breeding population

ALRTIG will deploy the first cycle of the main breeding population in progeny trials at three sites: one each in Victoria, NSW and Western Australia. Following assessment of early performance, at least one and possibly two trials will be developed by selective thinning into seedling seed orchards (SSOs).

5.4.3. Site selection

The sites for the trials will be located within the general range of climates in which the species is planted (350-750 mm annual rainfall, winter or uniform rainfall). It is likely that PT-SSOs will be located at the wetter end of this rainfall range.

Potential sites will be assessed by the following procedures:

- Sites will be level or gently sloping with no large environmental gradients nor irregularities within the area to be planted. The layout of the SSOs will be designed to account for any identified variability within the site.
- Isolated by at least 200 m from other stands of *E. tricarpa* to minimize contamination with unselected pollen.
- Land either owned/managed by a participating agency, or an agreement negotiated and signed with the land owner. This would give secure tenure and intellectual property rights to the trial for at least 12 years. It may be necessary to offer the landowner a share of the seeds to be produced, to secure such agreements.
- Site conveniently accessible to the relevant lead ALRTIG agency, for establishment and management of the planting, and seed collection.

- Soil profile structure will be established at depth, by hand or mechanical augering. The whole profile is to be analysed at 30 cm intervals for pH, salinity and structure, and physical characteristics described. In addition A and B (if any) horizons will be assayed for N, P and micronutrient content. The purpose is to confirm that the site should support reasonable growth and seed production of *E. tricarpa*. At least one of the three sites will be judged capable of supporting heavy, early flowering and seed production (ie it will have good fertility and soil water holding capacity to allow vigorous, early crown development).

The program will have two establishment years: 2000 for the sites in Victoria and NSW, and 2001 for the site in Western Australia.

Seedlings for the 2000 plantings are being raised at a nursery in Victoria. The progenies have been given a common set of field number codes for raising in the nursery, which will remain unchanged even if some progenies are not successfully raised, or are not planted at all sites.

5.4.4. Standard design of ALRTIG progeny trials with adjacent block planting

Assuming that there are no restrictions imposed by the shape of the planting area, the two PT-SSO plantings will use an identical layout and design. A different treatment randomisation will be used at each site. The standard design will be a latinised row column design with 5 replicates and one 4-tree line plot of each family in each replicate Assuming there are 130 families, this equates to 130 x 20 = 2600 trees. One external perimeter row increases the number of trees by about 260 plants to about 2860 trees. The initial spacing will be 4 m between field rows and 2 m between trees along rows. This planting density has been selected as optimum for the PT-SSOs. While lower initial stocking may delay the onset of thinning and reduce competition on the sites, problems with weed control and heavy branching may result. Though heavy lower branching can be managed by pruning, this is undesirable in a genetic trial.

The PT-CSO, to be planted in WA will differ from the PT-SSOs only in the initial spacing. The PT-CSO will be thinned later and will have an initial spacing of 4 m between rows and wider spacing, 2.5 m, between trees.

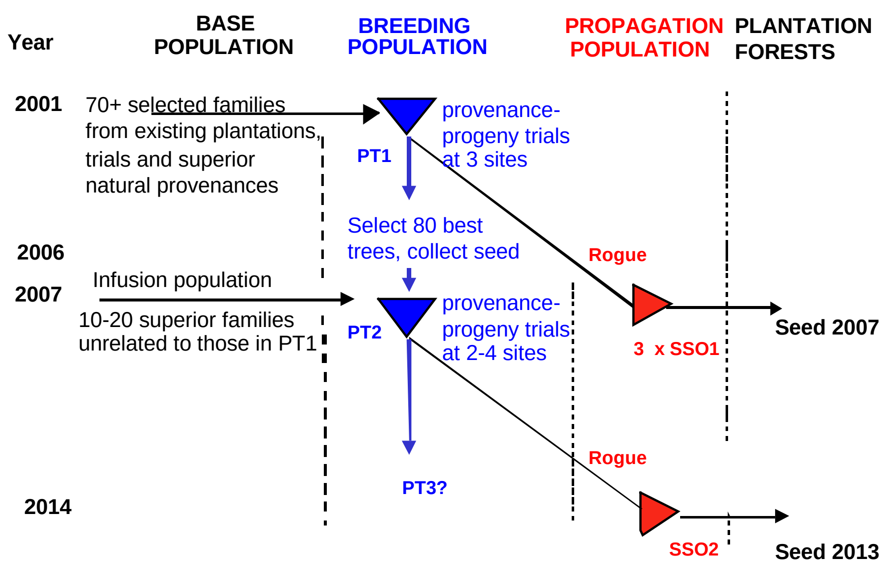
If needed, additional block of 144 trees (12 x 12) will be planted at one side of each trial, at the same spacing. This block will incorporate 12 trees from 12 families of the best performing seed sources. It will be left unthinned for at least 6 years, to demonstrate the stand performance of the best available seed sources of *E. tricarpa* in a block planting, under the climate and soil conditions prevailing at each site. These blocks will be valuable for further studies not directly related to breeding, for example water use, silvicultural thinning, pruning, nutrition, effect of trees on soil, etc. The close spacing of the trees should reduce flowering and any associated pollen contamination of the adjacent orchard. In some cases, these blocks may be unnecessary, due to the close proximity of nearby resource plantings. It is likely that resource plantings will be established and managed by ALRTIG agencies as plantation and silviculture trials using the same seed sources as the PT-SSOs.

The total area required for each planting will be of the order of 2.5 ha. Stand management in the first instance will entail standard soil preparation and weed control based on regional establishment processes. Sites will be fenced to stock proof standards, and rabbits and hares controlled by shooting, poisoning or construction of netted fences. A substantial allocation needs to be made to follow up maintenance to ensure uniform weed control, replacement of early losses, and monitoring. Fencing, site preparation, fertilizing, weed management and other management issues will be covered in individual working plans drawn up by the relevant lead agency for each site. Longer term management of these stands is detailed in the following sections.

5.4.5. Scheduling of operations to develop seedling seed orchards

A detailed description of operations for the first generation, together with a time scale for each stage, is presented below (see Box 1) and summarised diagrammatically in Figure 2. The time scale is approximate only. Different trials will probably grow at different rates, so the scheduling of operations may diverge at the different sites.

Figure 2. Improvement strategy for *E. tricarpa*: main breeding population



At least one of the PT-SSOs will be developed for improved seed production by heavy, early thinning. It will rapidly (within 6-8 years) deliver large quantities of improved seed. The SSOs will be developed from a broad and appropriate base (many families from known best provenances) on sites both representative of target planting environments and conducive to early, heavy flowering. However, the amount and quality of genetic information provided from the PT-SSO managed in this way will be modest, because the heavy selective thinning variably affects competition between trees and hence their relative performance.

In a regional environment where a species is less well-tested, provenance rankings are more uncertain, and there is not an urgent demand for large quantities of seed, the option of maintaining progeny trials with only light thinning, for at least 8-10 years, and then grafting out the best individuals into a CSO, is considered appropriate. The PT-CSO in WA will be managed in this way.

The early thinned PT-SSO and unthinned PT-CSO routes to improved seed production can be thought of as the two extremes of the way in which ALRTIG provenance-progeny trials of *E. tricarpa* could be managed. In practice, management can be adjusted according to circumstances. For example, if interim seed production areas produced high quality seed, that successfully met the demand for improved *E. tricarpa* seed over the period 2001-2006, the first thinning of ALRTIG *E. tricarpa* SSOs could be delayed at least until 2006 so as to improve the quality of genetic information obtained and make more accurate selections for the next generation of the breeding population and for grafting into CSOs. The quantity of seed produced by the SSOs, would, however be reduced, and the onset of seed production delayed.

Box 1. Chronological summary of tree improvement activities for *E. tricarpa*

2000	*Establishment of three ALRTIG progeny trials*
Purpose:	First cycle of breeding population; PT-SSOs to be converted later by selective thinning to first-cycle seedling seed orchards.

Material: Approximately 130 open pollinated families from superior natural provenances (Table 2).

Design: Randomised latinised row-column design with five replicates. Each family will be represented a single 4-tree row plot in each replication. The breeding population would be surrounded by an external perimeter row of surplus stock. Spacing will initially be 4 m between rows and 2 m within rows in the PT-SSOs; 4m between and 2.5 m within for the PT-CSO. Adjacent block planting of 144 (12 x 12 trees) to be left unthinned and planted at same spacing as adjacent stand.

2003 *First major assessment of progeny trials*

Age: Around 3-4 years (crowns touching along rows, mean tree height about 5 m).

Purpose: Assess height, dbh and proportion of trees that are forking/single-stemmed. First estimate of relative performances of different seed sources (natural provenances planted stands, and individual families).

2003 *First thinning of PT-SSOs*

Age: 3-4+ years, after the first major assessment is completed (trees to be thinned can be marked by the assessment team).

Selection: Remove up to worst two trees in each PT-SSO 4-tree row plot, retain two best trees. PT-CSO remains unthinned.

Purpose: Reduce stocking to maintain vigorous growth and deep crowns on the best trees within each family.

2005 *Second assessment of progeny trials*

Age: Around 5-6 years - exact timing will depend on actual growth and development at individual sites. Mean tree height about 7 m.

Purpose: Further assessment to compare families and allow estimation of age-age correlations and other genetic parameters. This assessment will provide performance data to assist selection of parents for the second cycle.

2006 *Second thinning of PT-SSOs to develop orchard function*

Age: Immediately following second assessment and analysis of assessment data.

Selection: Remove the worst of the two trees in the PT-SSOs to leave the single best tree, per family row plot. Also, completely remove the worst 15-20% of plots of the inferior families, to reduce stand density from around 312 to around 250 stems per hectare. Initial development of the orchard's seed production capacity will be achieved by this second thinning, as neighbouring trees will be unrelated enabling open pollinated matings to produced highly out-crossed seed. Thinning in the PT-CSO may be undertaken, to maintain stand vigour.

