



Conifers in the Dry Country

**A report for the RIRDC/L&W Australia/FWPRDC
Joint Venture Agroforestry Program**

by David Spencer
CSIRO Forestry and Forest Products

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Foreword

Australia's forest plantation area is set to increase threefold by the year 2020. Some of this expansion will take place in drier areas where candidate species and the products and benefits they will bring are less well known.

This report considers the question of farm forestry in the 400-600 mm/y rainfall zone, particularly in southern Australia, from the point of view of conifers, both native and exotic. A number of candidate species, their growth potential, products and characteristics are brought together for comparison. Some challenges for forestry in drier regions are discussed, together with the need for research and additional decision-making tools.

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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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Peter Core

Managing Director
Rural Industries Research and Development Corporation

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David Spencer

Abbreviations

AFOCEL	Association Forêt-Cellulose, a French pulping company
ALRTIG	Australian Low Rainfall Tree Improvement Group
BA	Basal area, the cross-sectional area of stem or stems of trees at 1.3 m above the ground; expressed in square metres
BA/ha	Basal area/hectare. Sum of the cross sectional areas at 1.3 m of all the trees on 1 ha; expressed as square metres per hectare
CALM	Department of Conservation and Land Management, Western Australia.
Dbh	Diameter of tree stem at breast height (1.3 m); usually expressed in centimetres
DSE	Dry Sheep Equivalent; a term used to compare different classes of livestock when establishing stocking rates on farms; defined as the amount of feed a 45 kg wether will eat in a day; other stock have DSE values based on ratios to the wether
EUFORGEN	European Forest Genetic Resources Programme
FORADAPT	Part of EUFORGEN, p. 9
FWPRDC	Forest and Wood Products Research and Development Corporation
Ht	Height, usually in metres
IRR	Internal rate of return; the rate of interest payable on an investment to break even
JVAP	Joint Venture Agroforestry Program; partners are RIRDC, LWRRDC and FWPRDC
LWRRDC	Land and Water Resources Research and Development Corporation
MAI	Mean annual increment; volume MAI is expressed as m ³ /ha, basal area MAI as m ² /ha; both may indicate the average growth rate over a period such as the life of a plantation
MPa	Megapascals; unit of pressure; 1 MPa = 0.1 kgf/mm ² = 10 kgf/cm ²
NHT	Natural Heritage Trust
NPV	Net present value. Estimates an interest rate and determines whether the investment will make a return and how much in today's dollars
NSW	New South Wales
QFRI	Queensland Forest Research Institute
RIRDC	Rural Industries Research and Development Corporation
SA	South Australia
SE Australia	South-east Australia
SFNSW	State Forests of New South Wales
Site index	The average height to which dominant trees in a stand are expected to grow by a specific age on a specified soil productivity type. In Australia most site indices are based on 25 y with a rotation age of 35-40 y. In Turkey average site indices are based on 30 y with an average rotation age of 65 y
spha	Stems per hectare; a measure of the density of planting per unit area
Vic	Victoria
WA	Western Australia

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Executive Summary

This paper reviews prospects for planting conifers in the temperate parts of Australia that receive between 400 and 600 mm of rainfall each year. As there is very little information on prospects for conifers in the drier tropical regions these areas have not been considered in detail.

Australia's national plantation strategy, *Plantations for Australia – The 2020 Vision* aims to foster expansion of the current 1.4 million ha of plantations to c. 3 million ha by 2020. Expansion will be in both hardwoods and softwoods; some will be in wetter and more fertile areas, but some must be in areas marginally dry for forestry. Our most important plantation species, *Pinus radiata*, rarely grows well under these conditions although the Mexican island provenances of the species, Guadalupe and Cedros, have not been properly tested. Other exotic conifers have been identified whose performance in dryer areas in Australia is known. These include *Pinus pinaster*, *P. halepensis*, *P. brutia*, *P. eldarica* and *P. canariensis*. In addition there are others, less-well-known, which should be more widely tested; these include pines from Mexico and the south-western USA, some cypress species from the Mediterranean, south-western USA and Mexico, and some junipers. Testing of these lesser-known species has been so haphazard, even when it has taken place, that comparisons are rarely useful. A more structured, national approach to testing is required. The JVAP's Australian Low Rainfall Tree Improvement Group (ALRTIG), is an example of such a program and aimed specifically at low-rainfall areas and the assessment of a number of provenances of each species.

The only native coniferous species that grow in Australia's low-rainfall areas belong to the genus *Callitris*. These are quite widely distributed, but it is the native stands of white cypress (*C. glaucophylla*) in NSW and Queensland that are most intensively managed for wood production. Few plantations have been established, partly because of slow growth and poor survival in early trials, but mainly because there is no economic justification. A significant native conifer that is successful in plantations, hoop pine (*Araucaria cunninghamii*), does not grow well if rainfall is <600 mm/y.

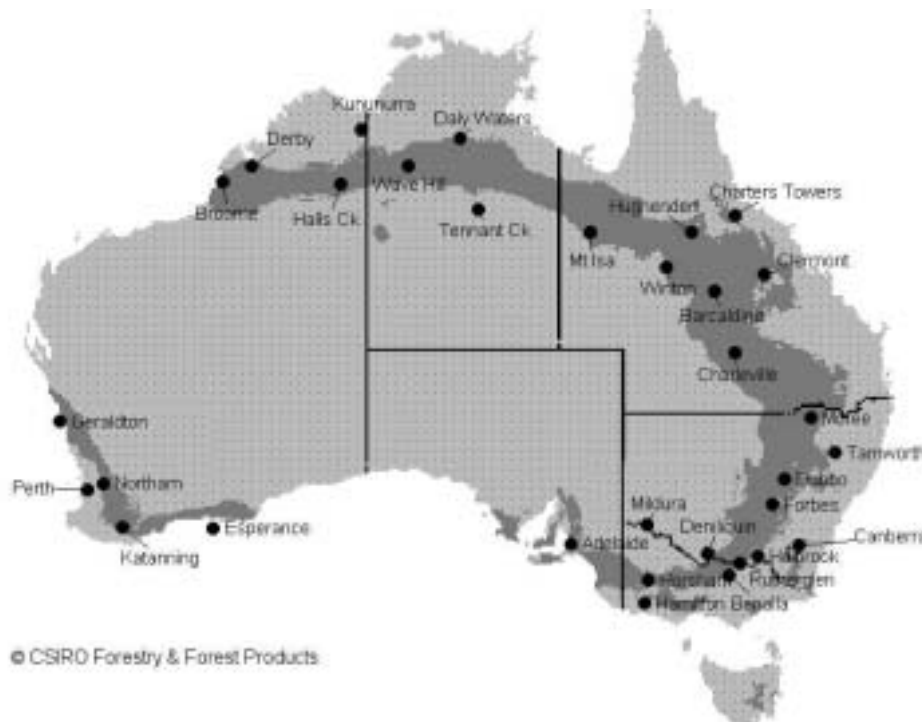
To develop links to international initiatives on conifers suited to dry environments, contact was made with the FORADAPT project which sponsored a meeting in Morocco in February 1999. This project is coordinated by the *Pinus brutia* network involving various European and North African research institutes. Its aim is to understand drought tolerance in the pine species of interest to Australia listed above, using quantitative and molecular techniques. Four geographic groups within *Pinus pinaster*, plus *P. halepensis* and *P. brutia*, have very high levels of diversity. Studies of drought resistance/tolerance are in progress for *P. brutia* and *P. pinaster*. Preliminary results for *P. pinaster* suggest, rather unexpectedly, that provenances from the wetter areas are also most drought tolerant.

Tree planting in drier areas will have a number of benefits ranging from production of wood and other products to environmental benefits such as salinity and waterlogging amelioration. The economics of wood production and the factors affecting its economic viability are reasonably well-known. Trees must grow at such a rate that there is a product to harvest within a reasonable time. Markets or processing facilities cannot be so far away from the plantation that transport costs are prohibitive. Calculation of the Net Present Values (NPVs) of wood production in a forestry enterprise in drier areas is now possible by several methods. Properties of wood from candidate species are at least partially known and there seem good prospects for solid wood, composites and paper products from most of them. As markets develop for non-wood products such as carbon credits or pine nuts, similar calculations will be possible for them. More difficult are calculations of the NPVs for enterprises with environmental benefits alone, or where these objectives are combined with plans to obtain income from wood or other products. Potential environmental benefits include amelioration of sites degraded by salinity or waterlogging, shelter from wind, and shade. It seems likely that such benefits will be very site-dependent and generalised solutions will not be possible. Farmers considering growing trees must be able to compare returns from their farms with and without the addition of a tree crop. Realistic estimates of the total economic benefits, from environmental amelioration as well as more directly from wood and other products, are vital so that forestry in drier areas may be fairly considered by potential investors.

1 Introduction

This study reviews research results and other information for coniferous species (natural or introduced) with potential for growth in drier areas and identifies those with the greatest potential to provide economic and/or social benefits. Coniferous species from the dry areas of many countries (particularly the Mediterranean conifers *Pinus halepensis*, *P. brutia*, *P. eldarica* and *P. pinaster*) have a potential role for this purpose. They have been introduced and tested in Australia and many other dry areas in the world over the last 100 y and have demonstrated reasonable growth and survival. Social benefits are difficult to quantify, yet in many rural communities and on farms the general aesthetic value is first cited as an advantage of planting a diverse range of species (Wilson and Tran 1995). In this report, the potential for establishing commercial plantations of coniferous species within the 400-600 mm rainfall zone (Fig. 1) of temperate SE Australia is emphasised. Problems currently preventing such conifer plantations being established are examined, as well as ways in which research could address these impediments. The 400-600 mm rainfall zone covers a much larger area in the subtropics and tropics, north of the NSW/Queensland border, than in the temperate south (see Fig. 1). This northern area is not discussed in detail, however, as there do not appear to have been serious attempts to evaluate conifers in these warmer climates. Nevertheless, further investigations of the potential of commercial plantations in drier northern areas could be fruitful.

Figure 1. Australia with 400-600 mm rainfall zone shown in dark grey



1.1 Rationale

Australia's 2020 Vision is to increase the national plantation area to 3 million ha by the year 2020. This initiative is industry-driven with Federal Government encouragement and non-financial support. Encouraging farmers to establish conifer plantations in the drier zones will support the 2020 Vision and also enable growers to address increasing problems of desertification, salinity from rising water tables and a general decline in rural productivity. Further support for the 2020 Vision is seen in investment by industrial companies with carbon debts. International pressure through the Kyoto Protocol to minimise the release of greenhouse gases such as CO₂ into the atmosphere and to find a means to sequester carbon is increasing. Establishment of forests and plantations may earn carbon credits important for Australia's international standing.

As part of the strategy to reforest large areas of rural Australia, encouraging the establishment of farm forestry plantations in drier areas is an attractive prospect. Within these areas there will be many requirements for tree species, including exotic conifers, for niches such as degraded landscapes and recharge sites, windbreaks to mitigate soil erosion and protect pastures, and amenity plantings which promise significant social benefit. A substantial re-evaluation of both coniferous and native species capable of meeting those needs is necessary. For softwood plantations in the temperate areas of Australia, species other than radiata pine will have to be considered because radiata plantations are not usually commercially viable below the 600 mm rainfall isohyet, and availability of additional land suited to radiata is diminishing.

Tropical and sub-tropical areas within the 400-600 mm zone do not appear to offer many opportunities at present for growing conifers as plantations. Very little research has been conducted to determine whether any conifers are suitable. The Queensland Forestry Department did establish small trial plots of a range of species, including conifers, from Dalby to Barakula in the central southern region of Queensland, but the plots have not been evaluated recently due to changes in research priorities and their current health status is not known. It is difficult to understand why little attention has been paid to the sub-tropics as an area with potential for conifer or indigenous species plantations. It may be a reflection of the lower population density and sparse infrastructure which would make investment very marginal. In contrast, given the availability of well-adapted species, the area of suitable land in SE and SW Australia between the 400-600 mm isohyets that could become available for plantations is large. Particular opportunities are available to prospective growers in those areas beyond the current limits of coniferous plantations but close enough to benefit from existing forest industry infrastructure necessary for commercial viability.

1.2 Potential commercial species

The *Pinus* species with the greatest commercial potential are those originating around the Mediterranean. For example maritime pine (*P. pinaster*), an important economic species in its native occurrence of SW France and Portugal, is planted as an exotic in coastal areas north and south of Perth as well as in the wheat belt of Western Australia. The Department of Conservation and Land Management, Western Australia (CALM) has made a large investment in selecting, breeding and improving the growth capability and wood quality of this pine over the last 50 y, especially in adaptation to low-rainfall areas.

P. halepensis (Aleppo pine), *P. brutia* (brutian pine) and *P. eldarica* (eldar pine), are closely related but are quite different in growth habit and site requirements, yet all exhibit high levels of drought tolerance. All three species have commercial plantation potential. *P. brutia* and *P. eldarica* generally have better stemform and growth than *P. halepensis*, but there is considerable provenance variation in all species. For example, some eastern Mediterranean provenances of *P. halepensis* are almost as good in growth and form as some of the better *P. brutia*. In inland SE Turkey *P. brutia* trees are straight and exhibit good growth rates, although close to the coast trees are of poor form and slower in growth (Isik 1986).

Conifers which produce edible seeds (*P. cembroides*, *P. monophylla*, *P. pinea*) originate in drier areas and may be able to contribute to the social/amenity benefits on properties. *P. pinea* (stone pine) has an unusual cultural niche in Australia's history and is often fondly remembered by many folk as being the 'nice shady tree in the school grounds', where many isolated trees still exist. Most of these species will not produce timber of any quality and those, like *P. pinea*, which will eventually grow to be large, will have a short bole with knotty wood, a consequence of irregular pruning. If grown as a woodlot, *P. pinea* would have potential to produce sawlogs but this would take at least 50 y in average 500 mm rainfall conditions.

Native conifers such as *Callitris* occur extensively in the 250-950 mm regions of Australia. Many species have no commercial value although natural stands of *C. glaucophylla* (white cypress) and *C. intratropica* (northern cypress) have been commercially exploited for over 100 years. *C. glaucophylla* grows from central southern Queensland southwards into New South Wales and then west into South Australia and Western Australia, as well as in parts of the Northern Territory, whereas *C. intratropica* grows in the tropical north of the Northern Territory. The commercial viability of *C. glaucophylla* being managed in natural regeneration or in plantations will be examined in Section 3.3.1.2 of this report.

There are some cypresses such as the rare *Cupressus dupreziana* (Saharan cypress) and *C. atlantica* (Atlantic cypress) which occur in very dry regions but have not been fully evaluated for commercial or amenity purposes. Other species such as *C. arizonica* (Arizona cypress) and *C. sempervirens* (Roman cypress) have been introduced to dry regions of Australia and have shown remarkable adaptability but are used only as an ornamental.

1.3 Relevance and benefits

Establishment of plantings of softwoods on a significant scale in the 400-600 mm rainfall belt could attract associated industries such as sawmills, harvesting operations and support businesses, as well as infusing money and people into small rural townships. Demonstrated economic benefits to the initial growers would encourage others to establish plantings in the region.

1.3.1 Communication

Attitudes to tree plantation development in low-rainfall zones can be both positive and negative, but unfortunately are more negative in rural communities. Misunderstanding or lack of information can lead to ill-informed decisions about or perceptions of the benefits of establishing plantations (R. Kuiper, Farm Forestry Extension Officer, Murray Riverina Farm Forestry, Wagga Wagga, NSW, *pers. comm.* 1999). Enticing landowners to consider investing in a plantation as a farm diversification activity is very difficult (H. Dunchue *pers. comm.* 1999). Eucalypt species are often more readily accepted than conifers, despite there being less evidence for potential return. This is perhaps an emotional response, especially to species of national interest or to conservation issues. National Landcare groups are raising awareness of the need to protect the land and treat it as a valuable resource. Publications such as *Agroforestry News* provide many articles on the environmental benefits of growing trees, costs and profitability. This information should be extended to raise awareness that conifers suited to dryland areas can be established in farm forestry plantations. Potential benefits will accrue not only in the usual commercial/economic way, but through mitigation of rising water tables and possible salinity. Reluctance by the rural community to adopt commercial levels of farm forestry has been a cause of concern to research agencies as well as planners in the forest industry, and is currently being investigated (Curtis and Race 1998).

Issues raised at rural community meetings reflect concern about establishing plantations. These include:

- **Current land use.** Land not suited to any farm activity is often thought suited to forestry. Plantations are generally not perceived to be another crop that should compete with usual crops on the basis of the best economic return (Dunchue 1999).

- **Local Government regulations.** Unlike forestry, most farm activities do not require lodgement of development applications to the Council/Shire office. For forestry, there are concerns regarding potential impact on infrastructure, the environment and land use. The perseverance required by an applicant to meet development criteria, and the complexity and cost of the process, deter most farmers (Hurditch 1999).
- **Perceived markets.** ‘Where will the market be in 40 years time?’ ‘Is there a market for woodchips?’ are typical questions reflecting realistic concerns. The time frame to produce an economic return concerns many, and can mean that the idea of farm forests is rejected without proper economic analysis (R. Kuiper *pers. comm.* 1999).
- **Perceptions.** Most believe that country receiving rainfall below 600 mm is not suited to farm forestry plantations, probably because *P. radiata* does not grow well in such conditions. Other perceptions are that plantations reduce water yield, that water quality is compromised and that plantations result in biological deserts, deplete soil nutrients and acidify the soil (Porada 1999).

1.4 Developments

Positive factors that would have an impact on plantation establishment include the enormous changes in technology over the last decade. Sawmills and processors in general have invested in modern, efficient equipment that can handle larger volumes and produce goods at competitive prices. Tree breeding has been estimated to have increased yields of first-generation *P. radiata* plantations by more than 20% (Matheson *et al.* 1986). White *et al.* (1999) estimate that the next cycle of breeding will almost double this gain. New conifer and eucalypt species such as *Corymbia maculata*, *Eucalyptus occidentalis*, *E. tricarpa*, *E. cladocaylx* and *E. camaldulensis* have been selected on their capacity to grow in low-rainfall zones by the Australian Low Rainfall Tree Improvement Group (ALRTIG) project. These species are being selectively bred to tolerate drier conditions yet increase productivity. Carbon trading will increase in influence. Carbon sinks such as plantations are being bought by industrial investors abroad to offset the carbon added to the environment by their CO₂ emissions.

1.4.1 Using known species - maritime pine

One species of high potential and about which much is known is maritime pine. This tree has become economically important, with plantations in SW France (1.0 million ha), Portugal (1.3 million ha) and in Western Australia (28 000 ha), where there has been a very high level of genetic improvement. Plans exist in Western Australia to try to minimise salinity problems by expanding plantations to 500 000 ha within the 400-600 mm rainfall belt. There are also large potential plantation areas on the western slopes of New South Wales and north of Mount Gambier in South Australia; both areas are close to existing forestry infrastructure and would be suited to brutian or maritime pine. Plantations in these areas would increase the resource base for existing industry as well as fostering development of new enterprises.

The time from planting to first thinning of maritime pine can vary enormously, depending on growth and available markets. In Western Australia first thinnings on drier sites can be delayed until age 20 years because of slower growth rates. Thinnings are currently being sold as woodchips for use in medium density fibreboard (MDF) production, while trees large enough for small sawlogs will yield about \$25-30/m³ as rounds for preservative treatment. In New South Wales the established market is dominated by radiata pine. Although Australian Newsprint Mills (ANM) has a paper mill at Albury in southern New South Wales, this company believes the wood properties of maritime pine are sufficiently different from those of radiata to be undesirable under current arrangements. However, this species is used successfully in southern France (AFOCEL) for papermaking and so technological solutions could be expected if the size of the resource merited the investment. A possible market for thinnings would be MDF manufacturing since the wood property requirements for MDF are less stringent than those for papermaking. An MDF plant at Wagga Wagga, operated by Laminex Industries, utilised some 80 000 m³/y of small timber but closed in 1998 as the cost of transporting timber became prohibitive. As the performance of most conifers as plantation species on the western slopes of New South Wales is largely unknown, the establishment of yield plots of area approximately

1.0 ha and larger would provide valuable early information on potential growth rates. In South Australia, maritime pine has been grown as a plantation species on sandy soils with a higher rainfall near the coast by Forestry SA (formerly the State Woods and Forests Department), especially since the early 1960s, and is processed by local sawmills.

1.4.2 Species with potential

Other conifers within the *Pinus* and *Cupressus* genera, and especially those from the Mediterranean and possibly Mexico, should be considered as plantation species. These conifers, as well as a few from other regions, have shown a capacity to grow in demanding environments and consequently may offer potential in terms of survival, growth and product yield in Australia. A good example is *C. sempervirens*. All around the Mediterranean this species is seen in both the spreading (tree) form and the fastigate (compact crown) form. In Australia it is mostly seen as the fastigate and planted as an ornamental. In the Mediterranean it grows in the driest areas and is planted for timber production as well as amenity purposes.

