Improved species climatic profiles

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

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Foreword

Selecting appropriate tree species for planting is one of the most important stages in establishing an agroforestry enterprise. It can cost as much to plant a species which may grow poorly or even die as a species which will flourish. Both climate and soil conditions are important in determining a species' capability to grow successfully at a particular site. However, climatic factors are particularly useful in indicating broad regions where particular species are worth considering. This study examines the climatic requirements of 27 tree species and subspecies, which have been identified as having potential for use in farm forestry. These include well-known species such as *Pinus radiata* (radiata pine) as well as lesser-known species such as *Eucalyptus kartzoffiana* (Araluen gum). The majority of the species are native to Australia, but two species are exotics. For the native species their distributions are mapped and climatic conditions within these natural distributions are analysed. Though analysis of natural distributions can provide some indication of species' climatic requirements many species can thrive under somewhat different climatic conditions. So for all species, results from trials both in Australia and overseas were reviewed and the descriptions of their climatic requirements were revised. Maps were then produced indicating areas within Australia that satisfy these climatic conditions.

The descriptions of climatic requirements developed in this report should assist those establishing farm forestry enterprises to develop a short list of species, which are worth considering for use in particular areas. However, they do not guarantee the success of a particular tree on a particular site. Other factors, particularly soil conditions and the products or services desired need to be considered carefully. The Agroforestry Design Guideline No. 3 on Site Selection for Farm Forestry (Harper *et al.*), currently being prepared for JVAP, and the previous JVAP publication "Design Principles for Farm Forestry" (Abel *et al.*, 1997) provide more detail on other factors that should be assessed.

Developing descriptions of climatic requirements is an iterative process. Some of the species described here have been included in few trials and their adaptability to different climatic environments is not clear. The authors welcome information which will assist them improve the descriptions.

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Disclaimer

Contents

Executive Summary

The objective of this project was to analyse the climatic requirements of at least 25 tree species that are important in, or have potential for use in farm forestry.

The first stage of the analysis involved the collation of information on the natural distribution of the species. Geocoded (i.e. latitude, longitude and elevation) data were obtained from databases maintained by the Environmental Resources Information Network (ERIN) and the Australian Tree Seed Centre (ATSC). Approximately 18 000 records were collated for the 27 species or subspecies analysed. The data were mapped for each species and inaccurate records were corrected or deleted. The corrected maps of natural distributions are included in the following species descriptions in case users desire to select species native to particular regions.

The second stage was a bioclimatic analysis of the natural distribution data, which produced estimates of six important climatic factors for each location within the natural distribution. The ranges of these factors produced a description of climatic requirements based on the natural distribution.

The analysis of the natural distributions produced a useful first impression of the climatic environments suitable for the different species. However, it is well known that many species can grow successfully under conditions that are somewhat different from those found in their natural distributions. Therefore, the third stage of the analysis involved reviewing hundreds of reports of species trials both within Australia and overseas. Climatic mapping programs produced by CSIRO Forestry and Forest Products were used to estimate mean climatic conditions at many of these trial sites. Where appropriate the descriptions of climatic requirements based on the natural distributions were then modified to take into account information from species trials.

Finally, the descriptions of climatic requirements based on both the natural and revised information were used to map climatically suitable areas for the species in Australia.

It is concluded that the descriptions of climatic requirements provided here will assist in selecting species suitable for use in different areas of Australia, though care should be taken to ensure that other important factors such as soil conditions are taken into consideration when selecting species for particular sites. Great care should be taken when selecting species for low rainfall environments to ensure that local conditions are suitable and appropriate planting densities are used.

How to Use this Information

How to use this information:

Climatically suitable areas are intended to be areas where species are worth considering for planting for farm forestry. Species may survive in different environments but may not be suitable for commercial production.

Caution should be used when introducing species into low rainfall environments. Many factors (in addition to climate) are important in selecting sites for species. It is recommended that species be evaluated in trials before large scale commercial plantings are established.

The maps provide an indication of revised climatic distributions, but are of very broad scale. Use the specific revised climatic requirements listed in the table to evaluate whether your local use might be suitable for a particular species.

1. Introduction

Descriptions of the climatic requirements of 27 species or subspecies, which are either important in farm forestry or have potential for use in farm forestry, have been created as part of a Joint Venture Agroforestry Program (JVAP) project on "Information Support for Commercial Farm Forestry". Species for analysis were selected from a list of priority species created for the "Seed and Information Support for Commercial Farm Forestry" project. The descriptions should assist species selection for different locations. "Climatically suitable areas" are intended to be areas where the species are worth considering for planting for farm forestry. Species may survive in more extreme environments but may not be suitable for commercial production. For lesser known species such as *Eucalyptus argophloia* these areas are tentative, whilst for better known species such as *Pinus radiata* they correspond more closely to commercially viable areas.

The analysis involved estimating mean climatic conditions for numerous locations within species' natural distributions to obtain preliminary information on their climatic requirements. However, it is well known that many species can grow successfully under conditions that may be somewhat different to those within their natural distribution. Therefore information was also obtained for climatic conditions at successful trial sites both within Australia and overseas. These data were used to modify the descriptions of climatic requirements for individual species. An Australian climatic mapping program was used to identify areas that satisfied the description of climatic requirements derived from both the natural distribution and results from trials.

Details of the method used to determine ranges of climatic factors are described in the following section and the results for particular species are summarised in individual sections.

2. Methods

2.1 Collation and examination of species distribution information

Geocoded location information (i.e. latitude, longitude and elevation) from species' natural distributions were collated from the ERIN (Environmental Resources Information Network) and CSIRO Australian Tree Seed Centre (ATSC) databases. The ERIN species data were downloaded from their web site and merged with the ATSC species collection data in a Microsoft Access database. Duplicate records between the two databases were removed. Approximately 18 000 records were collated for the 27 species or subspecies analysed.

2.2 Mapping of natural distribution information

Location information was mapped for individual species using the MapInfo computer package and checked for errors. This involved comparison with published species distribution maps and/or checks carried out by ATSC experts.

2.3 Determining climatic conditions for the natural distributions

Climate parameters for individual locations within species distributions were estimated using the ESOCLIM package (Hutchinson, 1989). This package allows long term mean monthly climatic factors to be estimated for any location in Australia. Location information (latitude, longitude and elevation) was input into the program and selected mean monthly values for climate parameters were output (for example, mean monthly rainfall). Once these values were determined the Climind program (Stein *et al.*, 1989) was used to derive range limits for selected climatic parameters, for example, to establish lower and upper limits for mean annual rainfall. Range limits were determined for the following six factors:

a) Mean annual rainfall (mm)

b) Rainfall regime (uniform/bimodal, summer, winter)

c) Dry season length (consecutive months with less than 40mm of precipitation)

d) Mean maximum temperature of the hottest month (ºC)

e) Mean minimum temperature of the coldest month (ºC)

f) Mean annual temperature (ºC)

These factors were originally used by Webb *et al.* (1980) and have been successfully used by Booth and Pryor (1991) and Booth and Jovanovic (1991). The set of factors have been adopted for use in CAB International's (2000) Forestry Compendium – Global Module CD-ROM.

2.4 Review of trials information

Computerised literature searches were carried out for each of the 27 species or subspecies. References containing adequate location and growth data were analysed to determine mean climatic conditions for trials growing successfully outside the natural climatic range limits. Information from tree performance databases such as TREDAT (Vercoe *et al.*, 1997) and the Multipurpose Tree and Shrub Database (Carlowitz, 1992) produced by the International Council for Research in

Agroforestry (ICRAF) were also used to revise climate descriptions. Information for successful trials is generally more useful than information from failed trials, as the reasons for failure are not always clearly stated and may not be related to climatic conditions. Where appropriate, information from trials was used to revise the descriptions of species' climatic requirements.

Published trials information varied considerably in terms of quality. Older reports of trials often lacked provenance detail, provided little or no climate detail, and most seriously, even lacked good quality location information. Where location names were given the latitude and longitude of sites could sometimes be identified using the GEONET gazetteer, but if reliable location detail was not available, climate could not be estimated. Recent trials reporting has significantly improved and greater attention is now paid to reporting seed source information, as well as climate and soils details.

2.5 Determination of climate at trials location

If no published climate information was available for a trial site the climate was estimated using climatic mapping programs for Africa (Booth and Jovanovic, in press), Australia (Booth and Jovanovic, in preparation), South East Asia (Booth *et al*., 1999), Latin America (Booth and Jones, 1998) and the World (Booth *et al.* in press). All these programs feature a moveable marker, which can be used to estimate mean climatic conditions at a particular location. The programs allow the rapid checking and improvement of climate profiles as a user can easily visualise a species' climatic profile by mapping its spatial distribution. This method has been successfully applied in the past to quickly improve descriptions of species' climatic requirements (Booth and Pryor, 1991).

As far as possible the revised descriptions were developed assuming the trees were rainfed and had no access to water from irrigation, groundwater or other non-rainfall sources.

2.6 Mapping of the species revised climatic ranges

The Ausgrd Australian climatic mapping program (Booth and Jovanovic, in preparation) was used to map species' revised climate profiles. The program has recently been significantly improved from the previous MS-DOS version (Booth, 1996). It is now Windows-based, has gridded data for approximately 400,000 (rather than 40,000) locations and allows the user to draw maps for individual Australian states.

2.7 Changes in Eucalypt nomenclature

The bloodwood group of eucalypts were formerly considered members of the genus *Eucalyptus* in the informal subgenus *Corymbia* (Pryor and Johnson, 1972). Hill and Johnson formally raised *Corymbia* to genus rank and within it erected the informal section *politaria* to accommodate the four smooth-barked bloodwoods: *Corymbia citriodora* (Hook.) K.D. Hill and L.A.S.Johnson, *C. maculata* (Hook.) K.D. Hill & L.A.S.Johnson, *C. henryi* (Blake) K.D. Hill & L.A.S. Johnson and *C. variegata* (F. Muell.) K.D. Hill and & L.A.S. Johnson. This report adopts these name changes for *C. henryi* and *C. maculata*, but *C. variegata* is treated as a subspecies under *C. citriodora* following the recommendations of McDonald and Bean (2000).

3. Discussion and recommendations

The descriptions of climatic requirements used here are based on ranges of factors. The factors used have been widely applied around the world to assist species selection (see, for example, CAB International, 2000). They have the advantage that they are based on simple monthly mean temperature and rainfall data, which are readily available for any location in Australia. However, the method has some limitations. The long-term average data used do not reflect year-to-year variations, so problems may be experienced if trees are established in low rainfall areas during a drought period. Another limitation is the lack of information about evaporation rates. Two locations receiving similar mean annual rainfalls may experience different plant water availability because they experience different evaporation rates. A few comments have been made in the text on evaporation rates in different regions (see for example, *E. globulus* subsp. *globulus* and *P. pinaster*). Information on the ratio between mean annual precipitation and evaporation has also been added to the Australian climatic mapping program. However, information on evaporation rates has not been included in the descriptions, as it is not generally available for the overseas sites that have been used to develop the descriptions of climatic requirements.

The purpose of developing descriptions of species climatic requirements is to assist in the choice of species for use in different regions. The descriptions developed here are designed to help select species or subspecies, which are worth considering for inclusion in trials in particular regions. However, particular caution should be taken when introducing species into low rainfall environments. In addition to climatic considerations many factors, particularly soil conditions, are also important in selecting suitable sites for particular species. It is always recommended that species be evaluated in small scale trials in a particular region before large-scale commercial plantations are established.

4. Species climatic descriptions

4.1 *Acacia mearnsii* De Wild. (Black wattle)

Acacia mearnsii is a fast growing but short-lived (approximately 15 years) leguminous tree adapted to a wide range of sites. In the past, native stands in Australia were the basis of a labour-intensive tannin extraction industry, but this demand is now met by overseas plantations. The species is currently used in Australia to a limited extent for timber for fuelwood and local crafts such as wood turning, as well as for erosion control, shade/shelter, windbreaks and soil improvement (Brown and Ho, 1997; Searle, 2000).

