



Australian Low Rainfall Tree Improvement Group: Compendium of Softwood Tree Improvement 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 softwood tree improvement strategies developed by the Australian Low Rainfall Tree Improvement Group (ALRTIG). ALRTIG aims at speeding the improvement process of tree improvement by coordinating efforts across Australia.

This project was supported funded by three R&D Corporations — RIRDC, L & W Australia and FWPRDC which are funded principally by the Federal Government. Additional funding also comes from the Natural Heritage Trust. 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 New South Wales.

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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ACRONYMS AND ABBREVIATIONS

Acronym	Expansion
AFFA	Commonwealth Department of Agriculture, Fisheries and Forestry
ALRTIG	Australian Low Rainfall Tree Improvement Group
ANU	Australian National University
CP	Control pollinated
CSO	Clonal seed orchard
CSIRO FFP	Commonwealth Scientific & Industrial Research Organisation Division of Forestry and Forest Products
DPIE	Commonwealth Department of Primary Industries and Energy (Now AFFA)
FPC-WA	Forest Products Corporation of Western Australia
JVAP	Joint Venture Agroforestry Program
MAI	Mean annual increment
NHT	Natural Heritage Trust
NSW	New South Wales
OP	Open pollinated
PFT	Private Forests Tasmania
PT-CSO	Progeny trial that can also serve as a CSO
RIRDC	Rural Industries Research and Development Corporation
SA	South Australia
SPA	Seed production area
SSO	Seedling seed orchard
TAS	Tasmania
VIC	Victoria
WA	Western Australia

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 tree improvement strategies for a number of hardwood and softwood species. The focus of this compendium is on softwood species. It includes the following parts:

1. Overview of species selection process and tree improvement strategies
2. Genetic improvement strategy for *Pinus brutia* in southern Australia
3. Genetic gain trial strategy for *Pinus pinaster* in southern Australia

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. This part was also published with the ALRTIG Compendium of Hardwood Breeding Strategies (RIRDC Publication No 01/100).

The other parts in this compendium, dealing with the two softwood '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 documents will be updated periodically as the tree improvement programs progress, and the ALRTIG Softwoods Technical Committee reviews the strategies.

Part 1: OVERVIEW OF SPECIES SELECTION PROCESS AND TREE IMPROVEMENT STRATEGIES

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Note: This paper has also been published in (and should be cited as part of) ALRTIG Compendium of Hardwood Breeding Strategies, RIRDC Publication 01/100, Canberra, 2001.

1. SUMMARY

1.1. Target Planting Zone

The Australian Low Rainfall Tree Improvement Group (ALRTIG) 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: New South Wales, 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 – *E. 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 New South Wales, 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°S (the northern New South Wales 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, Western Australia 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 (°C)	Annual pan evaporation (mm)	Mean annual rainfall deficit (mm)	Days/year colder than 0°C (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. This approach has helped explain the performance of bluegum plantations in southwest Western Australia (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, New South Wales 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.

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.

4.1. NEW SOUTH WALES

The two main areas of interest in New South Wales are the Monaro Tablelands around Cooma and a large band extending west from Moree to Bourke in the north, and from Wagga to Deniliquin in the south (Figure 1).

Figure 1. 400-600 mm annual rainfall zone (30 year average) for New South Wales

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 structure of whole sub-catchments in southern New South Wales (and northern Victoria) is currently being planned. One significant difference between the Monaro Tablelands and the western slopes of New South Wales 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 South Australian 400-600 mm annual rainfalls zone is 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 South Australia. 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 southeast, 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 in the Midlands region, 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



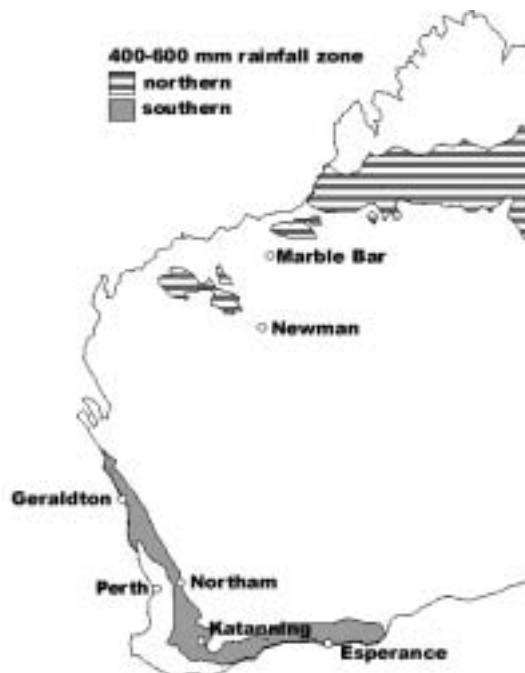
However, the main 400-600 mm rainfall areas in Victoria (Zones C and D in Figure 4) have had no broad-scale plantation potential studies conducted within them. These zones are likely to provide a large source of land potentially available for low rainfall species plantations. The Victorian and Commonwealth 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 Western Australia 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 South Australia. 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 New South Wales 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 m³/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: × Unsuitable ✓ 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. <i>E. grandis</i> x <i>camaldulensis</i> 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 (mean annual increment) 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).

Further reasons for selection of this species are the relatively good plantation resources, provenance information from planted trials across a range of sites, and demonstrated usefulness within the target planting zone. Some 1000 ha are 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 South Australia are largely a legacy of a 'free-tree scheme' in the late 19th 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 New South Wales, 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 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 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 Western Australia, 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, southwest New South Wales, receive annual rainfall of around 400 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 southwest Western Australia, although *C. maculata* from Casino provenance in northern New South Wales may also be useful. In western Victoria and inland southern New South Wales, *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 New South Wales 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. FPC-WA has managed a long-term tree breeding program for this species in Western Australia, where it is planted in significant areas. FPC-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 South Australia on low nutrition sites, otherwise suited to *P. radiata*), detailed information on the performance of FPC'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 FPC-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, New South Wales, the species have not been extensively trialled except in Western Australia. 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 FPC-WA and ANU/G.R. Davis Pty Ltd (of West Wyalong, New South Wales) 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 *E. 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 (Harwood et al. 2001). 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 provenances	Baseline standard for ALRTIG	For some species, large gains over use of inferior provenances
2.	Seed from interim seed production areas developed from planted stands of known best provenances	Modest improvement over 1	Gains depend on genetic base and degree of selective thinning. Genetic quality likely to be high for <i>E. cladocalyx</i> , at least.
3.	Seed from unthinned ALRTIG provenance-progeny trials	Modest improvement over 1?	Poor-quality pollen pool. Only small quantities of seed produced
4.	Seed from ALRTIG seedling seed orchards developed from provenance progeny trials	Significantly better than 2, in most cases	Provided SSO comprised predominantly from families from superior provenances. Large quantities of seed produced quickly.
5.	Seed from ALRTIG clonal seed orchards developed from outstanding trees in existing trials	Should be superior to 3 and 4, provided selection is done well, because selection intensity is higher than in SSOs	Genetic quality can be further improved by roguing inferior clones following progeny-testing. Can be scaled up to meet demand.
6.	Seed from ALRTIG clonal seed orchards developed from ALRTIG progeny trials	Higher quality than 5, for most species, because selecting from better genetic base	Would take at least 10 years to deliver any seed. Can be scaled up to meet demand. Long-term grafting success not confirmed for some species
7.	Seed families produced by controlled crossing between outstanding trees in ALRTIG breeding population	Higher quality than 1-6. Selfing eliminated	Expensive, limited quantity May be possible to produce operational quantities of seed, at acceptable cost if genetic gain 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). FPC-WA 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
<i>E. occidentalis</i>	1 PT-SSO ^[a]	1 PT-SSO	1 PT-SSO	1 PT-CSO ^[b]	Clone bank-CSO ^[c]
<i>E. cladocalyx</i>	1 PT-SSO	1 PT-SSO	1 PT-SSO	1 PT-CSO	-

<i>E. camaldulensis</i>	-	-	-	1 PT-CSO	Clone bank ^[d]
<i>C. maculata</i>	1 PT-SSO	-	-	1 PT-CSO	Clone bank-CSO
<i>C. variegata</i>	-	-	1 PT-SSO	-	-
<i>E. sideroxylon</i>	-	-	1 PT-SSO	-	-
<i>E. tricarpa</i>	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 FPC-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
<i>P. pinaster</i>	2 trial sites	2 trial sites	2 trial sites	2 trial sites	2 trial sites	-
<i>P. brutia</i>	-	-	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 (Part 3 of this Compendium).

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 (Part 2 of this Compendium).

8.3. Short Rotation Woody Crops

The ALRTIG Short Rotation Woody Crops Technical Committee originally developed plans to test 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 FPC-WA's existing resources and the Australian National University/GR. Davis *E. polybractea* seed orchard at West Wyalong, New South Wales.