Information from scattered trial plantings in the drier areas of SE Australia indicates that the potential for survival is high, with sustained growth producing marketable sawlogs. Unfortunately information regarding growth as larger plantations on Australian soils in the 400-600 mm rainfall zone is limited. Established plantations in the Mediterranean region (Morocco, Algeria and Israel) have low mean annual increments (MAIs) and it is difficult to determine whether this is a function of poor silvicultural practice, low genetic quality of the seed source or environmental factors. It would be unwise to use these plantings as a standard for expected performance in Australia. Plantations of *P. brutia* in Turkey have MAIs of about 12 m³/ha on sites classified as high quality (Class I), declining to 2.2 m³/ha on poor sites (Class III). Information from trials in New South Wales and South Australia indicates that there is no reason to doubt that such growth is possible in Australia, with the expectation that substantial gains could be made by selective breeding.

2 Species that Grow in Drier Areas

2.1 Exotics

The names used with most exotic coniferous species cited in this document are in accordance with those used by J. Silba (1986) who covers all coniferous species in *Phytologia Memoirs VIII*, and J.P. Perry (1991), who has an intimate knowledge of the Mexican conifers, in *The Pines of Mexico and Central America*. Perry's publication is used because of its level of information on a range of little-known conifer species growing in marginal rainfall areas in Mexico and which may offer possibilities in Australia with adequate testing. Throughout this report the members of the *P. halepensis*/*P. brutia* complex are treated as individual species and not as sub-species as by Silba and others. The aim is to avoid confusion as there are many different taxonomic treatments of this complex. Differences between these two authorities are noted where relevant.

Throughout the world many coniferous species grow in areas with rainfall lower than 400 mm. Many are shrubby to small trees with possible non-commercial uses. Only a few of the non-commercial species are identified in this report. The focus is upon those species which grow into a tree form at least 20 m tall and occur naturally in a low-rainfall environment (e.g. *P. halepensis*, *P. brutia*, *P. pinaster* and *P. canariensis*). In addition a range of species is identified in low-rainfall areas such as southern California and NW Mexico which may have possibilities (Boomsma 1999); these should not be overlooked even though we do not have examples growing in Australia. Priority should be given to introducing as many species as possible for evaluation. Care is needed when choosing species using rainfall alone as a criterion. Many occur at high altitudes and undoubtedly receive moisture through fog, mist or clouds. This means that while the precipitation may be low, total moisture received may be much higher than the actual rainfall. In Australia we are seeking species adapted to low rainfall at relatively low altitude. This does not necessarily preclude many of the species mentioned by Boomsma; rather it indicates that the performance of many of the listed species is unknown under our conditions. This highlights the need to introduce a wider range of new species/provenances for evaluation.

Some cypresses (e.g. *Cupressus dupreziana*, *C. arizonica*, *C. sempervirens*) occur naturally in drier regions and have shown remarkable adaptability in dry regions in Australia. While it is useful to know that such species grow well, it is unfortunate that such introductions have been located in limited trial plots and isolated individual plantings as these do not give any indication of the potential of these candidates when grown in farm forestry plantations.

Conifers that produce edible seeds (e.g. *P. cembroides*, *P. monophylla*, *P. pinea*) and that occur naturally in drier areas of several countries may be able to contribute to the social/amenity and perhaps commercial benefits on properties in Australia. Villagers in remote areas value these species as they derive an important component of their income by extracting the seed kernels and selling them in local markets.

Table 1 shows species that have potential or are worthy of further investigation. The selection is based on natural distribution in low-rainfall areas, and altitude. Factors such as adaptability, growth rates and wood quality are largely unknown, but attempts should be made to evaluate all species with possible potential. Wood quality characteristics are critical for commercial crops, yet these are often unknown even in the country of origin. The local people in the country of origin use wood from many of the listed species for many purposes. This does not imply that there will be a ready market in Australia for the wood even though there may be a niche market for 'exotic' timbers.

Table 1. Conifer species with potential to grow in low-rainfall areas of Australia

Species	Common name	Known uses			Possible uses		
		Timber	Amenity*	Other	Timber	Amenity*	Other
<i>Pinus canariensis</i>	Canary Island pine	Y	Y				
<i>brutia</i>	Brutian/Red/Turkey pine	Y	Y				
<i>halepensis</i>	Aleppo pine	Y	Y				
<i>eldarica</i>	Eldar/Afghan pine	Y	Y				
<i>torreyana</i>	Torrey pine		Y		Y		
<i>sabiniana</i>	Digger pine		Y		Y		
<i>coulteri</i>	Coulter pine		Y		Y		
<i>pinaster</i>	Maritime pine	Y	Y				
<i>roxburghii</i>	Chir pine	Y	Y				
<i>nigra</i>	Austrian pine	Y	Y				
<i>radiata</i>	Radiata pine/Monterey pine	Y	Y				
<i>cembroides</i>	Mexican Pinyon pine					Y	Nut
<i>monophylla</i>	Single leaf pinyon pine					Y	Nut
<i>pinea</i>	Stone pine		Y				Nut
<i>cooperi</i>	Cooper pine				Y	Y	
<i>durangensis</i>	Durango pine				Y	Y	
<i>geradiana</i>	Chilgoza/ Indian nut pine				Y	Y	
<i>jeffreyi</i>	Jeffrey pine				Y	Y	
<i>nigra</i> v. <i>caramanica</i>	Crimean pine				Y	Y	
<i>nigra</i> v. <i>maritima</i>	Corsican pine				Y	Y	
<i>lagunae</i>	Pinyon nut pine					Y	Nut
<i>Cupressus arizonica</i>	Arizona cypress	Y	Y				
<i>atlantica</i>	Atlantic cypress					Y	
<i>dupreziana</i>	Saharan/ Tassilian cypress				Y	Y	
<i>sempervirens</i>	Mediterranean cypress		Y		Y		
<i>guadalupensis</i>	Guadalupe cypress				Y	Y	
<i>Juniper deppeana</i> v. <i>pachyphlaea</i>	Western alligator juniper				Y	Y	
<i>drupacea</i>	Syrian juniper				Y	Y	
<i>durangensis</i>	Durango juniper					Y	
<i>flaccida</i>	Mexican weeping juniper					Y	
<i>foetidissima</i>	Crimean juniper				Y	Y	
<i>excelsa</i> v. <i>polycarpus</i>	Persian juniper				Y	Y	
<i>Pseudotsuga menziesii</i> v. <i>glauca</i>	Rocky Mountain Douglas-fir	Y			Y	Y	
<i>Cedrus atlantica</i>	Atlas cedar		Y		Y		
<i>deodara</i>	Deodar cedar		Y		Y		
<i>libani</i>	Lebanese cedar		Y		Y		

*Amenity includes purposes such as windbreaks, ornamental plantings and shade

Research issues

- Attempts should be made to introduce as many of the potential species as possible, including species not listed above, for trial planting throughout the 400-600 mm rainfall zone in Australia.
- Evaluation of species should be in a structured manner with a nationally-coordinated approach so that over time valid information is retrieved.

2.2 Indigenous species

Other than the *Callitris* genus (commonly called cypress pine), Australia does not have coniferous species that grow in the low-rainfall areas. Of the some 157 million ha of forest in Australia, 0.9 million ha (0.6%) are *Callitris* forests (National Forest Inventory 1997).

2.2.1 Araucaria

Hoop pine (*Araucaria cunninghamii* Ait.) grows naturally on basalt derived soils in subtropical rainforests of Queensland. These sites are called bastard scrubs with rainfall ranging from over 1100 mm down to 800 mm, which some consider 'dry'. Hoop pine does not grow well below 600 mm rainfall, especially on the poorer soils typical of the low rainfall areas.

2.2.2 Callitris

The genus *Callitris* belongs to the family *Cupressaceae*, whereas the genus *Pinus* (pine trees) belongs to the family *Pinaceae* (both are conifers). *Callitris* taxonomy used here is in accordance with *Flora of Australia* Vol. 48, 1998. The taxonomy of the genus has had many changes over the last century and only the most recent nomenclature is used. The genus *Callitris* has 17 species in Australia and 2 in New Caledonia. Most species are shrub-like to small trees and grow in areas with rainfall below 400 mm. A few species grow in the higher-rainfall coastal forests. While cypresses can be found in most places in Australia, many are restricted in their distribution and almost rare. Several species such as white cypress (*C. glaucophylla* syn. *columellaris*, *glaucophylla*, *hugelii*), black cypress (*C. endlicheri*) and Port Jackson pine (*C. rhomboidea*) have wide distributions. Several others such as slender pine (*C. gracilis*) are distributed in zones along most of the Murray River and northern cypress (*C. intratropica*) across the north of the Northern Territory.

Problems of managing natural stands of *C. glaucophylla* are discussed in Section 3.2.7. Planting seedlings of *C. glaucophylla* in Australia has not been very successful. Over a long period, the Queensland Forest Service Research Branch (now QFRI) established many trial plots of *C. glaucophylla* as seedlings. Survival was never high due to many factors, but almost all trials were terminated due to fire damage. Even into the mid-1980s, broadcast sowing was attempted without success (West 1989). State Forests of New South Wales established blocks (0.4- ±20 ha) of *C. glaucophylla* in the early and late 1950s near Baradine, Moree (Terry Hie Hie State Forest) and Forbes (P. Wells, Regional Forester, Western Region, State Forests of New South Wales, *pers. comm.* 1999). At 1600 spha the resulting stemform was poor and plots have been described as 'almost promising' (P. Wells *pers. comm.* 1999), but a plantation spot sown at Back Yamma State Forest in 1924 shows a significant improvement over planted seedlings (A. Deane, District Forester, SFNSW, Forbes. *pers. comm.* 1999). *C. glaucophylla* has been successfully introduced as a plantation species in South Africa where form and growth is good. The only other cypress species known to have been planted in blocks in Australia have been *C. endlicheri* and *C. intratropica*. *C. endlicheri* was included for evaluation in three of the CALM arboreta and has performed well on what were deemed the poorest plots at each site. An inspection in 1999 of Bussells Arboretum on a medium quality soil type with 968 mm rainfall showed 27-y-old *C. endlicheri* trees at 200 spha averaging 19 cm dbh (some trees greater than 35 cm dbh) with a mean height of 16.3 m. This growth indicates that the species performs better with extra moisture, but it is certain that such growth rates will not occur in low-rainfall areas.

During the period 1966-1975, some 1380 ha of *C. intratropica* plantation were established in areas near Darwin, the largest stands being on Melville Island (Burns *et al.* 1999). *C. intratropica* occurs mainly in the zone above the 1000 mm isohyet in the tropical north. Most of the northern region typically experiences weather of alternating wet and dry seasons, with high rainfall occurring in the summer months. While the total rainfall may be high, the long dry season indicates a need for trees to endure dry conditions. No records have been found to indicate successful trials of this species in dry zones that do not experience a pronounced wet season as in the Northern Territory.

Common commercial terms of ‘cypress’ or ‘cypress pine’ used throughout the remainder of this report refer to *C. glaucophylla*.

Research issues are addressed in section 3.2.7

2.3 FORADAPT meeting in Morocco

The Forest Genetic Resources Division of FAO and the International Plant Genetic Resources Institute (IPGRI) have strong cooperative links. IPGRI has staff in many European countries and was responsible for setting up the European Forest Genetic Resources Programme (EUFORGEN). IPGRI and FAO are members of the EUFORGEN management committee. EUFORGEN membership is mainly composed of European research institutes, and the participating countries finance the organisation. Most research is based on species networks. The FORADAPT project is coordinated by the *Pinus brutia* network and has the objective of determining the factors controlling drought tolerance and the extent to which these factors are under genetic control, and to find DNA markers associated with drought tolerance. This network has members from two institutes in Israel, two in Turkey, one in Morocco, three in France and one from Italy, and members met in Morocco in February 1999. FORADAPT is the acronym for the longer title ‘Global physiological and molecular responses to climatic stress of three Mediterranean conifers (pines of the *halepensis-brutia* section, maritime pine and Mediterranean cedars); consequences for optimal use, conservation and sustainable improvement of their genetic resources’.

There is strong emphasis in the FORADAPT project on identifying molecular markers associated with useful genes (quantitative trait loci, QTL) affecting drought tolerance. Substantial effort is being directed through tree physiology to understand drought tolerance mechanisms, and to develop techniques for tissue culture. The latter is used to multiply material so that technology can be applied to individual plants/families/provenances that could be then used for QTL work. A comprehensive database is being developed to record all past and present trial information, as well as links to all molecular work and associated literature.

Results so far are encouraging but very limited, as most work is still in progress. An extensive seed bank of families of known provenance for *P. pinaster*, *P. halepensis* and *P. brutia* has been collected, documented and stored at the INRA Institute, Avignon, France. Material from this bank is being used in trials, molecular analysis and physiological studies. Most of the provenance and progeny trials to be used in validating the molecular work have been planted only in the last two years and are usually located in three countries (France, Tunisia, Morocco for provenance trials and Turkey, France and Tunisia for progeny tests). An 8-y-old trial of similar provenance material was planted at Chatba in Morocco (400–450 mm rainfall). All the older trials (mid-1960s and mid-1970s) were primarily focused on *P. halepensis*.

Molecular studies aimed at finding QTL involved in drought response have been either global or targeted. The global approach has been to characterise genetic diversity within species in the group. For *P. pinaster* four groups have already been identified (northern Spain and western France, Italy and its islands, northern Africa and southern Spain) with high levels of intra-group genetic diversity. *P. halepensis* and *P. brutia* also have high levels of diversity. The proportion of the population with specific haplotypes is higher for both these species (88%) than for *P. pinaster* (73%). This result will be important for breeding when we will need to know the origins of seed of conifers growing in the dry regions of Australia. In the targeted approach, DNA from 20 seeds from each of 20 wide-ranging

provenances of *P. brutia* has been extracted and DNA markers identified (20 nuclear SSR primers and 100 RAPDs).

Several laboratories are investigating drought resistance/tolerance by various physiological methods, including measuring water potentials, stomatal conductance, transpiration rates and photosynthesis rates. Plants are thought to survive drought by several mechanisms: escape (quick breeding cycle), avoidance (stomatal closure) and tolerance (protein biosynthesis). It is the latter two mechanisms that are being explored. Seedlings and tissue-cultured explants from the 20 *P. brutia* provenances (mentioned above) have been subjected to cold and drought treatments in the nursery and laboratory to evaluate early selections. Water stress is highly correlated to freezing, so treatments varying from simple water exclusion to varying concentrations of PEG (polyethylene glycol) to freezing have been used to imitate drought and to elicit responses. Nursery results are currently being hindered by *P. brutia*'s complex growth morphogenesis – several growth cycles per annum without bud burst.

In the field, adult trees of the related species have been monitored for stomatal conductance and photosynthetic activity. Limited results so far indicate that *P. pinaster* provenances from the highest-rainfall areas have the best drought tolerance. Other early results indicate that *P. eldarica* has higher stomatal conductance than *P. brutia* and *P. halepensis* in mid-summer, but at these times its photosynthetic rate is much lower. Generally *P. eldarica*'s photosynthetic rate is higher throughout the year.

The *P. pinaster* outcome is counter-intuitive and requires validation. If it is correct, then the possibility of growing larger-volume trees in dry areas is closer to reality than previously thought. Being able to quantify the ability of a conifer to avoid or tolerate drought, as *P. eldarica* does, simplifies techniques for screening for potential breeding trees so that only those trees better adapted to dry conditions are used for seed production in any breeding strategy.

Benefits of attending the Brutia Network Workshop in Morocco

- Australia has been recognised as being seriously interested in *P. brutia* and a representative has been invited to attend further workshops.
- Information in the form of research papers and departmental reports previously not accessible has been made available.
- Genetically improved seed has been offered for trial and use in Australia.

3 Species with Potential for Wood Production

3.1 Factors creating a potential

3.1.1 Proximity to existing infrastructure

The profitability and often viability of almost any forest planting will depend on the scale of the operation. The larger the resource, the greater the chance of attracting processing industry and thus the greater the opportunity to sell product which is likely to have lower extraction costs. Plantings of dry-country conifers in areas adjacent to existing plantation resources will provide owners with greatly enhanced opportunities to sell thinnings and larger logs. Timber properties of most of the potentially useful conifers are similar to radiata pine and it is doubtful that sawmillers will discriminate against other species if the wood is of high quality. The areas best suited to planting dry-country conifers initially are in the 400 – 600 mm rainfall zones adjacent to existing plantations. Most existing radiata pine resources occur in the 600+ mm areas around Tumut on the SW slopes and Oberon/Bathurst on the central west slopes of New South Wales; Mt Gambier, Adelaide Hills and west of Jamestown in South Australia; Myrtleford in the north-east and Rennick in the south-west of Victoria; and south of Perth to Manjimup and west in the Stirling Ranges in Western Australia. Extensive plantations of maritime pine (*P. pinaster*) are planted to the north and north-west of Perth. Queensland has plantations in the south around Stanthorpe.

3.1.2 Plantation area density

Transport costs are a major factor in the profitability of a forestry venture. Plantation resources within 50 km of processing facilities are optimum. As transport distance increases towards 100 km, margins become narrower and wood volume then becomes the key factor. If growers in a region were to make a combined planting of 20 000 ha or more, as trees approach merchantable size processing capability could be attracted. If sustained yield is evident, the possibility of a permanent sawmill becoming established increases dramatically. In areas where a log buyer has a guaranteed resource and can strike a special deal with the grower, longer transport distances are feasible. For example, if a grower is say 70 km from a sawmill yet can manage the resource to maximise growth by thinning on time, then the log buyer is able to get a larger volume of logs from the one place and better accommodate the road haulage costs.

An important factor in considering potential plantations in the 400 – 600 mm rainfall zone is that most of the land is freehold and is often substantially cleared. Dunchue (1999) states that property owners on better quality sites suited to radiata pine can often utilise up to 20% of their land for forestry without severe impact on other operations. This is validated in the analysis made by J. Sykes (Agricultural and Farm Economist (J. Sykes Rural Consulting) Albury, NSW *pers. comm.* 2000) in Table 15. Reluctance by property owners to embrace new ventures on an adequate scale has often limited expansion of conifer farm forestry into ‘non-traditional areas’. Small trial plantings provide only general guidance. A larger block of say 40 ha will determine feasibility and profitability by reducing the impact of establishment and roading costs on the IRR.

3.1.3 Growth rates

Optimising the growth of planted trees in their early years will have a major impact on overall profitability of the plantation. The object is to get the trees as tall as possible in the early years before competition for resources (light, water, nutrients) slows the growth. If early growth is restricted, trees tend to remain ‘squat’ or at the least grow very slowly, resulting in short boles and thick branches. Early rapid growth ensures a greater degree of uniformity in the stand that will minimise branch size, resulting in a better quality sawlog at harvest. How this growth is achieved will depend on the genetic quality of the seedlings, site preparation suited to the soil type, weed control, pest control (insect and

animals) and nutrient requirements. Unless all issues are addressed together, any one could become limiting and thus reduce the potential growth of the stand.

Growth rates are often highly variable across sites. Mean annual increments (MAI) (expressed either as m^2/ha (basal area, or sectional area) or more commonly as m^3/ha (volume)) will not be the same for a species on low-rainfall sites as on a species' preferred site. Table 2 outlines growth rates of selected species without genetic improvement, across a range of sites with varying soil and rainfall. Basal area MAIs may seem low, but they are not disappointing considering that the extent of important provenance variation has not been taken into account in any systematic manner.

Tables 3 and 4 list the provenance means of two conifers for a dry site at Jerilderie, New South Wales (for details see Palmberg 1975 and Spencer 1985), showing what volume MAIs (m^3/ha) are produced under 'hard' conditions. Different management options might have produced different results (Spencer 1985), but without other information such ideas can only be speculative. The volume growth rates of *P. brutia* and *P. halepensis* provenances at Jerilderie, expressed as m^3/ha , range from 0.9 – 2.7 and 1.1 – 3.2 respectively at age 29 y. In Turkey the volume MAI for natural stands of *P. brutia* on the poorest sites (Site class III) with a site index of 10 m height, is 2.2 m^3/ha . This drops to 1.8 m^3/ha when corrected for similar stand density as at Jerilderie. A similar stand on Site class I in Turkey would have a volume increment of 6.1 $\text{m}^3/\text{ha}/\text{yr}$ (Usta 1993). With selective breeding this rate could be increased substantially. Fikret Isik (*pers. comm.* 1999), who visited the Jerilderie trial site in 1995, thought that taking into account the soil and rainfall, the Jerilderie site would be graded as being in the bottom end of the Turkish Site class III. Increased growth rates can be expected with increasing soil moisture. Results of the better *P. brutia* provenances at Jerilderie are encouraging when compared to the growth of *P. brutia* under similar conditions in Turkey.

The *P. halepensis* at Jerilderie has a better total volume MAI than *P. brutia* but the average stemform is much poorer than that of *P. brutia*. Nevertheless, there are provenances of *P. halepensis* that have very good stemform, indicating that with selective breeding an overall improvement in stem quality can be made.

3.1.4 Soil types and nutrient status

The soil types in the low-rainfall zones of Australia are diverse and it is not intended to describe them in detail here. In a broader context, soils can be considered as sandy, loamy or clayey with descriptors such as colour, structure, pH, salt-affected or degraded helping to further identify the soil type. Soil salinity and sodicity are two serious problems most often causing concern. Salinity is caused by dissolved salts in the soil (most often sodium chloride) increasing in concentration at the surface and restricting plant growth by toxicity. Soil sodicity is caused by increased levels of sodium ions being exchanged relative to calcium and magnesium. The exchangeable sodium percentage determines the total alkalinity that also restricts plant growth.