2005 *Selection of seed parents for the second cycle*

Age: 5+ years

Selection: Selection method to be determined based on analysis of assessment data. Extent of genotype-by-environment interaction will determine whether single or multiple breeding populations are appropriate for second cycle.

2005 *Promotion of heavy flowering*

Age: 5+ years

Method: Heavy fertilisation of orchards may be appropriate to improve flowering and seed set. The application of a flowering promoter such as paclobutrazol could also be considered. It may be appropriate to introduce hives of bees to the SSOs to promote cross-pollination if there are few pollinators on site (Moncur et al. 1995).

2006	*Seed collection for second cycle*
Age:	7+years. Seed should be collected from capsules resulting from flowering **after** the second thinning. Adequate flowering and seed set required (at least 60% of retained trees flowering and most of selections producing seed).
Method:	Seed will be collected and kept identified by individual parent tree.
2006	*Final thinning of C-1 seedling seed orchards*
Age:	7+years.
Purpose:	Upgrade the genetic quality of seed produced and promote abundant flowering.
Method:	The ideal final stocking for abundant seed production is probably around 200 trees per ha (average spacing between trees around 7-8 m). A lower density would run the risk of higher levels of selfing, because increasing inter-crown distances reduce movement of pollinators between crowns. Thinning to achieve this final density will be conducted using selection based on a multi-trait selection index (Cotterill & Dean 1990).

The details of the second cycle of the main breeding population will be determined after a review of the information obtained from the first cycle of breeding. One very important question that must be addressed is whether there is sufficient genotype-by-environment interaction to warrant two or more separate breeding populations in the second generation.

5.5. Additional Components of the Improvement Strategy

5.5.1. Treatments to promote flowering and seed production

Recent studies on *E. nitens* in Tasmania indicate that high levels of nitrogen, applied as urea, can greatly increase flowering and seed production. Application of paclobutrazol, as a root drench of Cultar™, may also stimulate flowering and seed production. It is recommended that a small scale replicated trial of these treatments be conducted on an existing trial in 2000, to see whether seed production on superior trees can be improved.

Experience with *E. camaldulensis, E. globulus* and *E. nitens* (Moncur et al. 1995) indicates that hives of honey bees located in seed orchards during flowering can increase the level of seed set and/or the outcrossing rate. This measure could be implemented at one of more of the seed orchards.

5.5.2. Vegetative propagation study

A small-scale study of the feasibility of propagating rooted stem cuttings of seedlings, will be conducted by CSIRO during year 2000. This will determine whether mass-production of selected genotypes for clonal forestry is a realistic option for *E. tricarpa*.

5.5.3. Clonal seed orchards

Small-scale trials of grafting selections from existing trials to seedling rootstocks will be carried out in year 2001. Once the success rate of grafting is established, it may be decided to develop one or more open-pollinated grafted clonal seed orchards (CSOs), depending upon demand for seed.

5.5.4. Nucleus breeding population

Given ALRTIG's limited resources, the limited information available on provenance variation in *E. tricarpa*, and the small number of existing planted stands for which provenance and progeny information is known, it is not considered worthwhile to set up a nucleus breeding population of the species immediately. The option of nucleus breeding will be reviewed once results from the first generation of the main breeding population become available.

5.5.5. Studies of wood and sawing properties

Washusen et al. (1998) showed that wood from 40-year-old plantation-grown *E. sideroxylon* (a close relative of *E. tricarpa*) met the requirements for high quality (appearance grade) sawn products. ALRTIG will closely monitor the progress of further planned studies by CSIRO Forestry and Forest Products on the natural durability of *E. tricarpa* wood, and any other studies on wood properties.

5.5.6. Provenance resource stands

ALRTIG will collaborate with individuals and organisations that are planting *E. tricarpa*, to develop a number of provenance resource stands (block plantings of known provenance). Given the agreement of the plantation owners, these can provide several valuable functions in the ALRTIG improvement program. These include a resource of candidate outstanding trees which could be grafted into the clone bank or supply seed, possible conversion of some stands to seed production areas by selective thinning, development of biomass equations, etc. ALRTIG will document the exact location, extent and provenance origin of potentially useful provenance resource stands, including those already established, in a database. ALRTIG may provide, or arrange provision, of seed of known superior sources for such plantings.

In Victorian programs, there are several possibilities for establishment of provenance resource stands, through the extension network. As regional staff will have to arrange virtually everything, the cost of plants may be on ALRTIG, as the lever for obtaining future access.

5.5.7. Genetic gain trials

Genetic gain trials are an important part of planning all tree improvement programs (Eldridge et al. 1993, p.180). If comparative trials were not planted it would never be known whether and by how much improvement has been achieved. Genetic gain trials, also known as yield trials, compare a small number of commercial varieties in well-designed replicated trials with large plots to allow for thinning and realistic measurement. As well as monitoring genetic gain, such trials can have a high value for extension: showing farmers how much they can increase productivity with new selections.

Seed from the proposed seed production areas, and from the collections of superior natural provenances, could be compared with 'routine' natural provenance seed in gain trials from year 2001. Such trials could be established by Regional Plantation Committees, Greening Australia and other agencies, with technical advice from ALRTIG and/or CSIRO's Farm Forestry Seed and Information Support Program. Seed from the SSOs established in 2000 by CFTT and SFNSW, and 2001 by CALM may be available for gain trials by year 2004 or 2005.

Later, gain trials should be established to compare the performance of the first commercial harvest of seed from the ALRTIG seedling seed orchards with seed production area seed and regular industry seedlots.

5.5.8. Genetic conservation

Most of the natural provenances of *E. tricarpa* sampled by the CFTT collections are from State Forests held in the public trust. There does not appear to be any threat to these stands given that there is considerable public interest and activity in conserving the small areas left. However, it is possible that some individual provenances in increasingly urbanised or subdivided areas could be lost through stresses arising from widespread land clearing for agriculture, leading to death of trees and entire stands. If known superior provenances are threatened in this way, it would be desirable for ALRTIG to support ex-situ conservation of these provenances. This could be achieved to some extent by long-term storage of seed from these provenances, and by well-documented planted stands representing many parents from a particular provenance.

6. Program Reviews

An essential component of genetic improvement programs is regular in-depth review, analysis, evaluation and subsequent revision. The first of such reviews for this program has been tentatively scheduled for mid 2001, when experience and results from the first 18 months of the program have been obtained. Further reviews would be conducted at least once every 2 years. There is sufficient expertise within ALRTIG to carry out the reviews, but it would be desirable for an outside expert not involved in the group to participate in the major reviews.

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PART 6: SPOTTED GUM

GENETIC IMPROVEMENT STRATEGY IN SOUTHERN AUSTRALIA

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1. Summary

Corymbia maculata and *C. variegata* are two species of spotted gums selected for a collaborative genetic improvement program by ALRTIG (the Australian Low Rainfall Tree Improvement Group). A strategy for the improvement of spotted gum, combining elements from several successful eucalypt improvement programs in Australia and elsewhere, is recommended and described.

The **improvement objective** is to maximise the value of logs produced by plantations in the target planting zones (areas receiving about 500 to 750 mm mean annual rainfall in southern Australia) on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles, and posts. The initial selection criteria are improved volume production, straight stem, absence of forking and tolerance to drought, pests and diseases. Selection and breeding for improved wood properties may also be appropriate once market prospects for different wood products become clearer, enabling important wood quality traits to be identified.

Superior natural provenances of the species displaying rapid growth and good stem form, have already been identified from the results of provenance trials in Western Australia, southern NSW and Victoria. In general, *C. maculata* appears to have better growth potential than *C. variegata* in these trials. Further seed collections of superior provenances will be undertaken, but seed production in some of these provenances has been low in recent years. Limited quantities of seed are now available from three CALM multi-provenance seed production areas established in WA in 1983. Two CSIRO seedling seed orchards planted near Deniliquin, southern NSW, in 1995 should commence seed production in 2001.

ALRTIG will establish new **main breeding populations** comprised of two provenance-progeny trials of *C. maculata* at carefully selected sites in Western Australia and Victoria, and one provenance-progeny trial of *C. variegata* in New South Wales. These trials will incorporate a total of at least 60 families per species from (i) superior mother trees in the known better provenances and (ii) superior trees in field trials and planted stands of these provenances.

The trials in Victoria and NSW will be managed for rapid seed production by early thinning, and are termed progeny trial - seedling seed orchards (PT-SSOs). The trial in WA will be thinned later and less aggressively, and will be a useful source of genetic information such as age-age correlations. The WA trial may also be used to produce scions for clonal seed orchard development. This trial is termed a progeny trial – clonal seed orchard (PT-CSO). All trials will be used to supply genetically improved material for the next generation.

Grafting of 25 or so outstanding trees of *C. maculata*, selected from existing field trials and other planted stands of known provenance origin, will be undertaken during years 2000-2001. The grafted clones will be maintained in a clone bank, enabling controlled pollination between elite trees, and establishment of one or more small-scale **grafted clonal seed orchards.** The CSOs will subsequently be rogued on the basis of progeny performance.

Vegetative propagation of spotted gums by stem cuttings is reported to be very difficult, with low levels of success reported by research groups worldwide. Micropropagation from seedlings is much more successful, but difficult to apply on a production scale. In the absence of major technical improvements, mass vegetative propagation for clonal forestry is unlikely to contribute to ALRTIG's improvement strategy.

2. Background

Natural stands of the spotted gum group of eucalypts make an important contribution to commercial wood production in NSW and Queensland forests. The group consists of four species *Corymbia citriodora* (lemon scented gum), *C. henryi* (large leafed spotted gum) *C. maculata* (spotted gum) and *C. variegata* (spotted gum). *Corymbia citriodora* is commercially grown for its wood, leaf oils and as an ornamental tree in countries around the world (Eldridge et al. 1993). The remaining species are important sources of timber harvested from native stands. The wood of spotted gums is hard and strong and is suitable for tool handles, mining timber, and housing construction (Boland et al. 1984). The sapwood is wide and very susceptible to the powder post beetle (*Lyctus*) (Hall et al. 1972, Cremer 1990).