	Climatic requirements (natural distribution)	**Climatic requirements (revised)**
Mean annual rainfall (mm)	440 – 1600	700 – 2300
Rainfall regime	uniform, winter	uniform, winter, summer
Dry season length	0 – 6 months	0 – 6 months
Mean max. temp. hot. mth (°C)	21 – 29	21 – 30
Mean min. temp. cold. mth (°C)	-3 – 7	0 – 15
Mean annual temp. (°C)	10 – 18	10 - 20

Revisions to the climatic range of the natural distribution

A. mearnsii's natural distribution includes locations with annual rainfalls as low as 440 mm. It can be grown in locations with rainfalls just above this level, but most commercial plantations overseas are generally found in areas where the rainfall is at least 700 mm. For example, *A. mearnsii* is a major plantation species in South Africa and most plantations there are found in the 1400-2000 mm rainfall range, though some plantations in Africa reach rainfalls as high as 2300 mm (Sherry, 1971; Schonau, 1969). Mean annual temperatures at these South African plantations are about 14-20°C.

Plantations in Africa and China include locations with summer rainfall seasonality. Mean maximum temperature of the hottest month reaches as high as 36°C at plantation locations such as Belgaum (India), whilst the upper limit of the mean minimum temperature of the coldest month can be as high as 17°C at plantation locations in Java (Berenschot *et al.* 1988). However, *A. mearnsii* does not thrive in such warm locations in Australia. In similar locations in Queenland, for example, it may grow very well for a few years and then die (P. Ryan , pers. comm..). Accordingly, the upper limits of temperature ranges given above reflect those found in South African plantations, rather than at locations in India and Indonesia.

Though *A. mearnsii* grows naturally in Australia only in areas southeast of Sydney, analysis of climatic conditions at successful plantations overseas clearly indicates that it is worth considering in areas that are somewhat wetter and warmer than those of its natural distribution. Mean annual rainfalls above 850 mm and mean annual temperatures above 16°C will probably provide the fastest growth rates (Schonau and Schulze, 1984). If slower growth rates are acceptable, the species is also worth considering for planting in colder and drier environments.

***A. mearnsii* continued.**

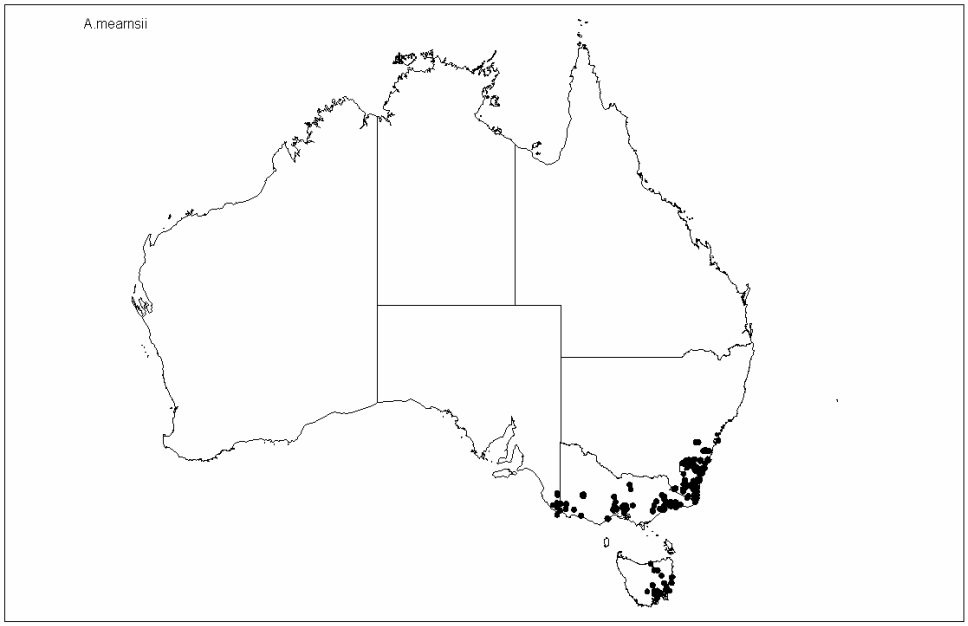

Fig. 4.1.1 Natural distribution of *A. mearnsii*

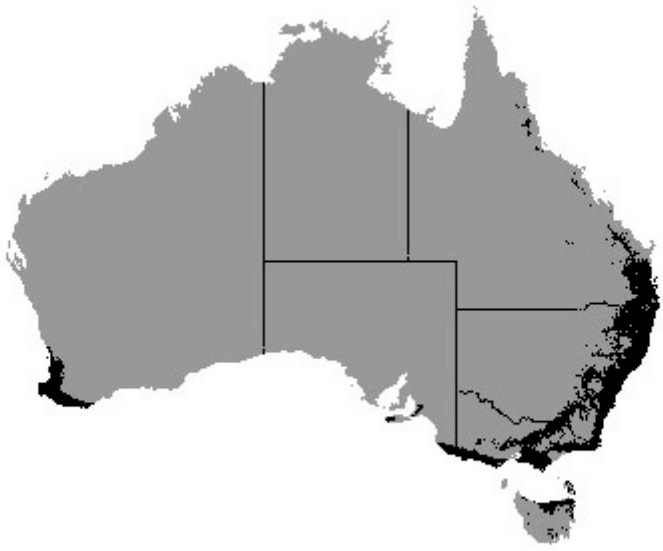

Fig. 4.1.2 Climatically suitable areas for *A. mearnsii* shown in black

4.2 *Araucaria cunninghamii* Aiton ex D. Don (Hoop pine)

Hoop pine's natural distribution consists mainly of small patches, within a distance of approximately 160km from the sea, from Shelburn Bay in North Queensland to the Macleay River in Northern New South Wales (latitudes 12°S – 31°S). The wood of the species has an attractive light appearance. It can be used for a number of products and end uses including plywood, veneer, furniture, flooring and boat building (Boland *et al.*, 1989).

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	660 – 2700	750-2700
Rainfall regime	Summer	Summer, uniform
Dry season length	0 – 7 months	0 – 2 months
Mean max. temp. hot. mth. (°C)	24 – 34	24 – 34
Mean min. temp. cold. mth (°C)	2 – 19	2 – 19
Mean annual temp. (°C)	15 – 26	15 - 26

Revisions to the climatic range of the natural distribution

Booth and Jovanovic (1991) have previously assigned climatic limits to this species. Differences to the limits specified in this report can be accounted for by improved climatic surfaces. Although hoop pine is found naturally in sites with mean annual rainfall as low as 660 mm commercial plantations are typically found in locations receiving more than 750 mm, for example, in the Brisbane valley around Yarraman and Benarkin (P. Ryan pers. comm.). Sites in Papua New Guinea suggest the species is suitable for uniform as well as summer rainfall environments. Dry season length at commercial plantations is usually less than two months.

***Araucaria cunninghamii* continued.**

Fig. 4.2.1 Natural distribution of *A. cunninghamii*

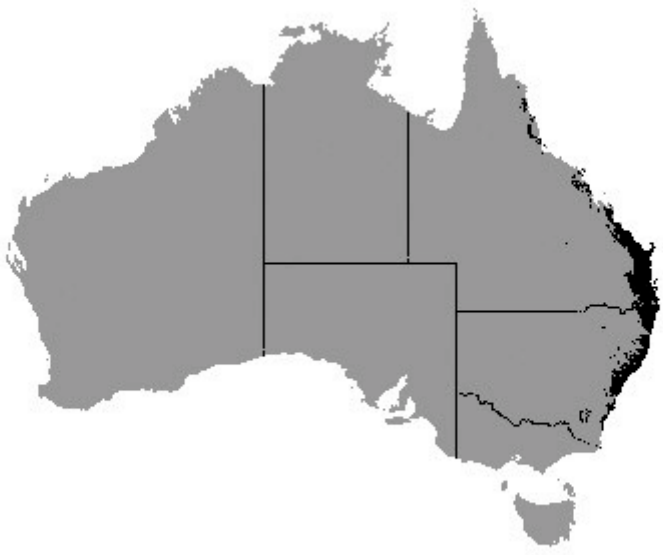

Fig. 4.2.2 Climatically suitable areas for *A. cunninghamii* shown in black

4.3 *Eucalyptus argophloia* Blakely (Chinchilla white gum)

Chinchilla white gum has a very limited natural distribution confined to an area near Chinchilla in southern Queensland. It has a strong, durable heartwood that has been used for general construction and fencing.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	640 – 690	550 – 850
Rainfall regime	Summer	Summer, uniform, winter
Dry season length	5 – 6 months	0 – 8 months
Mean max. temp. hot. mth. (°C)	31 – 32	31 – 33
Mean min. temp. cold. mth (°C)	3 – 5	2 – 5
Mean annual temp. (°C)	17 – 20	14 – 20

Revisions to the climatic range of the natural distribution

Little information currently exists on the performance of Chinchilla white gum in trials, although the species is now being grown in southern locations such as Wagga Wagga (Allworth 2000) and near Benalla. The species is reported to have grown well in a trial in subhumid south-east Queensland (Wilson, 1998) and this is indicated as a climatically suitable area by the Australian climatic mapping program. The species is also reported to have good drought tolerance, though about 550-600 mm may well be the minimum annual rainfall for trees grown for timber production (P. Ryan, pers. comm.). The inclusion of plantings in locations such as Wagga Wagga and a site near Benalla has lowered the dry season length to 0 months. Plantings in Warwick (Allworth Ibid.) have seen the upper limit for dry season length increased to 8 months. The rainfall regime has been altered to include a winter and uniform rainfall regime while the lower limit for the mean annual temperature has been dropped from 17°C to 14°C with the inclusion of plantings from Wagga Wagga and Benalla. The minimum temperature of the coldest month has been dropped from 3°C to 2°C with the inclusion of analysis of climate from Warwick, Drayton and Wagga (Allworth Ibid.). Several of the trials are very young, so the modified requirements shown above are tentative.

Fig. 4.3.1 Natural distribution of *E. argophloia*

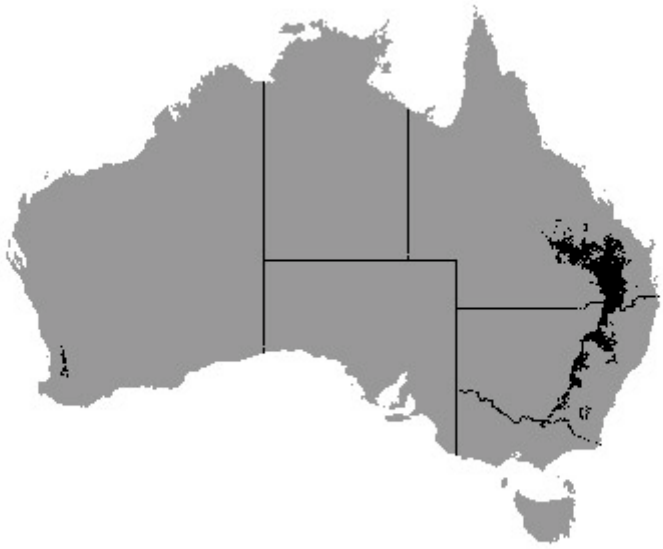

Fig. 4.3.2 Climatically suitable areas for *E. argophloia* shown in black

4.4 *Eucalyptus badjensis* Beuzev. & Welch

Eucalyptus badjensis has a restricted natural distribution confined to a small region on the southern tablelands of south-eastern New South Wales (Boland *et al.*, 1989). Its good growth rates at trials such as Wagga Wagga (Myers *et al.*, 1995) have generated considerable interest.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	580 – 1230	580 – 1230
Rainfall regime	Uniform/bimodal, summer	Uniform/bimodal, summer
Dry season length	0 – 3 months	0 – 5 months
Mean max. temp hot. mth. (°C)	22 – 24	22 – 27
Mean min. temp. cold. mth. (°C)	-3 – 0	-3 – 3
Mean annual temp. (°C)	7 – 11	7 - 15

Revisions to the climatic range of the natural distribution

Revisions to the climatic range for the natural distribution include an increase in the dry season length from three to five months. This was a result of analysis of climatic conditions at Petrusvlei and Draycott in South Africa (Gardner and Swain, 1996), where the dry season length estimated from the African climatic mapping program was five months. These locations also extend the upper range for the mean annual temperature from 11°C to 15°C. A number of locations extend the upper range for the maximum temperature of the hottest month from 24°C to 27°C, including information from trials at Draycott and Petrusvlei and from species trials in New South Wales (NSW) at Wagga Wagga (Myers *et al*., 1995) and fuelwood trials in the ACT (Urriara, Kowen and Stromlo; Clarke *et al.*, 1997). These trials also extend the upper range for the mean minimum temperature of the coldest month.