Unfortunately many soils in the low-rainfall zone are poor, and they often need supplemental nutrients and ripping to make them suitable for plantation establishment. These are generally the clayey types with a structure that makes them erodible and easily degraded. Salt from rising water tables is becoming a major problem in the Murray Darling Basin. The area of land now considered to be salt-affected is increasing rapidly and, while plantations of trees are envisaged as a possible remedy, wood production from such plantations should not be the primary purpose without selection and/or breeding for salt-tolerance as well as wood production.

Table 2. Mean annual increments of basal area of *Pinus brutia*, *P. halepensis* (Aleppo), *P. pinaster* and *P. radiata* across sites

Location	Species	Age (y)	Density (stems/ha)	Rainfall (mm)	BA (m ² /ha)	BA MAI (m ² /ha)
Jerilderie provenance trial, western NSW						
Best 3 of 22 provenances	<i>Brutia</i>	29	514	385	18.3	0.63
Best 3 of 22 provenances	<i>Aleppo</i>	29	514	385	20.0	0.69
'100 acres' Yanchep, north of Perth WA						
Unselected Cyprus provenance	<i>Brutia</i>	47	600	750	75.4	1.44
Bussell's Arboretum, south of Collie, WA						
Bucak provenance, Turkey	<i>Brutia</i>	31	200	968	56.5	1.82
Bucak provenance, Turkey	<i>Brutia</i>	12	250	968	6.8	0.57
Monterey provenance	<i>Radiata</i>	10	250	968	8.7	0.87
Portugal provenance	<i>Pinaster</i>	12	250	968	9.5	0.79
Wirrabara and Bundaleer SF, east of Port Pirie, SA						
Unselected Cyprus provenance (1620)	<i>Brutia</i>	25	900	600	53.6	2.14

Table 3. *Pinus brutia*, Jerilderie provenance trial, planted 1968, measured at age 29 years

	Species	Provenance	Latitude (N)	Longitude (E)	Altitude (m)	Mean dbh (cm)	Mean height (m)	MAI volume (m ³ /ha)
1	<i>P. pithyusa</i>	USSR	45°00'	35°00'	<50	21.0	11.2	2.40
2	<i>P. stankewiczii</i>	USSR	44°30'	34°09'	<50	18.2	10.6	1.86
3	<i>P. brutia</i>	Turkey	37°30'	30°30'	700	21.6	11.8	2.62
4	<i>P. brutia</i>	Iraq	37°00'	43°25'	900	14.9	8.7	0.98
5	<i>P. brutia</i>	Greece (Rhodes)	36°26'	28°18'	200	20.3	10.8	2.15
6	<i>P. brutia</i>	Cyprus	35°17'	33°00'	500	20.8	11.5	2.39
7	<i>P. brutia</i>	Cyprus	35°00'	33°00'	500-1000	21.4	12.7	2.79
8	<i>P. brutia</i>	Cyprus	34°57'	33°14'	500-1000	19.0	12.1	2.13
9	<i>P. eldarica</i>	Iran	34°40'	60°20'	1300	20.2	10.3	2.02
10	<i>P. brutia</i>	Lebanon	34°00'	36°00'	400	18.2	11.1	1.85
11	<i>P. brutia</i>	Israel ex Greece				20.7	11.1	2.37
12	<i>P. brutia</i>	Turkey	37°44'	30°17'	600-700	20.0	11.4	2.14
13	<i>P. brutia</i>	Turkey	36°05'	36°03'	400-700	20.2	10.9	2.13
14	<i>P. brutia</i>	Turkey	36°12'	29°38'	800-1000	20.9	11.7	2.51
15	<i>P. brutia</i>	Turkey	36°57'	28°40'	50	20.0	11.1	2.23
16	<i>P. brutia</i>	Turkey	36°37'	29°08'	700	19.4	10.9	2.01
17	<i>P. brutia</i>	Turkey	37°45'	36°40'	800-1100	17.7	10.2	1.62
18	<i>P. brutia</i>	Turkey	41°34'	35°56'	<300	19.9	11.0	2.10
19	<i>P. brutia</i>	Turkey	37°21'	28°25'	800	20.5	11.3	2.32
20	<i>P. brutia</i>	Greece (Rhodes)	36°00'	28°00'	400	20.1	10.9	2.13
21	<i>P. brutia</i>	Greece (Thasos)	40°42'	25°00'	600	20.5	11.2	2.29
22	<i>P. eldarica</i>	Iran	35°48'	50°58'	1300	20.7	10.5	2.16
Differences between provenances are significant at the 0.1% level					s.e.d.	1.298	0.51	

Table 4. *Pinus halepensis*, Jerilderie provenance trial, planted 1968, measured at age 29 years

	Species	Provenance	Latitude	Longitude	Altitude (m)	Mean dbh (cm)	Mean height (m)	MAI volume (m ³ /ha)
1	<i>P. halepensis</i>	France	43°31'N	5°00'E	133	19.6	11.7	2.04
2	<i>P. halepensis</i>	Italy	42°34'N	12°38'E	433	19.1	11.3	2.07
3	<i>P. halepensis</i>	Italy	41°54'N	16°00'E	167-333	22.4	12.8	3.02
4	<i>P. halepensis</i>	Italy	40°35'N	17°07'E	17	22.1	11.9	2.76
5	<i>P. halepensis</i>	Spain (Balearic Is.)	30°30'N	3°00'E		19.8	11.9	2.38
6	<i>P. halepensis</i>	Spain	38°00'N	1°00'W		20.9	12.4	2.65
7	<i>P. halepensis</i>	Greece	37°41'N	21°23'E	117-433	21.7	12.5	2.87
8	<i>P. halepensis</i>	Tunisia	36°53'N	10°47'E	55	15.9	10.6	1.20
9	<i>P. halepensis</i>	Tunisia	36°48'N	10°35'E	220	15.2	10.4	1.20
10	<i>P. halepensis</i>	Tunisia	36°42'N	10°40'E	220	15.4	11.0	1.23
11	<i>P. halepensis</i>	Tunisia	36°32'N	9°32'E	333	16.4	10.5	1.38
12	<i>P. halepensis</i>	Tunisia	36°32'N	10°17'E	220	14.2	9.7	1.01
13	<i>P. halepensis</i>	Tunisia	36°23'N	9°20'E	717	17.7	11.2	1.69
14	<i>P. halepensis</i>	Tunisia	36°22'N	8°25'E	770	18.9	12.0	2.09
15	<i>P. halepensis</i>	Tunisia	36°22'N	10°05'E	440	14.8	9.9	1.13
16	<i>P. halepensis</i>	Tunisia	36°22'N	10°25'E	110	16.1	10.7	1.33
17	<i>P. halepensis</i>	Tunisia	36°17'N	9°44'E	330	16.3	10.4	1.34
18	<i>P. halepensis</i>	Tunisia	36°16'N	8°37'E	383	21.4	12.4	2.76
19	<i>P. halepensis</i>	Tunisia	36°15'N	9°58'E	550	17.9	10.9	1.69
20	<i>P. halepensis</i>	Tunisia	36°12'N	8°30'E	880	18	11.3	1.92
21	<i>P. halepensis</i>	Tunisia	36°02'N	9°35'E	800			
22	<i>P. halepensis</i>	Tunisia	35°36'N	9°35'E	770	17.5	11.1	1.62
23	<i>P. halepensis</i>	Tunisia	35°52'N	9°25'E	990	17.5	10.8	1.59
24	<i>P. halepensis</i>	Tunisia	35°48'N	9°45'E	333	16.5	10.4	1.39
25	<i>P. halepensis</i>	Tunisia	35°28'N	8°37'E	1067	19.3	11.5	2.12
26	<i>P. halepensis</i>	Tunisia	35°20'N	8°50'E	1333	17.5	10.9	1.64
27	<i>P. halepensis</i>	Tunisia	35°20'N	9°12'E	800	20.1	12.0	2.36
28	<i>P. halepensis</i>	Tunisia	35°12'N	8°42'E	1683	19.1	11.4	2.00
29	<i>P. halepensis</i>	Tunisia	35°08'N	9°08'E	662	17.8	11.4	1.68
30	<i>P. halepensis</i>	Tunisia	35°07'N	8°30'E	383	18.1	11.2	1.85
31	<i>P. halepensis</i>	Malta	35°55'N	14°30'E		16.8	10.1	1.35
32	<i>P. halepensis</i>	Lebanon	34°00'N	36°00'E	330	17.5	11.2	1.90
33	<i>P. halepensis</i>	Israel	32°44'N	35°00'E	400	18.1	12.2	1.90
34	<i>P. halepensis</i>	Morocco	31°30'N	7°00'W	1251	18.6	11.4	1.95
35	<i>P. halepensis</i>	Jordan	31°32'N	35°06'E	1017	21.4	12.3	2.62
36	<i>P. halepensis</i>	Algeria	35°44'N	7°22'E	1100	18.6	10.8	1.85
37	<i>P. halepensis</i>	Algeria	34°50'N	0°50'W	1313	18.3	11.3	1.81
38	<i>P. halepensis</i>	Algeria	34°52'N	1°20'W	883	17.4	10.7	1.45
39	<i>P. halepensis</i>	Algeria	35°22'N	8°25'E	1430	16.6	10.4	1.45
40	<i>P. halepensis</i>	Algeria	34°39'N	3°14'E		19.3	11.2	2.01
41	<i>P. halepensis</i>	Turkey	37°09'N	35°32'E	328	18.8	12.3	2.10
42	<i>P. halepensis</i>	Greece	39°45'N	23°30'E	547	22.3	13.0	3.20
Differences between provenances are significant at the 0.1% level					s.e.d.	0.49	0.196	

3.1.5 Genetic improvement

The financial benefits of using genetically improved material have been well documented for eucalypts (Eldridge *et al.* 1993), *P. radiata* (Eldridge 1982; Wright and Eldridge 1985; Matheson *et al.* 1986; CSIRO 1999) and *P. pinaster* (Butcher and Hopkins 1992, 1993) in Australia. The process of selection and breeding takes many years but is vital if a species' potential is to be realised. For dry-country conifers the basic step is to identify those seed sources (provenances) of selected species which are best adapted to Australian soils and weather patterns. This alone can substantially increase product yield and quality. Further selection and breeding can lift the benefit to around 15% or more above base population levels each breeding generation (CSIRO 1999).

Traits for improvement include drought and salt tolerance, and adaptation to low-fertility soils. This type of breeding has been the focus of the *brutia* network in Europe (see 2.4 above). In Western Australia there has been selective breeding for drought tolerance in *P. pinaster* for many years, and the species' ability to grow on the low rainfall, sandy sites to the north and east of Perth has been greatly enhanced. A programme with similar aims has been initiated for *P. brutia* under the Australian Low Rainfall Tree Improvement (ALRTIG) project supported by the RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program and the National Heritage Trust (NHT).

3.1.6 Opportunities for processing

As indicated in Section 3.1.1, growers close to existing industry infrastructure can manage their plantation by thinning for pulplogs, preservation logs and finally sawlogs. More distant growers will need to manage the plantation as a two-stage sawlog regime (one sawlog thinning and a final sawlog crop); early thinnings will have to be cut to waste.

Wood products that can be sold from most *radiata* plantations are pulpwood, preservation logs, woodchips and sawlogs. In regional inland areas the same options will not be available while the resource base is small, and in particular markets for early thinnings will often be limited. This does not imply that resourceful individuals will not be able to find a market for their logs.

Stumpage prices (the price of the wood in a standing tree) paid by mills are influenced by the quality of the resource being harvested and transport distance. At distances greater than 70 km from a mill, transport costs for small volumes increase substantially (Bhati 1999) and consequently profits decrease. Logs from thinnings are converted into woodchips, in the forest, in the Mount Gambier region for export and in West Australian plantations for MDF production; elsewhere this is not a common practice. Processors prefer to chip logs and mill residues at the mill.

There are other options for processing logs. Examples exist demonstrating how growers have used first thinnings for preservation logs: Anderson (1998) cites the case of a grower who harvested logs from his plantation and had them preserved by a commercial company. He then used the preserved logs on his farm, making a saving greater than 50% compared with buying them off-farm. There is no restriction on growers processing their own logs using a portable sawmill (Stewart and Hanson 1998). Having a market or a use for the final product is essential.

Many of the conifers that would grow in the drier zones have wood properties that make processing a logical choice. In their natural range, conifers are routinely harvested and processed for a range of products. Some conifers have a resin content higher than that of *P. radiata* that is familiar to most Australian sawmillers. High resin content may well be a problem in pulp mills using the thermo-mechanical pulping process, as at Albury NSW and Millicent SA. Although the resin does slow down processing operations in large sawmills with high volume throughputs, smaller mills with a total throughput of less than 200 000 m³/annum would not notice the difference (G. Meacham *pers. comm.* 1999).

3.1.7 Weeds, pests and diseases

Initial weed control can have a profound effect on the successful establishment of a plantation, especially in those areas where competition for limited moisture can be severe. Most forest operations control weeds in strips along tree rows. Organisations such as ForestrySA which are planting into marginal *P. radiata* areas have adopted a strategy of total weed control to ensure acceptable survival.

Browsing by cattle, sheep or wallabies while the plant is small can retard growth and will often result in poor stem form. These problems can be controlled with adequate management. Large-scale insect damage to conifers in Australia has been virtually non-existent until recently. Being introduced species, natural predators are absent. A recently introduced pest that is causing significant problems in radiata plantations is the pine aphid (*Essigella californica*). Aphid infestation causes the tree to lose a great deal of growing ability and may enhance infection by needle cast, *Cyclaneusma minus* (syn. *Naemacyclus minor*), reducing economic potential. An insect causing substantial economic losses in *P. halepensis* plantations around the Mediterranean is the pine bark scale (*Matsucoccus josephi*). Although endemic to *P. brutia*, it apparently has minimal effect on that species (Schiller 1994). This insect has not yet arrived in Australia.

Several pathogens already in Australia have had an economic impact on *P. radiata* plantations but it is doubtful whether these pathogens could proliferate in the drier 400-600 mm rainfall zones. The most severe has been *Dothistroma septospora* (syn. *D. pini*) but others such as *Armillaria* spp. and *Sphaeropsis sapinea* (syn. *Diplodea pinea*) have had limited effects and are usually localised. A major pathogen that is spreading into several conifer species around the world is pitch canker (*Fusarium circinatum*). This pathogen, if introduced to Australia, would be a disaster for our radiata plantations. This pathogen is known to attack *P. pinaster* which is closely related to the other Mediterranean conifers of interest for the drier areas of Australia.

3.2 Species

The species listed have been chosen as candidate dry-country conifers for Australia based mainly on published information, research trials in Australia and, in the absence of published information, observations of the many isolated plantings throughout Australia.

<i>Pinus pinaster</i>	Maritime pine
<i>Pinus brutia</i>	Brutian pine/ Red pine/ Turkey pine/ Calabrian pine
<i>Pinus canariensis</i>	Canary Island pine
<i>Pinus eldarica</i>	Eldarica / Eldar pine/ Afghan pine
<i>Pinus halepensis</i>	Aleppo pine
<i>Pinus radiata</i>	Radiata pine/Monterey pine
<i>Callitris glaucophylla</i>	Cypress pine/ White cypress

The first five species listed have definite capacity to grow in the drier regions and produce commercial sawlogs. Radiata pine is included because several forestry organisations have developed silvicultural practices within some established plantation areas which appear to enable the species to grow as far down as the 550 mm rainfall isohyet. Young radiata plantations in new areas are exhibiting high survival and rapid initial growth. Whether such growth rates can be sustained under increasing competition for moisture remains to be seen. Cypress pine is included because it is a natural inhabitant of much of the zone under consideration.

3.2.1 *Pinus pinaster*

Species summary

Maritime pine. Occurs throughout Spain and Portugal, on the SW Atlantic coast of France, in NW Italy on the coast and in North Africa from Morocco to Tunisia. Exhibits considerable provenance variation. The Leiria provenance of Portugal has been selectively bred in WA. More recent breeding has aimed at adaptability to low-rainfall sites. An important economic species in SW France (1.0 million ha) and Portugal (1.3 million ha), and in Western Australia (28 000 ha) where there has been a very high level of genetic improvement. Plans exist to enlarge this species' land base in WA to 150 000 ha by expanding plantations within the 400-600 mm rainfall wheatbelt zone. Wood density and general strength is higher than for *radiata* pine. Wood is processed routinely with *radiata* pine in WA, with both having similar properties for the building market. This species is used in southern France (AFOCEL) for papermaking and sawmilling. In South Australia *P. pinaster* has been grown by ForestrySA (formerly South Australian Woods & Forests Department) as a plantation species near the coast on sandy soils, especially since the early 1960s, and is processed without difficulty by local industry.

The natural distribution of *P. pinaster* is around the western end of the Mediterranean (Fig. 2). Plantations have been established in Portugal (1.3 million ha) and in south-western France (1.0 million ha) where rainfall ranges from 700 mm to 1400 mm. Spain has more than 1 million ha of natural forest. The *P. pinaster* in these areas is not generally considered as a high quality resource. Most sawlogs cut from the French plantations are only 2.4 m long. Sawn products from this resource are predominantly green pallet wood and linerboards for the DIY (do-it-yourself) market. In Spain and Portugal, too, mostly logs are cut short and are used in furniture manufacture (G. Meachem, Wespine Pty Ltd, Dardanup, WA, *pers. comm.* 1999). *P. pinaster* has been established as plantations in other countries since around 1900. In South Africa, *P. pinaster* has been found to grow very well in plantations on deep sands (height = 31 m, diameter = 38 cm at age 25 y) (Keet 1929).

P. pinaster was first established as a plantation species in Western Australia in 1923 with seed from the Landes provenance in France. Trials established in 1926 demonstrated that the Leirian provenance from Portugal was greatly superior to others and consequently all plantings after 1942 came from this source (Butcher and Hopkins 1999). By 1973 selective breeding had produced trees with 35% greater volume, 44% straighter and 35% improvement in branch size and angle (Butcher and Hopkins 1992, 1993).

CALM anticipates additional gains of some 40% for volume production by 2020 through the use of vegetative propagation to multiply elite families. Breeding since 1973 has produced drought-tolerant lines suitable for planting in the 400-600 mm rainfall zones north and south-east of Perth.

The effects on wood yield of growing *P. pinaster* plantations on the sandy soils of Western Australia were examined in the mid 1970s (Butcher and Havel 1976; Butcher 1977, 1979). The outcome was a change in management that minimised competition between trees for moisture and optimised growth and yield. The effects of this strategy will need to be recognised in spacing and management regimes adopted for farm forestry plantings in the eastern States where soil types are more variable and availability of soil moisture less certain.

Some 500 000 ha of land may be available in Western Australia to plant with *P. pinaster* (Shea 1998). CALM has planned to establish 150 000 ha within the next ten years to minimise the impact of rapidly increasing salinity problems caused by broadscale clearing in the past (Butcher and Hopkins 1999). Most plantings will be joint ventures with property owners. The Northern Maritime Division of CALM, which is driving the joint venture scheme, anticipates that the lowest growth rates will be an MAI of 8 m³/ha and an average of around 12 m³/ha. Returns from the first silvicultural thinning operations should start in year 12 when stand density may be reduced by up to 60%. Growers in Western Australia have the advantage of a market demand for first thinning products. This market will not always be present for most plantations established in the same rainfall zone in the eastern States.

The next thinning is planned at age 20 with a possible further 50% reduction in stand density, leaving a minimum residual of 250 spha. These figures will vary from property to property due to small-scale changes in soil and management practices. The gross return for such a venture based on a minimum 32-year rotation and stumpage rates current in 1998, should be between \$7100 for 8 m³/ha MAI to around \$11 000 for the average MAI and higher on the better sites (CALM 1998). This represents a possible minimum gross return of \$221/ha/y which, after direct establishment costs that can range from \$850 at 1515spha, will still return \$195/ha/y. On the poor white sands, land is valued at less than 1 DSE/ha with the prospect of about \$5/ha/y return from sheep. Gross returns from higher rainfall sites are not discussed in this report as the focus is on the returns from plantation species suited to the lower rainfall zones.

Silvicultural practice developed for planting in the drier sandy soils of Western Australia varies from the standard practice in several ways, demonstrating the need to continuously evolve and appraise new techniques to suit sites. The most obvious is site preparation, where the top layer of the profile is scalped to about 10 cm deep and 1.0 m wide on the contour. The trees are planted in the centre of the scalp line. In areas considered likely to be 'wet', mounds are formed instead. Early, heavy thinning also reflects the need to minimise competition for moisture. Early plantings had spacings with rows 3.0 m apart and trees 2.2 m apart within the row (1550 spha). Current operations now plant at 1800 – 2000 spha (O. Donovan, Area Co-ordinator, North Maritime Pine Division, Department of Conservation and Land Management, Western Australia, *pers.comm.* 2000).

Trials of *P. pinaster* planted in central western New South Wales in 1999 had rows 3.0 m apart but 3.5 m between trees within a row (952 spha), reflecting concern about early competition for moisture in a regime where there is no planned return from first thinnings and the cost of falling to waste.

Seedlings from crosses among first-generation pinaster selections were planted in 1969 in the Latrobe Valley, Gippsland, Victoria. The site has a rainfall of 450 mm/y and soil consists of a grey sand over clay. Trees were planted at 1670 spha and by age 31 had not been thinned. Although stemform is good, the trial average MAI of 13.8 m³/ha is lower than could be anticipated with regular management (Table 5). The comparisons between best and poorest families highlights genotype x environment interactions and the importance of testing families over a range of sites to ensure that only the best performers are used in further plantings.