Corymbia variegata is one of the species selected for large-scale joint-venture plantations in NE NSW and SE Queensland. Spotted gum plantation area (mostly *C. variegata*) in NE NSW planted to date is about 6300 ha, with an average planting rate of 1260 ha/year. Smaller areas have been planted in SE Queensland. It is mostly being planted away from the coast, on ex-pasture sites with heavier yellow podzolic soils, where the original forest was spotted gum/ box/ ironbark. These sites may have shallow soils and be subject to periodic drought, but mean annual rainfall generally exceeds 800 mm. *Corymbia variegata* is the subject of genetic improvement programs by QFRI and SFNSW for these plantations (D. Lee, QFRI and I. Johnson, SFNSW, pers. comms. 2000). The target planting environments, which are outside the ALRTIG target zone, have a summer maximum rainfall environment and mean annual rainfalls in the range 800-1500 mm. Resistance to attack by the fungal pathogen *Ramularia,* which causes severe dieback and deformation of leading shoots in young saplings, is an important selection criterion for these environments. Susceptibility to *Ramularia* attack rules out the use of *C. maculata*, *C. henryi*, and *C. variegata* from inland, low rainfall provenances in the SE Queensland plantation program (D. Lee, QFRI, pers. comm. 2000).

Spotted gums have been planted widely in farm forestry trials within ALRTIG's target area of operation (southern Australia, areas receiving 400-600+ mm mean annual rainfall) and display considerable potential, particularly at and above the 600 mm rainfall isohyet. In WA, spotted gums are among the most highly favoured timber species for agroforestry, and they are highly rated also in western Victoria. Although *C. henryi* also shows promise in some trials within ALRTIG's target area, in view of limited available resources ALRTIG will concentrate on *C. maculata* and *C. variegata*.

3. Basic Elements of Planning Tree Improvement

3.1. Need for a Well Defined Strategy and Plan

Tree improvement programs aim to develop new plantations superior to their predecessors in one or several key economic traits. Programs start with a carefully chosen improvement strategy implemented through a dependent improvement plan. These key components of tree breeding are defined as follows (after Eldridge et al. 1993).

Improvement strategy (a conceptual plan) **-** the framework of ideas, the conceptual overview, or philosophy of the management of genetic improvement of a tree species used in plantations. Its essential elements are:

(a) Population improvement by a combination of a particular type of **selection** and a particular type of **mating**, starting with a well adapted broad genetic base, and
(b) An efficient system for **mass propagation** of outstanding selected individuals either as seed or cuttings.

Improvement plan - having decided which Breeding Strategy (particular combination of selection and mating) will provide the greatest genetic gain per decade at an acceptable cost for a particular plantation program, and appropriate methods of mass propagation, the tree breeder can prepare a detailed Improvement Plan to implement the Strategy. Typically the plan includes a set of objectives and a flow chart of what is to be done each month for several years ahead and is subject to regular revision, every 2-5 years (Eldridge et al. 1993).

3.2. Clear Objectives

Tree improvement projects should have a clear set of objectives defining the improvements required and identifying the traits for which to select.

3.3. Hierarchy of Populations in a Breeding Strategy

As an ongoing recurrent process, a breeding strategy accumulates benefits over successive generations of a cycle of testing, selection and mating (Figure 1). Every effective breeding strategy involves the maintenance of a hierarchy of three major types of population which can continue to meet the demand for genetically improved planting stock for a fourth population, the wood-producing plantations. These four populations are summarised as follows:

Base population - The base or gene resource population consists of the natural forests of spotted gum and some plantations in which selection can be carried out; these broadly-based reserves will continue to be a source of a wide range of genetic variation to meet future needs.

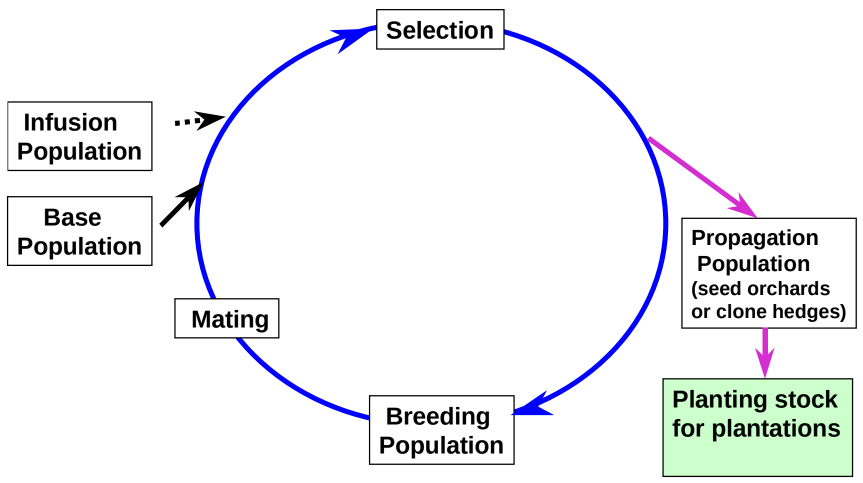
Breeding population - The selected trees and their progeny in a series of progeny trials and possibly clonal archives in which the breeding cycle of selection and mating will be repeated over many generations. This is the tree breeder’s main area of work.

Propagation population - The intensively selected trees (commonly fewer than 100 selected trees) propagated in seed orchards or cuttings multiplication areas where the combinations of genes selected in the breeding population are mass-produced as genetically improved planting stock.

Production population - The major plantation areas established using the improved germplasm.

A fifth type of population, the infusion population, describes additional material from the base population brought into the breeding population in the second and later generations to maintain adequate genetic diversity and provide additional superior genetic material.

Figure 1. Activity cycle for tree improvement



3.4. Selection and Mating

Selection and mating are key activities in breeding. They accumulate genes, which influence yield and adaptation, increasing over successive generations the frequency of superior trees. Every successful breeding strategy, therefore, requires efficient methods of selecting superior material including the progeny tests in which the selection is carried out, appropriate measurement techniques and selection technology (e.g. selection indices). Mating systems include both open pollination or controlled pollination. Either method should be planned to minimise the potential for inbreeding, which has been shown to be strongly deleterious in eucalypts.

In pursuing its principal functions of efficient selection and mating, a strategy should aim to assess the variation within a species, generate genetic information about it and ensure that genetic resources for future selection are conserved.

3.5. Personnel and Funding

Availability of technical expertise and institutional support as well as an appropriate level of funding over the longer term are key elements in determining the type of breeding strategy adopted.

4. Determinants of the ALRTIG Genetic Improvement Strategy for Spotted Gum in Southern Australia

4.1. Improvement Objective

For both *C. variegata* and *C. maculata* the breeding objective is to maximise the value (per hectare per year) of logs produced by plantations in the ALRTIG target planting areas on a rotation of 20-30 years. The main products are expected to be sawlogs, with poles and posts produced from thinnings during stand development.

4.2. Target Planting Areas

ALRTIG's aim is to develop improved planting stock for the spotted gum target planting zone. In the context of the entire ALRTIG program, this is defined as areas in southern Australia receiving 400-600 mm of rainfall per annum, with winter-peak or uniform distribution (Bush et al. 2000). However, spotted gum material developed by ALRTIG would be expected to perform well on sites receiving 500- 800 mm or more, in and adjacent to the primary target zone. Spotted gum has not performed well on non-irrigated sites receiving less than around 500 mm. It will survive in some instances (for example at Wail, western Victoria, which receives only around 450 mm), but growth and health will suffer.

It appears that the fungal pathogen *Ramularia* is effective only in environments with high humidity and rainfall in summer. *Ramularia* attack has not been reported in any spotted gum plantations or trials in the ALRTIG target planting areas, which receive lower rainfalls with winter-maximum or uniform seasonal distribution. Thus, selection criteria and the composition of breeding populations may diverge widely between the ALRTIG improvement program and the improvement program for *C. variegata* in NE NSW/SE Queensland. The latter program will be based on coastal provenances of *C. variegata* such as Woondum, Queensland which have shown superior resistance to *Ramularia* in field trials (D. Lee, QFRI, pers. comm. 2000).

Spotted gums are reported to prefer well-drained soils, but have an ability to extend roots into heavy-textured soils. They can occur naturally on 'hard' sites such as stony ridges and slopes (Cremer 1990). In their natural environment, they can tolerate prolonged drought by the adaptive mechanism of leaf-shedding of up to 90% of the canopy, followed by rapid resprouting from epicormic buds on the branches once the drought ends (Pook 1985). Neither species is noted for tolerance to salinity (Marcar et al. 1995) or waterlogging, and this will exclude them from waterlogged and saline sites within the ALRTIG target zone; on these sites *E. occidentalis*, and *E. camaldulensis* and its hybrids, would be preferred species for eucalypt plantations. Spotted gums are also known to be susceptible to frost in the first 1-2 years after planting.

Consideration of the limiting factors of drought, salinity, waterlogging and frost, supported by practical experience in western Victoria, suggests that spotted gum plantations in western Victoria are best restricted to mid and upper hill slopes receiving over 500 mm mean annual rainfall, with free air drainage. Valley-bottom, frost-prone sites, which are also more likely to have salinity and waterlogging problems, should be avoided (R Bird, pers. comm. 2000). CSIRO's irrigated provenance-progeny trials planted on three non-saline, level sites around Deniliquin, SW NSW, receive annual rainfall of around 500 mm and 300-400 mm supplementary irrigation water. Frost damage has not been a serious problem in these plantings. Much better growth (twice the height growth, at age 3 years) has been obtained on red loamy earths than on heavy grey-brown clays. Because the ALRTIG target zone is close to the lower limit of the acceptable rainfall for the species, it will be prudent to restrict plantings to soils which allow unimpeded root access to a soil profile at least 2 m deep, enabling substantial 'buffering' during drought years from stored soil water.

The two species may be suited to different geographic regions within ALRTIG's target planting zone. Evidence to hand (Mazanec 1999) suggests that *C. maculata* is the preferred species for SW WA, although *C. variegata* from the Richmond Range provenance in northern NSW may also be useful. In western Victoria and inland southern NSW, *C. maculata* also outperforms *C. variegata* (Bird et al. 2000, Tibbitts 1999, CSIRO unpublished). On the basis of the two species' natural distributions (Figure 2), *C. variegata* might well outperform *C. maculata* further north in NSW on dry sites west of the Great Dividing Range, at latitudes where the former species replaces the latter in natural forests. This still needs to be tested.