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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
<i>A. dealbata</i>	silver wattle	9	High		Commercial stems only in 900 mm plus rainfall zone	US
<i>A. falciformis</i>	hickory wattle	9	Unknown			
<i>A. melanoxylon</i>	blackwood	9	Medium	ST	Good soil, high rainfall and shelter for good form	US
<i>Allocasuarina luehmannii</i>	bull-oak	9	Low	ST	Very attractive appearance timber, v. slow growth	SS
<i>A. verticillata</i>	drooping she-oak	9,10	Medium		Poor form common	
<i>Casuarina cunninghamiana</i>	river she-oak	2,5,9	Medium	ST	Waterlogged or riverine soils	US
<i>C. glauca</i>	grey she-oak	4,5,9	Medium	ST	Suited to waterlogged and alkaline sites	
<i>C. obesa</i>	swamp she-oak	4	Medium	ST	Suited to waterlogged and alkaline sites	
<i>Corymbia maculata</i>	spotted gum	1,2,5,6,9,10	med. High	ST	Excellent form, frost sensitive	VS
<i>C. variegata</i>	spotted gum	1,2,5,6	med. High	ST	Excellent form, frost sensitive	VS
<i>C. henryi</i>	spotted gum	1,2	med. High	ST	Excellent form, frost sensitive	VS
<i>C. citriodora</i>	lemon scented gum	6	med. High	ST,O	Prefers northern sites, higher rainfall	SS
<i>E. astringens</i>	brown mallet	2,9	Low		Slow growth a problem, good drought tolerance	S
<i>E. baxteri</i>	brown stringybark	9	Medium		Suited to sandy coastal soils	SS
<i>E. benthamii</i>	Camden white gum	1,10	med-High	ST	Requires higher rainfall	US
<i>E. botryoides</i>	southern mahogany	5,6,9	med-High	ST	Requires higher rainfall	
<i>E. bosistoana</i>	Gippsland grey box	9	Medium	ST	Maybe quite site specific; lack of available information	S
<i>E. brookerana</i>		5			Requires higher rainfall	US
<i>E. camaldulensis</i>	river red gum	2,4,5,9,10	Medium	ST,O	Good salt and waterlog tolerance. Good hybrid parent	VS
<i>E. cladocalyx</i>	sugar gum	2,5,6,9,10	Medium	ST	Good form & drought tolerance; some frost sensitivity	VS
<i>E. cornuta</i>	yate	9	Medium		Tough, grows well but form a problem	
<i>E. cypellocarpa</i>	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
<i>E. dunnii</i>	Dunn's white gum	6	High-v. high		Probably better suited to northern regions	SS
<i>E. fastigata</i>	brown barrel	9	High	ST	Requires higher rainfall for good growth	US
<i>E. globulus subsp globulus</i>	Tasmanian blue gum	4,5,6,9,10	V. high	ST,O	Better suited to higher (600+mm) rainfall	US
<i>E. globulus subsp bicostata</i>	southern blue gum	2,4,6,9	V. high	ST	Better suited to higher (600+mm) rainfall	US
<i>E. gomphocephala</i>	tuart	9	High		Good drought tolerance	SS
<i>E. grandis</i>	flooded gum	2,4,5,6,9	V. high	ST,P	Exc. Form. Prefers higher rainfall. Hybrid more hardy w/ good form	VS
<i>E. largiflorens</i>	black box	2	Low		Poor form, poor commercial prospects	SS
<i>E. leucoxydon/leucoxydon</i>	SA bluegum/ yellow gum	2,9,10	Med.-high		Good form & drought tolerance; best subspecies	S
<i>E. leucoxydon/megalocarpa</i>	red flowering yellow gum	2	Medium		Inferior to subsp. <i>leucoxydon</i>	SS
<i>E. leucoxydon/pauperita</i>	SA bluegum/ yellow gum	2	Low-medium		Inferior to subsp. <i>leucoxydon</i>	SS
<i>E. leucoxydon/pruinosa</i>	SA bluegum/ yellow gum	2	Low-medium		Inferior to subsp. <i>leucoxydon</i>	SS
<i>E. macrorhyncha</i>	red stringybark	6,9	Medium		Prefers dry, well drained soils	SS
<i>E. melliodora</i>	yellow box	9	Medium	F	Form is fair only; can be good on light soils	SS
<i>E. microcarpa</i>	grey box	9	Medium		Suited to intermediate flats, 500-700 mm rainfall	SS
<i>E. muelleriana</i>	yellow stringybark	9	Med.-high		Requires higher rainfall	US
<i>E. nitens</i>	shining gum	9	V. high	P	Drought tolerance fair at best. Needs good water availability	US
<i>E. obliqua</i>	messmate stringybark	9	High	ST	Needs good water availability. Suited to higher rainfall	SS
<i>E. occidentalis</i>	swamp yate	2,5,9,10	Med.-high	ST,P	Tolerates drought, salt and waterlogging. Form varies w/ provenance	VS
<i>E. ovata</i>	swamp gum	2,9	Medium		Requires plenty of non-saline water	US
<i>E. paniculata</i>	grey ironbark	9	Medium	ST	Good heavy timber, suited to higher rainfall	SS
<i>E. polyanthemos</i>	red box	9	Medium			
<i>E. porosa</i>	black mallee box	2	Medium			
<i>E. punctata</i>	grey gum	2	Medium			
<i>E. saligna</i>	Sydney blue gum	2,4,6,9	High	ST	Good form, growth rate and reasonable hardiness	S
<i>E. sideroxydon subsp. sideroxydon</i>	red ironbark	2,5,6,9,10	Medium		Performs well on loam/ sands and sedimentary derived soils	VS
<i>E. sideroxydon subsp. tricarpa</i>	red ironbark	2,5,6,9,10	Medium		Performs well on loam/ sands and sedimentary derived soils	VS
<i>E. tereticornis</i>	forest red gum	2,9	High		Northern close relative of <i>E. camal.</i> , which is probably better	SS
<i>E. viminalis</i>	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
<i>Grevillea robusta</i>	silky oak	2	Low	ST	Better suited to northern areas	US
<i>Melaleuca uncinata</i>	broom honey-myrtle	2	Medium			
<i>Melia azaderach</i>	white cedar	2	Low			
<i>Paulownia tomentosa</i>	royal paulownia	2	High	ST	Prefers much higher rainfall/ very good water availability	US
<i>Populus alba</i>	white poplar	12	High	ST	Needs reasonable water availability, tolerates flooding	SS
<i>P. euphratica</i>	Euphrates poplar	12	Medium	ST	Good salinity tolerance, tolerates flooding	SS
<i>Quercus ilex</i>	oak	12	Low	ST	Poor apical dominance and stem form	SS
<i>Q. suber</i>	cork oak	12	Low	Cork	Bark is stripped for production of cork	SS
<i>Robinia pseudoacacia</i>	black locust	2	Medium		Used for fodder, soil nitrification	SS
Softwoods						
<i>Abies grandis</i>	grand fir	8	Low	ST	Low rainfall provenances exist, but not extensively tested	SS
<i>Callitris glaucophylla</i>	white cypress pine	3,9	Low	ST	Excellent timber properties; very drought tolerant	SS
<i>C. preissii</i>	Murray pine	9	Low	ST	Excellent timber properties; very drought tolerant	SS
<i>C. gracilis</i>		10	Low	ST	Excellent timber properties; very drought tolerant	SS
<i>Cupressus arizonica</i>	Arizona cypress	3			Very hardy, form good, limited testing in Australia	SS
<i>C. atlantica</i>	Atlas cypress	3			Likely very drought tolerant. Little information	SS
<i>C. dupreziana</i>	Saharan cypress	3	Low		Likely very drought tolerant. Little information	SS
<i>C. libani</i>	Lebanese cedar	3			Likely very drought tolerant. Little information	SS
<i>C. lusitanica</i>	Mexican cypress	2,4	Medium	ST	Sap problems in low rainfall; better than <i>C. macrocarpa</i>	S
<i>C. macrocarpa</i>	Monterey cypress	2,4	Medium	ST	Sap problems in low rainfall; good sawn timber properties	S
<i>Larix occidentalis</i>	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
<i>Pinus albicaulis</i>	whitebark pine	8			Low rainfall provenances exist. Largely untested	SS
<i>P. attenuata</i>	knobcone pine	8			Low rainfall/ cold tolerant hybrid when crossed with <i>P. radiata</i>	SS
<i>P. arizonica</i>	Arizona cypress	8			Mexican low rainfall sp. Largely untested	SS
<i>P. brutia</i>	Brutian pine	3	Medium	ST	alkaline soil tolerant, very plastic. Good drought, cold tolerance, form.	VS
<i>P. canariensis</i>	Canary Island pine	3	Low-med.	ST	fire resistant, generally good form	S
<i>P. cembroides</i>	Mexican nut pine	3		F	Short tree (7 m) produces edible nuts	SS
<i>P. contorta</i>	lodgepole pine	8			Tree improvement program in USA. Largely untested in Australia	SS
<i>P. coulteri</i>	Coulter pine	8			Low rainfall provenances exist. Largely untested	SS
<i>P. eldarica</i>	Eldar pine	3	Medium	ST	alkaline soil tolerant, very plastic. Good drought, cold tolerance, form.	VS
<i>P. edulis</i>	pinyon pine	3	Low	F	Tree to 15 m. Produces edible nuts	SS
<i>P. engelmannii</i>	Apache pine	8			Mexican low rainfall sp. Largely untested	SS
<i>P. flexilis</i>	limber pine	8			Low rainfall provenances exist. Largely untested	SS
<i>P. greggii</i>	Gregg pine	8			Interest as radiata hybrid. STBA planning some plantings	S
<i>P. halepensis</i>	Aleppo pine	3,9	Medium		Form of Australian population very poor. Very hardy	SS
<i>P. jeffreyi</i>	Jeffrey pine	8			Related <i>P. ponderosa</i> (hybrids?). Largely untested	SS
<i>P. leiophylla</i> var. <i>chihuahuana</i>	Chihuahuana pine	8			Mexican low rainfall sp. Largely untested	SS
<i>P. lumholtzii</i>	Lumholtz pine	8			Mexican low rainfall sp. Largely untested	SS
<i>P. monticola</i>	white pine	8			Tree improvement program in USA. Largely untested in Australia	SS
<i>P. pinaster</i>	maritime pine	3,7	High	ST,P	FPC-WA has bred and tested extensively; very good all-round	VS
<i>P. pinea</i>	stone pine	3			good drought tolerance and shade	SS
<i>P. ponderosa</i>	ponderosa pine	8			Tree improvement program in USA. Largely untested in Australia	SS
<i>P. radiata</i>	Monterey pine	4,6,9	V. high	ST,P	V. plastic sp; better above 600 mm. Other orgs. breeding for high rainfall applications	S
<i>P. roxburghii</i>	chir pine	3			Generally good form	SS
<i>P. sabiniana</i>	digger pine	8			Low rainfall provenances exist. Largely untested	SS
<i>P. torreyana</i>	Torrey pine	3,8			Low rainfall provenances exist. Largely untested	SS
<i>Pseudotsuga menziesii</i>	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
<i>E. angustissima</i>		11	V. good oil producer		Commercial plantation and breeding in WA	VS
<i>E. horistes</i>	oil mallee	11	V. good oil producer		Commercial plantation and breeding in WA	VS
<i>E. kochii ssp kochii</i>		11	V. good oil producer		Commercial plantation and breeding in WA	VS
<i>E. kochii ssp plenissima</i>		11	V. good oil producer		Commercial plantation and breeding in WA	VS
<i>E. loxophleba ssp. lissophloia</i>		11	V. good oil producer		Commercial plantation and breeding in WA	VS
<i>E. polybractea</i>	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

PART 2: GENETIC IMPROVEMENT STRATEGY FOR PINUS BRUTIA IN SOUTHERN AUSTRALIA

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1. INTRODUCTION

Pinus brutia (Brutian pine) is a species selected for genetic improvement by the Australian Low Rainfall Tree Improvement Group (ALRTIG) (Bush et al. 2001). A strategy for the improvement of *P. brutia*, based on proven softwood tree improvement techniques and current knowledge of the species is outlined.

The **improvement objective** is to maximise the value of logs (per hectare per year) produced by plantations in the target planting zone (the southern Australian 400-600 mm rainfall zone). A rotation length of 20-40 years is anticipated. It is envisaged that these plantations would produce small logs suited to sawn timber, post and pole manufacture. In the first round of breeding, traits to be selected for include superior stem-form, light, low-angled branching and apparent resistance to disease. In later generations, wood properties, particularly resin content, may be added to the selection criteria.

Australian plantings of the species have already been surveyed, and the diversity and size of the main breeding population have been estimated. It is likely that infusion of material from the natural populations in the Mediterranean would be worthwhile, since the Australian population is mainly based on Cyprus provenances.

In the short-term, good quality existing plantings will be selectively thinned to create seed production areas. These will meet immediate requirements for genetically improved seed.

ALRTIG will embark on a nucleus breeding strategy, with seed production capacity based on clonal seed orchards. This strategy entails concentrating on a small clonal nucleus of elite trees, while the larger main breeding population is maintained as a series of seedling based progeny tests. Selections can be exchanged between the nucleus and main populations as breeding values are obtained. Both open pollinated and control pollinated progeny will be produced from these populations.

2. BACKGROUND

P. brutia is an important forest species in parts of the Mediterranean, where both plantations and native forests are managed. The species is extremely hardy, and can withstand extremes of temperature, moisture availability and soil conditions. It is used for a variety of wood products, including sawn timber and resin production.

In Australia, *P. brutia* has not been widely planted, though *P. halepensis* (Aleppo pine), a close relative, has been planted extensively in wind-breaks throughout southern Australia. This species is similarly hardy, but in Australia, has displayed relatively poor stem form, and is therefore of less use for creating wood products such as sawn timber, posts and poles.

It is envisaged that *P. brutia* may play an important role in Australian forestry in future. At present, the predominantly planted softwood in southern Australia is radiata pine (*P. radiata*). While this species is highly adaptable, it is not well suited to low rainfall areas (those receiving an average of less than 600 mm per year). Below this threshold, maritime pine (*P. pinaster*) can be usefully planted, down to a limit of 500 mm and possibly lower. Below this rainfall limit, *P. brutia* is the species of choice. *P. brutia* also has tolerance of a wide range of soil types including heavy soil textures and highly alkaline conditions. For this reason it may be the species of choice for a wide range of sites in the 400-600 mm rainfall zone. It is viewed as being complementary to other species selected for tree improvement by ALRTIG (Bush et al. 2001).