***Eucalyptus badjensis* continued.**

Fig. 4.4.1 Natural distribution of *E. badjensis*

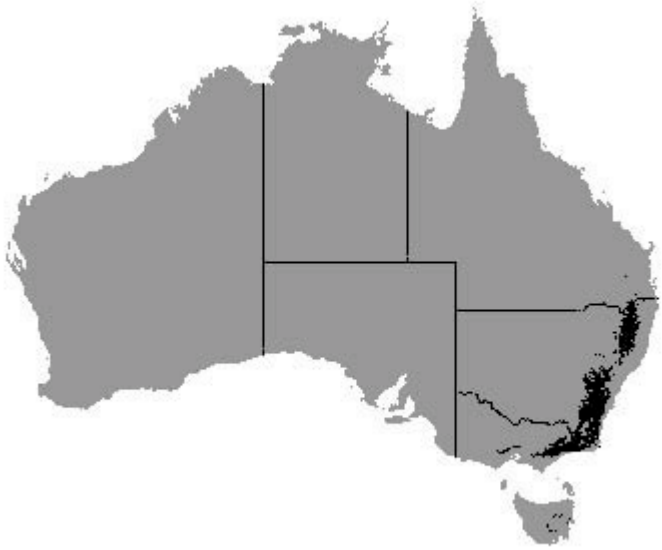

Fig. 4.4.2 Climatically suitable areas for *E. badjensis* shown in black

4.5 *Eucalyptus benthamii* Maiden & Cambage (Camden white gum)

Camden white gum has a restricted natural distribution confined to a small area west of Sydney. This species has produced relatively high growth rates in trials in Australia and overseas. Timber uses are still being evaluated. However, the species is viewed as having good potential for commercial timber production. It is relatively frost hardy and drought tolerant.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	730 – 1010	730 – 1010
Rainfall regime	summer	Uniform/bimodal, summer
Dry season length	0 – 3 months	0 – 5 months
Mean max. temp. hot. Mth. (°C)	26 – 30	26 – 30
Mean min. temp. cold. mth. (°C)	1 – 3	-1 – 3
Mean annual temp. (°C)	13 – 17	13 - 17

Revisions to the climatic range of the natural distribution

Revisions to the climatic range for the natural distribution include an increase in the dry season length from three to five months with the inclusion of species trials at Petrusvlei and Draycott in South Africa (Gardner and Swain, 1996) and Reyes and Santa Barbara in Argentina (Mendonza, 1983). The lower range for the mean minimum temperature of the coldest month was lowered from 1°C to -1°C to include climate estimates for the trials at Draycott and Reyes. The species is growing well under irrigation at Deniliquin in NSW and at Benalla in Victoria (Roger Arnold pers. comm.). The rainfall regime was altered to include a uniform regime with the inclusion of information from fuelwood trials in the ACT.

***Eucalyptus benthamii* continued**

Fig. 4.5.1 Natural distribution of *E. benthamii*

Fig. 4.5.2 Climatically suitable areas for *E. benthamii* shown in black

4.6 *Eucalyptus camaldulensis* Dehnh. (River red gum)

River Red Gum is one of the most widely grown trees in the world. Its natural distribution covers most of the Australian landmass with the exception of the Nullabor plain and coastal margins of south eastern Australia and Queensland (Boland *et al*., 1989). The natural distribution covers a wide range of environment types. *E. camaldulensis* is commonly found on or near watercourses which often allows it to survive in arid and semi-arid regions. The species exhibits large provenance variation in response to salinity and waterlogging (Marcar *et al*., 1995). The timber can be used for a range of uses including heavy construction, railway sleepers, woodturning and pulp (Boland *et al*., 1989). The species has been divided into northern and southern provenances for climatic analysis. No formal boundary exists between northern and southern forms; rather studies suggest a gradual change over the range (Marcar *et al*., 1995).

Climatic requirements (natural distribution)		**Climatic requirements(revised)**
Northern Provenances		
Mean annual rainfall (mm)	220 – 1500	400[A] – 2500
Rainfall regime	summer	summer
Dry season length	2 – 8 months	2 – 8 months
Mean max. temp. hot. mth. (°C)	34 – 41	22 – 41
Mean min. temp. cold. mth. (°C)	1 – 17	1 – 24
Mean annual temp. (°C)	18 – 29	18 - 29

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Southern Provenances		
Mean annual rainfall (mm)	110 – 1400	400[A] – 2000
Rainfall regime	uniform, winter	uniform, winter
Dry season length	0 – 7 months	0 – 7 months
Mean max. temp. hot. mth. (°C)	23 – 41	21 – 41
Mean min. temp. cold. mth. (°C)	0 – 10	0 – 14
Mean annual temp. (°C)	10 – 25	10 – 25

[A] Particular care should be taken when planting the species in low rainfall environments to ensure that local conditions are suitable and appropriate planting densities are used.

***Eucalyptus camaldulensis* continued**

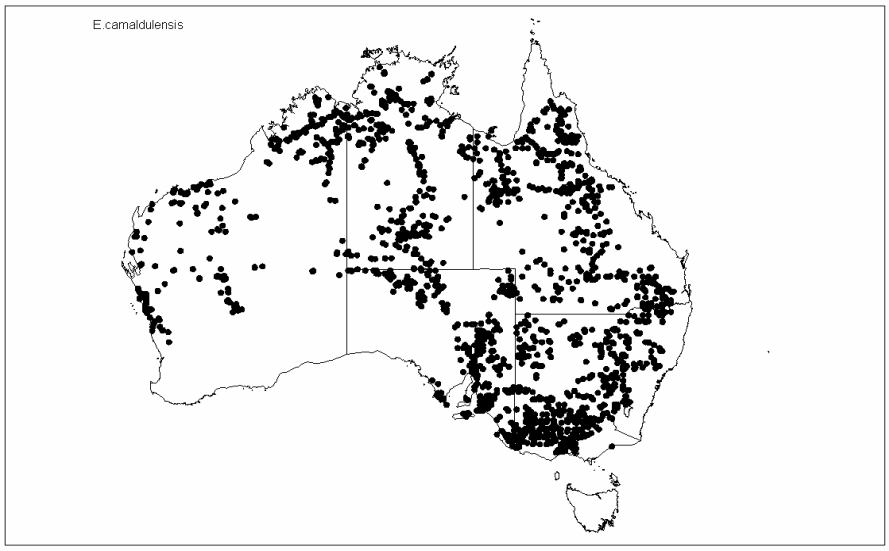

Fig. 4.6.1 Natural distribution of *E. camaldulensis*

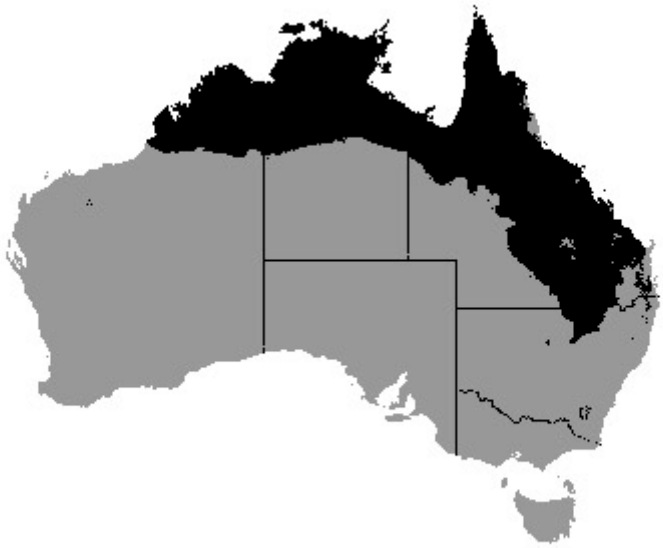

Fig. 4.6.2 Climatically suitable areas for northern provenances of *E. camaldulensis* shown in black

Revisions to the climatic range of the natural distribution

The climatic ranges for the southern and northern provenances of this species have previously been described by Booth and Pryor (1991) and Marcar *et al*. (1995). The species is often found naturally along watercourses, so low rainfalls at these locations do not always indicate the species drought tolerance. Changes to the limits described here are a result of the use of improved climatic surfaces and additional collection records from both ERIN and the CSIRO's Australian Tree Seed Centre databases. For example, the mean annual temperature range for southern provenances is now 10^{o} to 25^{o}C instead of 13^{o}C to 22^{o}C as reported by Marcar *et al.* (1995). Similarly, the lower limit of the mean minimum temperature of the coldest month has been adjusted from 6^{o}C to 1^{o}C for the northern provenances.

Northern provenances are not generally successful in coastal areas of Queensland because of problems with foliar pathogens and insects (P. Ryan, pers. comm.). In low rainfall areas, provenances such as Tennant Creek may superior to popular provenances such as Petford.

***Eucalyptus camaldulensis* Dehnh continued**

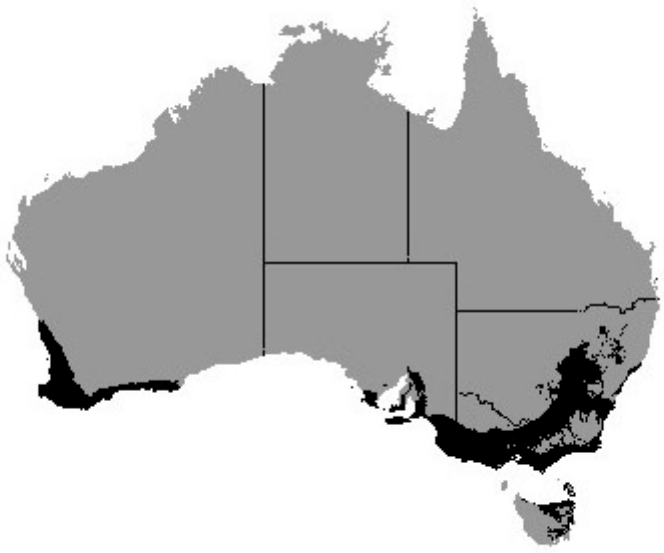

Fig. 4.6.2 Climatically suitable areas for southern provenances of *E. camaldulensis* shown in black

4.7 *Eucalyptus cladocalyx* F. Muell. (Sugar gum)

Sugar gum has heavy and durable heartwood suitable for construction and sleepers, provides excellent fuelwood and is a good species for nectar production (Cremer, 1990). It has a distribution centred on the Spencer Gulf, St Vincents Gulf and Kangaroo Island region of South Australia. The species is noted for its drought tolerance and its ability to grow on alkaline and saline soils (Marcar *et al.*, 1995).

	Climatic requirements (natural distribution)	**Climatic requirements (revised)**
Mean annual rainfall (mm)	245 – 790	400[A] – 1010
Rainfall regime	winter	uniform, winter
Dry season length	4 – 12 months	0 – 8 months
Mean max. temp hot. mth. (°C)	23 – 32	23 – 34
Mean min. temp. cold. mth. (°C)	1 – 9	1 – 11
Mean annual temp. (°C)	12 – 18	12 - 21

[A] Particular care should be taken when planting the species in low rainfall environments to ensure that local conditions are suitable and appropriate planting densities are used.