4.3. Anticipated Scale of Planting in the ALRTIG Target Planting Area

Within the ALRTIG target area, planting of spotted gum is largely pre-commercial. Seedling sales by forestry nurseries, and demand for seed from CSIRO's ATSC, indicate that current planting rates in southern NSW, Victoria and SA total around 300 ha per year. Given the growing popularity of the species in agroforestry in the 500–700 mm rainfall zone in southern Australia it is anticipated that areas planted will increase significantly over the next few years

4.4. Selection Criteria and Traits for Selection

The ideal *C. maculata* or *C. variegata* tree for farm forestry plantations within ALRTIG's target planting zone would have good drought and frost tolerance, resistance to pests and diseases, good vigour as expressed by rapid growth in stem volume, a straight single bole, and light lower branches that self-prune. Selection traits to be used in achieving ALRTIG's genetic improvement objectives for both species will include:

- Survival rate (frost and drought may reduce survival at some sites)
- usable stem volume to top height of 10 cm, estimated from stem height and diameter over bark
- absence of forking
- stem straightness

Spotted gum (primarily *C. maculata*) grown in plantations in 600-800 mm annual rainfall zone of Victoria has been shown to have good potential for high quality appearance products with high recovery of select grade timber. It has also been shown to suffer minimal drying degrade (Washusen et al. 1998). Strength of sawn wood products was high in this study, and there would appear to be no need to select for high wood density as part of an improvement objective. Wood density is generally considered too high for the species to be valuable for pulp production. Inclusion of stem straightness and absence of forking as criteria in the first generation of selection should contribute to increased value of solid wood products. Selection for light branching may also be warranted if this trait is shown to be heritable. Kino rings have presented a problem for utilization of *C. maculata* in southern Africa (Poynton 1992) and absence of kino rings might be considered a trait for selection if the problem emerges in ALRTIG's improvement program.

Assessment of these traits in well-designed trials will enable breeders to estimate genetic parameters for each of these traits and subsequently determine the effectiveness of breeding and selection.

Standard guidelines for assessing stem form and branching in spotted gum will be developed for use across all ALRTIG trials.

4.5. Institutional Setting, Personnel and Available Funding

ALRTIG's partners (Table 1) have existing scientific and technical staff experienced in eucalypt breeding and propagation who will implement the improvement strategy for spotted gum. They will be assisted until December 2001 by ALRTIG's National Coordinator, who will coordinate activities, oversee expenditure, and help to ensure that milestones and deadlines are met.

Table 1. Details of ALRTIG partners and collaborators

Partner/ collaborator organisation	State	Current involvement
State Forests New South Wales	NSW	All programs
ForestrySA	SA	All programs
Primary Industries & Resources SA	SA	All programs
Private Forests Tasmania	TAS	Softwoods program only
Department of Natural Resources and Environment (Includes Centre for Forest Tree Technology and Hamilton Pastoral and Veterinary Institute)	VIC	All programs
Department of Conservation and Land Management	WA	All programs
Australian National University Department of Forestry	National	Mallees (short-rotation crops) program only
CSIRO Forestry and Forest Products	National	All programs

Short-term funding to support ALRTIG's collaborative activities has been provided by RIRDC via the Joint Venture Agroforestry Program. Funds available to ALRTIG for work on spotted gum total about $50 000, to be spent over the period June 1999 to June 2001 (extended to December 2001 because of the late start of the project), at which time this funding will cease. The RIRDC funding will be used to cover the direct salary costs of days worked by scientists and technicians on spotted gum, and other direct costs such as travel, seed collection, nursery operations and trial establishment and management.

The participating agencies will make matching funding contributions to meet the balance of staff salaries and organisational overheads. They also bring to the project considerable intellectual property and established genetic resources of the species (seed collections and field trials). They will provide the land required for genetic trials and seed orchards, or negotiate secure tenure for these plantings with other land holders.

The agencies will carry on the improvement program after June 2001, under collaborative or individual-agency management arrangements yet to be determined. Sales of seed will generate revenues to support the collaborative project.

4.6. Information on the Species

A recent review of published information on *C. maculata* is available (Larmour 2000). *Corymbia variegata* may be expected to be very similar in most respects. A summary of information relevant to development of improvement strategies for the two species is presented below.

4.6.1. Natural distribution

Figure 2 shows the natural distribution of the four species of spotted gums recognised by Hill & Johnson (1995).

4.6.2. Taxonomic variation and hybrids

The spotted gum group of eucalypts was formally reclassified from the genus *Eucalyptus* subgenus Corymbia to genus *Corymbia*, section Politaria (Hill & Johnson 1995). *Corymbia citriodora*, *C. variegata, C. henryi* and *C. maculata* are the four recognised species in this section. The ranking of taxa in this group is still under debate. McDonald and Bean (2000) argue that while *C. maculata* and *C. henryi* are genetically and morphologically allied, they should retain species status, while *C. variegata* should be subsumed under *C. citriodora* at subspecies rank.

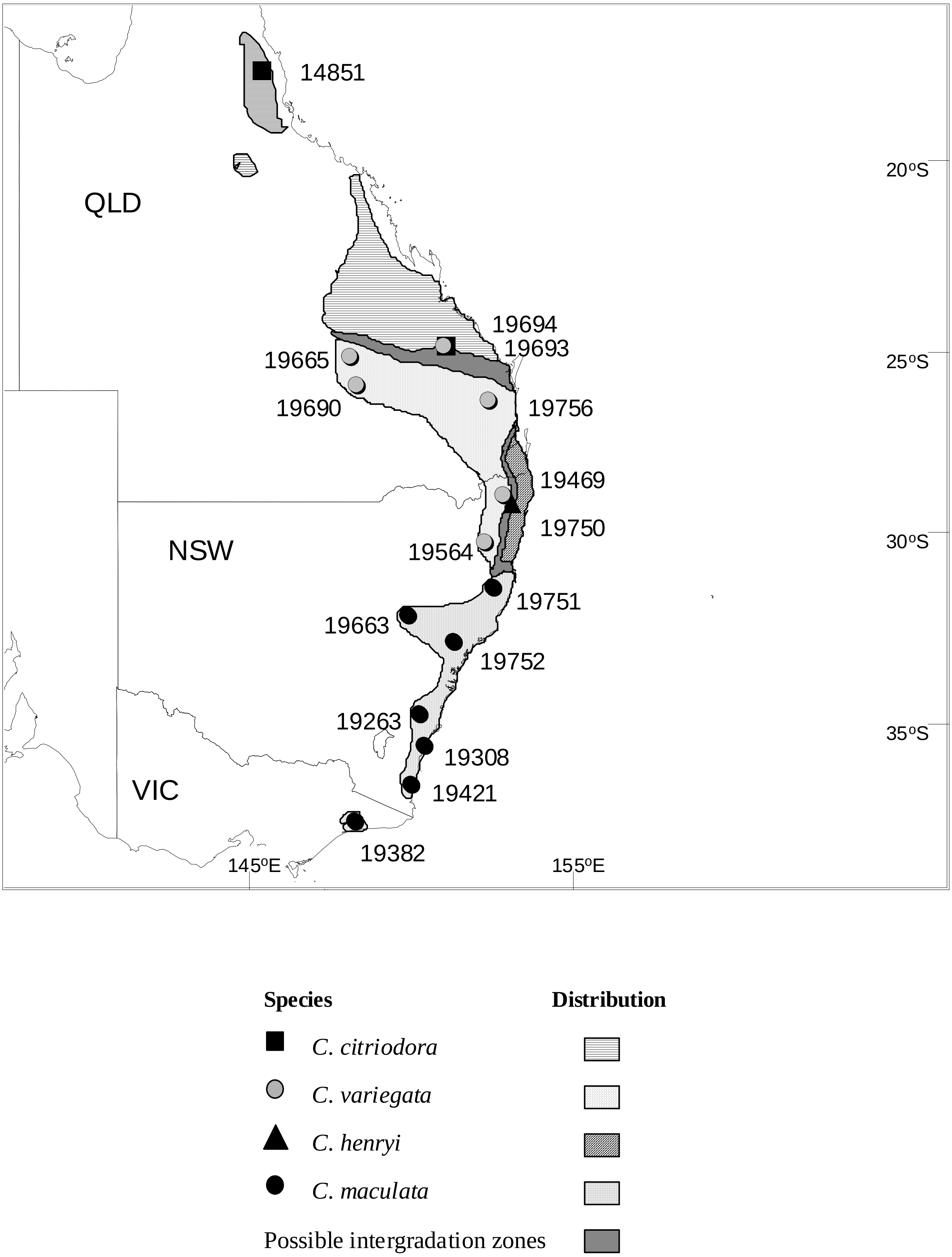
In a recent isozyme study McDonald et al. (2000) found no detectable difference in allelic frequencies between *C. citriodora* and *C. variegata*. These two species separated very clearly from *C. henryi* and *C. maculata*, and the latter two species were found to be genetically distinct from one another. *Corymbia henryi* had the highest genetic diversity within the group, but the smallest differences between populations. By contrast, *C. maculata* had the greatest genetic differentiation among populations but the lowest allelic diversity in the group overall.

Natural hybrids between *C. henryi* and *C. maculata* are known to exist (McDonald et al. 2000), and are likely between *C. henryi* and *C. variegata (*Hill & Johnson 1995). Natural hybrids between *C. variegata* and *C. torelliana* are vigorous and of commercial interest, and artificial hybrids of this cross have been produced by controlled pollination (T. de Assiz, Riocell Co., Brazil, pers. comm. 2000).