3. BASIC ELEMENTS OF 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 in the following sections (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

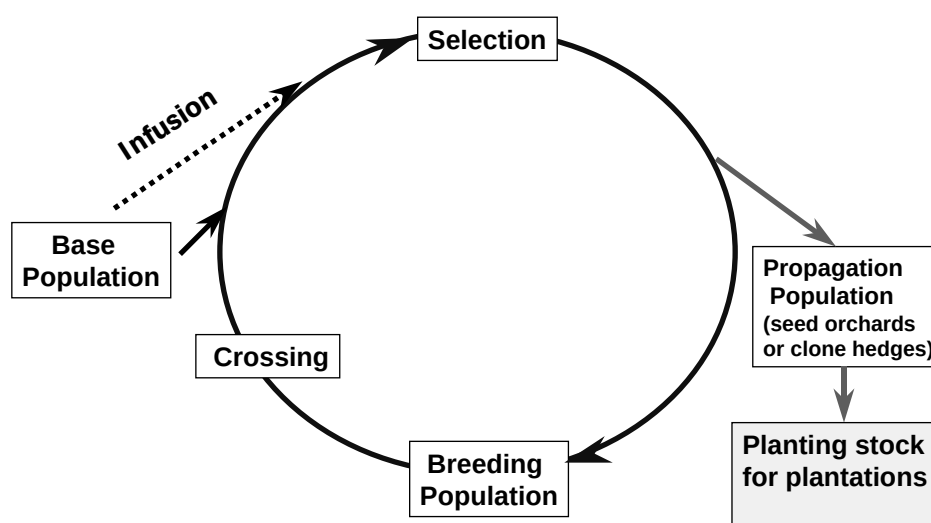
As an ongoing recurrent process, a breeding strategy accumulates benefits over successive generations of a cycle of testing, selection and mating (Figure 1). Every effective breeding strategy involves the maintenance of a hierarchy of four major types of population which are summarised as follows:

Base population - The base or gene resource population for *P. brutia* can be considered to consist of two components: the natural forests in the Mediterranean, and the *ex situ* plantings in Australia. In the first instance, the *ex situ* populations will be the primary source of selection, because of difficulty in accessing the native stands. These places in which initial selection can be carried out will continue to be a source of a wide range of genetic variation to meet future needs. Introduction of material from the base population into the breeding population after the initial selections have been made is referred to as infusion. It is standard practice to infuse material to ensure adequate genetic diversity and to add new-found superior selections.

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

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.

In pursuing the 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 IMPROVEMENT STRATEGY FOR *P. BRUTIA* IN SOUTHERN AUSTRALIA

4.1. Improvement Objective

The improvement objective for *P. brutia* is to maximise the value of logs produced by plantations within the target planting zone. Rotations of between 20 and 40 years are anticipated. The aim is to produce small logs, primarily intended for production of untreated sawn product, and possibly poles, posts and sawn timber for preservative treatment. To meet this goal, selection will initially be for traits that lead to long lengths of knot-free timber; ie light, low-angled branches and a straight stem. In later generations, it may be desirable to select for wood property traits, especially low resin content, which is expected to be significantly higher than that of *P. radiata* and somewhat higher than *P. pinaster*. This may have significant implications for the utilisation of the species.

A further objective is to produce sufficient improved seed to meet demand as quickly as possible. At present, *P. brutia* seed is very difficult to obtain, due to the lack of seed production facilities in Australia. The dual requirements to produce somewhat improved seed in the short-term and substantially improved germplasm in the long-run will have to be met.

4.2. Target Planting Areas and Anticipated Scale of Planting

Pinus brutia is a very hardy conifer; its drought tolerance exceeds that of both *P. radiata* and *P. pinaster*. Moreover, it is able to tolerate both a wider variety of soil types - including strongly alkaline soils - and extremely low temperatures. Within the ALRTIG planting zone (the southern Australian 400 – 600 mm rainfall zone), *P. brutia* is suited to many sites where growth and survival of the other conifers is marginal. This would include areas receiving less than 500 mm of rainfall – possibly as little as 350 mm per year; those with strongly alkaline soils; those with a heavy soil texture and; areas where climate or microclimatic effects such as cold air drainage cause frequent exposure to temperatures well below freezing.

It is intended that this species could substitute for *P. halepensis*, which is widely planted as a wind break on harsh sites throughout southern Australia, particularly in South Australia, where it is one of very few species that will tolerate contact with limestone at shallow depth. While *P. halepensis* can achieve good growth rates in tough environments, form is typically very poor, which has discounted its use for purposes other than shelter. *P. brutia* should have comparable survival and growth, as well as better stem form.

The species may also find application in areas where rising saline ground-water is a problem. Significant areas of Australia, including the Western Australian wheat belt and the Murray Darling Basin suffer from surface soil salinity, and this species may be usefully planted in recharge areas.

4.3. Selection Criteria and Traits for Selection

In the first cycle of selection and breeding, the following traits will be used as grounds for phenotypic selection of the plus trees:

- Growth and vigour
- Form (stem and branch)
- Apparent disease resistance

A strong need to study a number of additional traits within the breeding population has been identified. These traits include:

- Cone persistence
- Flowering compatibility
- Wood resin content
- Spiral grain tendency
- Wood density
- Other timber properties such as modulus of rupture and modulus of elasticity

It is intended that the additional traits will be incorporated for selection in later generations as necessary (see section 5.4.1). ALRTIG is actively supporting the study of wood property traits by third parties. At present, CSIRO FFP is carrying out a separate program of wood (sawn timber) property testing for this species. FPC-WA is also carrying out wood property studies on five clones from Rottne Island.

4.4. Information on the Species

4.4.1. Taxonomy

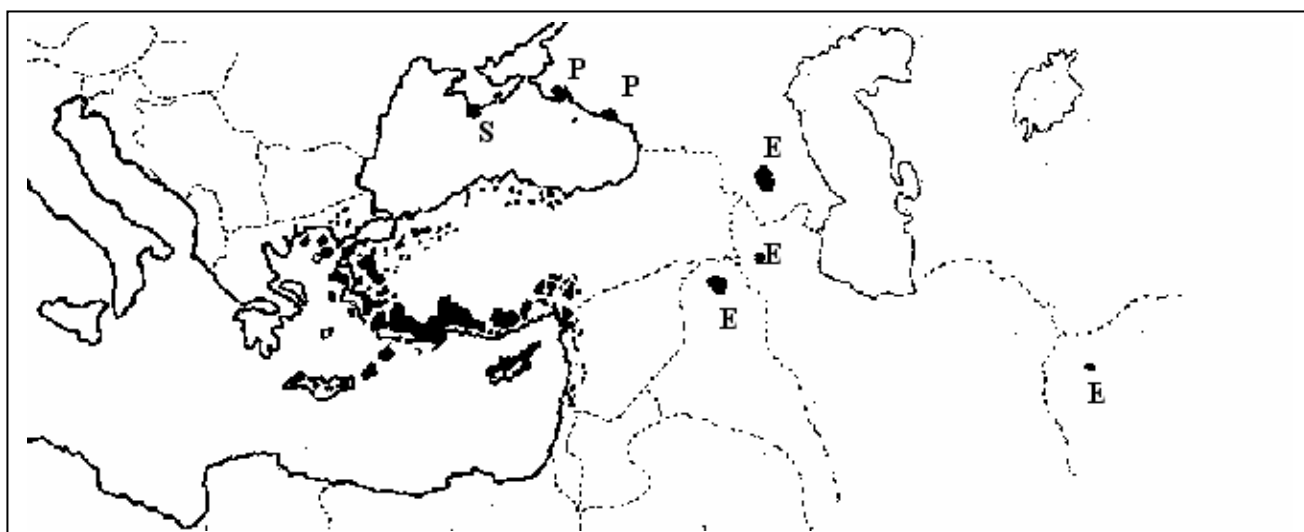
The members of the *Pinus halepensis/ brutia* complex, (*P. halepensis* (Mill.); *P. brutia* (Ten); *P. pithyusa* (Steven); *P. stankewiczii* ([Suk] Fom). and; *P. eldarica* (Medw.) occur naturally in the Mediterranean Middle East. Authorities vary in their taxonomic treatment of the group. Studies by Nahal (1962) and Debazac & Tomassone (1965) advocated that *P. halepensis* be treated as a species separate from the other four in the complex. More recently, evidence from isozyme studies has indicated that the four other species are very closely related, and could be considered as subspecies of *P. brutia* (Panetsos & Panetsos 1981, Nahal 1983 & 1984, Calamassi et al. 1988, Conkle et al. 1988, Schiller 1994). The members of the complex are considered to be distinct species for the purposes of this strategy.

4.4.2. Natural range

P. brutia occurs in the north-eastern areas of the Mediterranean, mainly around the Aegean, and southern regions of Turkey where it grows from sea level (Black Sea shore near Marmara) to 1200 m altitude (inland in the Taurus Mountains), (Figure 2). Other populations are found in Cyprus, Crete, Rhodes, Samos and Thasos as well as in Syria, Iraq and Lebanon. Populations of Eldar pine (*P. eldarica*) are scattered eastward from northern Iraq, Iran, Azerbaijan, Afghanistan and Pakistan. The only known natural population occurs in the eastern Transcaucasian region of Azerbaijan. The other two species are relict populations, with *P. pithyusa* occurring on the east shore of the Black Sea and *P. stankewiczii* on the Crimean peninsula.

Isozyme studies (Schiller 1994) provide strong evidence that *P. stankewiczii* is the progenitor of the entire *P. halepensis/brutia* complex and that the Iraq population of *P. brutia* is closest to *P. eldarica*. Eldar pine is possibly the most plastic of the group, as it grows under a wide range of conditions. Genetic variation is considerable and Australian introductions have shown clearly that the eastern provenances of Afghanistan grow better than those further west upon which most trial results are based.

Figure 2. Mediterranean region showing natural distribution of *P. brutia*



Key to Figure 2: S= *P. stankewiczii*; P= *P. pithyusa*; E= *P. eldarica*

4.4.3. Provenance variation

The diverse environments in which *P. brutia* grows has long been recognised (Selik 1958, Emberger et al. 1963, Mirov 1967, Oppenheimer 1967, Arbez 1974) and provenance trials covering the

environmental range of the species complex have been established in numerous places (Allegrì 1973, Palmberg 1975, Panetsos & Panetsos 1981, Spencer 1985, Iktueren 1986, Fisher et al. 1986, Eccher et al. 1987, Weinstein 1989).

In general, studies in the natural populations (Arbez 1974) and provenance trials (Iktueren 1986, Eccher 1987, Boardman, pers. comm. 1999, Sbay pers. comm. 1999) have shown that stem straightness varies with two gradients in the natural range. Stem straightness of *P. brutia*, and especially of *P. halepensis*, is known to improve moving from the western provenances towards the eastern. A relationship between altitude of the natural *P. brutia* populations and stem form, growth and branching has also been reported (Isik 1986, Kara et al. 1997, Isik & Kara 1997, Isik et al. 1999). Aside from these trends, the superiority of the Cyprus provenance in terms of stem form has been noted overseas (Arbez 1974, Panetsos & Panetsos 1981) and in Australia (Butcher pers. comm. 1999). However, this observation in the Australian population may reflect selection for superior stem form prior to introduction. Destructive exploitation of the Crete population over a long period has resulted in trees of poor form but, the trees still growing in an inaccessible stand in the Samara Gorge are of very good form (Panetsos & Panetsos 1981).

4.4.4. Tree improvement overseas

P. brutia is a very significant forest tree species in Turkey. Timber production is a major industry, with wood being used for pulp and paper, construction and furniture. Between 1985 and 1991, 296,000 ha of plantations were established. This is some 42,000 ha/yr or approximately 37% of the total area planted annually (Gunay & Tacenur 1993). Most of the seed for planting comes from the 61 seed stands in the country. Only a small percentage of the seed is from the 48 clonal orchards established, as seed production from them has only just begun (Isik & Kara 1997). Information on how these seed production facilities were established and the breeding objectives used is not currently available, though it would appear possible that resin production is a desirable trait in at least some lines. In Australia this trait would be selected against, as resin is seen as problematic in sawmills designed for radiata pine.

4.4.5. Wood and resin properties

The scarcity of scientific literature on wood properties and resin production of *P. brutia* makes it difficult to pre-select best bet provenances for evaluation trials in Australia. Available information indicates that the species has wood properties similar to radiata pine (Spencer 2001). However, *P. brutia* is known to be used for both sawn timber and resin production overseas, particularly in Turkey. In Australia these end uses would be viewed as mutually exclusive: sawmillers object to sawing softwoods that are highly resinous compared with radiata pine. It is clear that information on these properties will have a significant bearing on the ALRTIG genetic improvement program. While the Forest Research Institute (OAE) of Turkey Forestry Department has been conducting research into wood properties and resin production for decades, much of the information is held as internal reports and has been difficult to access. Indications are that this situation will improve.