Revisions to the climatic range of the natural distribution

Revisions to the climatic range for the natural distribution include the alteration of the rainfall regime to include a uniform regime with the inclusion of trials information from Condoblin and Mumbil (Nico Marcar pers. comm.). The lower mean annual rainfall limit for plantation establishment was taken to be 400 mm, though more information on the species suitability for dry environments would be desirable. The upper limit for mean annual rainfall was increased from 790mm to 1010mm on the basis of trials information from Africa (Booth *et al.*, 1988). The upper limit for the mean maximum temperature of the hottest month was raised from 32°C to 34°C with the inclusion of trials information from East Belka, Holleton and Trayning in Western Australia (George, 1991) and Kyabram (Edgar *et al.*, 1978). The upper limit for the mean minimum temperature was also revised from 9°C to 11°C by including trials information from Empangani in South Africa (Poynton, 1979). The upper limit for mean annual temperature was extended from 18°C to 21°C by also including information from Empangeni in South Africa. An examination of overseas and Australian trials information suggests that the upper limit for dry season length be dropped from 12 to 8 months, though results from recently established trials in drier low rainfall areas may eventually indicate the species is suitable for areas with longer dry seasons.

***Eucalyptus cladocalyx* continued**

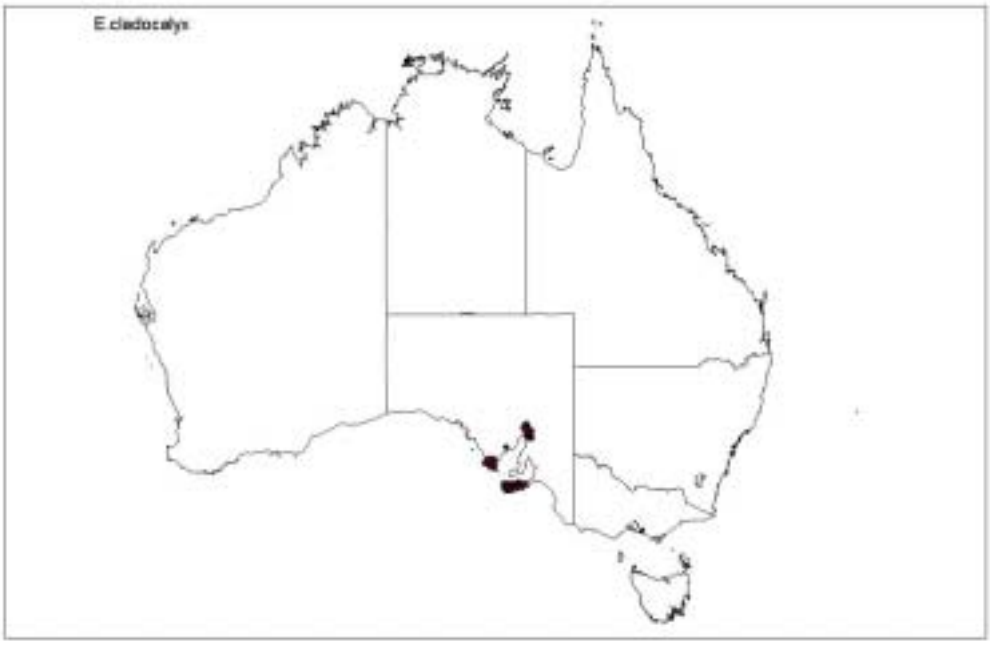

Fig. 4.7.1 Natural distribution of *E. cladocalyx*

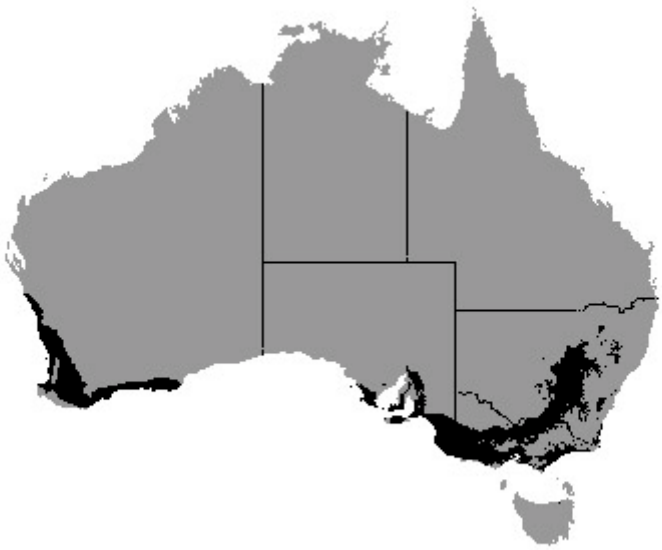

Fig. 4.7.2 Climatically suitable areas for *E. cladocalyx* shown in black

4.8 *Eucalyptus cloeziana* F. Muell. (Gympie messmate)

The natural distribution of *E. cloeziana* is confined to Queensland from latitudes 15-27ºS with the bulk of the distribution in Southern Queensland. The wood is noted for its durability. It has limited use for general construction purposes and can also be used for heavy construction.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	450 – 2845	650 – 2845
Rainfall regime	summer	summer, winter
Dry season length	0 – 8 months	0 – 5 months
Mean max. temp hot. mth. (°C)	27 – 36	27 – 36
Mean min. temp. cold. mth. (°C)	3 – 17	3 – 20
Mean annual temp. (°C)	16 – 23	16 - 27

Revisions to the climatic range of the natural distribution

Revisions to the range of climatic requirements include an increase in the upper limit for the mean minimum temperature for the coldest month from 17ºC to 20ºC by including results from trials in Inhambupe and Cardeal de Silva in Brazil (Pires and Ferriara 1982), Pointe Noire in Congo (Bouvet and Delwaulle 1983), Michafutene in Mozambique (Mugasha et al. 1998), Pittamaruwa in Sri Lanka (Phillips and Weerawardane, 1991a,b) and Melville Island in Australia (Craciun, 1978). These locations also extend the upper range for the mean annual temperature from 23ºC to 27ºC. Trial results from Pittamaruwa in Sri Lanka (Phillips and Weerawardane, 1991a; 1991b) and Inhambupe and Cardeal de Silva in Brazil (Pires, 1982) suggest the species is suitable for winter rainfall environments, though winter rainfall environments in Australia are colder than the species requires. The lower limit for mean annual rainfall has been increased to 650mm, but most commercial plantings in the world are in areas receiving more than 1000 mm. The dry season has also been lowered to 5 months using information from commercial plantings.

***Eucalyptus cloeziana* continued**

Fig. 4.8.1 Natural distribution of *E. cloeziana*

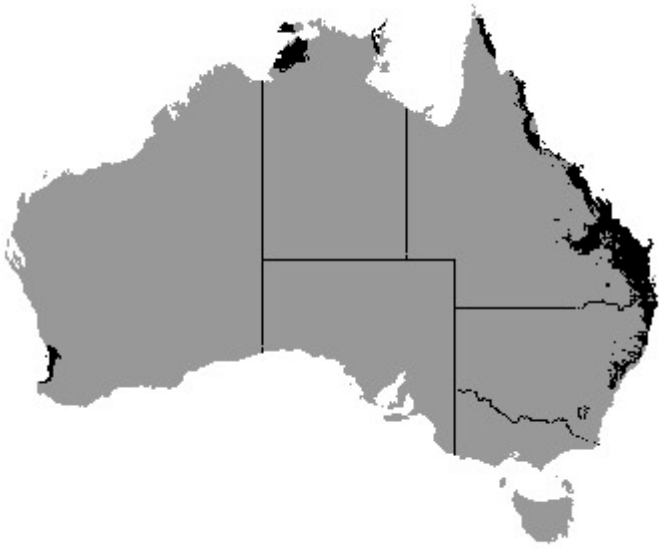

Fig. 4.8.2 Climatically suitable areas for *E. cloeziana* shown in black

4.9 *Eucalyptus dunnii* Maiden (Dunn's white gum)

Eucalyptus dunnii has a limited natural distribution, confined mainly to north-eastern NSW and south-east Queensland. The species is noted for its frost tolerance (Nixon and Hagedorn, 1984) and is grown commercially for pulp in South America.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	845 – 1950	845 – 1950
Rainfall regime	summer	uniform, summer
Dry season length	0 – 2 months	0 – 5 months
Mean max. temp hot. mth. (°C)	24 – 29	24 – 31
Mean min. temp. cold. mth. (°C)	-1 – 7	-1 – 17
Mean annual temp. (°C)	14 – 18	12 - 22

Revisions to the climatic range of the natural distribution

The species has previously been revised by Jovanovic *et al.* (2000). The rainfall regime was altered to include a uniform regime as represented by fuelwood trials in the ACT at Urriara and Stromlo (Clarke *et al.*, 1997). The upper limit for the maximum temperature of the hottest month was extended from 29°C to 31°C to include trials at Guilin and Satang in China (Mannion and Zhang, 1989; Wang *et al.*, 1998). Trial information for locations in Brazil at Aracruz, São Mateus, Uberaba and Viçosa (Ferreira and Couto, 1981) shows that *E. dunnii* can withstand temperatures above the upper limit for the mean minimum temperature of the coldest month within its natural distribution, so this was increased from 7°C to 17°C in the revised requirements. The lower limit for mean annual temperature was dropped from 14°C to 12°C on the basis of information from fuelwood trials in the ACT at Urriara, Kowen and Stromlo (Clarke *et al.*, 1997). The upper limit for mean annual temperature was raised to 22°C on the basis of information from Aracruz, São Mateus and Uberaba. Trials information from South Africa at Liff and Greenpoint (Nixon and Hagedorn, 1984) and at John Meikle Forest Reserve in Zimbabwe (Poynton, 1979) show that the species can cope with a dry season length of about five months rather than the two months indicated in its natural range.

E. dunnii will grow reasonably well in Queensland for a few years, but is generally only suited to cooler higher elevation areas (P. Ryan, pers. comm..).

***Eucalyptus dunnii* continued**

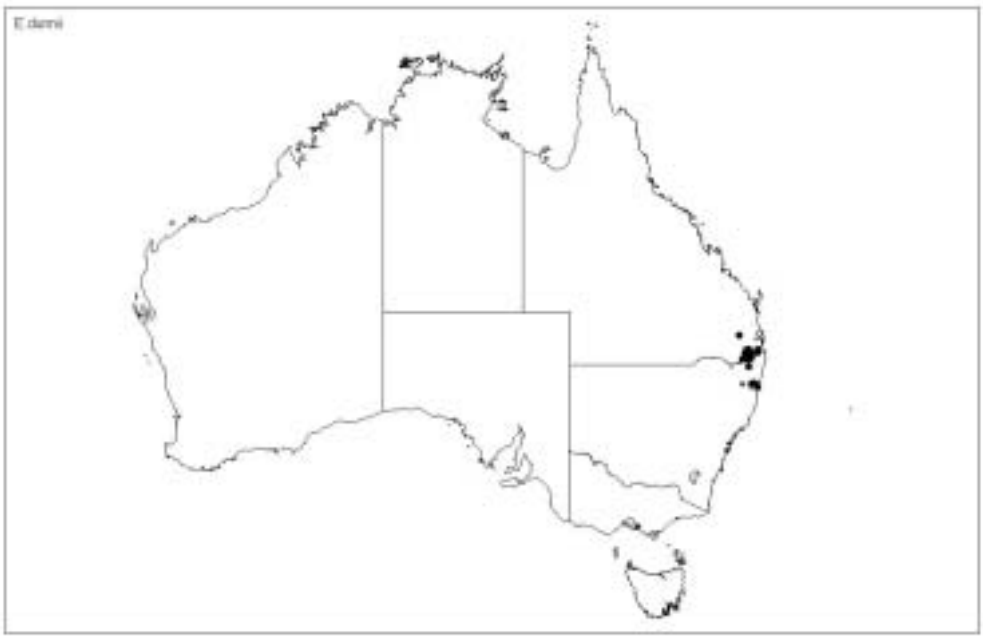

Fig. 4.9.1 Natural distribution of *E. dunnii*

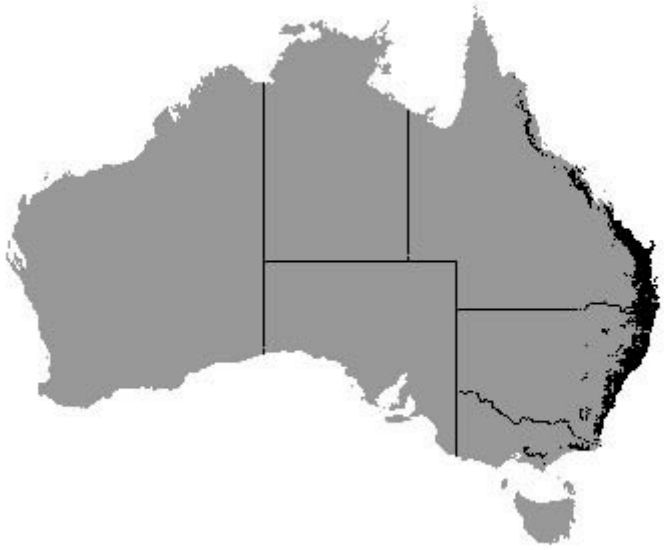

Fig. 4.9.2 Climatically suitable areas for *E. dunnii* shown in black

4.10 *Eucalyptus fraxinoides* Dean & Maiden (White mountain ash)