4.6.3. Pollination and breeding system

By analogy with *Eucalyptus* species with similar-sized flowers, it seems highly likely that insects (primarily flies and bees) are the main pollinators with nectarivorous birds also playing a significant role. Spotted gum flowers are morphologically bisexual. Individual flowers are protandrous, meaning pollen is shed before the stigma is receptive and thus self-pollination is avoided at this level. In spotted gum, as in many eucalypt species, individual trees produce many flowers over a long period in any given flowering season. Therefore, there is ample opportunity for selfing within the crown, as flowers on individual trees develop at different times. Most *Eucalyptus* species investigated to date have a mixed mating system, with open-pollinated seed being comprised of a mix of outcrossed and inbred seed, the latter including both selfed seed and that arising from matings between close relatives.

Figure 2. Natural distribution of the four species of spotted gums, showing locations of some CSIRO seedlots (from Larmour et al. 2000)



The proportions of outcrossed and inbred seed in natural provenances of spotted gum are not known. However, Yeh et al. (1983) surveyed the mating system of the closely related *C. citriodora* in a planted seed production area in Brazil, and found that it displayed a high level of outcrossing 85%.

4.6.4. Inbreeding depression

Although not formally investigated, it is likely that spotted gums have a similar breeding biology to the eucalypts. Isolated trees, stands where only a few trees flower, or stands that have a very narrow genetic base of only one or a few parents, can be expected to produce inbred seed. Plants that are poor in quality, have lower survival, slow growth and poor stem form can be expected, because inbreeding depression is strong in all *Eucalyptus* species investigated to date (Eldridge et al. 1993).

4.6.5. Vegetative propagation

McComb & Wroth (1986) experimented with rooting of *C. maculata* stem cuttings from coppice sprouts obtained following felling of young trees, but found limited success in glasshouse conditions achieving a maximum of 2% rooting from one tree. Better success was achieved using micropropagation techniques. Catesby & Walker (1997) also obtained less than 2% successful rooting, using stem cuttings of *C. variegata* seedlings. As vegetative propagation by rooted cuttings using currently known techniques is unsuccessful, and mass production via micropropagation is not economical under Australian cost structures, it appears very unlikely that clonal forestry with spotted gums will be feasible in the short term.

CALM experience has demonstrated that grafting of spotted gum scions from selected superior trees onto rootstocks is easily achieved with very low mortality. This means that establishment of clonal seed orchards is feasible.

4.6.6. Flowering

Vigorous individuals of *C. variegata* have been seen to flower after 3-4 years in NE NSW/SE QLD (I. Johnson, pers. comm. 2000), and most individuals in CSIRO’s spotted gum progeny trials near Deniliquin in southern NSW have heavy bud crops at age 4-5 years. Depending on site and silviculture, spotted gum seed orchards within the ALRTIG target area may be expected to start yielding seed crops after about 5-6 years.

The timing of anthesis for spotted gums in the natural environment is generally recorded as ranging from May to September (Boland et al. 1984). Time from visible flower bud initiation to anthesis is at least 12 months, and time from anthesis to seed maturity is believed to be about 12 months (unpubl. observations by J. Larmour, CSIRO). Observations in CSIRO’s seed orchards at Deniliquin, southern NSW, indicate that *C. maculata* flowers some 6 weeks earlier than *C. variegata* at this location. Seed can be retained for substantial periods of time, seed collectors occasionally reporting two seed crops on a single tree. There are typically about 5-6 viable seeds per capsule in open-pollinated seed crops (D.J. Boland, pers. comm. 1999).

4.6.7. Genetic variation

Considerable scope exists in spotted gum for genetic improvement. Data from trials carried out in SW WA, southern NSW and western Victoria show that strong differences exist between provenances and species for growth and form traits (Mazanec 1999, Bird et al. 2000). Some provenance variation in frost resistance is also evident (Larmour et al. 2000).

Significant genetic variation in growth and form were shown to exist in a 13-year-old trial of spotted gum established in the Wellington catchment of WA. *Corymbia maculata* was the preferred species, most provenances producing higher volumes of wood than *C. variegata*. One exception was the Richmond Range provenance of *C. variegata* from near Casino, NSW that produced the highest volume in the trial. Provenance differences existed within both species for height diameter, mean annual volume increment, forking and straightness (Mazanec 1999). Analysis of data from two 13.5 year-old trials (Mazanec 2000, unpublished data) established on bauxite mines in the high rainfall zone (>1000mm) of the northern jarrah forest in WA, indicated similar trends. In both these trials, *C. maculata* was superior to *C. variegata* for volume per hectare.

Significant differences existed for most traits at the species level and at the provenance within species level. Bird et al. (2000) found *C. maculata* to be faster growing than *C. variegata* in 3-4 year old species-provenance trials on six sites near Hamilton in western Victoria. The Batemans Bay and Orbost provenances of *C. maculata* were consistently good performers in these trials.

In irrigated trials in southern NSW and northern Victoria, *C. maculata* was again somewhat superior in volume production to *C. variegata* (Tibbits & Sasse 1999).

Breeding of spotted gum has been carried out in South Africa, as reported by Andrew (1970), Hodgson (1974) and Darrow (1985). All these authors noted significant provenance variation in various traits. Some of the provenance variation in these trials is actually attributable to species differences between *C. henryi, C. variegata* and *C. maculata.*

4.6.8. Estimates of genetic parameters

Heritabilities. To date, estimates for heritability of any trait have not been published. The majority of trials within the ALRTIG target zone have not included identified individual families. Analysis of 3-year and 4-year data from CSIRO's irrigated provenance-progeny trials has shown that heritabilities for height, diameter and stem volume are low (in the range 0.10 to 0.17, using a coefficient of relationship within open-pollinated families of 0.4). Corresponding within-provenance, individual-tree heritability for stem straightness was also significant but lower (0.07), while that for forking was non-significant.

Genotype-by-environment (GxE) interaction. Site-by-species interactions in the analysis of two trials in the northern jarrah forest in WA were not significant. It may be that this is the case fairly generally in WA. For example, *C. maculata* yielded superior volume in the Wellington catchment, an area with about 700 mm rainfall compared to the 1100 mm received in the northern jarrah forest area. Site by provenance within species interactions also were not significant, however some changes in provenance rankings within species did occur between sites.

Bird et al. (2000) found statistically significant provenance by site interactions for height across six sites around Hamilton, for spotted gum aged between two and four years, but concluded that these were small relative to differences between provenances and of no practical importance.

Some information on GxE interactions at the family level is available from 3-year results of provenance-progeny trials established by CSIRO, CFTT and collaborators in southern NSW and northern Victoria (Tibbits 1999). Further study is required to explore these interactions, which appear to be moderate at this stage.

4.7. Available Planted Genetic Resources

Considerable planted genetic resources within the ALRTIG target area are available, and these are summarised in Table 2. It is intended that seed collections will be carried out during 2000-2001 from trees of superior phenotype in CSIRO's seedling seed orchards around Deniliquin, NSW, and provenance trials in WA and Victoria.

Table 2. Planted genetic resources of C. maculata *and* C. variegata *available to ALRTIG*

Organisation and location	Planting date	Number of species	Number of provenances	Number of sites	Number of families	Total trees	Last measure
CALM[a]							
Moira, WA	1996		Unknown	1		Unknown	-
Wellington, WA	1983		16	3		10500	1997
CFTT							
Shepparton, VIC	1994	1	3	1		225	1997
CFTT/CSIRO							
Undera, VIC	1995	3	8	1	40	1600	1999
CSIRO							
Wangaratta, VIC	1996	3	9	1		1000	1999
Benalla, VIC	1996	3	14	1		1000	1999
Holbrook, NSW	1996	3	9	1	77	1000	1999
Deniliquin, NSW	1995	3	12	3	99	4500	1999
DNRE							
Hamilton, VIC	1984		You Yangs	1		90	-
Hamilton, VIC	1985		Unknown	1		150	-
Hamilton, VIC	1985		Unknown	1		48	-
Hamilton, VIC	1995		9-10	1		48	1998
Hamilton: Plantings at multiple locations – see Appendix 1						14700	Various
PIRSA							
Kalangadoo, SA	1993		4	1		72	-
SFNSW							
Deniliquin, NSW	1997	2	6	1		350	1999
Private							
Pine Lake, VIC	Low rainfall seed source						-
Total trees						*20,000+*	

[a] 13 clones from CALM CSO not included.

5. Proposed Improvement Strategy for *C. maculata* and *C. variegata*, and Summary of Improvement Plans

5.1. Outline of Proposed Improvement Strategy

Until ALRTIG's own seed orchards commence seed production (by year 2006 at the earliest), superior seed of *C. variegata* and *C. maculata* must be provided from superior trees in the best natural provenances and from already-established seed production areas and seed orchards. Because of the significant provenance differences and heritability of economic traits already identified, these sources should be considerably superior to unselected seed from 'average' or inferior natural provenances or planted stands. CSIRO has made some collections from superior natural provenances in 1999 and 2000. A small quantity of seed was collected from CALM's WA provenance trials in year 2000. It is anticipated that CSIRO's seed orchards will provide some seed in 2001.

ALRTIG will establish two large, family-identified progeny trials of at least 60 families of *C. maculata*, in WA and Victoria, and one similar trial of *C. variegata* in NSW. Because of the clear genetic difference between the two species established by the isozyme study of McDonald et al. (2000), and their different flowering times, they will be managed in two separate breeding programs. The stands in NSW and Victoria will be progressively thinned to become seedling seed orchards. The breeding strategy in the main breeding population can be defined as recurrent selection for general combining ability with open pollination in single populations keeping family identity (Eldridge et al. 1993). Details of the strategy and plan are given below, and in diagrammatic form in Figure 3.

This strategy combines the breeding and propagation populations of each species in a single plantation on each site for each generation. These plantations serve sequentially as progeny tests of trees selected in the previous generation, as a basis for selection and breeding for the next generation, and finally as commercial seed orchards. They also function as both progeny and provenance trials to identify planted stands and areas in the natural range of interest for future seed collection, and provide estimates of genetic parameters (heritabilities, genotype by environment interactions, age-age correlations) for *C. variegata* and *C. maculata.* Regeneration of the main ALRTIG breeding populations is based on open pollination.