Breeding emphasis in Greece is on wood quality and quantity rather than resin production, due to the comparatively high resin yields from *P. halepensis* (Papamichael 1970 in Panetsos & Panetsos 1981). However, numerous OAE reports from Turkey indicate that a resin production industry there is based on some of the lower altitude provenances of *P. brutia*. Timber production forests are situated in the mid-to-high altitudes.

4.4.6. Environmental tolerance

The capacity of *P. brutia* to survive and grow on a range of harsh site types in the low rainfall zone in Australia (eg Spencer 1985) and overseas (eg Weinstein 1989) indicates substantial drought tolerance. Evidence of provenance variation with respect to drought tolerance also exists. For example, Isik (1986) advocates the genetic conservation of the drought tolerant lower altitude

populations: they have been largely ignored for plantation purposes due to their poor form and slow growth. Selected families from these provenances may be introduced into a breeding program to enhance the survival and drought tolerance of the higher altitude *P. brutia* selections. Reports of *P. eldarica* and *P. starkewiczii* surviving the dry climate and saline soils, as well as winters of -22°C, in the Leninabad Botanical Gardens in Tajikistan (Gabisovqa 1984), indicates potential stress tolerance that could be of great advantage in Australia.

Evidence from controlled burns in Western Australia suggests that *P. brutia* may tolerate fire. In recently burnt compartments in Western Australia, larger trees did not exhibit any dead crown due to scorch and bark did not appear to be seriously damaged.

The FORADAPT *P. brutia* network is a European forest genetics research group with a strong molecular genetics focus. Their principal goal is to find the markers Quantitative Trait Locus (QTL) associated with drought tolerance in *P. brutia*. Also in the group are physiologists and geneticists who are working together using physical methods to identify individual plants/families/provenances that could then be used for Restriction Fragment Length Polymorphism (RFLP) and QTL work. Outcomes from this work could be valuable to ALRTIG in choosing the provenances best adapted for introduction and subsequent breeding.

4.4.7. Growth rate

Growth rates are highly variable and site dependent. For example, higher growth rates can be achieved on sites with greater moisture availability and fertility. Growth rates across a range of sites with varying soils and rainfall (average mm/year) and species are compared in Table 1. Table 2 provides a summary by provenance for the dry Jerilderie site in southern New South Wales. In general, the absolute growth potential of *P. brutia* is lower than that of either *P. radiata* or *P. pinaster*. It will be unlikely to compare favourably with these species on sites capable of supporting them. However, on sites that are too dry, heavy, alkaline or cold for radiata and maritime pine to survive, *P. brutia* is the species of choice.

Table 1. Mean Annual Increments (basal area) of *P. brutia* and other species

Location	Species	Age (years)	Stocking (stem/ha)	Rainfall (mm)	BA/ha (m ²)	MAI (m ² /ha/year)
Jerilderie provenance trial, western NSW						
Best 3 of 22 provenances	Brutia	30	514	385	18.88	0.63
Best 3 of 22 provenances	Aleppo	30	514	385	20.00	0.69
'100 acres' Yanchep, north Perth WA.						
Unselected Cyprus provenance	Brutia	47	600	750	75.43	1.45
Bussell's Arboretum. South of Collie, WA						
Bucak provenance, Turkey	Brutia	31	200	968	56.57	1.83
Bucak provenance, Turkey	Brutia	12	250	968	6.86	0.57
Monterey provenance USA	Radiata	10	250	968	8.75	0.88
Portugal provenance	Pinaster	12	250	968	9.59	0.78
Wirrabara & Bundaleer SF, east of Port Pirie, SA						
Unselected Cyprus provenance 1620	Brutia	25	900	600	53.65	2.15

Table 2. *Jerilderie provenance trial growth data at age 29 years*

Species	Provenance	Lat. N	Long. E	Altitude (m ASL)	DBH (cm)	Ht. (m)	Vol. MAI (m ³ /ha/yr)
<i>P. pithyusa</i>	USSR	45° 00'	35° 00'	<50	21.0	11.2	2.41
<i>P. stankewiczii</i>	USSR	44° 30'	34° 09'	<50	18.2	10.6	1.86
<i>P. brutia</i>	Turkey	37° 30'	30° 30'	700	21.6	11.8	2.63
<i>P. brutia</i>	Iraq	37° 00'	43° 25'	900	14.9	8.7	0.99
<i>P. brutia</i>	Greece (Rhodes)	36° 26'	28° 18'	200	20.3	10.8	2.16
<i>P. brutia</i>	Cyprus	35° 17'	33° 00'	500	20.8	11.5	2.39
<i>P. brutia</i>	Cyprus	35° 00'	33° 00'	500-1000	21.4	12.7	2.79
<i>P. brutia</i>	Cyprus	34° 57'	33° 14'	500-1000	19.0	12.1	2.14
<i>P. eldarica</i>	Iran	34° 40'	60° 20'	1300	20.2	10.3	2.03
<i>P. brutia</i>	Lebanon	34° 00'	36° 00'	400	18.2	11.1	1.85
<i>P. brutia</i>	Israel ex Greece	-	-	-	20.7	11.1	2.37
<i>P. brutia</i>	Turkey	37° 44'	30° 17'	600-700	20.0	11.4	2.15
<i>P. brutia</i>	Turkey	36° 05'	36° 03'	400-700	20.2	10.9	2.13
<i>P. brutia</i>	Turkey	36° 12'	29° 38'	800-1000	20.9	11.7	2.52
<i>P. brutia</i>	Turkey	36° 57'	28° 40'	50	20.0	11.1	2.24
<i>P. brutia</i>	Turkey	36° 37'	29° 08'	700	19.4	10.9	2.02
<i>P. brutia</i>	Turkey	37° 45'	36° 40'	800-1100	17.7	10.2	1.62
<i>P. brutia</i>	Turkey	41° 34'	35° 56'	<300	19.9	11.0	2.10
<i>P. brutia</i>	Turkey	37° 21'	28° 25'	800	20.5	11.3	2.32
<i>P. brutia</i>	Greece (Rhodes)	36° 00'	27° 00'	400	20.1	10.9	2.13
<i>P. brutia</i>	Greece (Thasos)	40° 42'	25° 00'	600	20.5	11.2	2.29
<i>P. eldarica</i>	Iran	35° 48'	50° 58'	1300	20.7	10.5	2.16
Provenance differences significant at 0.001				s.e.d.	1.298	0.51	

4.5. Available Genetic Resources

4.5.1. Australian resources and growth rates

Most of the genetic resources of *P. brutia* in Australia are from Cyprus. A limited range of genetically diverse material from provenances across the natural range is included in the 1968 IUFRO sponsored trials in South Australia and New South Wales. In Western Australia there are several Turkish sources existing as single plots in three arboreta. Fortunately the Cyprus provenances grow well in Australia, have good form and vigour, and are comparable with best provenances in the natural range (Schiller pers. comm. 2000).

The Australian *P. brutia* base population is comprised of a number of existing trials and woodlots (Table 3). The number of trees that could potentially be included in the breeding population from each stand (at appropriate selection intensity) has also been estimated.

Table 3. *Genetic resources for P. brutia in Australia*

State	Site/ description of material	Number of trees (breeding population selections)
NSW	Jerilderie Prov Trial ^[a]	26 ^[b]
NSW	Wagga Agricultural College (2 Cyprus provenances)	5 ^[b]
NSW	Back Yamma (Cyprus)	5 ^[b]
SA	Bundaleer provenance trial ^[a] and other stands	55 ^[b]
SA	Wirrabara Other material ex Cyprus	35 ^[b]
VIC	Wail planting (needs proper ID first)	4 ^[b]
WA	Rottneest Is clones ^[a]	5
WA	Bussells/Aspens arboreta B18 Bucak	4
WA	Bussells/Aspens arboreta H1 Turkey	4
WA	Bussells/Aspens arboreta H3 Turkey	4
WA	Bussells/Aspens arboreta C10 Cyprus	4
WA	Bussells/Aspens arboreta F12 Turkey	4
WA	100 Acres (Cyprus)	10
WA	P56 small pilot plots	10
WA	Mundaring 15 mixed families	5
	Total	180

^[a] Denotes stand to be converted to SPA ^[b] Denotes selection and scoring of trees complete

Given the relatively narrow range of introductions of *P. brutia* material in Australia, attention to importation of infusion material will be given in second and later generations.

5. PROPOSED ALRTIG IMPROVEMENT STRATEGY AND SUMMARY OF IMPROVEMENT PLAN

5.1. Outline of Proposed Plan

ALRTIG aims to provide significantly improved sources of germplasm to meet the potential plantation requirements for *P. brutia*. At present, there is very little seed available in Australia. In the short-term, the goal will be met through selective thinning of existing stands to create seed production areas (SPAs). These will produce seed of 'moderately improved' quality. In the medium to long term, ALRTIG's proposed program of clonal seed orchard (CSO) seed production should produce large quantities of significantly improved seed. It may also be possible to produce large quantities of clonal planting stock (cuttings). This option would impart the highest genetic gains to the production population. ALRTIG partners will establish:

- **Seed Production Areas (SPAs)** created in several existing high quality plantations. These will provide seed in the interim period before the CSOs become productive
- **Clonal Seed Orchards (CSOs)**, which will produce seed with a significant genetic improvement.

The proposed strategy will provide the best genetic planting material at any given point in time, starting from a unselected base population. Initial improvements will be based on phenotypic selection. This approach will be progressively modified, as breeding values are determined for the elite selections in the main population.

In order to meet the objective of rapid seed deployment, an accelerated first generation program will be implemented, where several functions will occur concurrently rather than sequentially, as is the convention. This approach will ensure that the genetic quality of the seed being made available for planting is being progressively improved in small increments until such time as seed from the fully tested families can be deployed from clonal orchards.