White Mountain Ash grows in a narrow belt from the Howe Range in the north-eastern corner of Victoria to upper elevation regions of the Southern Tablelands down to the lower slopes of the coastal escarpment. The species is used for purposes such as flooring, joinery and construction.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	640 – 1660	640 – 1660
Rainfall regime	uniform, summer	uniform, winter, summer
Dry season length	0 – 1 months	0 – 5 months
Mean max. temp. hot. mth. (°C)	16 – 30	16 – 30
Mean min. temp. cold. mth. (°C)	-3 – 7	-3 – 7
Mean annual temp. (°C)	5 – 14	5 - 15

Revisions to the climatic range of the natural distribution

Revisions to the climatic range include the altering of the rainfall regime to allow for the winter regime experienced by trials at Mt Gambier (Cotterill *et al.*, 1985). The dry season length was altered from one to five months on the basis of trials at Draycott and Balgowan in South Africa (AF, Gardner and Swain, 1996). The upper limit for the mean annual temperature was also revised from 14°C to 15°C to include conditions at Draycott (Gardner and Swain, 1996) and Lothair in South Africa (Darrow 1996).

***Eucalyptus fraxinoides* continued**

Fig. 4.10.1 Natural distribution of *E. fraxinoides*

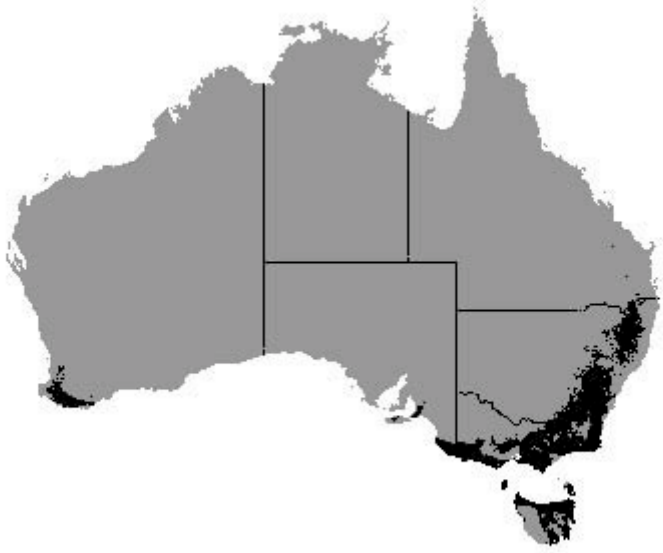

Fig. 4.10.2 Climatically suitable areas for *E. fraxinoides* shown in black

4.11 *Eucalyptus globulus* Labill. subsp. *globulus* (Tasmanian blue gum)

Tasmanian blue gum has a natural distribution centred mainly on the east coast of Tasmania. In mainland Australia it inhabits a narrow belt of southern Victoria from Cape Otway to the Strezlecki Ranges to Wilsons Promontory. It is also found on Flinders and King Islands in Bass Strait (Boland, 1989). The wood can be used for construction, poles and railway sleepers and the species is widely planted for pulp.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	500 – 2600	600 – 1500
Rainfall regime	Uniform/winter	Uniform[A]/winter (NSW winter only)
Dry season length	0 – 5 months	0 – 5 months
Mean max. temp. hot. mth. (°C)	13 – 25	13 – 29
Mean min. temp. cold. mth. (°C)	-1 – 8	-1 – 12
Mean annual temp. (°C)	4 – 14	4 - 18

[A]See comments below on potential disease problems in uniform rainfall areas of NSW.

Revisions to the climatic range of the natural distribution

The species has previously been climatically analysed by Booth and Pryor (1991) and Marcar *et al* (1995). Improved climatic surfaces and an increased number of collection locations have altered the climatic limits from those originally published in Marcar *et al*. (1995). For example, the lower limit for the mean minimum temperature of the coldest month has been dropped from 2ºC to -1ºC and the lower limit for the mean maximum temperature of the hottest month has been lowered from 19ºC to 13ºC. Although there are a small number of high rainfall locations in the natural distribution the species is generally grown in plantations in areas with rainfall less than 1500 mm. Though other subspecies of *E. globulus*, particularly subspecies *maidenii* and *bicostata*, grow naturally in parts of New South Wales *E. globulus* subsp. *globulus* is not generally suitable for summer rainfall environments because of fungal disease problems (G.A. Kile, pers. comm.). This may also be a problem in some uniform rainfall areas, so particular care should be taken in evaluating any planting areas in New South Wales. It is also not recommended for the area north of Bunbury in Western Australia because of the high evaporative rate in this area.

***Eucalyptus globulus* continued**

Fig. 4.11.1 Natural distribution of *Eucalyptus globulus* subsp. *globulus*

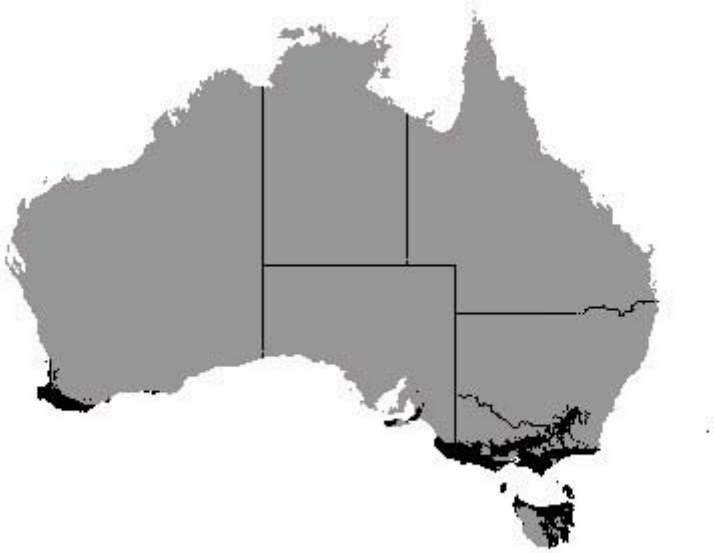

Fig. 4.11.2 Climatically suitable areas for *E. globulus* subsp. *globulus* shown in black (note -fungal diseases may be a problem in parts of NSW – see text)

4.12 *Eucalyptus grandis* Hill ex Maiden (Flooded gum)

Flooded gum is a species of major importance with over 1 million hectares of plantations in Brazil, about 300 000 hectares in South Africa and significant areas in several other countries. Flooded gum's natural distribution on or near the coast extends from northern Queensland, northwest of Townsville (16°S) to Newcastle in NSW (32°S). In northern Queensland the species occurs at higher elevations (Boland *et al*., 1989) often within very narrow bands (frequently only 100-200m wide). The timber has a range of uses including flooring, general construction, panelling and plywood. It is also a species grown for pulp.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	725 – 3730	725 – 3730
Rainfall regime	uniform, summer	uniform, summer
Dry season length	0 – 7 months	0 – 7 months
Mean max. temp. hot. Mth. (°C)	22 – 33	22 – 34
Mean min. temp. cold. Mth. (°C)	0 – 15	0 – 16
Mean annual temp. (°C)	12 – 24	12 – 25

Revisions to the climatic range of the natural distribution

The upper limit for the mean minimum temperature was revised from 33°C to 34°C to include trials information from Maharashtra (Dayal., 1984) and Rudrapur (Chandra *et al.*, 1998) in India. Including these locations, and Pittamaruwa in Sri Lanka (Phillips and Weerawardane, 1991b), also raises the upper limit for mean annual temperature from 24°C to 25°C. The species has experienced problems with fungal pathogens in areas with high temperatures and high humidity, such as Thailand and northern Australia. The upper limit of mean minimum temperature of the coldest month has been raised to 16°C on the basis of information from trials at La Arcadia in Columbia (Endo and Easley, 1991), Pattipola in Sri Lanka (Phillips and Weerawardane, 1991a) and Teluk Sirih in Indonesia (Vercoe *et al.*, 1997).

Although the species may be considered in areas with rainfalls as low as 725 mm over 1000 mm is desirable for good growth. Though Figure 4.12.2 suggests a rather wider climatically suitable area, in practice in Queensland climatically suitable areas correspond very closely to the areas of natural distribution (P. Ryan, pers. comm.). If adequate irrigation water is available the species can be grown successfully in relatively dry uniform rainfall areas of Australia, for example, Wagga Wagga (Myers *et al*., 1995), Deniliquin (M. Pisasale pers. comm.) and Shepparton (Hamlet and Morris, 1996), but the revised climatic description shown above only includes information from rainfed locations.

***Eucalyptus grandis* continued**

Fig. 4.12.1 Natural distribution of *E. grandis*

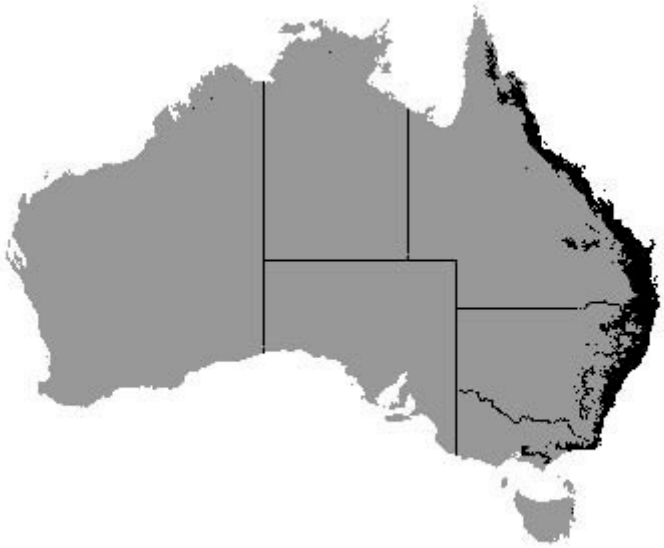

Fig. 4.12.2 Climatically suitable areas for *E. grandis* shown in black

4.13 *Eucalyptus kartzoffiana* L. Johnson (Araluen gum)

Araluen Gum has a restricted distribution between Majors Creek and the Araluen Valley, NSW.

Climatic requirements (natural distribution)

Mean annual rainfall (mm)	760 – 1030
Rainfall regime	uniform/bimodal
Dry season length	0 months
Mean max. temp hot. mth. (°C)	25 – 27
Mean min. temp. cold. mth. (°C)	0 – 3
Mean annual temp. (°C)	11 – 16

Revisions to the climatic range of the natural distribution

The species was described by Cole and Hall (1975). Limited trials information exists for the species (see, for example, Clarke *et al.,* 1997), so climatic requirements are based solely on information from the natural distribution.