Trial plantings of *P. pinaster* of unknown provenance were made at Carabost on the SW slopes of southern New South Wales in the early 1930s, and nearby in the mid 1980s with improved families from Western Australia. The soil is a gravelly clay and the mainly winter rainfall averages 696 mm/y. Unfortunately in 90% of the seasons the rainfall is less than 470 mm. Summers are dry and hot. This is an area considered sub-optimal for *P. radiata* but in which plantations have been established. Growth data for the *P. pinaster* and adjacent plantations of *P. radiata* are given in Table 6.

Table 5. Growth of first-generation families of *Pinus pinaster* in Gippsland

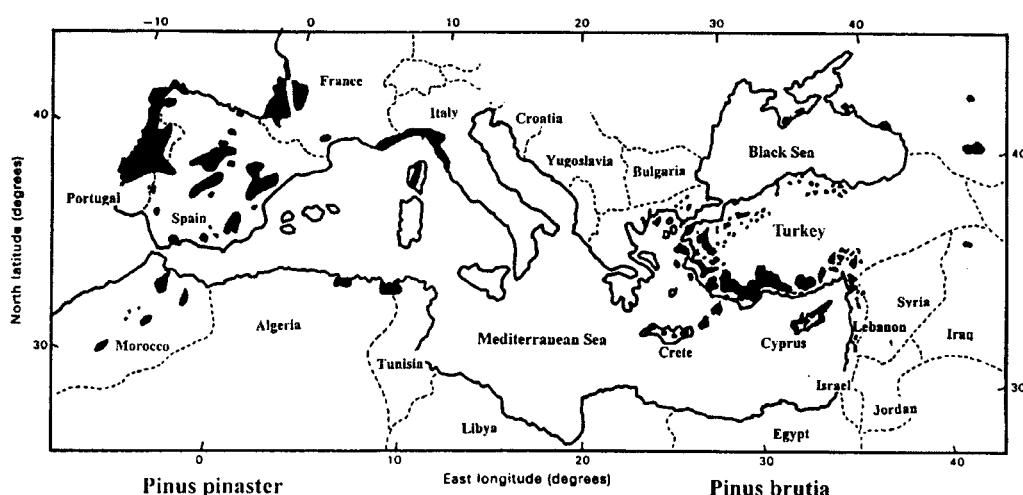
Source	Age (y)	Density (stems/ha)	Age last measure (y)	Height (m)	Dbh (cm)	Volume MAI (m ³ /ha)	BA (m ² /ha)
Poorest family	31	1670	30	14.9	19.5	9.3	49.3
Best family	31	1670	30	18.3	26.0	19.4	83.3
Trial average	31	1670	30	17.0	23.0	13.8	69.3

Information CSIRO Forestry and Forest Products

Table 6. Growth of *Pinus pinaster* and nearby *P. radiata* at Carabost, NSW

Source	Age (y)	Density (stems/ha)	Age at last measure (y)	Height (m)	Dbh (cm)	Volume MAI (m ³ /ha)	BA (m ² /ha)
<i>P. pinaster</i> unimproved	66	818	61	23.3	25.3	5.7	44.7
<i>P. pinaster</i> improved	13	853	13	14.2	20.5	10.2	28
<i>P. radiata</i>	20	995	15	20.4	19.9	13.8	30.5

* Information courtesy State Forests of New South Wales

Figure 2. Natural distribution of *Pinus brutia* (in the eastern zone), and *P. pinaster* (in the western zone) in the Mediterranean

Research issues

CALM in Western Australia has a strong research programme covering all aspects of the species. Areas that may need closer investigation are:

- More intensive screening at the family level for salt tolerance. Is it a family trait? Results may be used in selections in the other closely related species of commercial interest. If material is available, screen 3-4 species concurrently.

Adaptability trials of the 'WA strain' to conditions in other temperate zones in Australia are underway with ALRTIG.

- Further testing of *P. pinaster* adaptability should be encouraged within rural communities with simple trials such as one-hectare block plantings.

3.2.2 *Pinus brutia*

Species summary

Brutian pine/ Brutia/ Redpine/ Turkish pine/ Calabrian pine. Common in the eastern Mediterranean through NE Greece, the Black Sea, Turkey, Crete, Cyprus, Syria and Lebanon. Distribution narrower than *P. halepensis*. Grows from sea level to 1500 m. Reasonably strong apical dominance. Stemform and branchform are much better than for Aleppo pine. The effect of provenance on form is very strong. Withstands cold, high temperatures and drought. Tolerant of alkaline soils. Has been successfully grown in plantations in the 600 mm rainfall zone at Wirrabara, South Australia. Performs well at wide spacing (50 spha) as well as at closer spacing (1100 spha). A good pulping species with long fibres; the solid wood properties are similar to those of radiata pine.

Natural distribution for the species is shown in Figure 2. Appendix 2 contains a review of *P. brutia* detailing how it is linked to closely related species, utilisation of wood from the tree in the areas of natural distribution, genetic variation of the species as a whole and heritabilities of specific growth traits, a review of the current plantings in Australia, and a breeding strategy which can utilise the genetic resources available in Australia. Thomas and Borough (1997) highlight many of the virtues of *P. brutia* from trial data overseas and comment on a more recent examination of some of the trial plots in western New South Wales. They conclude, from this information on growth on a range of soil types, that there is potential for the species in the Murray Darling Basin, especially in relation to helping mitigate salinity problems.

The silvicultural requirements of *P. brutia* would seem to be the same as those of *P. radiata* or *P. pinaster*. Agroforestry trials near Wagga Wagga, NSW, have shown that *P. brutia* planted at 12 x 12 m spacing and managed by pruning can produce quality butt logs. Block plantings of *P. brutia* planted beside *P. radiata* at Bundaleer and Wirrabara in South Australia and beside *P. pinaster* at Gnangara in Western Australia indicate that closer initial spacings (1600 spha) are preferable to wider spacings (750 spha), but both sites receive >600 mm of rainfall per year. In both plantings, thinning was carried out late, yet trees did not appear to carry discernibly less volume than their better-managed neighbours. Thinnings trials in Israel near the Sea of Galilee (rainfall 528 mm/y) found that 'gradual, moderate thinning yielded the best result in terms of quality of the wood' (Heth 1993). Two of the most positive traits of *P. brutia* are its ability to grow on a wide range of soil types, especially those that are alkaline, and its drought tolerance (Selik 1958; Arbez 1974; Fisher *et al.* 1986).

Research issues

- Introductions of seed at the family level should be a matter of priority so that the ALRTIG initiative to produce genetically improved seed of the species is enhanced to the greatest possible extent.
- Intensive studies of wood properties are required to confirm published data and ensure that, as a future resource, it has properties utilisable by Australian industry.
- Protocols should be developed for the vegetative propagation of the species. Genetic gains can be realised faster by vegetative deployment of selectively bred families than by seed.

3.2.3 Pinus canariensis

Species summary

Canary Island pine. Occurs naturally on only five of the seven Canary Islands. Grows on a wide range of habitats at altitudes of 500 – 2300 m. Rainfall (not related to altitude here) varies from an average of 271 to 1328 mm/y. Has adapted well to low altitudes in Australia and can often be found growing in public areas in low rainfall zones. Good form and, although slower in growth, very drought tolerant. Least fire susceptible of all conifers. Wood density high and considered a 'hard' timber. Spiral grain is a problem in immature wood.

The natural distribution of this species is restricted to 5 of the 7 Canary Islands off the north-west coast of Africa at approximately 27°-29°N latitude. Two natural variants occur based on the colour of the heartwood, 'White timber' and 'Light-brown timber' (Bolza and Keating 1972). Despite its restricted distribution, there is considerable genetic variation within populations (Korol *et al.* 1999; Schiller *et al.* 1999). Forests occur on a wide range of habitats and soils types at altitudes of 500 – 2300 m. Most rain falls in winter (average 790 mm), and falls in summer are very low (average 17 mm). Rainfall is highly variable between the islands and does not appear to be closely related to altitude (Schiller 1999). Away from the Canary Islands, the species appears to adapt readily to most soil types and altitudes and has demonstrated that it is the least fire susceptible of all conifers. Trees are generally of good form and, although slower in growth than comparable species, very drought tolerant.

In South Africa *P. canariensis* was established as a plantation species from 1880 and at 50 y of age had achieved heights of 27 m and diameters of 75 cm. The South Africans found the species to be suited to both low (525 mm) and high (1550 mm) rainfalls and altitudes, as well as being tolerant of a wide range of soils but preferring deep, well-drained types (Byles 1932). Plantations were also established with great success in Chile at the turn of the 20th century. In Australia, trees are mostly seen in small group plantings, in parks as single trees and occasionally in windbreaks in the low-rainfall areas. Canary Island Pine was planted in many of Adelaide's parks and surrounding areas around the turn of the century. An example is the long row of very large specimens growing on the Waite Institute's northern boundary adjacent to the suburb of Urrbrae (rainfall 623 mm). Large individuals can be found in many of the long-established parks and gardens in rural areas. It would seem to have been fashionable to include a few Canary Island pines in any garden design. Trial plots have been planted (Kuitpo SA 1.0 ha in 1903 and Bundaleer 0.3 ha about 1902; Benarkin Qld 0.2 ha in 1924; Back Yamma NSW 0.1 ha in 1930 and 0.3 ha in 1953). No evidence of larger plantings as plantation blocks has been found although they may exist. The plot at Back Yamma State Forest in western New South Wales near Forbes was measured in 1998. This site is a typical, productive cypress pine forest in the 500 mm rainfall zone. Neither the seed source nor provenance is known for the two plantings in 1930 and 1953. Data (Table 7) show that the younger stand planted at a wider spacing (1000 spha) is growing faster than the older stand which was probably established at 1600 spha (current stocking is 1185 spha). The two seedlots are morphologically quite different. The older stand has trees with finer, flatter angled branches, little taper and few crown defects. The younger stand has steeper-angled branches and an unacceptable number of forked trees. The poorer form could be due to trees being from a different provenance, but is more likely caused by the seeds being collected from one or two parent trees of poor form chosen because their cones were accessible. This problem is not uncommon in older plantings of many species. Observations by the author would indicate that this species is tolerant of almost any spacing and, with attention to pruning, will produce fine sawlogs in the future.

3.2.4 *Pinus eldarica*

Species summary

Eldar pine. Closely related to *P. brutia*. Exists now only as a relic population in northern Azerbaijan. Rainfall 200–250 mm/y. Grows from sea level to 1200 m in environments with temperature ranges of 20°C to 40°C. Foliage is denser than that of *P. brutia*. Has a multinodal branching habit (averaging 7 whorls of branches per year) and retains lower branches in open situations. Wood properties similar to those of *P. radiata*. Good survival capacity and fast initial growth. Seed difficult to obtain.

Schiller's (1994) isozyme studies of the *P. brutia*/*P. eldarica*/*P. pithyusa*/*P. stankewiczii*/*P. halepensis* species complex indicate that the *P. brutia* population consists of two groups: the western and more genetically diverse group centred in western Turkey (*P. brutia*), and the less genetically diverse group to the east (subspecies of *P. brutia* and including the recognised species *P. eldarica*, *P. stankewiczii* and *P. pithyusa*). *Pinus halepensis* was quite separate from the other species in the complex.

Table 7. Growth to 1998 of *Pinus canariensis* planted at Back Yamma State Forest, NSW

Year planted	Density (stems/ha)	Average dbh (cm)	Average stand basal area (m ² /ha)	Top height (m)	Standing volume (m ³ /ha)	Volume MAI (m ³ /ha)
1953	1000	25.4	54.6	17.1	228	4.9
1930	1185	23.5	45.9	22.0	282	4.0

Information courtesy State Forests NSW

Much less attention has been paid to *P. eldarica*, as a conifer of any significance, than to *P. brutia* despite their being closely related. Descriptions of some of the harsh environments in which *P. eldarica* will grow are provided by Tutayuk (1959), Allegri (1973) and Eccher *et al.* (1982). Allegri (1973) provides clear details of the excellent stem and branching characteristics. Trial plantings of 7 seed sources of *P. eldarica*, 7 provenances of *P. brutia* and 9 provenances of *P. halepensis* were established

in 1978 in southern New Mexico, USA, on a site described as ‘annual precipitation and temperature range from 200-250 mm and from -23° to 43°C . Alkaline soils (pH 7.8-8.0)’. At age 5 y *P. eldarica* averaged 5.9 m in height and 10.3 cm in dbh, and produced 6 whorls of branches per year; *P. brutia* was 3.7 m in height and 4.8 cm in dbh, with 4.2 whorls per year; and *P. halepensis* was 3.6 m in height and 4.6 cm in dbh, with 3.9 whorls per year. The coefficients of variation were very low for *P. eldarica* across traits but variable and much higher for the other two species (Fisher *et al.* 1986). At La Cruz, 15-y-old plantings of *P. eldarica* were 16 m tall (Fisher and Widmoyer 1978) indicating the trial results are reasonable for the site. The trial received supplemental irrigation of 400 mm in 5 applications in the first summer, thus accounting for its very high survival.

Similar trials in southern California were planted on two faces of a mountain range; the moist slope with 750 mm rainfall and the colder, drier slope on the desert side with 375 mm rainfall. The moist slope trees at age 8 y were 6-8 m tall whereas on the drier slope they were 4.5-5 m tall. Krugman (1979) notes that the dry summer in southern California is ‘very long and very harsh’. Other plantings of *P. eldarica* on the alkaline Oklahoma plains near Woodward have achieved heights of 10 m with diameters of 40 cm in 17 y. This growth is remarkable for an area that has a rainfall of 575 mm, 157 days of frost/y, mean maximum temperature of 41°C and mean minimum of -13°C (Fisher and Widmoyer 1978). Fisher (1985) determines that *P. eldarica* has great potential as a plantation species for a very large zone across the southern part of the USA into Texas. Trials indicate biomass production comparable to *P. radiata* and *P. caribaea* on good sites elsewhere. The above examples highlight the great adaptability or ‘plasticity’ of the species, which indicates that it would be highly desirable for many drier, salinity-affected or degraded areas in the Murray-Darling Basin.

Research issues

- Attempts should be made to introduce a collection of seed of this species from the natural stand as well as from plantings ranging from Afghanistan to Iraq. Early trials in Australia used an inferior seed source. Evidence exists that better ‘provenance’ sources are to be found. This species could be one of the most hardy of all conifers and certainly worthy of further detailed investigation.

3.2.5 *Pinus halepensis*

Species summary

Aleppo pine. Common in the western Mediterranean across to the eastern side of Greece and from Morocco to Libya in North Africa. Provenance selection is important. Stemform improves from west to east. Grows from sea level to 1500 m. Very tolerant of calcareous soils. Provides high yields of resin. Makes good pulp due to long fibre. The wood is considered resinous and tough (c.f. *P. radiata*). Has potential as timber species if grown at 1100 – 1300 spha. Trees can be found throughout the dry areas of Australia (down to 300 mm rainfall). Used mainly as windbreaks because of the deep, dense crown often due to early crown break in open situations.

This conifer is one of the most widely planted trees in the drier zones of Australia. Original introductions may have been around the 1850s when many exotic species were introduced by F. Mueller, Director of the Melbourne Botanic Gardens. Specimens were generously distributed and these may have provided the original seed sources for the large increase in plantings post World War II. Curiously, *P. brutia* was not introduced until after WWII, possibly because until then very few recognised the phenotypic differences between the two species and *P. brutia* was classed as a subspecies of *P. halepensis*.

Where the environment is favourable to the flowering of *P. halepensis*, such as the area north of the Clare valley, SA, prolific regeneration occurs in paddocks and along roadsides, often being a pest to the landowner. Regrettably, the stemform of most of the trees planted is so poor that it precludes their use for sawlogs, but this may not be important as most were planted for their excellent windbreak properties and capacity to survive in hard conditions.

Heth (1968) found that *P. halepensis* will grow on areas with rainfall lower than the 400 mm that limits *P. brutia*, but that it but did not have the same mechanisms as *P. brutia* to tolerate drought. What is evident to a tree breeder is the enormous variability within plantings, indicating potential for selection and breeding for straighter trees. Amongst the many windbreaks and plots seen with forked and crooked trees, occasionally there is a planting with straight well-formed specimens, suggesting that the seed from which these trees were grown came from selected parents.

For *P. halepensis* to become a useful plantation crop, attention to provenance source and stand management will be important (Eccher *et al.* 1982; Heth and Spetter 1983; Weinstein 1989). Results from trials in Morocco (H. Sbay, Senior Tree Breeder, Dept. Agronomy and Plant Breeding, Institut Agronomique et Veterinaire Hassan II, Rabat, Morocco, *pers. comm.* 1999), Israel (G. Schiller *pers. comm.* 1999) and Italy (Eccher *et al.* 1982) indicate that, in general, the stemform gets better towards the eastern end of the species distribution and that the Greek provenances are the straightest and most vigorous. Generalities do not always apply and diversity should be the main criterion in choosing seedlots for any provenance evaluation. For example, a Tunisian provenance (Chambi region) planted in the arboretum at Bussells, near Collie, WA (rainfall 968 mm) has shown exceptional vigour (at age 31, average height 22 m, largest trees 45 cm dbh) and stemform. Results at age 29 y from a wide-ranging provenance trial established in 1968 at Jerilderie, NSW by CSIRO (Palmberg 1975; Spencer 1985) were similar, in that 2 of the 3 top-ranked families (by volume) were of Greek origin (Table 4). G. Schiller (*pers. comm.* 1999) believes that, from the many trials and plantings he observed, Australia could improve the quality (stemform and vigour) of *P. halepensis* in a single round of selection and breeding with the resources currently available, but it would take time. He emphasised the need to select against heavily coning individuals, as flowering detracts from wood production, and not to neglect the introduction of further germplasm. He has offered CSIRO seed from an Israeli seed orchard consisting of Greek and Israeli clones selected for vigour, fine branching, drought tolerance and little cone production.

Hybrids between *P. halepensis* and *P. brutia* can be made artificially (Panetsos 1975, 1986) and do occur naturally (Panetsos 1986; Schiller and Mendel 1995). Mouloupoulos and Bassiotis (1961) were the first to prove that the cross is predominantly one-way, the pollen parent being *P. halepensis* and not *P. brutia*. Schiller *et al.* (1986) using isozymes and Bucci *et al.* (1998) using SSR markers validated this by showing introgression of *P. halepensis* chloroplast haplotypes in *P. brutia* seeds. If hybrids were to prove successful in Australian conditions, knowing the mating pattern would make orchard design simpler. Panetsos (1975, 1986) has noted that the growth and form of the hybrids is good, with more of the *P. brutia* stemform and cold tolerance characteristics prevailing.

Research issues

- Growth potential of the hybrids should be evaluated using introduced seed in the first instance and control pollinated seed in the second instance.
- Wood properties need to be evaluated by further laboratory tests (taking the lead from Crammond's 1999 study) using material grown in Australia. Results can then be compared with natural stands through a comprehensive review of published literature.
- A study tour in the natural range of the species may provide a better insight as to how the timber is used in provincial areas and to what extent these uses are linked to wood properties and whether there is an opportunity for similar products to be made in Australia.
- New family x provenance introductions need to be made to expand the genetic resources of the species in Australia. Many native stands will already be unavailable due to the spread of pitch canker in the western Mediterranean. Collections should be made from those still available as soon as possible.
- Seed orchard grade seed should be introduced for evaluation to determine whether stands already growing in Australia are of reasonable quality or need to be improved.

3.2.6 *Pinus radiata*

Species summary

Radiata pine/Monterey pine. The most important commercial softwood species in Australia; more than 700 000 ha established in plantations. There are no stands of commercial importance in its native California although there are small plantations in Mexico. Best growth is on good soils above 600 mm rainfall and from sea level up to 900 m altitude. Highly bred over 50 years with gains of over 20% for volume from the first round of breeding. Very good wood properties for use in the building industry and paper manufacture.

The published information available on *P. radiata* is substantial, covering almost every aspect of its growth, silvicultural management, breeding, wood properties, uses and products,. It is not intended to review the literature in this document. *P. radiata* is included in this report because it is the conifer industry benchmark in Australia. Most *P. radiata* plantations are located on the better soils in areas with a predominantly winter annual rainfall above 600 mm. Some plantations are located on sites receiving 600 mm or slightly less and remain commercial through to the second rotation. This indicates that the species has some potential as a dry-country conifer on selected sites. Almost all plantations in Australia are now derived from genetically improved seed from parents selected from the two northern populations of Año Nuevo and Monterey in California. Selective breeding in the seventies increased wood volume yields in the first generation of breeding by more than 20% (Matheson *et al.* 1986; CSIRO 1999).

Radiata provenance trial plantings at Wirrabara Forest Reserve, South Australia (600 mm) indicate that the provenances from Guadalupe Is. and Cedros Is. off the coast of Baja California, Mexico, are well adapted to lower rainfall. Results indicate that trees have stemform and growth rates equal to the other provenances under these conditions. These provenances should be exploited as potential low-rainfall farm forestry and commercial plantation ‘species’ by using selective breeding.