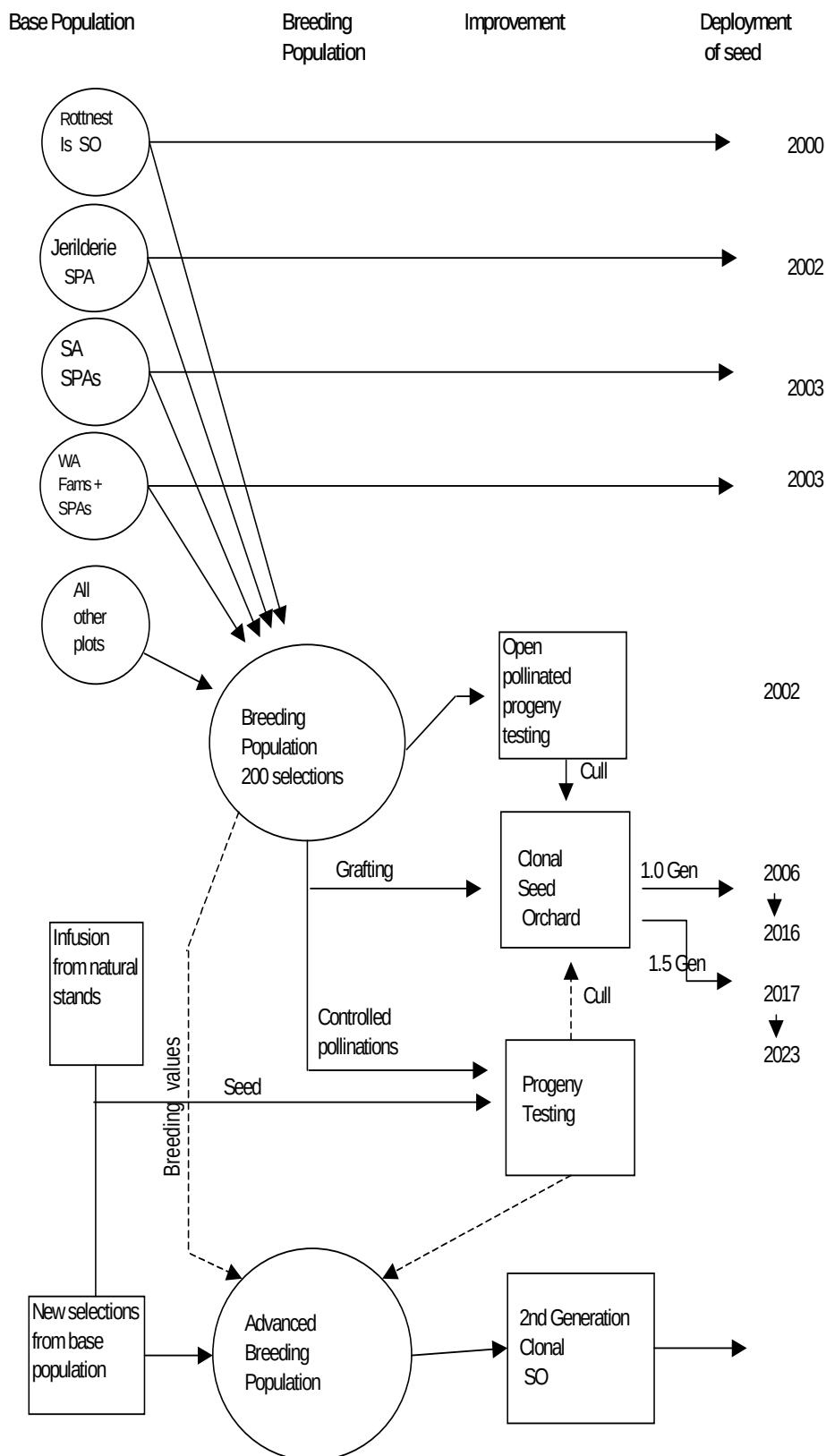
The concurrent operations of this strategy will involve:

- Conversion of selected stands to SPAs by phenotypic selection and thinning as an interim seed source
- Selecting and ranking superior phenotypes from all existing resources in Australia to form a breeding population
- Establishing replicated clonal seed orchards of the phenotypically selected best 30 individuals in the breeding population. These selections will form a first stage nucleus breeding population
- Establishing open pollinated progeny tests based on the nucleus selections and the rest of the breeding population
- Augmenting the Australian *ex situ* breeding population with new germplasm from range-wide provenance seed collections in the natural stands.

Figure 3 gives an overview of the strategy.

5.2. Expected Genetic Gains

Information on the heritabilities of traits considered important in breeding for this species (such as stem form, branch angle and size, growth vigour) have been reported by Isik et al. (1999) and Isik & Isik (2000). The study was based on a relatively narrow selection of material: 10 families from each of 6 populations, two from each of three altitudes ranging from the coast in the Antalya region to the Taurus mountains. Genetic variability of the species is considered to be higher in the mid-altitude

Figure 3. Representation of the *P. brutia* Breeding Strategy

populations of western Turkey than the perimeter populations such as on the Black Sea, Cyprus, Crete and east Greece (Calamassi et al. 1988). This means that the narrowness of the sample may give slightly high heritability estimates.

It was found that within-family variation was generally over 80% for all traits, meaning that within-family selection is desirable. The genetic base should be kept broad and genetic gains maximized with sequential selections in the breeding population.

A brief summary of the findings of Isik et al. (1999) are as follows:

- Mid-altitude populations had better growth, stem straightness and allocated a higher proportion of biomass to the stem
- for stem straightness, more than 25% of the total variation originated from between population differences
- family heritability values were highly correlated to individual heritabilities
- narrow crown families had straighter stems and better stem diameter growth
- faster growing trees have less forking

Individual heritability estimates (denoted h^2) are compared with those of *P. radiata* (Table 4). Heritabilities between 0.10 and 0.30 are considered to be intermediate (Cotterill & Dean, 1990). Both *P. brutia* and *P. radiata* would appear to be broadly similar for this range of traits, including relatively high heritability of the growth cycle (branch whorls) trait. If the heritability estimates of Isik et al. (1999) are a guide, the prospects for genetic improvement of *P. brutia* should be similar to those of *P. radiata*.

Table 4. Comparison of indicative h^2 values for *P. radiata* (Cotterill & Dean, 1990) and *P. brutia* (Isik et al. 1999)

Species	Height	Diameter	Stem straightness	Growth cycles ^[a]	Forking	Bark thickness	Taper
<i>P. brutia</i>	0.12	0.21	0.21	0.42	0.14	0.17	0.25
<i>P. radiata</i>	0.21	0.20	0.27	0.50	0.05	-	-

[a] The trait reported for *P. radiata* is whorl number

5.3. Interim Seed Sources for 2000-2006

In the short-term, seed can be sourced from plantings throughout Australia. However, this source is probably insufficient given that:

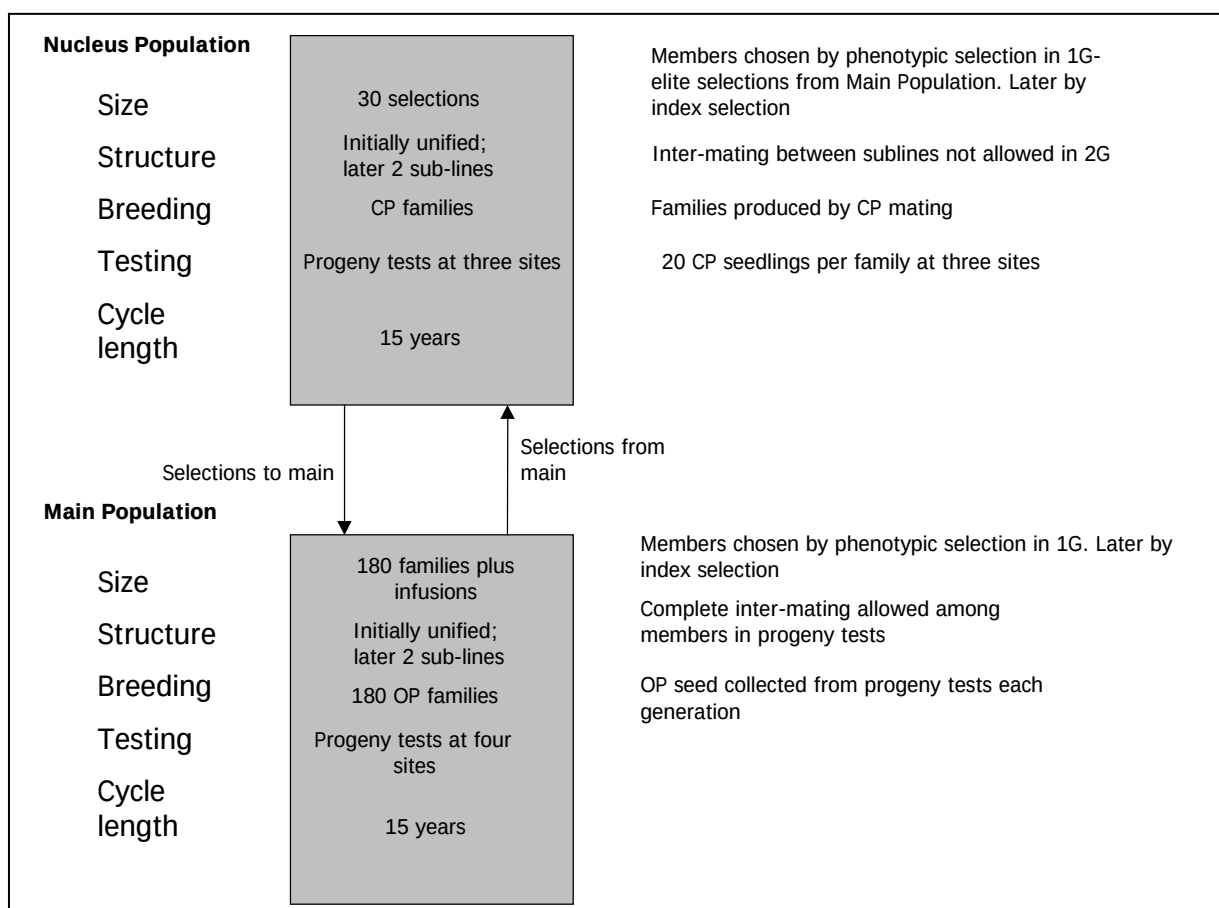
- ❖ Cone crops in many stands are small due to lack of crown depth
- ❖ Browsing of cones by birds is a severe problem in Western Australia
- ❖ The seed from some stands may be of poor quality, due to inbreeding
- ❖ Hybridisation with nearby *P. halepensis* may have positive or negative effects

Four seed production areas (SPAs) will be created by selective thinning of stands and provenance trials in South Australia, Western Australia and New South Wales by Spring 2000. The SPAs will start to bear cones containing improved seed by 2002. Cone crops will increase in the years after thinning, as crown-depth increases after release. Fertiliser may be applied to these SPAs to encourage crown development.

5.4. Nucleus Breeding

The ALRTIG Softwoods Technical Committee has adopted the concept of a nucleus breeding strategy (White et al. 1999), incorporating clonal seed orchards (CSOs). The primary distinguishing feature of nucleus breeding is the arrangement of the breeding population, which is split into the nucleus population and the main population (Figure 4). The aim of nucleus breeding is to maximize genetic gain per unit time. The small, elite 'nucleus' receives prime emphasis. Maintenance of genetic variation will be through management of the nucleus population and the main population, initially three to four times as large as the nucleus. Over time, as breeding values are obtained from progeny trials within the main population, there will be two-way transfer of material between the populations. Poor performers in the nucleus will be relegated to the main population and good performers from the main population promoted to the nucleus as vacancies occur. The nucleus is upgraded for each generation of breeding.

Figure 4. Relationship between Nucleus and Main Breeding Populations
(After White et al. 1999).



5.4.1. Main population

The target main population membership is about 300. Initially, it will include 180 phenotypic selections from the Australian *ex situ* part of the base population, which is mainly composed of Cyprus provenances (see Table 3). Open pollinated (OP) seed will be collected from the selections. This will be supplemented by selections from range-wide collections in the natural populations, planned for collection in late 2000.

Initially, the main population will be established as a series of well-designed progeny tests at three locations. After OP progeny trials have supplied estimates of genetic parameters and data on variation in growth, they may optionally be converted by selective thinning to seedling seed orchards (SSOs), depending on seed requirements. The option of splitting the main population into two sub-lines (once breeding values have been determined) will be considered.

5.4.2. Nucleus population

The nucleus population will consist of the top 30 ranked selections from the main population. Initially the nucleus will contain 30 phenotypically selected individuals; highest ranking plus trees from the main population. Three replicates of the nucleus population will be established at three field locations. Trees within the nucleus breeding population will be mated by control pollination (paired mating, diallel or other appropriate system).

In second and later generations, (once breeding values have been established) the nucleus may be split into separate breeding sub-lines. Each line will have no members with the same pedigree. This arrangement allows management of inbreeding in the propagation population, and if necessary, breeding for different objectives.

5.5. Technical Issues Related to Breeding Strategy

5.5.1. Flowering and seeding

The age at which seed is first produced in *P. brutia* is normally about 10 years. Depending on site and silviculture, *P. brutia* clonal seed orchards may be expected to yield at least moderate seed crops from 4-6 years after grafting. Seedling seed orchards would be expected to yield moderate crops after 10 years without flowering enhancement techniques.

5.5.2. Controlled pollination

Methods of controlled pollination are well established. The Southern Tree Breeding Association (STBA) has promoted training in techniques. No basic problems are anticipated for *P. brutia*. Some monitoring will be needed to determine phenological patterns such as the number of days of peak receptivity and period of peak pollen flow.