***Eucalyptus kartzoffiana* continued**

Fig. 4.13.1 Natural distribution of *E. kartzoffiana*

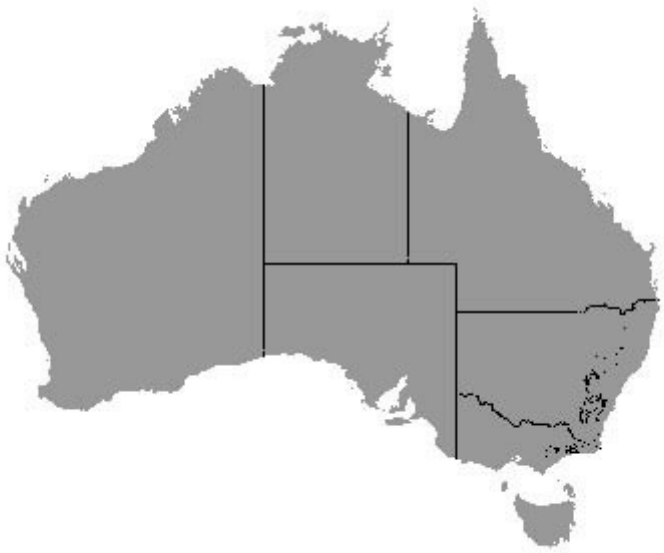

Fig. 4.13.2 Climatically suitable areas for *E. kartzoffiana* shown in black

4.14 *Eucalyptus nitens* (Dean & Maiden) Maiden (Shining gum)

The natural distribution of shining gum consists of disjunct stands in the Great Dividing Range from Northern NSW, where it occurs at elevations of 1600 metres to the Victorian Alps. The wood is used for a number of purposes including pulp, furniture, flooring and joinery (Boland *et al.* 1989).

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	550 – 2300	700 – 2300
Rainfall regime	Uniform, winter, summer	Uniform, winter, summer
Dry season length	0 – 5 months	0 – 5 months
Mean max. temp hot. mth. (°C)	19 – 27	19 – 29
Mean min. temp. cold. mth. (°C)	-3 – 4	-3 – 4
Mean annual temp. (°C)	5 – 15	5 – 17

Revisions to the climatic range of the natural distribution

The species has previously undergone climatic review by Booth and Jovanovic (1991) and also Richardson and McMahon (1992), who analysed climatic data for the natural distribution and successful plantings in Australia and South Africa. Richardson found South African trials sites to be warmer than climatic data for the natural distribution. For example, values for the maximum temperature of the hottest month are increased from 27ºC to 29ºC with the inclusion of successful South African trial sites. The upper limit for mean annual temperature is also increased from 15ºC to 17ºC with the inclusion of data from these sites and sites in Columbia (Restrepo and Atehortua, 1989) and Brazil, (Shimizu, 1986). Commercial plantations are usually grown in areas that receive a mean annual rainfall of at least 700 mm.

***Eucalyptus nitens* continued**

Fig. 4.14.1 Natural distribution of *E. nitens*

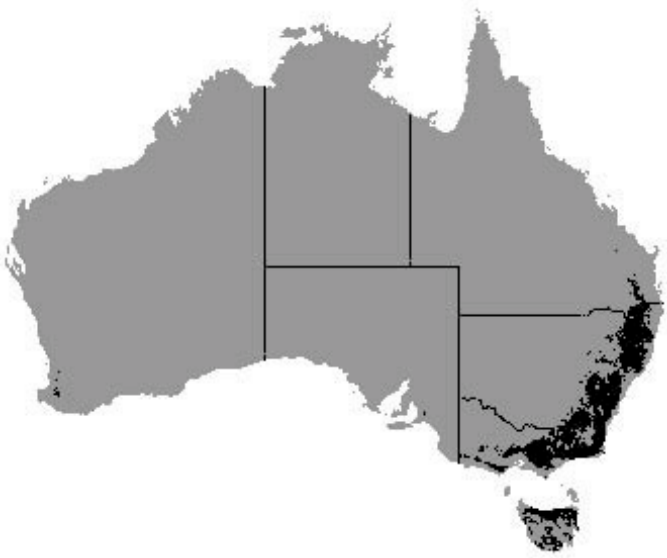

Fig. 4.14.2 Climatically suitable areas for *E. nitens* shown in black

4.15 *Eucalyptus occidentalis* Eudl. (Flat-topped Yate)

Flat-topped yate is native to south-west Western Australia. The species is tolerant of poorly drained conditions and will withstand moderate to high levels of salinity (Marcar *et al.,* 1995). The timber is hard and durable and may be used for construction.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	300 – 910	400[A] – 910
Rainfall regime	Winter	Uniform, winter
Dry season length	4 – 12 months	0 – 12 months
Mean max. temp hot. mth. (°C)	23 – 31	23 – 34
Mean min. temp. cold. mth. (°C)	4 – 9	2 – 9
Mean annual temp. (°C)	12 – 17	12 – 18

[A] Particular care should be taken when planting the species in low rainfall environments to ensure that local conditions are suitable and appropriate planting densities are used.

Revisions to the climatic range of the natural distribution

Previous revisions to the climate profile were carried out by Marcar *et al.* (1995). This species has exhibited frost and drought tolerance as well as performing well on saline irrigated sites (Marcar *et al.,* 1995). The species has survived and grown in hot and dry environments, for example in Snaim in Israel (Zohar *et al.,* 1988) where plantings have been grown in 'limans' (water gathering basins), where the mean annual rainfall is below 200mm. The length of the dry season was dropped from four to zero months on the basis of results from trials at Wellington in NSW (Benyon *et al.,* 1999). Successful trials at Wagga (Myers *et al.,* 1995) and Wellington (Benyon *et al.,* 1999) also resulted in the modification of the rainfall regime to include a uniform rainfall distribution. The mean minimum temperature of the coldest month has also been lowered to 2ºC on the basis of trials at these locations and Barmera (Vercoe *et al.,* 1997). The species can stand higher temperatures as witnessed by growth in trials in Israel (Zohar *et al.,* 1988; Zohar and Moreshet, 1987) where mean maximum temperatures for the hottest month reached 34ºC. Information from trials at Condoblin have seen the upper limit for mean annual temperature increased from 17ºC to 18ºC.

***Eucalyptus occidentalis* continued**

Fig. 4.15.1 Natural distribution of *E. occidentalis*

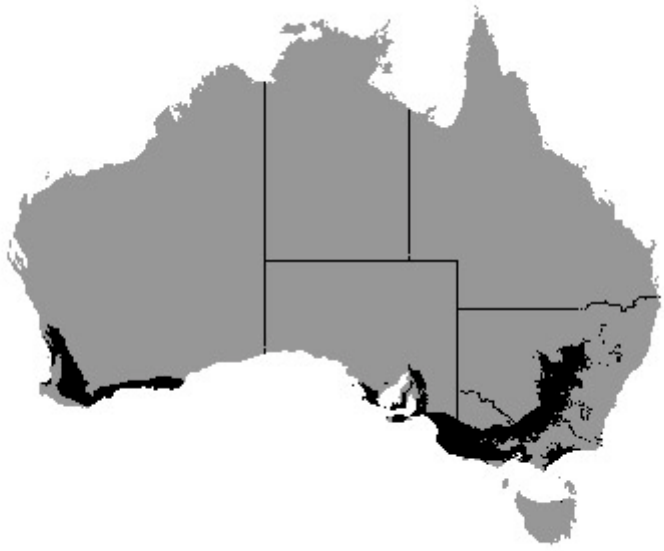

Fig. 4.15.2 Climatically suitable areas for *E. occidentalis* shown in black

4.16 *Eucalyptus pellita* F. Muell. (Large-fruited Red Mahogany)

Eucalyptus pellita occurs naturally in northern Queensland, within 50 km of the coast from latitudes 12ºS – 18ºS. The species also grows in southern New Guinea around the Oriomo Plateau/Fly-Digol shelf region (Harwood, 1998). The timber is suitable for purposes such as poles, sleepers and general construction and is easily sawn and seasoned (Bootle, 1998).

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	1080 – 3550	1080 – 3550
Rainfall regime	Summer	Uniform/bimodal/summer
Dry season length	0 – 6 months	0 – 6 months
Mean max. temp hot. mth. (°C)	28 – 33	28 – 34
Mean min. temp. cold. mth. (°C)	10 – 19	10 – 22
Mean annual temp. (°C)	19 – 25	19 – 27

Revisions to the climatic range of the natural distribution

A recent study of early growth and survival of *E. pellita* provenances (Harwood *et al.,* 1997) has shown that Papua New Guinea provenances appear superior in growth and disease resistance to Australian provenances. Climate information for a limited number of Papua New Guinea sites was estimated using the World program (Booth and Jovanovic, in press). Inclusion of Papua New Guinea seed sources alters the climate profile for the natural distribution and raises the upper limit for mean minimum temperature for the coldest month from 19ºC to 22ºC and the mean annual temperature from 25ºC to 27ºC. Papua New Guinea sites have no dry season. Inclusion of trials at sites at Leanyer and Humpty Doo (Craciun, 1978) also increases the mean annual temperature to 27ºC and the maximum temperature of the hottest month to 34ºC. More provenance testing, in particular with Papua New Guinea seed sources is needed to establish possible patterns of disease resistance and better growth performance. On soils with low water holding capacity, the lower limit for mean annual rainfall should be set at 1300 mm (Harwood ibid.).

***Eucalyptus pellita* continued**

Fig. 4.16.1 Natural distribution of *E. pellita* in Australia

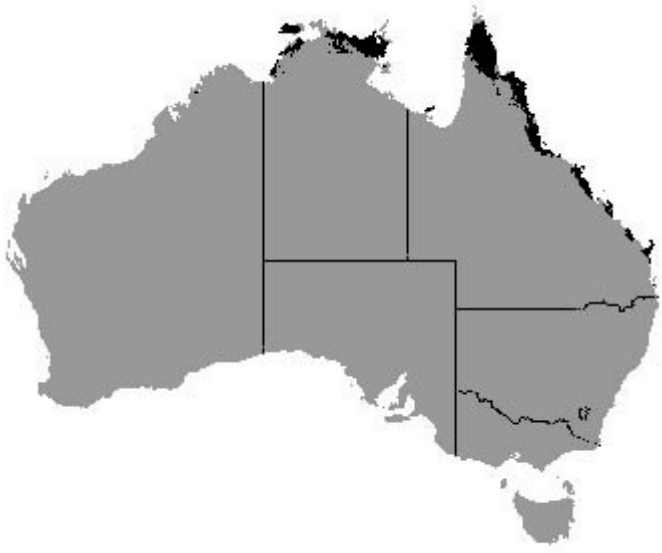

Fig. 4.16.2 Climatically suitable areas for *E. pellita* shown in black

4.17 *Eucalyptus pilularis* Smith (Blackbutt)

Eucalyptus *pilularis* (Blackbutt) is prominent in coastal forests of New South Wales and southern Queensland, between latitudes 25º S and 37º S (Burgess, 1975). The species occurs mainly in the lowlands, but ascends to 1000m in several places in the northern part of its distribution. Blackbutt is one of the most important hardwoods in Australia and is highly regarded as a general purpose construction timber.

Climatic requirements (natural distribution)

Mean annual rainfall (mm)	730 – 2460
Rainfall regime	bimodal/summer
Dry season length	0 – 4 months
Mean max. temp. hot. mth. (°C)	22 – 31
Mean min. temp. cold. mth. (°C)	3 – 12
Mean annual temp. (°C)	10 – 22

Revisions to the climatic range of the natural distribution

Previous revisions to the climatic profile include Booth and Jovanovic (1991). These limits were altered using new values obtained from improved climatic surfaces. Of the trials references reviewed only one article (Garthe, 1983), citing trials on Fraser Island in Queensland, indicated a possible need to alter the natural profile. This suggested a raising of the upper limit for mean minimum temperature of the coldest month from 12ºC to 14ºC. However, as this was only one observation, no changes were made to the natural profile. Although mean minimum temperatures of 0ºC for the coldest month are experienced in the species natural range, the lower limit for this factor has been raised to 3ºC so that frost prone areas inland from the coast are not highlighted as climatically suitable.