Examples of *P. radiata* plantations on low-rainfall sites include:

- Wirrabara and Bundaleer Forests (ForestrySA) in the southern Flinders Ranges north of Adelaide
- Kowen and Stromlo forests (ACT Forests) in the ACT
- Carabost (SFNSW) on the SW Slopes of NSW

The Australian Capital Territory and South Australian plantations have more than half the forest reserve plantation area under second-rotation planting. The Australian Capital Territory plantations at Kowen and Stromlo are a good example of radiata pine growing under low rainfall. Canberra has an average rainfall of 620 mm and both plantations are within 10 km of the city. Both plantations have similar ‘effective’ rainfall, a range of site qualities within a small area, and productivities ranging from 16 to 8 m³/ha/yr with an average of 12.4 m³/ha/yr. In order to get improved estimates of the projected yield of wood volume, ACT Forests use ‘effective’ rainfall in their growth models. Basically, the method takes account of the rain falling during the active growing season (August to December inclusive + March to May inclusive) although the calculation is not simple. For example Kowen has an average rainfall of 664 mm but an effective one of 478 mm; Stromlo has an average of 710 mm with an effective one of 468 mm.

Although low MAIs are accepted by respective managers, new silvicultural techniques are constantly tested to optimise and increase returns. It might be possible to plant species other than radiata pine in drier farm forests by adopting existing ‘best silvicultural practice’ initially, but managers would have to be prepared to modify techniques as required.

Research issues

Selective breeding of *P. radiata* should be able to produce families tolerant of low rainfall and possibly salinity. Areas to research include:

- estimates of family heritabilities to the tolerance of low moisture and salinity, without loss of growth, which can be used in breeding strategies.
- trials of selections by family from the Guadalupe Island and Cedros Island populations growing *ex situ* in Australia to evaluate low moisture and possibly salinity tolerance.

3.2.7 *Callitris glaucophylla*

Species summary

White cypress/Cypress. A conifer native to most of the continent but concentrated in central eastern Australia. Has a wide distribution, growing naturally in drier regions (mainly 350–600 mm zone) on sandier or well drained soils. Not grown as a plantation species; natural forests are harvested. Trees are slow growing, fire sensitive and may take 100 y to mature. MAIs are 0.2–0.3 m³/ha. Rotation ages to commercial products are about 30 y for first thinning, with larger logs becoming available by 50 y. On better sites may reach 30 m height but more commonly 25 m with a diameter of 60 cm. Excellent wood properties of heartwood durability, ‘hardness’ for flooring, stability, and white ant resistance. Disadvantages are knottiness, brittleness, low durability of sapwood and the need for specific nailing techniques.

The question of why has cypress pine not been established as a plantation species is often raised. The answer is not altogether simple as it involves perceptions and economics that keep changing. This species is native and has evolved here, but do we know how to manage or exploit its unique capacity to survive in relatively dry conditions? Management strategies to take advantage of stand dynamics are constantly being improved through research and application. Current methodologies are aimed at boosting growth, sustaining the yield and meeting environmental requirements without compromising economic viability. Emphasis remains on manipulating the natural resource rather than creating plantations which are still deemed to be economically unviable. Understanding cypress pine stand dynamics requires background information. A brief synopsis is given below.

3.2.7.1 The resource

Although white cypress pine is found in all mainland states of Australia, the main distribution occurs from just north of Injune in central western Queensland through the western region of New South Wales to the Murray River. Cypress pine forests represent 0.6% (0.9 million ha) of the total forested area in Australia with about 35% occurring on leasehold land, 34% in multiple use forests, 23% on private lands and 8% in conservation reserves (National Forest Inventory 1997).



Figure 3. Natural distribution of cypress pine (*Callitris glaucophylla*) in Australia

The main commercial forests occur in the Inglewood – Millmerran areas, the Chinchilla – Miles areas and the Roma – Injune – Augathella areas of southern Queensland and in the Baradine – Narrabri areas (Pillaga Scrub) and the Forbes and Cobar areas in New South Wales. The New South Wales stands are mainly mixed with hardwoods or in small remnant patches amongst agricultural activities, whereas the Queensland stands are in grazing country and the cypress tends to be dominant.

Resource tenure varies by State. In New South Wales most cypress occurs on crown land (State Forests) whereas in Queensland most is on freehold and leasehold land with the crown controlling the harvest on the leasehold land (Table 8). The total volume of timber harvested each year in New South Wales is about half that in Queensland (Table 9). The pattern of land tenure results in the governments of New South Wales and Queensland supplying some 75% of the total Australian cut each year.

As a native species, cypress pine has always been treated as a resource that was available ‘in perpetuity’. Current harvest operations are removing the trees from the 1890 wave of regeneration and thinnings from the 1950s regeneration. The notion of establishing plantations of this species has always been rejected because of the long time intervals between harvests and because the species naturally regenerates prolifically. The management practice that has evolved is similar to that for native eucalypt forests, i.e. harvest on a sustained yield basis. This means that the amount of timber removed matches that which has accrued since the previous harvest. This allows the forest to continue producing timber at a similar rate. Sustained yield management is achieved by selective logging in Queensland and ‘release’ logging and thinning in New South Wales.

Table 8. Location of cypress pine resource by land tenure

State	National Park	State Forests	Leasehold	Freehold
New South Wales ¹	2%	Reliable estimates of commercial cypress forests on freehold and leasehold lands are unavailable.		
Queensland ²	2%	8%	36%	55%

Sources: ¹SFNSW; ²DNR 1996. A Review of Cypress Pine Management on Leasehold Land, Queensland.

Table 9. Volume of cypress cut in 1993/94 by land tenure

State	State Forests	Leasehold	Freehold	Volume harvested (m ³ /yr)
New South Wales ¹	91%	1%	8%	113 318
Queensland ²	37%	32%	31%	200 076

Sources: ¹ACSP 1996. Australian Cypress Strategic Plan for NSW Industry

²DNR 1996. A Review of Cypress Pine Management on Leasehold Land, Queensland.

In cypress forests, it was found that if a highly stocked regeneration stand is thinned (removal of excess regeneration and competing species), the productivity increases substantially. Untreated dense regeneration stands stagnate with negligible increment. Treatment has been a standard practice for decades and is still practised in many of the New South Wales State Forests though on a lesser scale. The practice has all but ceased in Queensland, being deemed uneconomic in terms of the return on the investment.

The return from managing the cypress resource is not insignificant. State Forests of New South Wales earns a royalty of \$3 million/y from a cut of 113 000 m³ from an estate of about 440 000 ha (SFNSW 1998). Queensland earns a royalty of \$3.4 million/y from a cut of 200 000 m³ from a considerably larger estate of 1.9 million ha of which the State controls 69% (DNR 1996). The lesser rate of return in Queensland reflects the lower royalties in the western areas where transport distances are greater.

3.2.7.2 Growth

Standing basal area (BA) as square metres of sectional area per hectare, or volume mean annual increment (MAI) in cubic metres per hectare, are the two most common methods of describing growth. The BA is used more as a management tool to describe stand density whereas the volume MAI indicates the rate at which the amount of wood per unit area is accumulating. The interplay between

growth, regeneration and silvicultural management is a complex issue that has been investigated by many scientists and foresters over a long period.

One of the big problems in management has been a lack of reasonable estimates of productivity (standing volumes and expected MAIs) related to site quality. Because of the great diversity of climate and soils involved, patterns are never regular and so making estimates of volume is complex. State Forests of New South Wales have no satisfactory index, but researchers in Queensland have developed a method using height /diameter relationships to quantify 'site form'. This is the expected height of a 25 cm dbh tree predicted from the stand height/diameter relationship. The method is simple to use and has positive correlations with other indicators of productivity such as diameter increment, maximum stand height, volume and BA increment. Using this system, a site with form of less than 14 has no commercial importance (Vanclay and Henry 1988).

Growth rates of cypress vary between zones, but on average Queensland and New South Wales have the same $0.24 \text{ m}^3/\text{ha}/\text{yr}$ with a similar range of $0.12 - 0.41 \text{ m}^3/\text{ha}/\text{yr}$ (ACSP 1996 p. 18, Table 2; SCMG 1999 p. 26). Compared with other short-rotation conifers which have growth rates of $15-27 \text{ m}^3/\text{ha}/\text{yr}$, cypress is very much slower. There have been several estimates of the standing basal area (BA) for which the BA increment a stand of trees is maximised (Johnston 1975; Vanclay 1985). Experience in New South Wales indicates that the optimum increments occur in stands thinned to a residual BA of $8-13 \text{ m}^2/\text{ha}$ (SFNSW 1998). The BA of a stand has a strong influence on the regeneration capacity of trees in terms of seed production as well as influencing the growth of the emerging stratum of regeneration (Lacey 1972, 1973; Johnston 1975). Thus BA is an effective stand management tool if used properly.

3.2.7.3 Regeneration

Cypress pine will flower from about age six years and usually produces heavy crops of seed every three years, with smaller crops of lower viability in other years. This by itself does not ensure good regeneration. The combination of a good seed crop with a viability of 30%-40%, absence of fire, adequate ground litter to prevent excessive insolation (Johnston 1967) and favourable climatic conditions leads to 'wheatfield' regeneration. These occasions arise no more than 1 in 12 years in Queensland (Hawkins 1966). In New South Wales they are believed to be less frequent but regeneration is denser (A. Deane *pers. comm.* 1999). In 1952 and 1956 widespread regeneration occurred in the cypress forests due to a combination of good seed crops, favourable seasons and the demise of rabbits by myxomatosis. Some stands grew at densities of $>500\,000$ seedlings/ha (Horne 1990) though more often at $100\,000$ seedlings/ha. Seedlings are very tolerant of competition and can remain 'locked-up' for 40 y with heights of 3-5 m and diameters of 2-5 cm yet, when released (thinned to about 300 spha), respond quite vigorously. Seed production and survival is closely tied to stand density. A standing basal area of $14 \text{ m}^2/\text{ha}$ will prevent seeding while ' $7-9 \text{ m}^2/\text{ha}$ will allow seedlings to survive without excessively high numbers becoming established' (SFNSW 1998).

3.2.7.4 Management

The way a stand has been managed in the past will have a strong influence on its growth and overall productivity. Queensland and New South Wales use different systems of stand management to achieve the same objective of sustained yield. Queensland's goal is to manage stands to maximise long-term volume yields without compromising log sizes. Stands in Queensland tend to be multi-aged due to more frequent regeneration success because of the summer rainfall. Consequently, management is based on a multi-tiered selection system with an upper cutting limit around 35-39 cm dbh.

Stands in New South Wales are mostly even-aged due to infrequent regeneration events. This has resulted in State Forests using an even-aged management system based on a modified shelterwood silvicultural method which they believe leads to a better return. Both States have been thinning 30-40-y-old stands to about 300 spha. New South Wales adopted a 6 m x 6 m spacing and Queensland a 5 m x 5 m spacing. The cost of this type of management ranges from \$250 - 400/ha. While New South Wales is maintaining the thinning programme, Queensland feels that, at current royalties, the operation is not

economic and has ceased this type of thinning treatment. More details of each method can be found in the publications recommended for reading.

3.2.7.5 Future

There is an overall concern within the industry that resources are diminishing, and coupled with the realisation that cypress pine cannot compete with radiata and other softwoods in what was the traditional the cypress market, the industry has had to redefine itself. While a healthy market still exists in Brisbane, Sydney and Melbourne for framing timbers, the industry is attempting to capitalise on the unique qualities of cypress through the specialty market.

Stand management on leasehold land has become an issue in Queensland. Timber on pastoral leases and grazing homestead perpetual leases belongs to the crown. Timber on agricultural farm/perpetual lease selections belongs to the crown for the first two years and farmers converting leasehold to freehold have to pay for the value of the timber during the term of the conversion. None of these arrangements returned a dividend to the farmer and so the incentive to manage stands does not exist. Farmers in turn are not allowed to remove any timber without approval. In more recent times the main complaint is that the cypress pine regeneration is invading pastures causing farmers economic loss because under the legislation they cannot remove the regeneration. The SCMG (1999) has proposed several alternatives whereby the farmer is rewarded in various ways for managing stands, thus ensuring availability of a timber resource in the future. The proposals are being considered by Queensland Forestry.

Since the mid 1980s, State Forests of New South Wales has shared the royalty from timber cut on a lease with the lessee. This rate is currently set at 33% gross which translates to about 20% nett after costs are removed. Under this system State Forests has almost complete control over all timbers cut and is able to regulate the yield across a wide region. This is important because sales from freehold land are consistently reducing, and the volume harvested in 1998 was less than 10 000 m³.

The justification for not establishing plantations appears to be well entrenched in a long history of developing management techniques and research. The economic rationale is not discussed here but is well outlined in the SCMG (1999) report. In Queensland in particular, the cost of treatment is much higher than the returns. Whether treatment should 'pay its way' without regard to the future is a political issue. Whatever the outcome regarding future management, the cypress pine industry needs to continue to focus on the value-added products highlighting the unique properties of the timber, thereby increasing the value of whatever supplies are available.

Research issues

1. Investigate whether economical methods of plantation establishment exist or whether such plantings are warranted and in what circumstances.
2. Anecdote has it that the Queensland cypress grows better than the NSW stock. There does not appear to have been any attempt to validate this with range-wide provenance trials across sites. Collections should be made from the full range of the species and-
 - (a) seed stored for the long term to conserve maximum diversity in germplasm.
 - (b) trials established to determine which provenances will return the highest yield.
 - (c) *in situ* conservation stands explored to represent the natural germplasm diversity.
3. Determine the pattern of genetic diversity in *C. glaucophylla* using molecular techniques.
4. Wood oils and extracts of cypress pine have γ -lactones and other constituents implicated in termiticidal and fungicidal activity. Exploiting these properties as additives to other wood composites and preservation techniques may have commercial advantages. If oils could be extracted from small thinnings in the field, an incentive will be created for property owners to manage the young stands for the future with little cost to themselves. Areas to investigate include:

- (a) variation of the oil composition across the species range.
- (b) preservation techniques using oil extractives.
- (c) wood composites using oil extractives.
- (d) techniques of utilising small thinnings to extract oils.

Recommended reading

The following publications give a detailed description of the cypress industry, issues affecting growth and productivity and future directions:

1. Baur, G.N. (compiler) 1988. Cypress pine types. Notes on the silviculture of major NSW Forest Types. No. 10. Forestry Commission of NSW, Sydney.
2. Lacey, C.J. 1973. Silvicultural characteristics of white cypress pine. Research Note 26. Forestry Commission of NSW, Sydney.
3. SCMG 1999. Management plan for the cypress industry in Queensland. Sustainable Cypress Management Group's report, April 1999.
4. Ryan, T. 1996. Sustainable cypress timber management scoping study. Maranoa Economic & Tourism Development Association Inc. (Qld).
5. DNR 1996. A review of cypress pine management on leasehold land. Department of Natural Resources, Queensland. Policy Options paper.
6. ACSP 1996. Australian cypress strategic plan for the New South Wales industry. Forest Products Australia and State Forests of New South Wales joint report.

3.3 Wood properties and uses

Descriptions of wood values can be difficult to compare as laboratories may not use the same test equipment. The material being tested is extremely variable due to many factors such as differences in the age of the trees, sample height, soil type, nutrient status, site aspect, rainfall total and pattern, how the plots or stands of trees are managed, origin of the material and whether any genetic improvement has occurred. In this report a range of published results have been collated, but the data presented in Tables 10 and 11 are by no means exhaustive as they aim to give only an indication of the wood properties of each species. An empty cell in the tables does not imply that the information has not been determined. Often information with high scientific integrity (including published reports) is difficult to obtain and reliance has to be placed on trends in results.

One of the most frequently measured traits of wood is basic density or air-dry density. Some characters are rarely measured, such as resin content or spiral grain, again reflecting the relative importance of that trait to the researcher or the field in which the person operates. Table 10 shows some results for density as well as resin content and spiral grain where information was found.

When comparing density measurements, the age of the tree and the height at which it was sampled are two important factors to consider. In each species, the pattern of an increase in density from the pith outwards and a decrease in density following up the stem is similar. It is the rate of change that varies considerably. The age of a tree determines the ratio of juvenile wood (lower density) to mature wood (higher density).

Table 10. General wood properties. The values in brackets are standard errors of the mean

Species	Basic density(mean) (kg/m ³)	Density –air dry (mean) (kg/m ³)	Resin content (in sapwood) (%)	Spiral grain (degrees from stem axis)
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Species with potential for wood production

<i>Pinus radiata</i>	430 ¹	358 ⁶	395(42) ¹⁴	485(7) ⁵	530 ²	540 ¹⁰	593(9) ⁵	520(65) ¹⁴	1.8 ¹	7.1(2.8) ¹⁴
<i>Pinus pinaster</i>	440 ¹	458(55) ⁴	425(60) ¹⁴		540 ¹⁰	558(74) ²	570(85) ¹⁴		5.5 ¹	7.5(3.2) ¹⁴
	490(9) ⁵	346 ⁶			589(48) ³	596(11) ⁵	553(81) ⁴			
<i>Pinus brutia</i>	491 ⁶	492 ^{7a}	558(40) ¹²	413 ^{7b}	536(50) ⁹					
<i>Pinus eldarica</i>					660 ⁸					
<i>Pinus halepensis</i>	571(42) ¹²				610 ¹⁰					
<i>Pinus canariensis</i>					765 ¹⁰	735 ¹¹				
<i>Callitris glaucophylla</i>	680 ¹⁰	675 ¹⁵	570(44) ¹⁶	690 ¹⁷						

See Table 10 for a key to the sources of information.

Table 11. Mechanical wood properties at 12% moisture content. The values in brackets are standard errors of the mean

Species	Modulus of rupture		Modulus of elasticity		Crushing strength		Shearing strength	Shrinkage, tangential		Shrinkage, radial	
	(MPa)		(MPa)		(MPa)		(MPa)	(%)		(%)	
<i>Pinus radiata</i>	95.3 ¹	87.2 ²	10 020 ¹	9 900 ¹⁰	48.3 ²	47.4 ¹	12.9 ¹	4.1 ¹	4.1 ¹⁰	2.7 ¹	2.1 ¹⁰
	73.2 ¹⁰		11 480 ²		43.0 ¹⁰		11.0 ¹⁰	5.1(0.1) ⁵		3.4(0.1) ⁵	
<i>Pinus pinaster</i>	96.6 ¹	86.5 ¹⁰	10 490 ¹	11 500 ¹⁰	45.1(10.3) ²		12.0 ¹	3.4 ¹	3.3 ¹⁰	2.1 ¹	1.6 ¹⁰
	82.6(18.9) ²		11 681 (3079) ²		59.9 ¹	49.8 ¹⁰	12.4 ¹⁰	5.0(.02) ⁵		3.0(0.1) ⁵	
<i>Pinus brutia</i>							7.2(.9) ⁹	6.8(1.5) ⁹		4.3(1.2) ⁹	
<i>Pinus eldarica</i> (a)	79.5 ¹³		8 155 ¹³		40.5 ¹³		11.9 ¹³				
<i>Pinus halepensis</i>	86.5 ¹⁰		11 500 ¹⁰		49.8 ¹⁰		12.4 ¹⁰	4.8 ¹⁰		2.5 ¹⁰	
<i>Pinus canariensis</i>	103.8 ¹⁰		13 300 ¹⁰		57.7 ¹⁰		14.1 ¹⁰	4.1 ¹⁰		2.0 ¹⁰	
<i>Callitris glaucophylla</i>	73.2 ¹⁰		9 900 ¹⁰		43.0 ¹⁰		11.0 ¹⁰	1.2 ¹⁰	2.6 ¹⁶	1.0 ¹⁰	2.4 ¹⁶

Information sources (see References for details) and comments on data for Tables 10 and 11

1. Anon. 1976. What's New in Forest Research, FRI NZ. No.44 (North Is trees only)
2. Siemon 1983.
3. Meachem, G. (Wespine mill study 1998; 30 yo+ trees). Wespine Pty. Ltd., Dardanup, WA. *pers. comm.* 1999
4. Siemon 1998. (Genetically improved trees)
5. Kingston and Risdon 1961. CSIRO (Genetically unimproved material 30 yo)
6. Tank *et al.* 1990. Turkey.
7. Goksel and Ozden 1993. Turkey (a = 36 yo trees, b = 12 yo trees)
8. Ali-Zade, V. Deputy Director Institute Botany, Azerbaijan Academy of Sciences *pers. comm.* 1999
9. Oktem *et al.* 1993. Turkey (Large sample sizes)
10. Bolza and Keating 1973.
11. Chapman 1928. Woods and Forests SA.
12. Crammond 1999. RIRDC report (Small sample size)
13. Fisher 1985. (Results from juvenile timber)
14. Siemon 1995. (11-24 y old trees from Donnybrook sunklands)
15. Cause *et al.* 1989. Queensland.
16. QFRI data. (Range-wide younger trees. 10 trees/site x 7 sites)
17. QFRI data. (10 trees/site x 3 sites)

3.3.1 Mechanical wood properties and utilisation

Plantations are established to provide a resource for sawn and pulp material. The proportion diverted to each end use depends on the age of the plantation. Younger plantations can have up to 80% of the material harvested being pulped, the proportion decreasing with subsequent harvests as the plantation matures. For logs to be used as sawn timber in Australia, the wood properties need to meet a minimum standard as set by the industry or legislation. For example, the Radiata Pine Association of Australia has a Standard (100-1979) relating to high temperature seasoning, under restraint, of heart-in radiata pine structural material. Standards Association of Australia publishes timber engineering codes for all species relating to properties of strength (MOR and MOE) of green and seasoned material. These standards set out the mechanical properties that wood must possess for it to be utilised safely by industry for construction purposes. Other countries may not have the same industry standards but, by comparing specific performance characters, species can be compared. Table 11 compares some of the more important mechanical characteristics.