5.5.3. Vegetative propagation

Vegetative propagation by rooted cuttings is feasible for *P. brutia*. Micro-propagation at an operational level has been practised with *P. radiata* for several years. Clonal propagation of seedlings produced by controlled crosses between elite trees, followed by testing to identify the best clones, and maintenance of juvenile hedge plants by repeated hedging, may be a viable commercial route to deployment. Use of this technique will be subject to demand and will be reviewed in future.

Grafting of scions from selected superior trees onto seedling rootstocks is feasible. Slow early growth rate of seedling shoots may impose a time restraint. This may require 2-year old seedlings to match scion size for size. Enhancement of first season shoot growth rate is currently being investigated. The

use of *P. pinaster* root-stocks with *P. brutia* scions has also been trialled, though with limited success (T. Butcher pers. comm.).

5.6. Deployment Program and Seed Production

5.6.1. Creation of seed orchards

Three clonal seed orchards (CSOs) will be created under the ALRTIG program. The sites will be selected on the likelihood of good flowering and seed-set, and proximity to collectors and extraction facilities. Low rainfall is not a site selection parameter for the orchards. Desirable locations may have maritime climates, as experience suggests this tends to improve seed set (eg at Rottne Island in *P. brutia* and Mt Schank for other pines).

Pollen isolation zones will be needed between breeding sub-lines and segregation of members of each line in seed orchards will be a necessary consideration in later generation SO design.

- The orchards will be situated in South Australia, Western Australia and in New South Wales.
- Thirty ortets will be selected from within the breeding population for the nucleus.
- Selection will be on the basis of index scoring based on phenotype. Scored variables will include stem volume, straightness score, branch angle and weight and where appropriate, dominance within the stand. Limits will be placed on numbers selected within a single stand, to ensure genetic breadth. Collection of scions for grafting will require 25 ramets per ortet. Propagation and grafting work will be conducted at CSIRO FFP, FPC-WA and ForestrySA.
- Other statistics for the CSOs are summarised in Table 5.

Table 5. Summary statistics associated with CSOs

Item	Description	Number
A	Number of seed orchards	3
B	Number of ortets represented per orchard	30
C	Number of block reps per orchard	4
D	Number of grafted plants per orchard	120 (AxB)
E	Total number of grafted plants required	360 (AxD)
F	Number of ramets per ortet to be collected	25 (including allowance for graft failure)
G	Total scions to be collected	750 (AxBxF) (allows for graft success rate of approx. 50%)

5.6.2. Tasks associated with creation of seed orchards

- Selection of orchard sites will be made by state representatives on the ALRTIG Softwoods Technical Committee.
- Collection of scions supervised by experienced technical staff
- Propagation of rootstock and grafting of scions will be carried out at two locations. Limitations on this process include adherence to quarantine restrictions;
- South Australia and Western Australia can interchange plants with any of the others,
- New South Wales can only interchange with Victoria.

5.7. Genetic Evaluation

5.7.1. Working Plans for progeny testing

Progeny testing would include any suitable stock for which heritability estimates are required. These would follow the experience with *Pinus radiata* breeding obtained by the STBA. In order of availability and increasing refinement, these are:

1. Open pollinated progeny from Plus tree seed collections.
2. Open-pollinated restricted polycross Seed Orchard seed identified by female parent
3. Control pollinated seedlots (diallel, NCII or other mating designs).

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

Five progeny-test plantings will use an identical layout and design if there are no restrictions on the shape of the planting area. The standard design will be a latinised row column design with five replicates and one five tree line-plot of each family in each replicate. Treatments will be randomised individually for each site. On the basis of 180 families, this equates to $180 \times 20 = 3600$ trees. The initial spacing dimensions will be agreed between partners in the range 6.5 to 8 m²/tree.

An 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 each of the 12 families expected to perform best on indices available at the time. It will be left unthinned for at least five years, to demonstrate the stand performance of the best available seed sources 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, pruning, silvicultural thinning, nutrition, effect of trees on soil, etc. The possibility of pollen contamination of the subsequent SSO adjacent must be considered. Insertion of a hedge of an alternate vigorous species to form a pollen shield, planted at the same time is one option for reducing the hazard.

The total area required for each planting will be of the order of 3 ha. Stand management in the first instance will entail standard soil preparation and weed control as meeting local best management practices. Sites will be fenced to prevent browsing and damage by native animals, stock, rabbits and hares. Follow up maintenance to ensure uniform weed control, replacement of early losses, and monitoring is a necessary part of the Working Plans. Individual working plans covering each progeny test will be prepared by the lead agency managing each site, based on a standard model plan drawn up the Steering Committee.

5.7.3. Genetic gain trials

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

Seed from the proposed seed production areas, and SOs (later) and from the introductions of superior natural provenances, can be compared with unselected “wild” seed sources (to provide a base level control) in gain trials from 2002. Such trials could be established in cooperation with Regional Plantation Committees or kindred groups.

5.8. Genetic Conservation

Most of the natural provenances of *P. brutia* represented in Australian collections are from State forests in the western Mediterranean region, 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 forest in these countries. However, it is possible that quarantine measures, adverse public reactions to non-native Australian species and perceived risk of weediness in non-plantation areas, may prevent further import of genetic material from the native stands. It is also possible that some provenances are under threat from agricultural land clearance and urbanization. Consequently, it would be desirable for ALRTIG to support *ex-situ* conservation of these provenances. This could be achieved by establishing well-documented planted stands representing many parents from a particular provenance, and long-term storage of seed.

5.9. Provenance Resource Stands

ALRTIG will collaborate with individuals and organisations that are planting *P. brutia* 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, eg development of biomass equations, etc. ALRTIG will be responsible for the documentation: the exact location, extent and provenance origin of potentially useful provenance resource stands, including those already established, in a database. ALRTIG may provide, or facilitate provision of seed of known superior sources for such plantings.

6. PROGRAM REVIEW

Essential components of genetic improvement programs are 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 two 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: GENETIC GAIN TRIAL STRATEGY FOR PINUS PINASTER IN SOUTHERN AUSTRALIA

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1. SUMMARY

The need to establish deep-rooted perennial vegetation in regions of southern Australia that receive 400-600 mm mean annual rainfall is increasing, due to the threat of land degradation through factors such as erosion and salinity, and the need to diversify agricultural industry. In this target environment, genetic improvement and testing of certain species will be required, to realise the vision of drought hardy plantations that will produce valuable forest products. Maritime pine (*Pinus pinaster*) is one of the potential plantation species on which ALRTIG is focusing.

The Australian Low Rainfall Tree Improvement Group (ALRTIG) has recognised that *P. pinaster* is a tree crop with great promise for combating land degradation and providing a commercial return in the low to medium rainfall zone of Western Australia, and considers that it may well have potential in other areas of southern Australia. The species has been the subject of a research and development program that spans several decades in Western Australia, and a viable softwood industry centred on a resource of *P. pinaster* planted in the Perth region has been established. *P. pinaster* is the major southern Australian alternative to radiata pine, and the successful Western Australian breeding program has produced a useable tree that has ready markets. A big advantage is that the harvesting and milling infrastructure already exists in some areas, and using *P. pinaster* for marginal low rainfall areas, unsuitable for radiata pine (*P. radiata*), improves the viability of the wood processing industry. Planting of a vigorous well formed and drought tolerant *P. pinaster* tree will have very significant ramifications for Australia's rural industry.

ALRTIG will establish FPC-WA improved breeds of *P. pinaster* in genetic gains trials across southern Australia. These plantings will demonstrate the suitability of the improved species across a range of low rainfall sites representative of the potential target planting zone.

This report gives a background to the breeding program that FPC-WA has conducted over the last 50 years, provides a rationale for the trials, and outlines how they will be managed to provide information, which can potentially be used to realise *P. pinaster*'s commercial and environmental potential throughout southern Australia.

2. ALRTIG PROJECT SYNOPSIS

ALRTIG is a cooperative tree improvement organisation with a partnership comprised of State and Commonwealth Government organisations (Table 1). Each of these partners will be involved in the *P. pinaster* genetic gain trials.

Table 1: ALRTIG Partner organisation with *P. pinaster* genetic gain trials

Partner organisation	State	No. sites
Forest Products Commission	Western Australia	2
State Forests of NSW	New South Wales	2
Department of Natural Resources and Environment	Victoria	2
ForestrySA	South Australia	2
Private Forests Tasmania	Tasmania	2

The ALRTIG is organised into three functional 'modules' that deal with Hardwood, Softwood and Short-rotation Woody Crop tree improvement (see Bush et al. 2001, this compendium). In addition to the *P. pinaster* yield trials outlined here, tree improvement strategies and working plans will be developed for breeding of the highest-priority low rainfall species (*C. maculata*, *E. camaldulensis*, *E. cladocalyx*, *E. occidentalis*, *E. sideroxylon* and *P. brutia*). Short-term seed demand for these species will be met by identifying the best currently available seed sources, with early production and distribution of seed from these sources following. Fast tracked mass-production of genetically improved planting material from new stands of eucalypts and *Pinus brutia* established by the collaborators will ensure continuing genetic

gains and best-quality planting material in the future. The breeding programs will focus on adaptation, vigour and form for sawn timber production.

Pinus pinaster has already been genetically improved for low rainfall zones in Western Australia, so the project will seek to evaluate and utilise the improved genetic resources of this species in the eastern States. The project will allow an evaluation of the suitability of the species throughout southern Australia, which is a first step towards realising the potential economic and environmental benefits that this species offers.

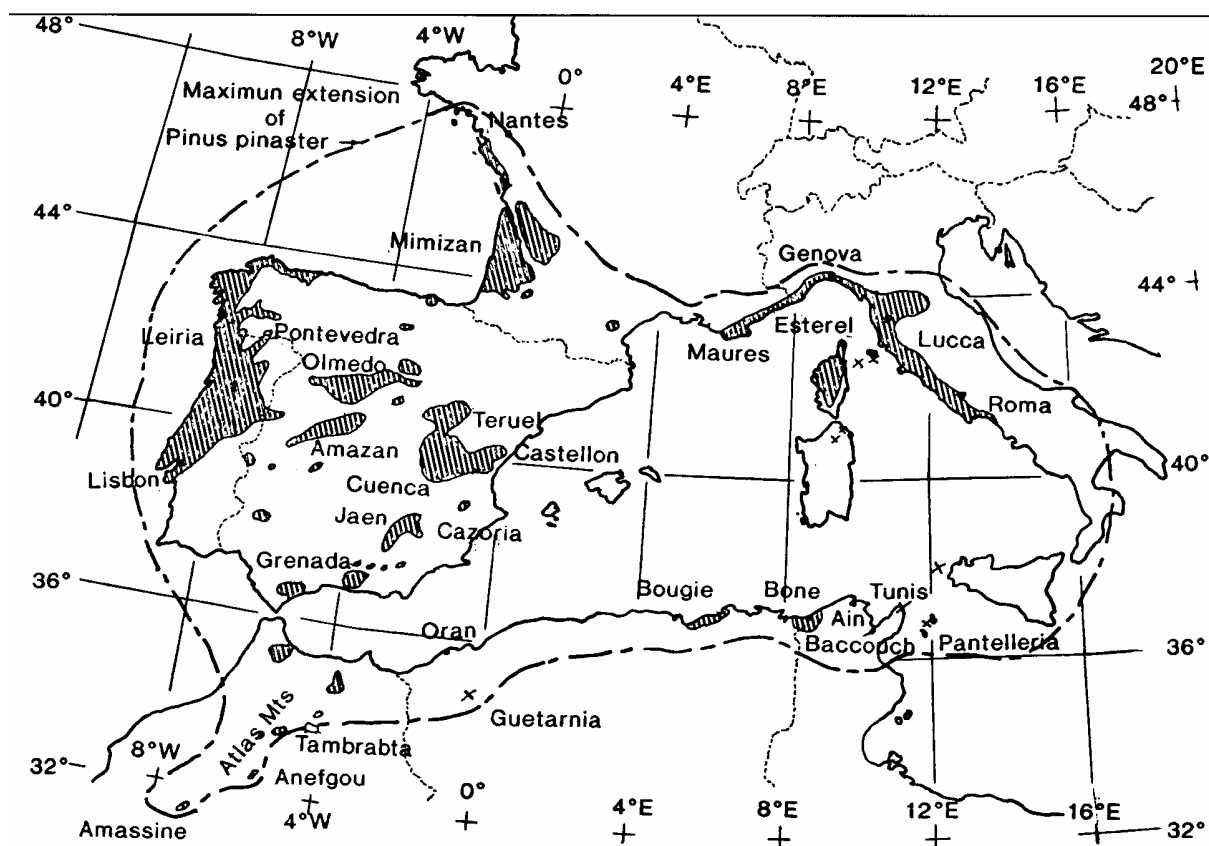
3. BACKGROUND - OVERVIEW OF PINUS PINASTER

3.1. Natural Distribution

There are more than four million hectares of *P. pinaster* (maritime or cluster pine) forest in France, Portugal, Spain, Italy and northern Africa (Figure 1). The species consists of five major races, based on tree vigour and phenotypic appearance: (1) Atlantic group, occupying the coastal plains and seaboard of the Atlantic coast from Lisbon (Portugal) to Nantes (France); (2) Mediterranean coast from Tarragona (Spain) to Tivoli (Italy); (3) Corsican group restricted to islands of Corsica and Sardinia; (4) Continental group of the Iberian mountain regions and includes the Atlas mountains in Morocco; (5) North Africa coastal group in Algeria and Tunisia.