Eucalyptus pilularis **continued**

Fig. 4.17.1 Natural distribution of *E. pilularis*

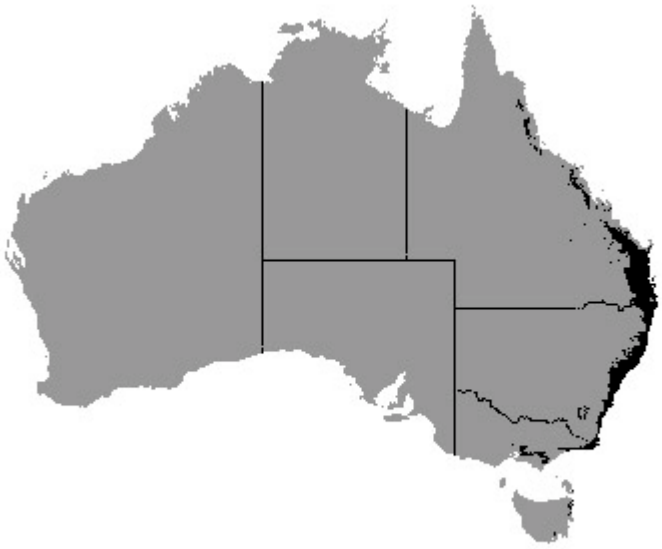

Fig. 4.17.2 Climatically suitable areas for *E. pilularis* shown in black

4.18 *Eucalyptus saligna* Smith (Sydney Blue Gum)

Sydney blue gum's natural range extends from Maryborough in Queensland to the south coast region of New South Wales. It is mainly found within 120km of the coastline. Disjunct populations of the species exist further north in the Kroombit Tableland near Gladstone, the Blackdown Tableland near Blackwater, and the Consuelo Tableland and Carnarvon Gorge regions (Boland *et al.*, 1989). The wood is moderately durable and can be used for general construction, flooring and panelling.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	615 – 2300	700 – 2300
Rainfall regime	uniform, summer	uniform, summer, winter
Dry season length	0 – 6 months	0 – 6 months
Mean max. temp hot. mth. (°C)	24 – 34	23 – 34
Mean min. temp. cold. mth. (°C)	-1 – 11	-1 – 17
Mean annual temp. (°C)	10 – 22	10 – 22

Revisions to the climatic range of the natural distribution

Improved climatic surfaces have altered the climatic profile originally published by Booth and Jovanovic (1991). Other revisions include the altering of the rainfall regime to include a winter regime by including trials information from Kericho (Wachira *et al.*, 1994) and Londiani (Konuche, 1989; both in Kenya), Mount Gambier (Cotterill *et al.*, 1985), Hawaii (Schubert and Whitesell, 1985) and the Pelloponese region in Greece (Panetsos, 1975). The upper limit for mean minimum temperature of the coldest month was raised from 11°C to 17°C using trials information from Hawaii (Schubert and Whitsell, 1985; Whitesell, 1976), Turbo (Kimondo and Konuche, 1989), Port Durnford in South Africa (Darrow, 1983; 1997), Caldas in Columbia (Restrepo and Atehorta, 1989), Vanuatu (Neil, 1986), Western Maharashtra India (Dayal, 1984) and Pattipola in Sri Lanka (Phillips and Weerawardane, 1991a). The lower limit for mean maximum temperature of the hottest month was dropped from 24°C to 23°C with the inclusion of trials information from Liff in South Africa (Nixon and Hagedorn,1984) and Rotoehu in New Zealand (Johnson and Wilcox, 1989). Information from the literature review suggested the lower limit for mean annual rainfall for commercial growing should be raised from 615mm to 700mm. Though the species may be considered for planting in areas with rainfalls as low as 700 mm over 1000 mm is desirable for good growth.

***Eucalyptus saligna* continued**

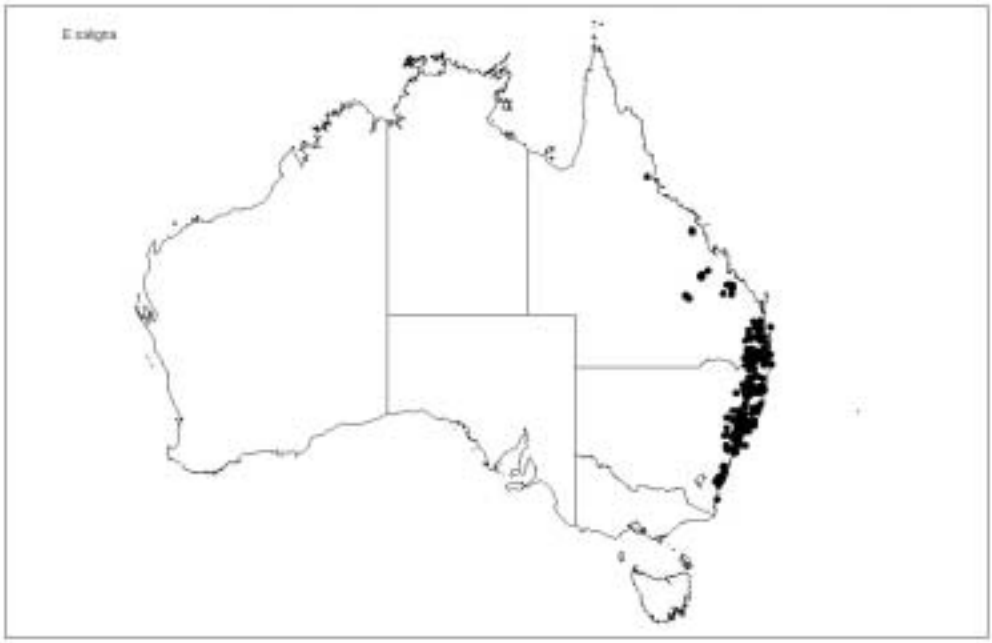

Fig. 4.18.1 Natural distribution of *E. saligna*

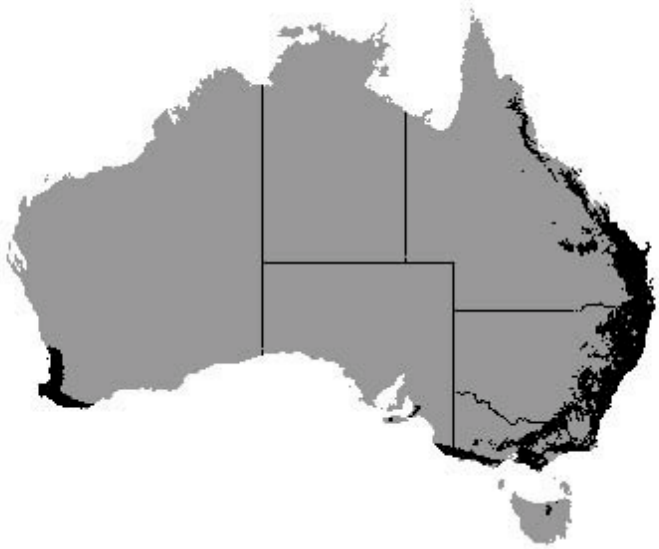

Fig. 4.18.2 Climatically suitable areas for *E. saligna* shown in black

4.19 *Eucalyptus sideroxylon* Cunn. ex Woolls subsp. *sideroxylon* (Red Ironbark)

Red ironbark is distributed from Wangaratta in Victoria through to NSW and Consuelo in southern Queensland. Its easterly occurrences are located near Sydney and the Hunter valley (Boland *et al.*, 1989). Its distribution also extends to the western slopes of NSW. The species is important for honey production and the timber is very strong and is suited where durability is required; for heavy construction and sleepers (Cremer, 1990).

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	305 – 1340	400[A] – 1340
Rainfall regime	uniform, winter, summer	uniform, winter, summer
Dry season length	0 – 12 months	0 – 12 months
Mean max. temp. hot. mth. (°C)	24 – 34	24 – 34
Mean min. temp. cold. mth. (°C)	0 – 6	0 – 13
Mean annual temp. (°C)	12 – 19	12 – 23

[A] Particular care should be taken when planting the species in low rainfall environments to ensure that local conditions are suitable and appropriate planting densities are used.

Revisions to the climatic range of the natural distribution

The species has previously undergone climate review (Booth *et al.*, 1988) where the species' performance was assessed in 38 trials in eight African countries. The analysis carried out for the present study resulted in increasing the upper limits for mean annual temperature (from 19°C to 23°C) and the mean minimum temperature of the coldest month (from 6°C to 13°C). Differences between previously published climatic suitability ranges for the natural distribution (from -2°C to 0°C for the lower limit of the minimum temperature of the coldest month, and 23°C to 24°C for the lower limit of the maximum temperature of the hottest month) and the ranges presented in this analysis can be attributed to the use of more data and improved climatic surfaces. The species is noted for its acceptable growth in, and tolerance of dry conditions in other parts of the world (e.g. for Chile, Jayawickrama *et al.*, 1993). However, 500 mm or more of annual rainfall is preferable when growing for commercial purposes.

***Eucalyptus sideroxylon* continued**

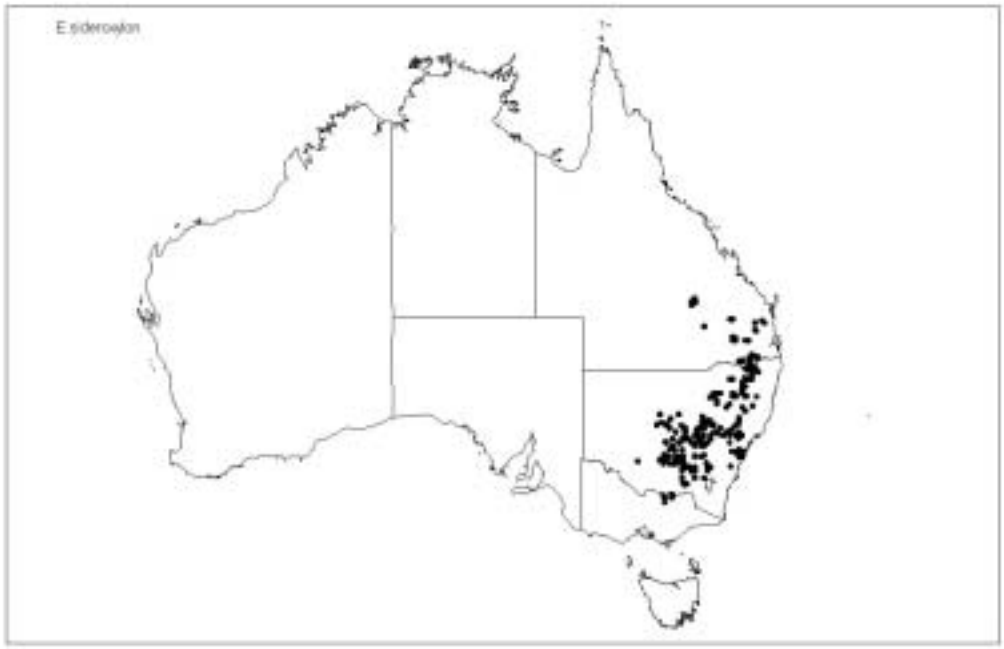

Fig. 4.19.1 Natural distribution of *E. sideroxylon subsp. sideroxylon*

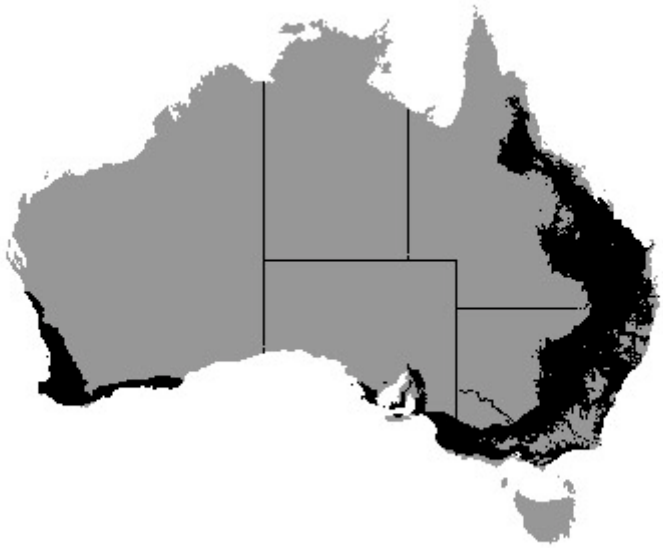

Fig. 4.19.2 Climatically suitable areas for *E. sideroxylon subsp. sideroxylon* shown in black

4.20 *Eucalyptus smithii* R. Baker (Gully Gum)

Gully gum's distribution is confined to the southern end of the central and southern tablelands and the adjacent coastal escarpment, extending to the coastal lowlands of southern New South Wales. Its distribution also extends into Victoria into the eastern Gippsland region (Boland *et al.*, 1989). The wood can be used for general construction purposes.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	610 – 1930	610 – 1930
Rainfall regime	uniform, winter	uniform, winter
Dry season length	0 – 3 months	0 – 6 months
Mean max. temp. hot. mth. (°C)	20 – 27	20 – 27
Mean min. temp. cold. mth. (°C)	-3 – 7	-3 – 7
Mean annual temp. (°C)	7 – 17	7 – 17

Revisions to the climatic range of the natural distribution

Revisions have resulted in the raising of the dry season length from three to six months with the inclusion of trials information from Draycott, Lothair, and Mclean in South Africa (Darrow, 1996) and from climate estimates for Haikou in China (Zheng *et al.*, 1994).