The MOR and MOE values indicate the strength characters of stiffness and pliability in timbers. To the average person, this translates into what piece size is needed in a specific circumstance (beams across rooms or supporting a balcony).

Explanation of terms used in describing mechanical properties of wood

Modulus of rupture (MOR): Measure of the maximum fibre stress of timber, being bent, at the point of rupture

Modulus of elasticity (MOE): Measure of timber's resistance to bending under a load and its capacity to return to its original shape when the load is removed

Crushing strength: Measure of the resistance of timber to compression perpendicular to the grain

Shearing strength: Measure of the resistance of timber to compression parallel with the grain; as in standing a piece of timber vertically to support a beam

Shrinkage: The amount a piece of green timber shrinks after it has been dried (usually to 12% moisture content). Shrinkage occurs tangentially (parallel to the growth rings of the cross section) and radially (at right angles to the growth rings of the cross section).

3.3.1.1 Pinus canariensis

From Table 11 it is evident that Canary Island pine is a tough timber and dimensionally stable. Byles (1932) comments on this species as being 'a strong heavy timber, equal in strength to many of our [Australian] hardwoods'. He noted that it was the heartwood that was strongest and durable due to the high resin content, and that the wood saws and cuts cleanly but is tough to work and hard to nail. In South Africa, preservative-impregnated power poles of *P. radiata*, *P. pinaster* and *P. canariensis* are routinely used. *P. canariensis* is considered to make the best poles due to its toughness, lack of taper and good form (Krogh 1967).

Canary Island pine was established as a plantation species on high quality sites (see Section 3.2.3) in several countries in the early 1900s and subsequently as trial plantings in many others. Its growth rate is too slow for plantations to be commercially viable in most circumstances. If established as a longer-term project and accepting a low internal rate of return, it does have merit. As a crop for carbon credit trading it has value in that the carbon will be sequestered longer than in other species but the rate of sequestration will be low.

3.3.1.2 Callitris glaucophylla

Cypress pine is considered by many to be 'hard' yet its mechanical wood properties are in a similar range to radiata pine. Most framing timber on the market today is stress graded to Australian Standard AS2858-1986. Cypress timber is different from most in that the MOR decreases as the timber dries. In the past, without grading standards, house frames used larger piece sizes than were strictly necessary for safety. Traditional markets have been framing, bearers and joists, flooring, cladding and interior panels, the latter two being far more profitable than the former. Because the framing market is declining many sawmillers are being forced to invest in equipment upgrades to produce alternative higher quality products to compete with radiata pine. The dilemma for many is the quality of the resource. Larger logs often have windshakes which render them useful only for framing grade material. Flooring is mostly derived from the smaller diameter logs (30-35 cm mid-log diameter) from the better stands from which timber usually has no splits and smaller knots. Logs from these higher quality stands often have to be transported long distances, resulting in lower royalties to the grower.

A major use of cypress timber is for flooring where its grain features, knottiness and surface hardness are sought. Flooring is air dried and sold to Australian Standard AS 1810-1995. The other property for which cypress pine is well known is the resistance of the heartwood to termites, borers and decay both

in and above the ground. The sapwood may show signs of tunnels bored by beetles known to attack trees that have been stressed or have suffered fire damage. These include the cypress pine jewel beetle (*Diadoxus spp.*), longicorn beetle (*Oebarina spp.*) and pin hole borer (*Ambrosia spp.*). Disadvantages include brittleness, knots, difficulty in nailing and susceptibility of the sapwood to decay. The nailing problem has been largely overcome by the use of air gun nails that do not split the wood. Cypress timber can be used green for most purposes because of its high dimensional stability due to low shrinkage.

In order for the industry to remain profitable, new uses for the product have had to be found and aggressively marketed. Innovative uses include highly finished parquet flooring for the USA market which demands that the timber be dried to 12% moisture content. Another use is 'all-in-one' log cabin walls for which the exterior is rounded, the inner face chamfered and the top and bottom tongued and grooved to allow logs to interlock. Claddings for external walls and ceilings is also popular. In Victoria, an engineering firm is specialising in the manufacture of laminated beams and cypress pine is regularly used for products for the Japanese market.

3.3.1.3 *Pinus brutia*

Brutian pine is the principal forest timber in Turkey. Details of processing and the quantities of products produced are difficult to find. From an estate of 3 179 270 ha with an estimated standing volume of 161.7 M m³, some 3.75 M m³ of logs are processed annually (Turkmen 1993). From a good quality stand 50 y old and having an average stem diameter of 30 cm, harvesting will yield sawlogs (41%), poles (21%), industrial wood (18%) and fuelwood (20%) (Asan 1993). This distribution indicates that some 1.5 M m³ of sawlogs are cut per year, providing a significant volume of sawn timber and wood products.

3.3.1.4 *Pinus pinaster*

Maritime pine is used in the Australian construction industry interchangeably with radiata pine as it is graded under the same ASA code. In reality, smaller sections of maritime pine could be used for a given purpose because it has greater strength than radiata due to its higher density (Siemon 1983). Recent studies indicate that the pine is suited for laminated veneer lumber (LVL) manufacture by rotary peeling (Siemon 1998). Production of reconstituted products such as medium density fibreboard (MDF) and particle board from *P. pinaster* plantation thinnings is already at a high level. Demand for this species as a framing timber appears certain to increase in WA. Traditionally, houses were built with double brick walls since bricks were cheaper than pine. Observations in new housing developments suggest that almost half the houses are now brick veneer with pine frames as in eastern States.

3.3.1.5 *Pinus halepensis*

Aleppo pine is used structurally in buildings throughout the region where it occurs naturally but not in Australia; no ASA code has been established. This is largely a reflection of the size and quality of the resource available for processing. Logs of Aleppo pine were processed for several years at a sawmill at Wirrabara, SA, using thinnings from nearby plantation plots. The miller considered the wood similar to radiata pine to cut but the resin often made the saw 'gum up', and slowed processing (P. Morgan, sawmill owner, Wirrabara, SA, *pers. comm.* 1997). The sawmiller had a small local market for sawn Aleppo wood for use in decking for sheep jetting chutes where the wood was considered tougher and more durable than most other species. Another market was to supply BHP with gluts to put between steel blocks for transport to the USSR. Aleppo pine could withstand crushing better than alternatives.

3.3.1.6 *Pinus radiata*

Radiata pine is used in a wide range of applications that require the product to meet specific strength requirements. The framing market is probably the largest outlet for sawn products. In the 1960s some 46% of sawn timber was used for packaging, 25% for flooring, 26% for linings and 1% for framing. By the late 90s this had changed to 8% packaging, 1% flooring, 26% linings and 65% framing.

(L'Estrange 1999). Other radiata pine products where strength is critical include GLULAM beams (strips of solid wood glued together to form a laminate), laminated veneer lumber (LVL), plywood and trusses. Reconstituted products such as particle board and MDF also need to meet strength requirements. Because of radiata's great versatility in not only having excellent paper-making properties, but good solid wood properties of nail holding, glueing, screw holding, planing, lightness and stability in dimension when seasoned, it is the benchmark against which other species are inevitably compared (Bamber and Burley 1983).

There are other species better than radiata for several characteristics but not as good in others. They seem not to be grown because the bottom line is economics: radiata grows faster and a mature product is achievable in a shorter rotation time. This may change as the new land area available for optimum growth of radiata diminishes and new plantations have to be better equipped to tolerate drier conditions with consequent slower growth rates.

3.3.2 Paper-making properties

The fibre and kraft paper-making properties of the three more widely used species of the seven being reviewed are so similar that it would appear that there is very little difference, except for the lower resin content of *P. radiata* which gives it an advantage in mechanical pulping. Wood density is a critical component in determining the amount of pulp obtainable from a given volume of green wood as well as the quality of the final product (Jones and Corson 1996; Matheson *et al.* 1997). Many other fibre properties and structural components can affect the final quality of the paper. On the grounds of density alone, *P. canariensis*, *P. halepensis* and *P. eldarica*, which have densities greater than *P. radiata*, *P. pinaster* and *P. brutia*, should make better paper. However, no reported evidence to support this was found for *P. canariensis* and *P. halepensis*. *P. eldarica* has other wood properties that indicate it would make good paper, but no reports were found to validate this. Table 10 indicates that *P. brutia* has the highest average basic density followed by *P. pinaster* and then *P. radiata*.

Fibre length is the second most important wood property determining the quality of the product, though some would argue that it is the primary concern. The longer the fibre, the greater the number of contact points in the fibre mat that eventually becomes paper. The larger the diameter of the fibre and the thicker the cell wall, the harder it is for the fibre to collapse during processing and thus increase the contact area in a thin profile (Table 12).

Table 12. Wood fibre properties

Species	Trachied length (mm)	Fibre width (μ , microns)	Lumen (μ , microns)	Cellwall thickness (μ , microns)
<i>Pinus radiata</i>	2.02 ¹	16.28 ¹	10.15 ¹	3.06 ¹
<i>Pinus pinaster</i>	3.97 ¹	23.50 ¹	15.70 ¹	15.49 ¹
<i>Pinus brutia</i>	3.20 ¹	25.05 ¹	15.49 ¹	4.78 ¹
	2.88 ^{2a} 3.02 ^{2b}	33.01 ^{2a} 36.14 ^{2b}	13.11 ^{2a} 24.08 ^{2b}	9.95 ^{2a} 7.92 ^{2b}

Information sources (see References for details) and comments on data for Tables 12, 13 and 14-

¹Tank *et al.* 1990

²Goksel and Ozden 1993 Turkey (a = 36 yo trees, b = 12 yo trees)

³Usta 1993 Turkey

Another important consideration in paper manufacture is production cost. This is influenced by the amount of chemical needed to gain clean fibres (pulp yield). The chemicals are needed to dissolve the lignin binding the fibres and so the lignin content as well as the holocellulose percentage of wood as a whole is often important. Table 13 shows that while *P. radiata* and *P. brutia* have similar lignin and cellulose contents, *P. radiata* lignin dissolves more readily and gives a higher pulp yield than *P. brutia*. In general, long fibre pulp makes paper that has less chance of breaking (important in high-speed paper manufacture and processing), high burst and tear strengths, and stretches more easily. It is evident that *P. brutia* makes better paper (Kraft pulping) than *P. radiata* or *P. pinaster* with *P. radiata* better than

P. pinaster (Table 14). Tank *et al.* (1990) found that *P. brutia* ‘gave rather thick paper’ and that *P. radiata* paper ‘tended to have a thinner and harder paper formation’. Thick paper is ideal for packaging and industrial uses where toughness is important.

P. radiata is preferred for making soft paper such as newsprint, tissues and toilet paper because the smaller dimensions of the fibre make them more pliable.

3.4 Economic potential for growing conifers in the low rainfall zones

Forestry as a commercial enterprise in a low-rainfall zone will be marginal if comparisons are based on the usual methods of evaluating the returns against those of other agricultural enterprises. Forestry ventures are long term, with a large initial investment and no returns for a long period. Agricultural enterprises also have large initial capital investments as in machinery, but a return is obtained each year. Forestry enterprises in the drier regions need to be evaluated in ways that recognise low growth rates yet realistically reflect environmental benefits.

Most estimates of the viability of a forestry project are based on Net Present Value (NPV) or Internal Rate of Return (IRR). Both are used to estimate the long-term profitability of an investment in today’s dollars. The IRR calculates the rate of interest payable on the investment to break even whereas the NPV uses a chosen interest rate and determines whether the investment will make a return, and how much, at that rate. The IRR of the venture/project is the discount rate at which the difference between the future income and costs equal zero. NPV is the difference between the present value of future incomes and costs at a selected discount rate. A NPV of greater than zero indicates viability provided the discount rate chosen is realistic, i.e. the rate that the capital could earn elsewhere. The IRR is the discount rate at which the NPV is zero.

Table 13. Kraft pulping characteristics

Species	Pulp yield (%)		Total lignin (%)	Residual lignin (%)	Holo-cellulose (%)		Solubility in 1% NaOH (%)		
<i>Pinus radiata</i>	49.00 ¹		28.47 ¹	12.5 ¹	64.06 ¹		9.27 ¹		
<i>Pinus pinaster</i>	46.57 ¹		28.3 ¹	10.16 ¹	72.07 ¹		10.31 ¹		
<i>Pinus brutia</i>	46.45 ¹	45.75 ^{2a}	27.47 ¹	26.47 ^{2a}	9.46 ¹	65.46 ¹	79.97 ^{2a}	11.70 ¹	13.18 ^{2a} 10.75 ^{2b}
	45.31 ^{2b}		27.74 ^{2b}	28.53 ³		84.05 ^{2b}	69.02 ³		9.53 ³

Sources: see Table 12

Table 14. Paper properties

Species	Break length (m)		Burst (g/m ²)		Tear factor		Bulk (cm ³ /g)	Stretch (%)	
<i>Pinus radiata</i>	6227 ¹		51.6 ¹		83.0 ¹		1.25 ¹	4.20 ¹	
<i>Pinus pinaster</i>	6190 ¹		38.9 ¹		79.1 ¹		2.04 ¹	2.70 ¹	
<i>Pinus brutia</i>	8600 ¹		72.0 ¹		99.0 ¹		1.82 ¹	4.22 ¹	
	6836 ^{2a}	8408 ^{2b}	55.47 ^{2a}	61.8 ^{2b}	142.48 ^{2a}	68.99 ^{2b}		2.55 ^{2a}	1.99 ^{2b}

Sources: see Table 12

3.4.1 Investing in plantations

Most of the large conifer plantations in Australia have been established by government agencies. Plantation investment companies attract mainly non-landowner investors; projected returns are commonly optimistic. The investor’s funds are used to establish and manage the plantation and sell the product, after which time the investor gets a dividend. Other forms of forestry investment are joint venture arrangements, providing either a share of the income in the future or an annuity as in lease of the land. Investment as an individual is another option. In the drier regions, investment in conifer plantations is a new approach and protocols are only at the stage of being defined. Rates of return are expected to be lower in comparison to those from established plantations due to lower growth rates.

Conversations with landowners suggest that many are prepared to establish a plantation without expecting a return from timber at a commercial interest rate, but as a long-term investment with other benefits such as shade, shelter, erosion control, the lowering of water tables in wet areas and increased property value. Any return from timber harvested is considered a windfall. This approach is suited to those who have the capital to establish the plantation and maintain it over time, while those not so placed may need to enter into joint venture agreements with investors, usually from the forest industry.

3.4.2 Farming returns

Choosing which crop to grow in any season entails weighing expected returns against those from alternative farming activities. The form of comparison most commonly used is Gross Margin Analysis, the outcome of each alternative being indicated by the net returns. This technique takes into account the costs and returns of every aspect of the farming activities as well as the likely impact of reducing the returns from one crop to allow for another without generally taking overheads into account. Introducing the forestry enterprise will change the areas available for other activities on the farm and so can have a significant effect on the total income. Table 15 shows farm returns in an example in which income from a forestry enterprise has been calculated as an annuity so that the effect of the plantation can be seen in context with annual crops.

In Table 15 the inclusion of forest as 5% of the farm area has boosted income. Increasing this forest area at the expense of other activities reduced income. A shift in the return (%) on the forestry annuity substantially reduced income, as did the effect of increasing the forest area at the expense of cropping and pasture. Other impacts which would be significant to a predominantly cropping operation are the decrease in the return to assets, and equity. The example highlights the need to determine how much land should be established as plantation without affecting cash flow. The analysis does not account for any benefits to stock and pasture associated with the plantation such as shade, protection during lambing and reduced moisture loss from pasture.

This approach is suitable for comparisons where an annuity is paid (such as leasing fees or rent on land) on the forestry activity, but it is limited in making valid comparisons between normal farming enterprises and forestry.

3.4.3 Plantation returns

Too often landowners contemplating investment in a forest venture consider a piece of their property which is not used for any other enterprise to be suitable for the purpose. The fact that this land is not used indicates that the productivity is already low and while it may be planted, the return on the investment may be negligible. Dunchue (1999) stresses that forestry is like growing any other crop: the better the site quality, the better the return. He considers the minimal requirements for a plantation block to be:

- Area of 40 ha (because of the impact of scale on establishment costs and IRR)
- Slopes <18°, preferably <15° (harvesting costs increase by 50% on slopes above 18°)
- Shortest roads possible (length and gradients increase costs and impact on IRR)
- Soil depth – preferably 1.0 m or more.

Sykes (1999) used three methods (Gross Margin Analysis, Return on Capital and Internal Rate of Return) to determine the profitability of growing conifers (*P. radiata*) on land in the SW slopes region of New South Wales (rainfall >700 mm; MAI 16 m³/ha). The conclusion was that if current grazing land suited to conifer plantations does not have a stocking rate greater than 10 DSE/ha (or cropping equivalent), a well managed plantation is likely to be more profitable. The lowest IRR of 6.7% was for a forestry enterprise established by the landowner. For a similar environment, Dunchue (1999) states that the opportunity exists for landowners to make returns of 5%-6% on the value of the land under annuity joint venture arrangements.

From the same example as in Table 15 on the relatively flat country around Ardlethan, NSW (rainfall 500 mm total), examples of the effect of different rates of growth on the IRR are shown in Table 16.

The effect of two management regimes as well as a reduction in land value are included for comparison.

Unless an MAI of 12 m³/ha or thereabouts is achieved, the NPV will indicate the enterprise as unprofitable. Such growth rates are possible with selectively bred trees established with the best silvicultural practices currently used on good sites. A more realistic MAI would be 10 m³/ha. Effective rainfall would also impact on growth and consequently the IRR (Table 17).

Sensitivity to land value is another indicator of how finely balanced are the indicators (NPV and IRR), and provides a warning about relying on these indicators alone. Other factors that impact heavily on the IRR are roading and harvesting costs. Flat country is much cheaper to service than slopes, and consequently costs vary by more than 100%. Harvesting costs can increase by 50% on slopes over 18 degrees (Dunchue 1999). The cost of transporting logs to the processing plant determines the stumpage the grower receives. Distances up to 50 km are most economical; beyond that distance the costs increase significantly (Bhati 1999).

3.4.4 Comparing IRR values

Attempts are being made to provide tools such as the Agroforestry Calculator (AgricultureWA and Campbell White and Associates 1999) for making better estimates of likely returns in agroforestry and farm plantations. It would appear from current literature that the most common method of evaluating enterprise viability is the Internal Rate of Return (IRR). Tables 16 and 17 provide only an indication of possible IRRs. The package developed by J. Sykes (*pers. comm.*, 2000) and used to make the calculations in this report has taken most factors relevant to the district into account. The estimates are reasonably accurate but the package did not provide for benefits such as shade, increased lambing percentages, wind protection, or reduction in potential salinity damage to pastures. The package ReVal developed by the Department of Primary Industries and Resources, SA (P. Bulman, Senior Forester, Primary Industries and Resources, Adelaide, SA, *pers. comm.* 1999) includes many of the benefits omitted by others including a benefit from salinity mitigation (Bulman *et al.* 1997). Crammond (1999) used this package to estimate the viability of *P. halepensis* plantations in SA and found that the salinity benefit improved the NPV and IRR.

Comparing the IRR calculated from the above example with the IRR from another district or region is valid only so long as all the variables not incorporated into the calculation are understood. For instance, were farm overheads such as accounting fees, rates, electricity and other things included rather than just land maintenance? The following provides an example of the caution needed when making comparisons. Shea (1998) indicates that the future plantations in the lower rainfall areas will be profitable and provides estimates of costs and returns. Using all the WA information (published and unpublished) available to the author in the same package that provided values in Table 16, the IRR for the same MAI is lower and NPVs indicate that unless 12 m³/ha could be achieved, the venture is not viable (Table 18). **While the conclusion drawn is the same as the example in Table 16, the comparison is not valid since the variables used by Shea (1998) were not made explicit.**

Table 15. Farm net returns indicating sensitivity to income from forestry enterprises. Crop yields are based on the average for the Ardlethan district, NSW; rainfall 500 mm. The forest rotation is 35 y.