There are 1.8 million hectares of *P. pinaster* forest in France with 1 million in the Aquitaine (Landes) area, 90% of which is privately owned. The 10% public forest includes the protection forest on the

Figure 1. Natural Distribution of *Pinus pinaster*
(Hopkins and Butcher, 1993).



Atlantic coast dunes that was first established in 1774. Swamps were drained and 600,000 hectares of *P. pinaster* were established during the reign of Napoleon's Second Empire. 25% of France is forested; 45% of Aquitaine is forest and is the principal industry employing 30,000 workers. *P.*

pinaster is the principal species used in France for forest regeneration with 18,000 ha planted each year. Average productivity is $9 \text{ m}^3 \text{ ha}^{-1}$ and this increases to $15 \text{ m}^3 \text{ ha}^{-1}$ in the fertile area of south-west France. They harvest some 6.5 million m^3 of wood per annum. One third goes to pulpwood, 60% is sawlog and 6% is peeled. Because of poor form of the Landes race, log lengths are very short; typically 1.5 m. Sawn timber recovery is 50%.

In Portugal, there are 1.3 million hectares of *P. pinaster*, or about 44% of the forest area. It extends to the Spanish border all over Portugal north of the river Tagus. Only 30% of the total area, or about 300,000 ha belong to the State. Most of the area belongs to absentee landowners in very small lots of 1 to 2 ha and is poorly managed. *P. pinaster* is used for almost everything that wood can be used for, although trees from the Leiria forest are mainly used for high quality timber products. Resin tapping during the last two years of the rotation is still practiced.

The Leiria Pine Forest was first planted some 700 years ago. The Pinhal do Rei extends for over 11,000 ha along the Atlantic coast between latitude $39^\circ 42' 2''$ and $39^\circ 52' 49''$ west of Leiria. Production forest area of 8,782 ha or 81% of area and 1,880 ha of protection forest.

In Spain, there are more than 1 million hectares of *Pinus pinaster* forests covering an extreme range of climate and edaphic conditions. *P. pinaster* is found on the Atlantic coast in northern Spain ($>1000 \text{ mm}$ rainfall), central Spain and in southern and southeastern Spain (100 mm rainfall). Soil types also vary from sands and dunes to shallow rocky soils. Seed zones for commercial and native forests have been defined for all areas of Spain. It is commonly planted at all conditions within its range. 780,000 hectares were afforested between 1940 and 1982, for production and protection plantings on the Mediterranean coast and on the high plains of the Teleno - Ona Region.

3.2. *P. pinaster* in Western Australia

P. pinaster was first planted in trials in Western Australia in 1896. Plantations at Gnangara on the northern Swan coastal plain were commenced in 1923 using seed originating from France. Seed source, or provenance trials were planted in 1926 using seed from Portugal (Leiria), France (Landes and Esterel) and Corsica. They were conclusive in showing *P. pinaster* from Leiria to have the best growth rate and reasonable form for south-western Australian conditions (Perry, 1940). All *P. pinaster* plantations in Western Australia have been based on Leirian material since 1942. Subsequent testing of seed sources from Portugal, Spain, France, Corsica, Italy and Tunisia has confirmed the vigour superiority of the Leirian provenance (Hopkins, 1960; Hopkins and Butcher, 1993). Nicholls et al. (1963) assessed wood properties of Leiria, Landes, Corsica and Esterel races of *P. pinaster* and found that Leirian provenance had higher basic density, good fibre length and superior vigour and form compared with the others. Hopkins (1971), in a glasshouse study, showed Leiria provenance seedlings to have good drought tolerance. Hopkins and Butcher (1993) confirmed this result with field trials. Butcher (1976) reported areas planted with *P. pinaster* of 21,400 ha in Western Australia, 6,000 ha in South Australia, 1,400 ha in Victoria, 100 ha in New South Wales and 31,500 ha in South Africa.

3.3. Utilisation

P. pinaster timber is suitable for a range of uses including sawn timber, panel products, veneers and pulp and paper. In Western Australia, it is used mainly as structural grade timber and for panel products such as medium density fibreboard or particleboard. Appearance grade timber can be used for furniture and joinery. It is also used for pallets and in the past was widely used for packaging. Suitably treated with preservative, it can be used for power poles, sleepers and posts.

A softwood processing industry based on *P. pinaster* is well established in Western Australia. The industry is fully integrated with markets for both high and low value products. In 1995/6, 37 000m³ of *P. pinaster* sawlogs were harvested from State plantations.

In many cases *P. pinaster* is preferred to radiata pine because of its greater strength and density. It has particular appeal for structural veneers.

3.4. Western Australia - Breeding Plan

Pinus pinaster was the major plantation species in Western Australia in 1955 and the future planting of 80,000 hectares was envisioned. This would provide a major wood source for development in the State and a sound use for otherwise unproductive land on the coastal plain. In 1957, a breeding program was commenced to improve stem and branch quality and vigour within the Leirian provenance of *P. pinaster*. Western Australian plantations, older than 30 years, were searched for plus trees but this constraint limited the search area to only 400 ha. In 1964, the Western Australian Forests Department sent Dick Perry (Research Forester and Tree Breeder) to Portugal to select plus trees in the Forest of Leiria - this was recognised as the best and quickest route to the improvement of *P. pinaster* for Australia. Forest services in South Australia, Victoria, New Zealand and the Commonwealth Forestry and Timber Bureau provided financial support. Scion material of these Portugal selections was dispatched to breeding centres in Western Australia, South Australia, Victoria and New Zealand as part of the agreement. However, with the exception of Western Australia, grafting was a total failure. Subsequently, scion material was collected from the FPC-WA clonal archive and sent to the collaborating centres and also to South Africa. Importation was an outstanding success! 85 plus phenotypes were introduced to the Western Australian program as scions, seed and pollen (Perry & Hopkins 1967).

Further local plantations were searched in 1972 to 1974 and increased the number of local selections to 86. Pollen and seed was exchanged with the South African breeding program at this time. Another 110 plus trees were added to the Breeding Population in 1996 following an extensive search in mature age, unimproved plantations in Western Australia.

The Western Australian Base Breeding population consists of 304 individuals, selected in Western Australia (196), Portugal (85), South Africa (20) and South Australia (3). Work is under way to select plus phenotypes in Leiria origin plantations that have demonstrated an ability to survive severe drought conditions.

The Western Australian *P. pinaster* first generation pedigree database contains 830 control cross families. They are planted in a minimum of two trials and are usually represented with 50 trees in each trial. This and the open-pollinated (OP) families form the selection base for future breeding of the species in Western Australia. In the early 1970s, full-sib and polymix seedlots from the Western Australia program were sent to forest services in Victoria and South Australia, CSIRO in Canberra, New Zealand, Turkey, Portugal, South Africa, Morocco and Oklahoma USA. This series would provide information on performance of the FPC-WA improved *P. pinaster* across a range of environments.

Western Australia is the only centre actively involved in the genetic improvement of the Portuguese Leiria provenance of *P. pinaster*. AFOCEL in France has an active program with the Landes race

because of its frost tolerance and the Corsican race because of its good stem form. Western Australian trials planted in 1966 and 1967 have shown the best of the Landes program to be inferior to the routine Leirian source. Hybrid crossing with Leiria increased vigour of the Landes and Corsican tree but the hybrid was significantly less vigorous than Leiria. AFOCEL used Leiria pollens from FPC-WA program to create hybrids with Landes parents in 1979. Severe frosts in 1985 with two temperature peaks at -15°C over a week period, killed some 60,000 ha of Portugal origin stands in France while the hybrid trees survived and were the top ranked families for volume and form at age 15 years (Butcher, 1999). This shows the hybrid Landes-Leiria tree to be frost resistant. Hybrid crossing in France with Corsica race *P. pinaster* has significantly improved the stem and branching quality of Landes race *P. pinaster* without reducing vigour or frost resistance.

Some 101 breeding trials covering an area of 216 ha and 233,000 trees are established in Western Australia to provide the base population for breeding and database required quantifying genetic parameters of *P. pinaster*. Clonal seed orchards were first established in 1963 at Joondalup (14 ha) and 1970 at Mullaloo (11 ha) to provide seed for plantations. All *P. pinaster* plantations have used improved seed from clonal orchards since 1971. New and improved seed orchards were planted at Manjimup (7 ha) in 1986 to replace existing orchards and this now provides seed for the plantation program. The Manjimup CSO was designed to meet land use objectives of the Swan Coastal Plain, water and timber production (Butcher, 1977). Breeding traits emphasised were cylindrical volume and form of the 10m butt sawlog with reduced size limbs to minimise rainfall interception. Because stem and branch diameter is correlated, gains in volume have been reduced.

The Western Australian *P. pinaster* tree breeding program objective is to improve the quantity, quality and uniformity of wood produced for industrial use per unit of land area and time. Silvicultural characteristics that are the focus of selection include survival, growth rate, stem and crown form and wood properties. FPC-WA's advance generation breeding program is mainly based on selections made at an early age (8 to 10 years) in progeny trials for growth rate, stem and branch quality. In the early stages of the program, wood density of new selections were also assessed and the tree would be cloned for breeding and orchards if it was average or above average density for the population. Siemon (1998) reported on a FPC-WA Timber Technology study that showed whole tree basic density of 25 year-old trees to be similar for both orchard origin and unimproved trees although the mean ring width of orchard trees was greater.

3.5. Gains from the Breeding Program

Yield trials were planted in 1973 at Gnangara and Yanchep. At 18 years, trees from Joondalup orchard seed gave 10% more diameter growth (36% more volume) when compared with the routine unselected seed source. Even greater gains were achieved in stem form and branch quality that significantly increases the utilisable volume (Butcher and Hopkins, 1993). Progeny tests have been planted north of Yanchep, east of Mundaring, at Busselton and Pemberton in the south, with a consistent family response over these environments (Butcher, 1974). The seed and vegetative propagules being developed are suitable for all medium rainfall sites. More recently, in 1997, seedlings from 200 second generation selections were planted in large trials (10 ha) in the 400-600mm rainfall agricultural zone in high and low evaporation areas. And in 1999, 13 third generation control-pollinated (CP) families were planted at four low rainfall sites. The second generation pedigree database consists of 400 CP families.

For the orchards planted at Nannup (2 ha) and Manjimup (2 ha) in 1992, genetic gain in diameter is calculated to increase to 15%. This is a 50% increase over the gains from the first generation seed orchard. Clones used in these orchards had a greater selection weighting for vigour and a reduced emphasis on stem and crown form so that more industrial wood could be produced at first thinning. For the CP and OP orchards planted at Manjimup (13 ha) in 1996, a breeding value of 22% for diameter (equivalent to 70% volume gain) has been computed. This is a doubling of the genetic gains that were achieved from the first generation seed orchards: tree form gains will be maintained at about the same level.