To rapidly provide an alternative improved seed source, probably delivering higher genetic gains than the PT-SSOs, a clone bank and open-pollinated clonal seed orchard of *C. maculata*, incorporating 20 or more outstanding selections from existing trials, will be established and rogued following progeny testing of the selections.

Mass vegetative propagation of elite genotypes of *C. maculata* and *C. variegata* for clonal forestry appears unlikely to be feasible, but ALRTIG will keep this option under review. Cutting propagation of *C. maculata* will be assessed as part of ALRTIG's vegetative propagation study of other target species during year 2000.

5.2. Expected Genetic Gains

A significant proportion of the gains to be achieved in the first cycle will be due to release from 'neighbourhood inbreeding'. Natural stand eucalypt seed has a degree of inbreeding due to neighbourhood inbreeding effects (Eldridge et al. 1993; Burgess et al. 1996). Experience from other eucalypt breeding programs indicates that usable volume gains of up to 20% per generation can be anticipated from seed produced by the seedling seed orchards, over and above those from provenance selection, with substantial improvement in form traits as well (Meskimen 1983).

The actual magnitudes of longer-term genetic gains will depend on heritabilities and genetic variances of the traits of interest. These gains result from genetic selection during the selective thinning of the orchards (assuming that good flowering and high levels of outcrossing are achieved). Within-family heritabilities are low for growth traits and stem straightness, and differences between provenances are statistically significant for growth traits, stem straightness and forking. Because of this demonstrated genetic variation in established trials, it can safely be assumed that when a number of provenances are combined into a single breeding population, heritable genetic variation will exist for all these traits, enabling genetic improvement to be achieved.

Selection in the first cycle of this program will be carried out at young ages (3 to 6 years). To validate the worth and durability of such selections, studies of age-age correlations may be carried out. The PT-CSO established in WA will be kept unthinned or lightly thinned for the first 10 years for this purpose. Even if correlations of performance between the early selection ages and full rotation ages are only moderate, substantial genetic gains will still be provided by the rapid generation turnovers that will be achieved.

Clonal seed orchards that are developed with high selection intensities and rogueing based on progeny tests will offer significant additional gain per generation relative to the open-pollinated seedling seed orchards (Shelbourne 1992).

Gains beyond the first cycle will depend on accuracy in selecting the best genotypes and management of inbreeding in both the breeding and propagation populations.

5.3. Interim Seed Sources for Years 2000-2007

5.3.1. Natural-provenance seed

The ATSC is probably best-placed to collect seed from outstanding phenotypes in the natural provenances, which have proved superior in provenance trials. This will be done as a standard ATSC commercial operation, although ALRTIG will promote the use of such seed. However, seed crops in some of the superior natural provenances have been so poor in recent years that ATSC has not been able to meet demand.

5.3.2. CALM seed production areas

Three spotted gum trials established in 1983 may be a useful source of seed. Some seed collection was carried out in 2000 with small quantities of seed obtained. Further seed collections may be possible although some thinning of these trials is required to boost seed production.

5.3.3. CSIRO/CFTT seed orchards

Provenance-progeny trials with 4 replicates of 5-tree family row plots were planted in 1995 and 1996. Two of these trials were selectively thinned down to one tree per plot in late 1999, and now carry heavy bud crops. Mass flowering of the retained trees in autumn-winter 2000 will hopefully lead to production of good seed crops which will be harvestable by around June 2001. CSIRO’s rain-fed provenance-progeny trial at Holbrook, southern NSW and the irrigated provenance-progeny trial at Undera, northern Victoria being managed by CFTT could also be thinned for conversion to SSOs during 2000-2001, and might yield seed by year 2000.

5.3.4. Other planted seed production areas

Field inspections in February 2000 of planted stands, mostly provenance trials, established by PVI around Hamilton, western Victoria (see Appendix 1) suggested that these stands are not really suited to conversion to seed production areas by selective thinning, as provenance plot sizes are generally small. They can, however, be used to select outstanding individuals which could be grafted into CSOs, and provide open-pollinated seed for inclusion in the ALRTIG SSOs.

5.4. Main Breeding Populations and First Seedling Seed Orchards

5.4.1. Composition of ALRTIG main breeding populations

For a long-term breeding program running over several generations, it is desirable to have an initial breeding population of 200 or more unrelated families (Eldridge et al. 1993). This may be difficult to achieve immediately. Although the CSIRO seed centres currently hold over 100 families of *C. maculata* and 140 families of *C. variegata*, some of these are from provenances (or are individual progenies) which have performed poorly in provenance and progeny trials within ALRTIG's target zone, and may not be appropriate for inclusion in the breeding population. It is anticipated that seedlots collected from outstanding phenotypes in CALM's provenance trials, various trials in Victoria (see Table 2 and Appendix) and CSIRO's SSOs (if available in time), will be incorporated in ALRTIG's breeding populations.

A final review of the families to be included will be made by the ALRTIG Hardwoods Working Group in January 2001. Selecting the best families from among the above seed sources should give a total of at least 60 and perhaps as many as 80-100, families of each of *C. variegata* and *C. maculata,* for inclusion in the ALRTIG main breeding populations. Infusion of additional unrelated families will be possible in subsequent generations. Ten grams of seed of each family selected for the trials will be reserved for future requirements.

5.4.2. Deployment of main breeding populations

The ALRTIG Hardwood Technical Working Group has decided to deploy the first cycle of the *C. maculata* main breeding population in provenance-progeny trials at two sites: one each in WA, and Victoria, and the *C. variegata* main breeding population in a provenance-progeny trial at one site in NSW. Following assessment of early performance, these trials will be developed by selective thinning into seedling seed orchards (SSOs).

The sites will be selected according to the following criteria:

- Located within the general range of climates in which the species is planted (500-700 mm annual rainfall, winter or uniform rainfall).
- Detailed site assessment, involving coring or excavation to 3 m soil depth, to confirm that the site should support reasonable growth and seed production of each species. At least one of the PT-SSO sites will be judged capable of supporting heavy, early flowering and seed production.
- Sites should be level or gently sloping with no large environmental gradients nor irregularities within the area to be planted.
- Sites not prone to frost or waterlogging; ridge or mid-upper hill slopes preferred.
- Land either owned or managed by partner-manager agency, or an agreement negotiated and signed with landowner, giving secure tenure and intellectual property rights to the trial for at least 10 years (it may be necessary to offer the land-owner a share of the seeds to be produced, to secure such agreements).
- Site conveniently accessible to the relevant lead ALRTIG agency, for establishment and management of the planting, and seed collection.
- Isolated by at least 200 m from other stands of spotted gum to avoid contamination with unselected pollen.

The progenies will be given a common set of field codes for raising in nurseries, which will remain unchanged even if not all progenies are successfully raised, or planted at all sites.

5.4.3. Standard design of ALRTIG progeny trials with adjacent block planting

Assuming that there are no restrictions imposed by the shape of the planting area, the two PT-SSO plantings will use an identical layout and design. A different treatment randomisation will be used at each site. The standard design will be a latinised row column design with 5 replicates and one 4-tree line plot of each family in each replicate. Assuming there are 100 families, this equates to a total of 100 x 20 = 2000 trees. Two external perimeter rows will increase the number of trees to about 2400. The initial spacing will be 4 m between field rows and 2 m between trees along rows. This planting density has been selected as optimum for the PT-SSOs. While lower initial stocking may delay the onset of thinning and reduce competition on the sites, problems with weed control and heavy branching may result. Though heavy lower branching can be managed by pruning, this is undesirable in a genetic trial.

The PT-CSO, to be planted in WA will differ from the PT-SSOs only in the initial spacing. The PT-CSO will be thinned later and will have an initial spacing of 4 m between rows and wider spacing, 2.5 m, between trees.

If needed, additional block of 144 trees (12 x 12) will be planted at one side of each trial, at the same spacing. This block will incorporate 12 trees from 12 families of the best performing seed sources. It will be left unthinned for at least 6 years, to demonstrate the stand performance of the best available seed sources of *E. maculata* in a block planting, under the climate and soil conditions prevailing at each site. These blocks will be valuable for further studies not directly related to breeding, for example water use, silvicultural thinning, pruning, nutrition, effect of trees on soil, etc. The close spacing of the trees should reduce flowering and any associated pollen contamination of the adjacent orchard. In some cases, these blocks may be unnecessary, due to the close proximity of nearby resource plantings. It is likely that resource plantings will be established and managed by ALRTIG agencies as plantation and silviculture trials using the same seed sources as the PT-SSOs.

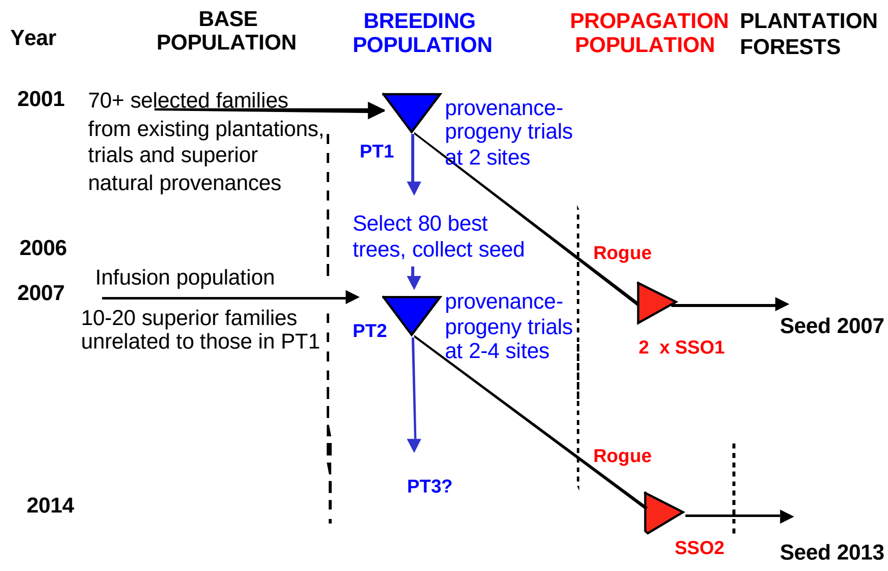
The total area required for each planting will be of the order of 1.3 ha. Fencing, site preparation, fertilising, weed management and other management issues will be covered in individual working plans drawn up by the relevant lead agency for each site.