Enterprises	Crop 70% Pasture 30% No forest	Crop 70% Pasture 25% Forest 5%	Crop 70% No pasture Forest 30%	Crop 50% Pasture 20% Forest 30%	Crop 50% Pasture 20% Forest 30%	Crop 50% Pasture 20% Forest 30%
INCOME						
Forestry (as annuity)	\$0	\$1 884	\$11 306	\$11 306	\$7 537	\$5 353
Crop	\$195 816	\$195 669	\$195 669	\$139 764	\$139 764	\$139 764
Cattle	\$0	\$0	\$0	\$0	\$0	\$0
Sheep	\$51 950	\$51 950	\$30	\$33 453	\$33 453	\$33 453
FARM TOTAL	\$247 766	\$249 504	\$207 005	\$184 522	\$180 754	\$178 570
EXPENSES						
Profit (Flow)	\$178 968	\$178 911	\$175 753	\$162 838	\$162 838	\$162 838
	\$68 798	\$70 593	\$31 252	\$21 685	\$17 916	\$15 732
INDICATORS						
Operating expenses/income	30%	30%	35%	33%	33%	34%
Equity	90%	90%	90%	90%	90%	91%
Debt	-\$91 611	-\$91 611	-\$91 611	-\$91 611	-\$91 611	-\$91 611
Income/total debt	270%	272%	226%	201%	197%	195%
Overheads (\$/ha)	\$237	\$237	\$241	\$257	\$257	\$257
Return to total assets	11.7%	10.9%	6.9%	5.6%	5.2%	4.5%
Return to equity	13.0%	12.1%	7.7%	6.3%	5.8%	5.0%
Return on forest annuity	0	6%	6%	6%	4%	2.5%
Sheep gross margin (GM: \$/ha)	\$217	\$260	\$0	\$204	\$204	\$204
Sheep - nett margin (NM: \$/ha)	\$15	\$51	\$0	-\$4	-\$4	-\$4
Wool cut (kg/head)	5.5	5.5	5.5	5.5	5.5	5.5
Stocking rate - winter	10.2	12.3	0.0	10.4	10.4	10.4
Cattle (NM - \$/ha)	\$0	\$0	\$0	\$0	\$0	\$0
Crop (GM - \$/ha)	\$340	\$340	\$310	\$315	\$315	\$315
Crop (NM - \$/ha)	\$103	\$103	\$70	\$58	\$58	\$58
WUE (Wheat)	-30.9	-30.9	-30.9	-30.9	-30.9	-30.9
Total area (ha)	571	571	571	571	571	571
Crop area (ha)	400	400	400	286	286	286
Forestry area (ha)	0	29	171	171	171	171

* Source: J. Sykes Rural Consulting, Albury, NSW

Table 16. Influence of growth on returns per hectare in the Ardlethan area, initially calculated in Table 15. Expected sales are mainly small and large sawlogs, little preservation material, no pulpwood. 500 mm total rainfall, 35 y rotation

Alternative management regimes and land value		Growth rate (MAI, m ³ /ha)			
		8	10	12	15
2 thinnings + clearfall	IRR	3.3	4.1	4.8	5.7
	NPV	- \$714	- \$239	\$235	\$947
1 thinning @ 20 y + clearfall	IRR	<0	3.6	4.2	4.9
	NPV		- \$624	- \$226	\$370
Land value reduced by \$100	IRR	3.4	4.3	5.0	5.8
	NPV	- \$618	- \$144	\$331	\$1043
Forest annuity	IRR	4.8%			

Table 17. Influence of growth on the IRR in the SW slopes of NSW. The comparison is based on 60 ha of *P. radiata* on sites receiving 700 mm and 900 mm of rainfall.

Mean annual increment (MAI, m ³ /ha)	IRR (%)
16	7.6
20	8.7

Source: Dunchue 1999

Table 18. Predicted IRR values for *P. pinaster* in WA

MAI (m ³ /ha)	IRR (%)	NPV (\$)
8	3.4	- 593
10	4.2	- 159
12	4.9	276

Thus reliance upon comparative information is not a reliable method of determining enterprise viability. With so many variables involved, each site needs to be evaluated critically against all available options for farm forestry, using the best information about the landowner's current expenses and incomes.

3.4.5 Other variables

So far methods of financial evaluation and the factors causing change have been emphasised. Other variables that may impact on the enterprise include:

- Size of the resource. For most forestry establishment costs, benefits of economies of scale accrue as the planted area increases. If the plantation is located with regard to future roads, then roading costs may also decrease.
- Proximity to existing forestry infrastructure. Plantations established near existing resources will have the benefit of access to processing plants, harvesting contractors with their equipment (harvesting machines, trucks, loaders) and most importantly, a market for log products.
- Carbon credits. Investment potential is increasing. External funding (carbon credits) to establish a plantation may make farm forestry competitive with most other farm enterprises. In drier zones and salinity areas, sequestration rates may be lower but the term of sequestration of carbon is longer. This may be attractive to investors if marketed advantageously. Benefits to the grower may be environmental alone.
- Management. Ensuring that the operations that will have the greatest impact on final log value are executed:
 - Planting at a density suited to the species or to control branching;
 - Maintaining strong weed and animal control for the first 3 y;
 - Thinning on time and removing the right number of trees; and
 - Selecting and pruning the final crop to enhance log value.

3.4.6 Future

Most of the tools used to determine economic viability indicate that the return on an investment in low-rainfall farm forestry is marginal. Expectations, however, are high as most case studies are from areas with higher rainfall. The concept of plantations in lower-rainfall zones is new to Australia. MAIs of 8-10 m³/ha are considered non-profitable, yet many countries in the drier zones of the world, which have substantial conifer plantations, consider such rates of growth very reasonable.

In Australia we need to rethink the profitability of farm forestry in more realistic terms. Benefits should not be thought of as just dollars or volume of timber in comparison to high yielding plantations. The longer-term benefits to the environment and to other farm enterprises could well exceed the deficit in direct financial return arising from low growth rates of the timber. With a renewed outlook, farm forestry in the drier zones of Australia could make a significant contribution to the national forest output.

Research issues

In order to make better estimates of the likely profitability of forest operations in drier zones:

- Determine likely returns from plantations using wide spacing, and what factors are limiting.
- Undertake sensitivity analysis of stumpage rates (or royalty). Prices received are not always affected by distance, though distance is usually a major factor. Buyers (mill door) prices also vary substantially.
- Evaluate haulage costs for the relatively flatter areas of the drier zones. Most costings used are based on operations in steeper areas.
- Design or modify profitability evaluation programs and packages to:
 1. include environmental long-term benefits
 2. be more user friendly – suited for use by farmers wishing to make their own determinations
 3. include subroutines that can estimate MAIs from rainfall and soil (e.g. ‘Plantgro’)
- Develop some method or procedure to make comparisons of IRR and NPV more valid.

4 Potential Uses other than Wood Production

4.1 Degraded sites

Degraded land in the context of this report is considered to be farmland that has progressively declined in productivity over many years to the point where the economic return from that land is substantially reduced for most enterprises and the area has difficulty sustaining vegetative cover. Causes are varied and include:

- Salinity from rising water tables due to overclearing of forests and woodlands;
- Soil acidity from pasture improvement resulting in higher than normal levels of nitrification;
- Loss of top soil and gully erosion through overgrazing, and heavy runoff after storm events; and
- Alkalinity from geological landforms.

The destruction of many forests and woodlands in agricultural areas has resulted in many environmental problems. Dryland salinity is emerging as one of Australia's greatest environmental problems. Estimates of the area already affected range from 2.5 – 5.0 million ha with the prospect of the area increasing to some 15 million ha within the next 50 y (Booth 1999). It is estimated that half of that area will be in NSW. The salinity problem is caused by the water table rising and increasing the concentration of soluble salts near the soil surface. As water evaporates, salts crystallise and remain as residues on the surface. Forests in the soil water recharge zone result in lower water tables.

The real challenge on degraded sites is to halt the problem. Insisting on a direct economic return on mitigation works such as tree planting is irrational when the property as a whole is under threat. The economic benefit of any mitigation works will accrue as the property returns to productivity. Environmental and social returns from such forestry activities often go well beyond the farm to substantial benefits to the district.

Establishment of farm forests will contribute to reclamation of degraded erodible sites, particularly on non-arable acid soils. Finding species that will grow on degraded sites is difficult. Knowledge of the tolerances of each species would simplify matters and make planning for reclamation easier. In many of the poorer sites, survival is a benefit even in the absence of any likely economic return on log sales.

On the less degraded sites there is potential to use those conifers described previously that have displayed characteristics of tolerance to drought resistance, alkaline and acid soils, low fertility and limited salinity. The genetic quality of seedlings of the selected species available now will offer a challenge to most other species. With selective breeding, traits suited for degraded sites can be enhanced in plantation trees to the point where sites previously classed as uneconomic will yield a return.

Over many years the author has maintained close links to rural activities through speaking about tree species, planting methods and management techniques at field days, as well as more recently participating in structured farm forestry workshops and conferences. Throughout this period some of the questions most frequently asked about conifers have related to misconceptions about the environmental effects conifers have on soils through acidification, nutrient depletion and competition for water resources. Although these beliefs are possibly the major cause of resistance by farmers to conifer planting, they are unfounded (Porada 1999).

Within drier areas there will be many requirements for tree species, including conifers, for niche plantings in degraded landscapes and on recharge sites, for windbreaks to mitigate soil erosion and protect pastures, and for amenity plantings which also provide a substantial social benefit. Additional benefits include the gaining of carbon credits, important for Australia's international standing. This will require a substantial re-evaluation of both coniferous and native species capable of meeting those goals.

Research issues

Results from intensive studies on drought tolerance mechanisms and genetics by the FORADPT *P. brutia* network in Europe will eventually become available. In the interim, investigations that should be initiated as soon as possible (because of the inevitably long lead time) include:

- Glasshouse trials to determine usefulness of the conifer species *P. brutia*, *P. eldarica*, *P. halepensis*, *P. canariensis* and *P. pinaster* in three regards:
 - tolerance of salinity;
 - tolerance of drought; and
 - tolerance of the combination of salinity and drought.
- Finding a method that will help growers to readily determine whether a farm forest should be managed for mitigation of a target problem or for a monetary return. This issue relates to the quality of the resource and its potential for utilisation.
- Trials of mixed species to demonstrate the potential of conifers and to construct positive perceptions of conifers and their performance.

4.2 Amenity purposes

4.2.1 Windbreaks

Windbreaks are the most conspicuous use of trees on properties for purposes other than forestry. Many see the windbreak as having a dual role of protection and timber production, but few windbreaks are managed so they will achieve the latter goal. This does not imply that these goals are not complementary, but that the farmer needs to be clear from the start as to the function or role of the break and manage it accordingly.

The function of a windbreak, coupled with the environment in which the break will be established, will often determine the choice of species. In the lower rainfall areas windbreaks appear to have three main uses:

- Reducing wind velocity across cultivated ground and pastures;
- Protection from cold winds for stock, especially ewes when lambing; and
- Aesthetics, such as along the drive into the homestead.

Given the hard conditions in the drier zones, growth will not be fast nor will the trees grow to be particularly tall. The location of windbreaks should be considered as part of an overall farm plan to optimise all farming activities. The specific structure of the planting will vary according to the function of the break, and advice on this aspect is readily available. Many people choose native species for windbreaks, combining function with aesthetics in harmony with the vegetation of the surrounding countryside. For functionality alone, however, conifers are difficult to ignore: their faster growth and often denser canopies provide benefits relatively quickly. To many, their aesthetic value is also important: the sight of dark green, evenly shaped lines of trees on an otherwise brownish landscape can be pleasing.

P. halepensis is an excellent species for windbreaks, as the extent of plantings in the drier zones of rural Australia testifies. As Crammond (1999) points out, most were planted not for timber but because of their ability to survive and grow in often tough conditions. Other conifers suited to this function would be *P. eldarica* in really dry areas, with *P. canariensis* (growing on reasonable soils) and *P. brutia* in areas with rainfall down to 400 mm. *P. eldarica* has dense, dark green foliage on many whorls and retains its crown to ground level if not shaded or browsed by stock. On reasonable soils in zones down to 450-500 mm rainfall, species such as *Cupressus arizonica* (Arizona cypress), *C. dupreziana*

(Sahara desert pine), *C. sempervirens* (Roman cypress) and *Cupressocyparis leylandii* (Leyland cypress) should be considered.

As indicated earlier, many other conifers occur naturally in dry environments in other countries but their performance in Australian conditions is unknown. Growers should be encouraged to try these species in limited trials.

4.2.2 Shade

Shade is important for stock, yet trees are seldom planted for this function alone. Cattle that have to walk long distances between the areas of good feed, shade and the water point will not gain as much condition as those that can rest in shade near both feed and water. Exotic species generally cast a denser shade than eucalypts, and the dry-country conifers are no exception. Combined with their toughness and adaptability, they make ideal shade trees.

Maximum benefit is achieved when planted in clumps of 10-15 trees at wider-than-normal spacings. Of the species mentioned for use in windbreaks, *P. brutia*, *P. eldarica*, *P. halepensis* and *P. canariensis* are best suited in areas of rainfall down to 400 mm, with *P. pinaster* and other conifers such as *P. pinea* (stone pine) and *Callitris glaucophylla* suited down to 450 mm. On reasonable soils, species such as *Cupressus arizonica*, *C. dupreziana*, *C. sempervirens* and *Cupressocyparis leylandii* would do well.

4.2.3 Visual

Mixed-species plantings including the year-round green of conifers can add aesthetic appeal to a property and increase its selling potential and value. Group plantings of unusual conifers such as *P. sabiniana* (digger pine), *P. coulteri* (Coulters pine), *P. torreyana* (Torrey pine) and *P. ponderosa* (ponderosa pine), as well as those mentioned previously, create visual interest and shade.

Research issues

The economic benefit of **windbreaks** on a property in exposed situations have been quantified by many. The benefit is clear, but further investigations should examine:

- The gross benefits of conifers verses other species;
- Do all species provide equal benefits?
- Are there some conifers better suited (structurally and adaptively) than others?

For **shade**, trials investigating species by spacings would benefit farmers by removing guess work, resulting in a productive outcome.

4.3 Pine nuts

In central and northern Mexico and the northern shores of the Mediterranean, extracting pine nuts for food is a common practice. In Mexico it often provides families with the only source of income. Planting the conifers that produce large seeds has in the past been suggested (Havel 1983) as a option to supplement farm income. The main species of interest has been *P. pinea* (stone pine) from the Mediterranean. Several other conifers from Mexico such as *P. cembroides* (Mexican pinyon pine), *P. monophylla* (single leaf pinyon pine) and *P. lagunae* (pinyon nut pine) all produce large seeds (1.5-2 cm long) and are harvested from trees in the natural stands.

Some pine nut species have been trialed in higher rainfall and altitude zones but have not flowered successfully (unpublished CSIRO data). *P. pinea* occurs naturally in a narrow zone around the western end of the Mediterranean and is considered to be 'fiercely and strictly winter-rainfall / Mediterranean climate' (C. Palmberg-Lerche, Chief, Forest Resources Development Service, Forest Resources Division, Forestry Department, FAO, Rome. *pers. comm.* 2000). In Australia it is found mainly as single trees or small group plantings throughout the inland regions (>450 mm) within the winter

rainfall zones. It is not known whether the species grows well outside this zone. The economics of growing pine nuts in Australia is unknown. High labour costs in Australia may be a limitation although mechanisation may be an option; participation of birdlife in the harvest may be a greater problem.

4.4 Recharge and discharge zones

While there is a need to address the salinity problem where it is manifest (the discharge zone), it may be more effective to tackle the problem at its origin. The clearing of forests and woodlands from upper slopes and foothills (recharge zones) has been the principal cause of dryland salinity in the low-rainfall pastoral zones. Precipitation enters the soil in the recharge zone then, under gravity, moves towards the lowlands. Trees planted in the recharge area intercept water before it enters the ground water system. Species with high water consumption are best, and can be identified as those species that have a large sapwood area, large leaf area and a deep and spreading root system (Marcar *et al.* 1995; White *et al.* 2001). The re-introduction of trees with demonstrated agroforestry benefits into both recharge and discharge zones can contribute to management of salinity by reducing the amount of water entering the recharge zone and drawing down that in the discharge zone.

Not all recharge zones are in areas of high rainfall. For example, the western slopes of southern NSW below the 600 mm isohyet are still part of the recharge zone of the Great Divide. This area has been largely cleared over time and now supports marginal grazing on slopes often too steep to cultivate. Revegetating these slopes will be difficult in many circumstances. Soils are often shallow and planted trees will be exposed to climatic extremes. Exclusion of grazing will allow native species to regenerate but growth rates will be slow. If there were more protection, growth rates could be better. Dry-country conifers could play an important role either by providing a nurse crop or as a farm forest since they have the capacity to survive and tolerate dry periods as experienced in most summers.

Fast-growing forest species tolerant of dry summers and drought such as *P. brutia* and *P. eldarica* would be better choices than *P. pinaster* on the upper slopes as they have deeper roots and are more tolerant of a wider range of soils and variable climatic conditions.

Research issues

Trials of dry-country conifers need to be established on a small plantation scale to determine which species provide the greatest environmental and possibly commercial benefit as farm forests in recharge areas.

4.5 Carbon credits

Increasing international concerns about the levels of carbon dioxide (CO₂) in the atmosphere led to an international agreement in 1997 to aim for a collective 5% reduction in emission levels by 2008. This has become known as the Kyoto Protocol. The protocol allows for CO₂ emissions to be offset by activities that absorb carbon, and recognised afforestation as an activity that would create sinks for carbon sequestration. These sinks can be used to gain carbon credits. The longer carbon is locked in woody tissue the greater the benefit. Carbon is accumulated in the total biomass of a tree and so the faster a tree grows, the quicker is the accumulation of carbon. The rate of accumulation in a plantation will plateau when the rate of fixation equals the rate of carbon released by respiration and decay. Shea *et al.* (1998) have shown that in a maritime pine plantation projected over three rotations of 30 y each, the carbon accumulated will increase from approximately 140 t/ha to over 200 t/ha. In a single rotation of 30 y, the average yield is expected to be 360 m³ of commercial timber generating an average carbon sink of 103 t/ha (Shea *et al.* 1998). NSW introduced carbon rights legislation in 1998 which allows organisations to trade in carbon credits. With current returns of approximately \$10-20/t of carbon sequestered, carbon credits in plantations are trading at about \$250/ha (O'Hara 1999). Investment opportunities in plantations are long term and therefore correspondingly robust in terms of security.

This allows 'up front costs' to be offset and makes investment more attractive. A benefit for dry-country plantings is that plantations do not have to be for timber.

The relevance of carbon credits to dry-country conifer plantations is that the incentive to establish plantations has been enhanced. The area of land available is substantial and species of suitable conifers, which will produce a far greater biomass than eucalypts in a shorter rotation, have been identified. With selective breeding, growth rates and corresponding sequestration will be increased significantly.

4.6 Potential problems

4.6.1 Genetic quality of planted material

Choosing the wrong seed source or collecting a few seeds from one or two trees on a neighbour's property can often lead to poor growth with resulting disappointment and a negative attitude towards conifers. Wood production is not the objective of all farm forestry plantings, but there is always merit in getting the best possible genetic material. The success or failure of introduced species is not always due to cultural factors, and interested growers should be aware that success may depend on informed choice of seed source.

4.6.2 Conifers as weeds

Some conifers may become weeds because of abundant, consistent seedling regeneration. In the examples below, the introduced conifers slash pine and Aleppo pine are not serious economic threats and so far do not appear to be environmental threats. Lodgepole pine has been classed as an environmental threat and vigorously eradicated in the ACT. Examples are:

- Slash pine (*Pinus elliottii* var. *elliottii*) in south-east Queensland north of Brisbane. Substantial plantation areas were established in the Caboolture/Beerwah areas from the early 1940s. The microclimate in this area is optimal for *P. elliottii* flowering, commonly resulting in regeneration in cultivated areas adjacent to the plantations. This has not been a major economic problem, but is a nuisance if control is neglected.
- Aleppo pine (*P. halepensis*) produces prolific seed crops in most areas where it is planted. Fortunately most areas are not conducive to the seeds germinating and trees remain solitary. In areas where the climatic conditions are favourable, such as north of Adelaide towards Wirrabara, regeneration is prolific in dense stands that continue to spread slowly as younger trees mature and contribute to the seed supply. *P. halepensis* was introduced to this area before WWI and still does not constitute a economic threat. The problem appears to be more of a nuisance than a threat, though the cost of controlling regeneration can become a burden to property owners who see the species as invasive on pasture land.
- Cypress pine (*Callitris glaucophylla*) is deemed a pest by many farmers in the western areas of NSW. Regeneration from residual trees and neighbouring stands will quickly invade agricultural land if it is not cultivated regularly. Similarly, grazing resources in open forests may decline as the growing seedlings shade out the pasture and in turn produce seed and seedlings. This 'problem' occurs over a much wider area than do the examples caused by introduced conifers.
- Lodgepole pine (*P. contorta*) was established in several arboreta in the Brindabella Ranges west of Canberra from 1929 to 1959. This species thrived on the climatic conditions at the higher altitudes and started regenerating into the surrounding native forests. Control quickly became difficult due to access and in 1977 the decision was made to remove all trees and plants while control was possible.

Not every introduction will be a threat as a weed, but introduced species should be regarded with vigilance. There is little perceived threat by most introduced conifers, sometimes because they have not yet encountered a suitable microclimate. The risk with most conifers is small due to their long growth cycle and the opportunity this provides to identify potential problems.

5 Recommendations for Further Investigation

Research issues identified earlier in this report are summarised here.