3.6 Western Australian Maritime Pine Project

Western Australia faces huge salinisation problems as the result of broad scale clearing of woodland for agriculture since European settlement. To stop the destruction of remnant woodland and low lying farmland by rising water tables, large areas of deep-rooted perennial crops need to be established to increase water use. *P. pinaster* was selected as the major species to be used to address this problem. The Government, in partnership with private landowners, plans to establish 150,000 ha of *P. pinaster* over the next ten years to demonstrate the capacity for the commercial viability of this species as an alternative commercially viable land use.

An additional 25 ha of advance-generation clonal seed orchards were established in 1995 and 1996 in the Manjimup region. A number of strategies were used. Small clonal blocks were planted with prolific flowering parents having good breeding values for volume and tree form. These ramets will be used for control pollination with very high breeding value (BV) pollens. This allows for immediate use of pollen from any new outstanding tree, and for inclusion of outstanding parents that would be normally be excluded from conventional orchards because of their very poor flowering. Conventional orchards were also planted using very high BV parents, but with unknown flowering potential. Research has shown that seed yield can be increased by 30% using GA^{4/7} hormone application and this is now routinely applied to ramets at Manjimup and Nannup.

Vegetative multiplication using juvenile cuttings of *P. pinaster* is a recent deployment option that has been developed by FPC-WA. This has the advantage of being able to immediately bulk improved seedlings as cuttings, but more importantly, the best genetic stock from the breeding program can be quickly deployed. Pollination programs in recent years have concentrated on making these elite crosses for cutting development. About 20 hectares of mother plants have been created for the taking of cuttings.

A major project just completed is the expansion of the West Manjimup nursery for the annual production of 45 million container plants including 15 million of *P. pinaster*.

Since commencement of the *P. pinaster* Project planting in 1996, 10,000 ha have been established in low rainfall agricultural areas. In 2000, another 6,000 ha of *P. pinaster* will be planted.

4. ALRTIG *PINUS PINASTER* GENETIC GAIN TRIALS

4.1. Objective

ALRTIG recognises that *P. pinaster* has already been genetically improved for low rainfall zones in Western Australia, so the project seeks to evaluate and utilise the improved genetic resource of this species in the eastern States. Although *P. pinaster* was included in early arboretum plantings in other Australian states, performance was poor if stock was not of the Atlantic race. In South Australia, for example, commercial *P. pinaster* plantations were established on higher rainfall sites unsuitable for radiata pine using stock derived from unselected Corsican provenance material, giving very poor results. Meanwhile, stands planted in Western Australia using the Portuguese Leiria provenance gave variable results in terms of tree form and productivity.

However, Western Australia's genetically improved material has shown itself to be significantly superior to even the best native seed sources. While the species was required for infertile, dry coastal plain sands north of Perth, it only showed its potential when seedlings derived from the breeding program were used. Apart from the Western Australian-bred family trial series planted in Victoria, New South Wales and South Australia in 1970, the improved breed of *P. pinaster* has not been adequately tested outside of Western Australia.

The Maritime Pine Project gave impetus for a new round of selection and breeding for new sites with the result that specific trait genetic sources have been developed for deployment. These are for high volume production, high quality stem and crown form and higher than average wood density. A new genetic source for increased drought tolerance is also being developed.

ALRTIG will evaluate the FPC-WA improved breeds of *P. pinaster* in a series of well-designed, structured genetic gain (or yield) trials. The trials will allow the partners to assess the potential of *P. pinaster* as a commercial species for low rainfall sites on a variety of site types throughout southern Australia.

4.2. Sites

Ten sites will be established across southern Australia in winter 2000 (Table 2).

Table 2. ALRTIG *P. pinaster* genetic gain trials site information

TBIMS ^[a] code	State	Location	Local name	Latitude	Longitude
XS.23 (2000)	WA	Esperance	Dimers	33°30'	121°30'
XS.24 (2000)	WA	Marchagee	O'Callaghan	30°01'	116°05'
XS.25 (2000)	NSW	Wagga - south	Lake Albert	35°09'	35°09'
XS.26 (2000)	NSW	Wagga - north	Harefield	34°57'	147°31'
XS.27 (2000)	Vic	Kamarooka	Amory	36°27'	144°18'
XS.28 (2000)	Vic	Shelford	Dashwood	38°00'	144°00'
XS.29 (2000)	SA	Telopea Downs	Thring	36°07'	141°06'
XS.30 (2000)	SA	Tintinara	Filmer	35°53'	139°53'
XS.31 (2000)	Tas	Carrick	Sillwood	41°31'	146°58'
XS.32 (2000)	Tas	Campbell Town	Kenilworth	41°52'	147°21'

[a] TBIMS = Tree Breeding Information Management System, Butcher (1993). It is used to control all operations and information for efficient running of FPC-WA Tree Breeding programs.

The sites selected will be indicative of large regional areas that could be potentially planted to this species. Adjacent blocks of *Pinus radiata* and where possible, *Pinus brutia* will be planted, to allow comparison with these alternative species.

Soils and climatic profiles (temperature, rainfall, evaporation) will be collected for each trial site. Site characterisation will use the methodology and approach suggested in McDonald et al. (1998).

4.3. Treatments

There are four types of improved genetic quality seedlings/cuttings that will be produced for deployment by FPC-WA's Manjimup Plant Propagation Centre. An unimproved seed source will also be used as a control, resulting in a total of five main 'yield treatment' groups (Table 3).

Table 3: ALRTIG P. pinaster Genetic Gains trials, description of treatments

Treatment	Treatment description
1. Vigour	Selected for high vigour, average stem and crown form
2. Stem and Crown Form	Selected for high stem and branching traits; average vigour.
3. Wood density	Clones with above average wood density; average vigour and form.
4. 1.5 generation	Backward selection, best first generation clones.
5. Unimproved	Unimproved seed collected in Leiria and from unimproved, unthinned stands in Western Australia.

Each of the improved yield treatments will be created by first identifying 16 clones located in second-generation clonal seed orchards with high breeding values for specific traits. TBIMS will then be used to identify the ramets with the highest breeding value neighbourhood pollen for specific traits. Four cones will be collected from each side of five ramets and bulked by clone.

CSIRO FFP will provide unimproved seed, code SN7969 imported from Forest of Leiria in Portugal (8000 seed to be sown). This will be supplemented with a seed mix collected from unthinned stands in Western Australia originating from seed imported from Leiria (2000 seed). Individual seed sources (400 seed sown) will be kept separate for each major yield treatment.

4.4. Trial Design

Each site will have a trial consisting of six replications of the five yield treatments planted in a randomised block design. Plot size will be 64 treatment seedlings made up with four seedlings from each of 16 yield families. Where space in the field permits, there will be a third row out-row of routine stock to facilitate thinning without loss of any improved material. Spacing between rows will be 3 m with 2.5 m between trees.

While yield treatment and individual family coding will initially be retained by FPC-WA, the information will not be revealed to other partners in the first instance, to afford greater security of FPC-WA intellectual property. Families will be nested in yield plots, enabling future analysis of genotype x environment and ranking of families within yield treatments. Family codes for all trees at each site will be given prior to the first major assessment of tree vigour, stem and branching form.

4.5. Trial Management and Maintenance

Site preparation and weed control will be to a standard consistent with best local practice. A complete record of these operations will be kept for each trial. Preliminary soil survey holes or pits will be excavated in each replicate, to ensure each site is even. This survey will be followed by a full soil characterisation once the trials have been established.

Trial layout will be accurately surveyed and pegged noting that a minimum of two *P. pinaster* trees will be planted as a surround to the trial to buffer edge effects (buffer depth up to two trees is sufficient to provide uniform protection of treatment trees from exposure).

Trials are to be regularly inspected, particularly in the first two years of establishment, for evidence of insect or animal damage and instant remedial action made. Landowners should be encouraged to take special interest in these demonstration trials. Where necessary, fertilizer will be applied, according to best local practice. Complete records of application rates and timing will be kept.

Trees can be pruned to facilitate access for measurement or for other reasons. All trees at a trial site must be treated similarly. Stands should have pre-dominant height of 7m before pruning to $\frac{1}{3}$ of height or a maximum of 2 m from the ground whichever is greater.

Plots will be thinned as required, following the schedule proposed in Table 4. First thinning will remove extraction rows, $\frac{1}{3}$ of planted trees thus freeing competition to the treatment trees. Subsequent thinnings will remove yield trees. As site size dictates that there will be no extraction rows planted in the Marchagee, Kamarooka, Tintinara and Carrick trials, first thinning will entail removal of yield trees.

Table 4: P. pinaster genetic gains trial, proposed management

Operation	Age	Residual Stocking	Plot	Description
Planting	0	1333 sph ^[a]	96	Spacing 3m x 2.5m
First Thinning	12-15	880 sph	64	Remove extraction rows (1/3)
Second Thinning	20-24	440 sph	32	Family stocking 4→2
Third Thinning	26-32	220 sph	16	Family stocking 2→1
Clearfell	32-40	0	0	

[a] sph=stems per hectare

4.6. Trial Measurement and Assessment

Regular inspection is expected for the duration of the trial. This will be frequent during early stages and reduce in later stages. Standard measurements will be tree height and diameter (breast height, over bark) (Table 5). Subsequent assessments (as a minimum schedule) will be made prior to thinning and clear felling.

Additional assessment will be required for any unexpected occurrence such as insect attack, fungal damage, severe frost, malformation etc. Special assessments may be detailed for wood quality.

Table 5. Summary of trial measurement schedule

Years post planting	Description of measurement
1	Survival and health
3	Height
8-10	Major trial assessment: height, diameter and tree form
12-15	Height, diameter and tree form
20-24	Height, diameter and tree form
26-32	Height, diameter and tree form
32-40	Height, diameter and tree volume by sectional method or volume table assessed post-felling

4.7. Data Analysis and Information Control

FPC-WA will provide protocol, measurement and program files for computer data loggers or formats for sheet recording. Standard data recording is essential to link performance of treatments across sites. Data collection and analysis will be managed with TBIMS. This database can be copied, on request, to partners and will contain only yield treatment information. After four years, trial family code and planting position information can be added to this database.

4.8. Intellectual Property

FPC-WA (formerly Forests Department of Western Australia and Department of Conservation and Land Management) has been actively involved in the genetic improvement of *Pinus pinaster* for over 40 years and has very significantly increased the value and productivity of the species. It can now be

considered as a viable option for commercial planting in low rainfall areas of southern Australia. Project partners are required to sign a Non-Propagation and Non-Breeding Agreement prior to a trial proceeding and acknowledge that FPC-WA is the sole owner of all pedigree information for the Western Australian *P. pinaster*. Continued access for non-damaging assessment is also required by FPC-WA during lifetime of trials.

4.9. Project Management

Management of the *P. pinaster* genetic gains trials will be reviewed in July 2001. At this stage, the successful trial establishment on 10 sites across southern Australia of some 25 hectares of genetically improved *P. pinaster* will be reported. Beyond this time, ALRTIG's partners will be required to support the assessment at age 3 years and age 8-10 years. FPC-WA will continue to manage the project, coordinate data collection and carry out the Australia wide analysis and report.

The information gathered from the ALRTIG trials will be linked to the entire FPC-WA database for *P. pinaster*, including 3rd generation trials that FPC-WA is planting concurrently with the ALRTIG trials.

4.10. Project Outcomes

Outcome is access to best products from FPC-WA's breeding program especially adapted to ALRTIG partner sites. This could simply be the definition of the breed for acquisition of seedlings, cuttings or seed. Because the seedlings were coded when planted, ALRTIG partners can get maximum value from the project by value adding deployment options. ALRTIG and parallel FPC-WA breeding trial information can be used in FPC-WA orchards to create control pollinated seed specifically for best use on partner sites and can then be provided either as seedlings or cuttings. Another deployment option could be to license specific clones for planting of clonal seed orchards for regional planting.

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