5.4.4. Scheduling of operations to develop seedling seed orchards

A detailed description of operations for the first generation, together with a time scale for each stage, is presented below (see Box 1) and summarised diagrammatically in Figure 3. The time scale is approximate only. Different trials will probably grow at different rates, so the scheduling of operations may diverge at the different sites.

The SSO route involves heavy, early thinning of a provenance-progeny trial. It will rapidly (within 6-8 years) deliver large quantities of improved seed, when SSOs are developed from a broad and appropriate base (many families from known best provenances) on sites both representative of target planting environments and conducive to early, heavy flowering. The amount and quality of genetic information provided from the SSO is only modest, because the heavy selective thinning variably affects competition between trees and hence their relative performance.

Figure 3. Improvement strategy for *C. maculata*: main breeding population



In a regional environment where a species is less well-tested, provenance rankings are more uncertain, and there is not an urgent demand for large quantities of seed, the option of maintaining a progeny trial with only light thinning for at least 8-10 years, and then grafting out the best individuals into a CSO, is considered appropriate. In practice, the PT-SSO and unthinned PT-CSO routes to improved seed production can be thought of as the two extremes of the way in which any ALRTIG provenance-progeny trial could be managed, with management adjusted according to circumstances. For example, if interim seed production areas produced high quality seed that successfully met the demand for improved spotted gum seed over the period 2001-2006, the first thinning of ALRTIG spotted gum SSOs could be delayed at least until 2006 so as to improve the quality of genetic information obtained and make more accurate selections for the next generation of the breeding population and for grafting into CSOs. The quantity of seed produced by the SSOs, would, however be reduced, and the onset of seed production delayed.

Box 1. Chronological summary of spotted gum tree breeding activities

Establishment of two ALRTIG progeny trials for *C. maculata* and
one ALRTIG progeny trials for *C. variegata*

2001	*Establishment of first cycle of breeding population*
Purpose:	First cycle of breeding population, later to be converted by selective thinning to first-cycle seedling seed orchards.
Material:	At least 60 open pollinated families from superior natural provenances and planted stands of these provenances (Table 2).
Design:	Randomised latinised row-column design with 4 replicates. Each family will be represented by a single 5-tree row plot in each replication, surrounded by a double perimeter row of surplus stock. Spacing will initially be 4 m between rows and 1.8 m within rows. Adjacent block planting of 144 (12 x 12 trees) to be left unthinned.
2004	*First major assessment of progeny trials*
Age:	Around 3 years (crowns touching along rows).
Purpose:	Assess height, dbh and proportion of trees that are forking/single-stemmed. First estimate of relative performances of different seed sources (natural provenances, planted stands, and individual families.

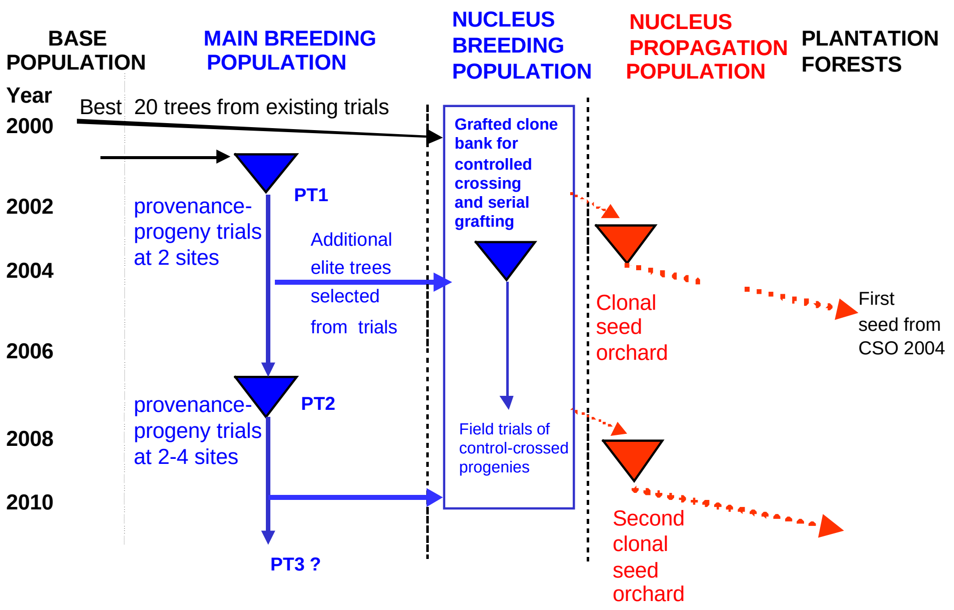
2004	*First thinning of progeny trials*
Age:	3+ years, after the first major assessment is completed (trees to be thinned can be marked by the assessment team). PT-CSO in WA remains unthinned for purpose of age – age correlations and genetic parameter estimation.
Selection:	Remove up to worst 2 trees in each 5-tree row plot, retain 3 best trees.
Purpose:	Reduce stocking to maintain vigorous growth and deep crowns on the best trees within each family.
2006-8	*Second assessment of progeny trials*
Age:	Around 5+ years - exact timing will depend on actual growth and development at individual sites.
Purpose:	Further assessment to compare families and allow estimation of age-age correlations and other genetic parameters. This assessment will provide performance data to assist selection of parents for the second cycle. Also enable culling of clonal orchards if initial selections prove incorrect.
2006-8	*Second thinning to develop orchard function of PT-SSOs*
Age:	Immediately following second assessment and analysis of assessment data
Selection:	Remove the worst 2 of the 3 trees in each plot to leave the single best one tree per family row plot. Also, completely remove the worst 10% of plots of the inferior families, so as to reduce stand density from around 280 to around 250 stems per hectare. Initial development of the orchard's seed production capacity will be achieved by this second thinning, as neighbouring trees will be unrelated enabling open pollinated matings to produced highly out-crossed seed.
2006-8	*Selection of seed parents for the second cycle*
Age:	5+ years
Selection:	Selection method to be determined based on analysis of assessment data. Extent of genotype-by-environment interaction will determine whether single or multiple breeding population is appropriate for second cycle.
2006-8	*Promotion of heavy flowering*
Age:	5+ years
Method:	Heavy fertilisation of orchards may be appropriate to improve flowering and seed set. The application of a flowering promoter such as paclobutrazol could also be considered. It may be appropriate to introduce hives of bees to the SSOs to promote cross-pollination if there are few pollinators on site (Moncur et al. 1995).
2006-8	*Seed collection for second cycle*
Age:	6+ years. Seed should be collected from capsules resulting from flowering after the second thinning. Adequate flowering and seed set required (at least 60% of retained trees flowering, and most of selections producing seed).
Method:	Seed will need to be collected and kept identified by individual parent tree.
2007-10	*Final thinning of C-1 seedling seed orchards*
Age:	6+ years.
Purpose:	Upgrade the genetic quality of seed to be produced and promote abundant flowering.
Method:	The ideal final stocking for abundant seed production is probably around 200 trees per ha (average spacing between trees around 7-8 m). A lower density would run the risk of higher levels of selfing, because increasing inter-crown distances reduce movement of pollinators between crowns. Thinning to achieve this final density will be conducted using selection based on a multi-trait selection index (Cotterill & Dean 1990).

The details of the second cycle of the main breeding population will be determined after a review of the information obtained from the first cycle of breeding. One very important question that must be addressed is whether there is sufficient genotype-by-environment interaction to warrant two or more separate breeding populations in the second generation.

5.5. Clonal Seed Orchards and Associated Progeny Testing

As mass vegetative propagation appears to be non-feasible for spotted gums, development of clonal seed orchards (CSOs) based on selections made at high selection intensity, and subsequently progeny tested, appears to be the best option for rapid genetic gain (Shelbourne 1992). Based on experience at CALM, CSIRO and several overseas companies, it is considered feasible to develop small-scale clonal seed orchards of spotted gums at relatively low cost. Given suitable management, spotted gum grafts can develop heavy flower crops within 2 years of grafting, and produce seed within 3 years of grafting (D. Lee, QFRI, pers. comm. 2000). Activities described below (see also Figure 4) to support the development of CSOs are directed only to *C. maculata*, which is considered to be generally the more important of the two species for the ALRTIG target zone.

Figure 4. Improvement strategy for *C. maculata*: clonal seed orchards and control-crossed progeny trials



5.5.1. Selection of candidate trees for grafting into clone bank

During years 2000 and 2001, existing trials and plantations of known provenance greater than 6 years old will be searched for outstanding *C. maculata* phenotypes. Ideally, each outstanding tree should be from a stand of known superior provenance, at least two standard deviations above the stand mean for the selection criteria (volume, absence of forking, and stem straightness), and healthy and acceptable for all other important traits. Overall, ALRTIG partners will aim to make at least 25 selections and successfully produce a minimum of 4 grafted ramets from each selection, during year 2001. Grafting stock will be raised during 2000-2001 from compatible provenances, and, where possible, from open-pollinated progeny of the selections.

5.5.2. Clonal seed orchards

CSIRO will develop a grafted CSO in Canberra, where good flowering and seed production of *C. maculata* protected from heavy frosts by light overhead shelter has been observed. Other ALRTIG member agencies may also choose to develop CSOs.

5.5.3. Controlled crossing in the clone banks

Grafts of the selections will be raised at CSIRO (and possibly other agencies), and managed intensively in clone banks so as to induce early flowering. They will then be available for controlled pollination.

5.5.4. Deployment of control-crossed seed

Once grafts in the clone bank are flowering, a systematic set of controlled crosses will be made to rank the selections for general combining ability (GCA). The simplest way to do this would be to use a polycross pollen mix (comprising pollen from all the selections) for crossing onto each selection. The progenies produced would be used for the following purposes:

1. Field trials would rank the original selections for their GCA. Selections with inferior GCA would be rogued from the clonal seed orchards
2. Providing small amounts of high-quality seed for demonstration plantings to show the benefits of genetic improvement

Once control-pollinated seed is available, about year 2004, it would be established in small field trials on at least 2 sites. With 25 families, 5-tree plots, 4 replicates and 4 x 2 m spacing, each trial would occupy 0.5 ha.