- As many candidate species as practical should be introduced for structured test planting throughout the 400-600 mm rainfall zone in Australia. There is very little information on performance of many high-rainfall species in drier areas and vice versa. Trials of low-rainfall species in plantations are required.
- CALM's strong maritime pine program should be enhanced through selection for salt tolerance in both this and related species. Simple trials of 1 ha blocks in rural localities should be encouraged.
- For *P. brutia*, new introductions of seeds identified at the family level are required. Further work is also required on wood properties and vegetative propagation.
- A rangewide collection of *P. eldarica* is required for testing in Australia.
- Growth potential of hybrids with *P. halepensis* should be evaluated.
- For *P. radiata*, research to improve growth in dry and salty conditions would be valuable, perhaps by using material from Guadalupe Island or Cedros Island.
- Work is needed to establish a need or otherwise for plantations of *Callitris*. New rangewide collections should be made for conservation and testing. Exploration of genetic diversity is required with a view to establishing *ex situ* conservation stands. Research is needed on the benefits of wood oils from *Callitris*.
- Estimates of profitability from forestry in the drier zone would be improved with data on wide-spaced plantations, variation in stumpage rates and any effect of flatter terrain on haulage costs. Profit evaluation packages need to be simpler, and or to include environmental benefits, and to enable estimates of MAI from rainfall and soil.
- For situations other than wood production, species need to be tested for salt and drought tolerance. Tools to help balance forest management for environmental amelioration vs other economic returns are required. Mixed plantings of conifers might help improve conifers' negative image.
- Objective comparisons of species' ability to provide windbreaks are needed.
- Species trials for recharge zones, at a small plantation scale, are required.

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7 Appendixes

7.1 Appendix 1. People contacted during the course of the study

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7.2 Appendix 2. *Pinus brutia*: What do we know about the species ?¹

7.2.1 Introduction

The selection of *Pinus brutia* as a potential low-rainfall commercial conifer did not occur by chance. Trial plantings in WA since 1926 and in NSW and SA during the mid-60s have demonstrated favourable growth characteristics including drought tolerance, good stem form and adaptability to a range of soil/site types. On more favourable sites the better provenances of *P. brutia* are capable of volume growth comparable to *P. radiata* and *P. pinaster*. On the poorer sites growth is better than *P. radiata* and equal to *P. pinaster*.

The species of the *Pinus halepensis/brutia* complex (*P. halepensis*, *P. brutia*, *P. pithyusa*, *P. stankewiczii* and *P. eldarica*) occur in the Mediterranean Middle East. They are drought hardy and capable of tolerating a wider range of environmental conditions than almost any other coniferous species. Studies by Nahal (1962) and Debazac and Tomassone (1965) were very thorough and supported *P. halepensis* being separate from the other four species in the group. In more recent times there has been clearer evidence from isozyme studies that the four other species are very closely related and could be considered as subspecies of *P. brutia* (Panetsos and Panetsos 1981; Nahal 1983, 1984; Calamassi *et al.* 1988; Conkle *et al.* 1988; Schiller 1994). Publications vary in their treatment of the taxonomic entities as species or subspecies; this document will consider all as distinct species.

P. brutia Ten. occurs in the north-eastern areas of the Mediterranean, mainly around the Aegean and southern regions of Turkey where it grows from sea level up to 1200 m altitude inland on the Taurus Mountains with some distribution along the shore of the Black Sea near Marmara; on Cyprus and the Greek islands of Crete, Rhodes, Samos and Thasos; and in Syria, Iraq and Lebanon (see Fig. 2 earlier in this volume). *P. eldarica* Medw. grows in scattered populations eastward from northern Syria into Iraq, Iran, Azerbaijan and Afghanistan. The largest populations occur in the eastern Transcaucasian region of Azerbaijan. The other two species are relict populations with *P. pithyusa* Steven. occurring on the eastern shore of the Black Sea and *P. stankewiczii* [Suk.] Fom. 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 in its natural habitat. Genetic variation is considerable and Australian introductions have clearly shown that the eastern provenances of Afghanistan grow better than those further west upon which most trial results are based. This report is focused on *P. brutia* and only complementary information on *P. eldarica* will be considered further. *P. eldarica* should not be disregarded as a potential low-rainfall zone plantation species.

7.2.2 Provenance variation of *P. brutia*

The diverse environments in which *P. brutia* grows have long been recognised (Selik 1958; Emberger *et al.* 1963; Mirov 1967; Oppenheimer 1967; Arbez 1974) and provenance trials covering the range and species of the group were established in many places (Allegri 1973; Palmberg 1975; Panetsos and Panetsos 1981; Spencer 1985; Fisher *et al.* 1986; Iktueren 1986; Eccher *et al.* 1982; Weinstein 1989). Results show many unusual environmental interactions but in general reflect what Arbez (1974) first noticed with *P. brutia* in natural stands and others found in provenance trials: the stem straightness generally improves among provenances the further east their origin (Iktueren 1986; Boardman 1999;

¹ This appendix is the same as the species review prepared by David Spencer for the Australian Low Rainfall Tree Improvement Group (ALRTIG) progress report to RIRDC in 2000. Some of the tables, figures and information from this review have been included in the foregoing report.

Sbay 1999). This change in stemform with longitude is more pronounced in *P. halepensis* than in the other species. One of the most descriptive and informative papers about *P. brutia* is that by Allegri (1973).

Provenance variation in *P. brutia* is strongly influenced by altitude, and in addition most studies report substantial genetic variation within provenances for traits such as stem form, growth and branching (Isik 1986; Isik and Kara 1997; Kara *et al.* 1997; Isik *et al.* 1999). Such variation can be used to make significant gains by breeding.

More recent studies by Isik *et al.* (1999) and Isik and Isik (in press) have determined levels of genetic variation and heritabilities for traits such as branching, crown structure, stem straightness, biomass and growth. In Australian plantings the Cyprus provenance has better stem form than do most other provenances (R. Boardman and T. Butcher *pers. comm.* 1999), possibly because some material introduced had been 'selected' for good stem form. Elsewhere only Panetsos and Panetsos (1981) and Arbez (1974) have noted this superiority. 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 are of very good form (Panetsos and Panetsos 1981).

7.2.3 Wood properties and resin production in Turkey

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 of this pine were established. This is some 42 000 ha/y or approximately 37% of the total area planted annually (Gunay and Tacenur 1993). Most of the seed for planting came from the 61 seed stands in the country; little came from the 48 established clonal orchards as seed production from these has only just begun (Isik and Kara 1997).

Panetsos and Panetsos (1981) quote Papamichael (1970) as stating that *P. brutia* resin production in Greece (Rhodes) is restricted compared with that from *P. halepensis*, and basically is not worth pursuing. He felt that emphasis in breeding should be on wood quality and quantity. This is not the case in Turkey. It is evident from a list of research projects conducted by the Forest Research Institute (OAE) that resin production in Turkey is an industry based mainly on lower-altitude provenances. Timber production forests are at the mid to higher altitudes. The OAE has investigated resin chemical properties (Acar 1988), the commercial value of resin produced from industrial processing (Gürsu 1965, 1966; Acar 1989), factors influencing resin formation and secretion (Selik 1966), and the effect of resin production on wood quality (Merkel and Mus 1956).

The scarcity of information in scientific literature on wood properties and resin production of *P. brutia* makes it difficult to select provenances for evaluation trials in Australia. Information available indicates that the species has wood properties similar to *P. radiata*. Knowing that the species is harvested for resin but not knowing the extent of the effect of resin on sawing will strongly influence the level of provenance testing required. The Forest Research Institute (OAE) of Turkey has been conducting research into wood properties and resin production for decades. Much of the information from the OAE trials is held as internal reports by the OAE and is difficult to access. Requests have been made for information but the severe earthquakes in late 1999 have created administrative difficulties throughout the country and requests may now take some time to satisfy (Fikret Isik *pers. comm.*).

7.2.4 Drought tolerance

The capacity of *P. brutia* to survive well and grow on a range of sites in the low-rainfall zone in Australia indicates substantial drought tolerance. In addition, provenance variation with respect to drought-tolerance also exists. Isik (1986) mainly discusses the genetic variation within seed sources but he does make a plea that the drought tolerant, lower-altitude populations be conserved because they have been largely ignored for plantation purposes due to their poor form and slow growth. The introduction of selected families from these provenances may be useful for interprovenance hybridisation to enhance the survival and drought tolerance of the *P. brutia* group. Reports of

P. eldarica and *P. stankewiczii* surviving the dry climate and saline soils, as well as winters of -22°C, in the Leninabad Botanical Gardens in Tajikistan (Gabisova 1984), indicate potential tolerance that could be of great advantage in Australia.

The FORADAPT *P. brutia* network is a group composed largely of molecular geneticists who are collaborating across laboratories in several countries. Their principal goal is to find the markers (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 be then used for RFLP and QTL work. Outcomes from this work could be immensely valuable to Australia's Low Rainfall Tree Improvement Group in choosing the best adapted provenances for introduction and subsequent breeding. FORADAPT is funded by the European Forest Genetic Resources Program (EUFORGEN). The Forest Genetic Resources Division of FAO and the International Plant Genetic Resources Institute (IPGRI), which has staff in many European countries and receives financial support from Australia via ACIAR, are members of the EUFORGEN management committee. EUFORGEN membership is mainly European research institutes and the participating countries finance the organisation.

7.2.5 Australian resources and growth rates

Most of the genetic resources of *P. brutia* in Australia lie in scattered small trials, plots and woodlots established by the government agencies of NSW, Victoria, SA, WA and the Commonwealth over many years. Most Australian plantings of *P. brutia* originated from seed collected from eastern Cyprus which, fortunately, grows well and has good form and acceptable branching compared to most provenances tested to date. There is a limited range of provenance material from across the natural distribution of the species. Apart from the block plantings of Cyprus provenance material and several sources from Turkey occurring as single plots in three arboreta in WA, the wide-range provenance introductions in the trials at Jerilderie NSW and Bundaleer SA are the only examples of *P. brutia* diversity growing in Australia.

Provenance source information is often limited but there are many plantings with known country of origin where the species shows considerable promise for tree form and adaptability across a range of sites. There are also indications that sufficient levels of genetic variability exist within the species to provide the basis for a genetic improvement program.

Existing trials and woodlots in Australia and information from overseas indicate the most suitable provenances for plantations for wood production. South Australia has some 16.5 ha of 6 separate introductions (SI 95, 140, 915, 425, 1620 and 1634) from Cyprus which were planted from 1958 – 1972 as well as a duplicate trial of the 22 provenances planted at Jerilderie in western NSW. CALM in WA has 40 ha from 77 introductions, mostly from Cyprus and planted between 1926 and 1999. Over 20.5 ha of established stands and blocks were searched to identify ALRTIG plus trees. One of the blocks is 13.6 ha planted in 1952 in the '100 acres', WA. This site has limestone protrusions throughout the area yet the *P. brutia* is growing at a rate comparable to the unselected *P. pinaster* in the adjacent 'less limestone' area. CALM also has several family plantings over 30 y old with about 30 families at each site. At the Wanneroo site (1962 planting; deep sand over limestone; 750 mm; 1600 spha) where the trial was unthinned, trees were 20-21 m tall with a wide range of diameters. If this stand was thinned to 300 spha, the average diameter would be close to 30 cm. The adjacent *P. radiata* (1962) had been thinned and fertilised and had larger diameters but the height was less than that of the *P. brutia*.

Another excellent *P. brutia* resource managed by CALM is the 1965 clonal orchard of five selected parents of Cyprus provenance (about 100 ramets) on Rottnest Island. These parents were the best trees selected in 1961 from a 12 ha stand planted in 1931 at Somerville in Western Australia. Seed was also collected from this thinned stand and used to plant the '100 acres' at Yanchep in 1952. The orchard looks like a tree-breeder's nightmare due to severe damage by the prevailing wind, but flowering is prolific. The same ramets were planted at a site at Mundaring in the same year; the resulting trees are possibly the finest ever seen, though flowering at this site is negligible.

A feature of *P. brutia* not referred to elsewhere but of considerable value is its ability to tolerate fire. Control burning in plantations is common in WA to reduce litter and subsequent fire risk. From observations in compartments recently burnt, larger trees did not exhibit any dead crown due to scorch, and bark did not appear to be damaged. On a 1978 planting in North Yanchep plantation, the scorch on the crowns was very evident and almost all litter had been burnt. The comment was that *P. brutia* is not affected in growth by such scorch but it would 'knock the adjacent (sic) pinaster around a little'. The effect the heat would have on the wood, considering that the resin content is higher than in *radiata*, is unknown. There must be evidence (e.g. dry sides) of the effect of fires on the bole of trees in Turkey, where fires in stands are relatively common.

Growth rates across all sites are highly variable and depend on the provenance interaction with the soil and climate at each site. Table 2 (see earlier in this volume) outlines growth rates across a range of sites with varying soil and rainfall. *P. brutia* MAIs are not disappointing considering that the extent of provenance variation has not been examined in any systematic manner. Table 3 provides a summary by provenance for the dry Jerilderie site to show what can be produced under 'hard' conditions. It is obvious that *P. brutia* will continue to increase its growth with increasing soil moisture.

7.2.6 Breeding strategy for Australia

From the range of phenotypic and isozyme studies (cited above) on *P. brutia*, it is apparent that the genetic diversity is high and that much of the diversity can be readily identified phenotypically. The choice of the Cyprus populations in the initial introductions must have been influenced by reports of the better qualities of the trees on the island. For example, a Forests Department of Western Australia file note on 24/05/46 to the then Conservator of Forests, Mr Lane Poole, reads *Pinus halepensis (brutia) - only small experimental areas of this species have been established. It is important to note that we introduced a new strain of this species in 1930, on the advice of Mr Unwin of Cyprus. This was a strain understood to be found only on the island of Cyprus.* Whatever the reason, it is now evident that if genetic improvement of the 'Australian' race is to proceed, the existing resource will provide a better than reasonable starting point (G. Schiller, Professor of Forestry, Department of Agronomy and Natural Resources, Volcani Center, Bet Dagan, Israel, *pers. comm.* 1999), provided the narrowness of the genetic base is recognised. Two hundred phenotypically selected trees from all available resources in Australia could provide the initial breeding population. This genetic base will need to be enhanced in time with selections from within further introductions and perhaps already-selected parents in Turkey, Cyprus and other provenances. From the initial breeding population the 30 best trees can be grafted for a clonal seed orchard as an initial source of improved seed. Concurrently with the establishment of the seed orchard, open-pollinated progeny tests need to be initiated with as many of the parents in the breeding population as possible. Until progeny tests from these selections can be evaluated, nothing will be known about the genetic quality of the selections. The information gained will allow the clonal orchard to be culled to the best families and yield a further gain on the initial orchard.

Until recently, very little was known about the heritabilities of traits considered important in breeding (stemform, branch angle and size, growth vigour). The recently completed PhD study by Fikret Isik and results published by Isik *et al.* (1999) and Isik and Isik (2000) have quantified the 'distribution of variation within the species (*P. brutia*) for various traits as well as evaluating the relative performances of different populations on different sites'. The study outcomes need to be regarded cautiously as only a narrow sample (of all *brutia* provenances) was used based on 10 families from each of 6 populations, two from each of 3 altitudes ranging from the coast in the Antalya region to the Taurus Mountains. Fortunately the genetic variability of the species is considered to be higher in the mid-altitude populations of western Turkey than the perimeter populations such as on the Black Sea, Cyprus, Crete and eastern Greece (Calamassi *et al.* 1988). Thus the narrowness of the sample will tend to give the results of Isik's study heritability estimates which may be on the upper side but, countering that, will be the high heterozygosity of the populations sampled.

Isik found that within-family variation was generally over 80% of the total for all traits, indicating strong within-family differences. This high variation means that within-family selection is desirable,

keeping the genetic base broad and maximising genetic gains with sequential selections in the breeding population.

A brief summary of Isik's findings follows:

- Mid-altitude populations had better growth and 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;
- Age 13 heritability estimates were best for most traits except for crown traits;
- Family heritability values were highly correlated to individual heritabilities;
- Heritabilities (ns at age 13 and often less than family estimates) for height = 0.12, straightness = 0.21, diameter = 0.21, longest branch = 0.26, branch angle = 0.36, number of growth cycles = 0.42, taper = 0.25, bark thickness @1.3 m = 0.17, forking = 0.14;
- Crown width decreased with altitude;
- Narrow-crowned families had straighter stems and better stem diameter growth; and
- Faster-growing trees had less forking.

The results indicate that substantial genetic gains are possible with even a modest selection program as anticipated by ALRTIG. The introduction and wider testing of new provenance material will be essential for the program to progress in the future. The current limited provenance trials will give some information and the block plantings will give indications but neither will yield satisfactory information for future development. There are too many examples of a species being propagated widely from natural stand seed because no planned evaluation had been conducted.

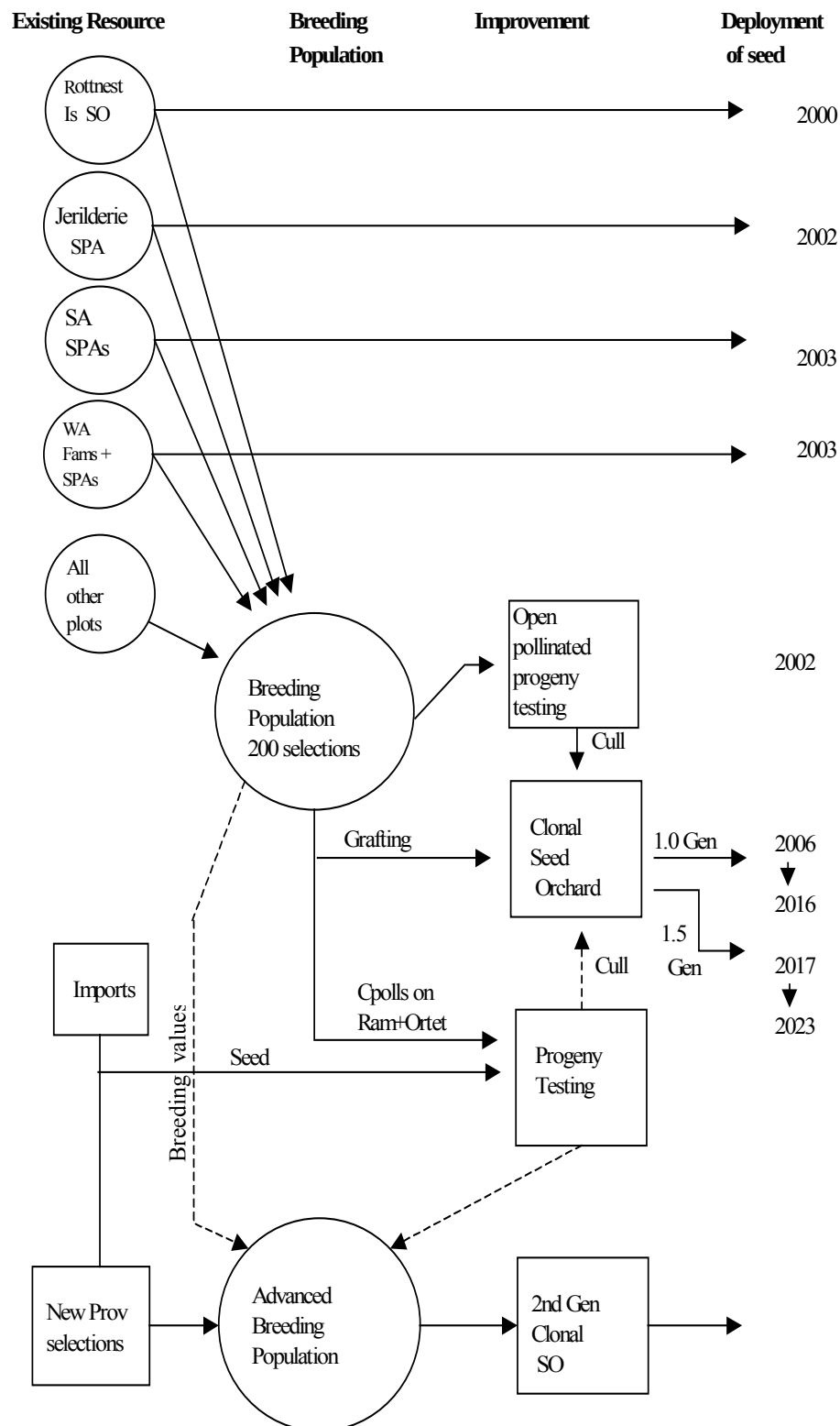
The ALRTIG project aims to make genetically improved seed available to growers as soon as possible so that there is minimal opportunity for unsourced, poor quality material to be planted in plantations in the dry areas of southern Australia.

In order to meet the aim, ALRTIG (Softwoods) members have agreed to contribute the genetic resources they have to a common pool with the objective of advancing the genetic quality of seed produced for the short term and into the longer term beyond the time horizon of the project.

Figure 1 provides a schematic overview of a suggested breeding strategy to take the project forward and to lead into the future after the project.

Figure 1.

***Pinus brutia* Breeding Strategy**



A strategy for making best use of resources already available is:

- Make seed production areas as soon as possible by converting suitable existing provenance trials, for example, thinning the 1969 provenance trial at Jerilderie, NSW;
- Review results from existing trials and plantings; identify associated soil types, rainfall, growth rates, stem form and flowering capacity;
- Select plus trees; collect scions and cones; establish three grafted, 30-clone seed orchards;
- Implement short-term strategies such as thinning plantings of known provenances to the best individuals to enable growers to access 'better' material than previously available;
- Identify the better provenance sources and determine if seed can be imported from these areas in the Mediterranean;
- Develop a breeding strategy that can meet short and longer-term requirements as well as fit in with available resources of staff, financial support and genetic material; and
- Establish open pollinated progeny tests of the selected individuals in the breeding population as soon as possible, as well as evaluating (imported) provenance material across a range of sites.

The current proposal to establish three clonal orchards (replicates) is more of a safety mechanism against any disaster rather than an attempt to produce large quantities of seed.

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