5.6. Additional Components of the Improvement Strategy

5.6.1. Treatments to promote flowering and seed production

Recent studies on *E. nitens* in Tasmania indicate that high levels of nitrogen, applied as urea, can greatly increase flowering and seed production. Individual trial management plans will ensure that adequate levels of fertilizers are applied to correct any nutrient deficiencies. Application of paclobutrazol, as a root drench of Cultar, may also stimulate flowering and seed production. Use of Cultar on SSOs is not planned at present but it would be of value to instigate trials to test the efficacy of these treatments in spotted gum.

Experience with *E. camaldulensis, E. globulus* and *E. nitens* (Moncur et al. 1995) indicates that hives of honey bees located in seed orchards during flowering can increase the level of seed set and/or the outcrossing rate. This measure could be implemented at one or more of the seed orchards if numbers of pollinators are found to be low.

5.6.2. Studies of wood and sawing properties

Results of preservative treatment and strength testing of small-sized poles of spotted gum thinnings from CSIRO's Deniliquin trials will be available in May 2000 (D. Scown, CSIRO Forestry and Forest Products, pers. comm. 2000). ALRTIG will closely monitor the progress of any further studies currently being carried out on wood properties and wood processing of plantation-grown spotted gum.

5.6.3. Provenance resource stands

ALRTIG will collaborate with individuals and organisations who are planting spotted gum to develop a number of provenance resource stands (block plantings of known provenance). Given the agreement of the plantation owners, these can provide several valuable functions in the ALRTIG improvement program, including a resource of candidate outstanding trees which could be grafted into the clone bank or supply seed, possible conversion of some stands to seed production areas by selective thinning, development of biomass equations, etc. ALRTIG will document the exact location, extent and provenance origin of potentially useful provenance resource stands, including those already established, in a database. ALRTIG may provide, or arrange provision, of seed of known superior seed sources for such plantings.

5.6.4. Genetic gain trials

Genetic gain trials are an important part of planning all tree improvement programs (Eldridge et al. 1993, p.180). If comparative trials are not planted it would never be known whether and by how much improvement has been achieved. Genetic gain trials, also known as yield trials, compare a small number of commercial varieties in well-designed replicated trials with large plots to allow for thinning and realistic measurement. As well as monitoring genetic gain, such trials can have a high value for extension: showing farmers how much they can increase productivity with new varieties.

Seed from the existing CALM and CSIRO seed production areas, and from collections of superior natural provenances by ATSC, could be compared with ‘routine’ natural provenance seed sources in gain trials from year 2001. Such trials could be established by Regional Plantation Committees, Greening Australia and other agencies, with technical advice from ALRTIG and/or CSIRO’s Farm Forestry Seed and Information Support Program.

Later, gain trials should be established to compare the performance of the first commercial harvest of seed from the ALRTIG seedling seed orchards with best natural provenances, seed production area seed and other commercially available seedlots.

5.6.5. Genetic conservation

Both *C. variegata* and *C. maculata* are classified as locally abundant over a wide area (Hill & Johnson 1995) and not at general risk. If, however, known superior provenances are threatened in any way, it would be appropriate for ALRTIG to support ex-situ conservation of these genetic resources. This could be achieved via long term seed storage or the establishment of ex-situ genetic conservation stands composed of a large number of individuals from the threatened provenances.

5.6.6. Interspecific hybridisation

There is a possibility that interspecific hybrid combinations with other species might be highly productive, in particular the crosses *C. torelliana* x *C. variegata* and *C. torelliana* x *C. maculata*. The first of these is reported to display much better rooting of stem cuttings than pure spotted gums, and clonal forestry of this hybrid is being implemented in Brazil (T. de Assiz, Riocell Co., Brazil, pers. comm. 2000). However, these hybrids might not be well-adapted to the ALRTIG target zone, given that *C. torelliana* is a tropical species native to northern Queensland. Crosses among *C. maculata*, *C. variegata* and *C. henryi* might also display hybrid vigour and/or complementary combinations of useful characteristics, but would appear very difficult to mass-produce, as poor rooting is to be expected from these hybrids.

6. Program Reviews

An essential component of genetic improvement programs is regular in-depth review, analysis, evaluation and subsequent revision. The first of such reviews for this program has been tentatively scheduled for mid 2001, when experience and results from the first 18 months of the program have been obtained. Further reviews would be conducted at least once every 2 years. There is sufficient expertise within ALRTIG to carry out the reviews, but it would be desirable for an outside expert not involved in the group to participate in the major reviews.

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Appendix 1. Plantings of potential use in ALRTIG program – PVI Hamilton 1999

Property owner	Location	Rainfall (mm/ year)	Year	Source	Trees	Project	Comment
Fenton J	Branxholme	750	1984	Geelong arb. Creswick N	90	150th Anniv.	Spacing trial 25-250 trees/ha
Brien F	Wando Dale	800	1985	ATSC 13608 NW Orbost	150	150th Anniv.	Spacing trial 25-625 trees/ha
Fenton J	Branxholme	750	1985	Geelong arb. Creswick N	48	150th Anniv.	With 47 others in species trial
Tully R	Melville Forest	650	1985	ATSC 13608 NW Orbost	48	150th Anniv.	With 39 others in species trial
Jowett D	Hensley Park	700	1989	Poolaijelo stand (NRCL 1957)		Don’s agroforest	Direct seeded 2 ha, very good stand
Christie I	North Byaduk	750	1993	Betts N (Poolaijelo?)	250	GRIFF demo	OK
Dundon J	Coojar	650	1993	Pine Lake, Wail N	500	GRIFF demo	Mostly dead
Gardner D	Melville Forest	650	1993	Pine Lake, Wail N	500	GRIFF demo	OK , 3 rows
Lyons P	Vasey	650	1993	Pine Lake, Wail N	50	GRIFF demo	
Speirs B	Wando Heights	750	1993	Pine Lake, Wail N	400	GRIFF demo	Poor weed control
Brody B	Gringegalgona		1994	Pine Lake, AgriTree N	300	GRIFF demo	
Castine L	Dorodong		1994	Pine Lake Wail N	300	GRIFF demo	Largely frosted and failed
Close S&L	Edenhope		1994	Pine Lake Wail N	300	GRIFF demo PSP	
Evans R	NW Hamilton		1994	Pine Lake, AgriTree N	400	GRIFF demo	
Harwood A	W Casterton		1994	Pine Lake Wail N + unknown extra	200 +	GRIFF demo	Extra block very good
Simm A	Ballarat		1994	Pine Lake, AgriTree N	400	GRIFF demo	
Smith D	S Balmoral		1994	LizFenton N	300	GRIFF demo PSP	
Smith T	S Balmoral		1994	Pine Lake AgriTree N	400	GRIFF demo	
Smith R	S Balmoral		1994	Pine Lake AgriTree N	400	GRIFF demo	
Watt M	S Balmoral		1994	Pine Lake Wail N	400	GRIFF demo	Rows between black wattle rows
Baulch P	E Branxholme		1995	Betts N?	450	GRIFF demo	
Baulch S	Willatook		1995	Betts N (Poolaijelo?)	400	GRIFF demo	
Blake B	Telangatuk		1995	Trial 7 provs	448	GRIFF research	With 2 provs *E. cyp* & 1 *E. vim*
Duffty S	Branxholme		1995	Betts N (Poolaijelo?)	250	GRIFF demo	Small
Fenton D	S Branxholme	750	1995	Trial 10 provs	640	GRIFF research	
Fenton P	Vasey	650	1995	Trial 10 provs & Poolaijelo’96	640	GRIFF research	67 of ’95 survived – 300 replanted ‘96
Field I	Victoria Valley	650	1995	Trial 1 prov (Pine Lake, Wail N)	128	GRIFF research	with 2 provs each of *E. vim*, *E. sal*, *E. cypel*
Fitzgerald J	E Casterton		1995	Betts N (Poolaijelo?)	750	GRIFF demo PSP	
Fry R	Heywood		1995	‘Langowan’,Branxholme	Direct seeded	GRIFF demo PSP	Direct-seed 0.6 ha circle, 3 m rows
Harman R	Gazette	700	1995	Betts N (Poolaijelo?)	300	GRIFF demo	
Jowett D	Hensley Park	690	1995	Trial 10 provs	480	GRIFF research	With 2 provs E. sal, 1 E. vim & 1 E. cyp

Property owner	Location	Rainfall (mm/ year)	Year	Source	Trees	Project	Comment
Last P	Branxholme	750	1995	Betts N (Poolaijelo?)	350	GRIFF demo	
Lawrance N	Gatum	650	1995	Trial 10 provs	640	GRIFF research	
McIntyre S	Victoria Valley	700	1995	Trial 6 provs	384	GRIFF research	With 4 provs E. sal
Oddie P	Streatham	650	1995	Betts N (Poolaijelo?)	500	GRIFF demo PSP	
PVI	Buckley Swamp	700	1995	Trial 10 provs	480	GRIFF research	
Wade	Chetwynd	650	1995	Trial 7 provs	448	GRIFF research	With 3 provs E. sal.
Martin B	Vasey	650	1994	Pine Lake AgriTree N	216	GRIFF research	Timberbelt 2-row (1 shelter species)
Downes G	N Byaduk	700	1994	Pine Lake AgriTree N	432	GRIFF research	Timberbelt 3-row (1 shelter species)
Veal B	Chatsworth	700	1994	Pine Lake AgriTree N	432	GRIFF research	Timberbelt 3-row (1 shelter species)
PVI	Buckley Swamp	700	1994	Pine Lake AgriTree N	432	GRIFF research	Timberbelt 3-row (1 shelter species)
Martin B	Vasey	650	1994	Pine Lake AgriTree N	648	GRIFF research	Timberbelt 4row(1 shelter species)