***Eucalyptus smithii* continued**

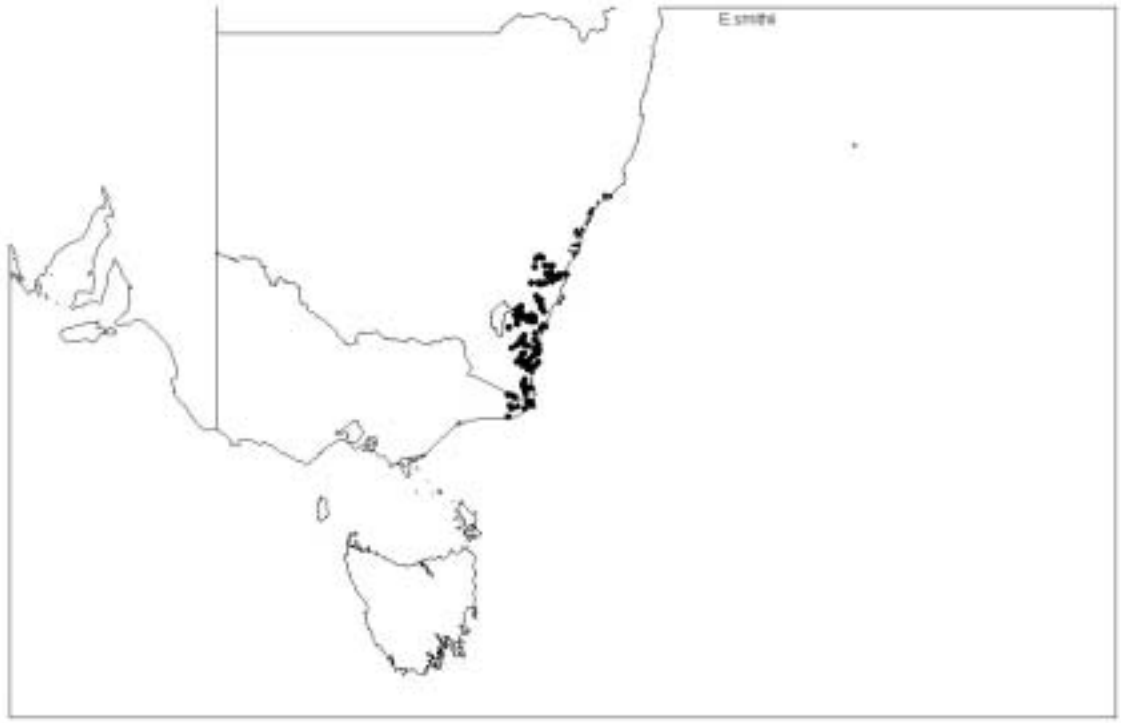

Fig. 4.20.1 Natural distribution of *E. smithii*

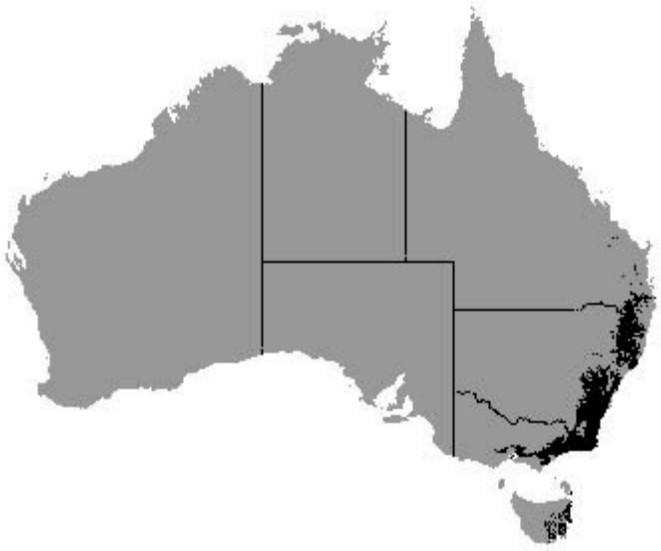

Fig. 4.20.2 Climatically suitable areas for *E. smithii* shown in black

4.21 E*ucalyptus viminalis* Labill. subsp. *viminalis* (Manna Gum)

Eucalyptus viminalis is widely distributed in south-eastern Australia between latitudes 28º S and 43º S. It is common in eastern Tasmania, the islands of Bass Strait and southern Victoria. In New South Wales it is found mainly on the tablelands with its distribution extending over the Queensland border. The altitudinal range is from sea level to 1400 m with the highest occurrences in New South Wales and the Australian Capital Territory. The species is noted for its frost tolerance (Gentillli, 1961) and has been grown experimentally in southern France (Marquestaut *et al.,* 1978). The timber is used for flooring, panelling and joinery (Bootle, 1971) and the wood from young trees is suitable for pulp.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	400 – 2125	500 – 2500
Rainfall regime	winter,uniform, summer	winter, uniform, summer
Dry season length	0 – 7 months	0 – 5 months
Mean max. temp. hot. mth. (°C)	21 – 32	21 – 32
Mean min. temp. cold. mth. (°C)	-4 – 9	-4 – 9
Mean annual temp. (°C)	4 – 17	4 – 17

Revisions to the climatic range of the natural distribution

This species has often exhibited a combination of frost resistance and growth vigour as shown at Jessievale, South Africa (Darrow, 1984), or Kunming in the People's Republic of China (Wang et al. 1989). The upper limit for mean annual rainfall was increased from 2127 mm to 2500 mm with the inclusion of trials information from Columbia (Restrepo and Atehorta, 1989). For farm forestry a minimum annual rainfall of at least 500 mm is recommended and higher rainfall is desirable for good growth.

***Eucalyptus viminalis* continued**

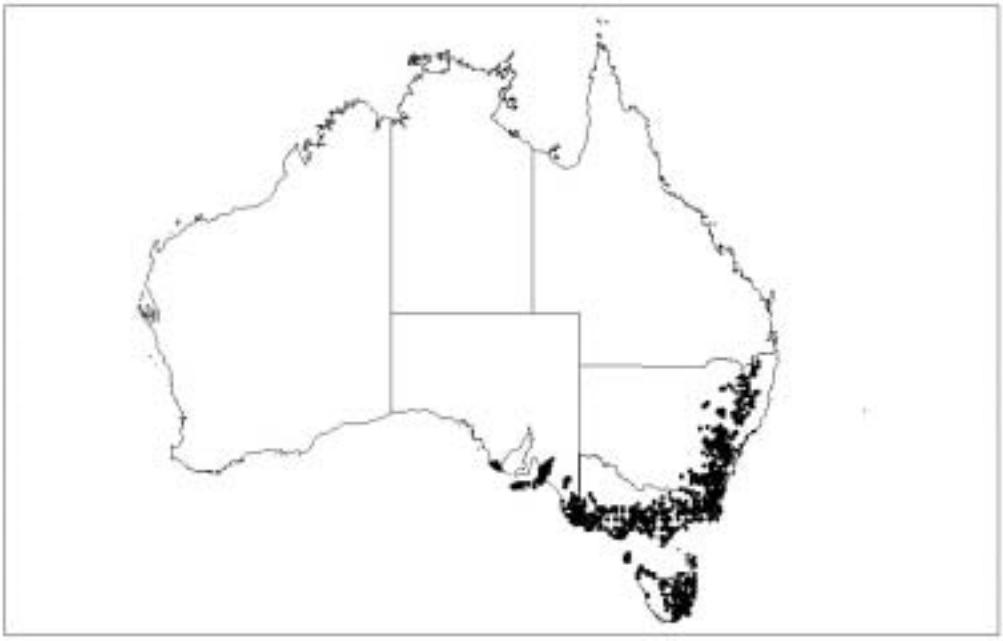

Fig. 4.21.1 Natural distribution of *E. viminalis*

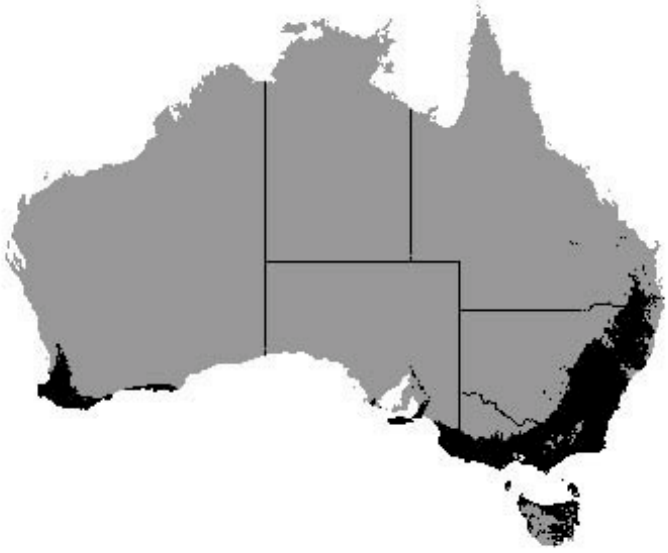

Fig. 4.21.2 Climatically suitable areas for *E. viminalis* shown in black

4.22 *Corymbia citriodora* subsp. *variegata* (F. Muell.) McDonald & Bean

Corymbia variegata was considered by Hill and Johnson (1995) to be a separate species, but McDonald and Bean (2000) suggest that it should be treated as a subspecies under *C. citriodora*. It has a reasonably wide distribution from near the Carnarvon and Dawes Ranges in Queensland to the upper Nymboida river in NSW. The timber uses are similar to those detailed for *Corymbia henryi*, which is found in Queensland - New South Wales border areas (see Figure 4.22.1).

Climatic requirements (natural distribution)

Mean annual rainfall (mm)	600 – 1610
Rainfall regime	summer
Dry season length	0 – 6 months
Mean max. temp. hot. mth. (°C)	22 – 34
Mean min. temp. cold. mth. (°C)	0 – 10
Mean annual temp. (°C)	11 – 21

Climatic range of the natural distribution

At present there is little provenance information to relate to the new taxonomic classification, so only a climate description based on the natural distribution and a map of this distribution are shown here. Provenances in older trials cannot be readily associated with the new subspecies assignment, so only the analysis of the natural distribution is shown here. A series of greenhouse trials looking at the cold tolerance of *C. maculata* group has recently been carried out in Australia (Larmour *et al.*, 1999)

***Corymbia citriodora* subsp. *variegata* continued**

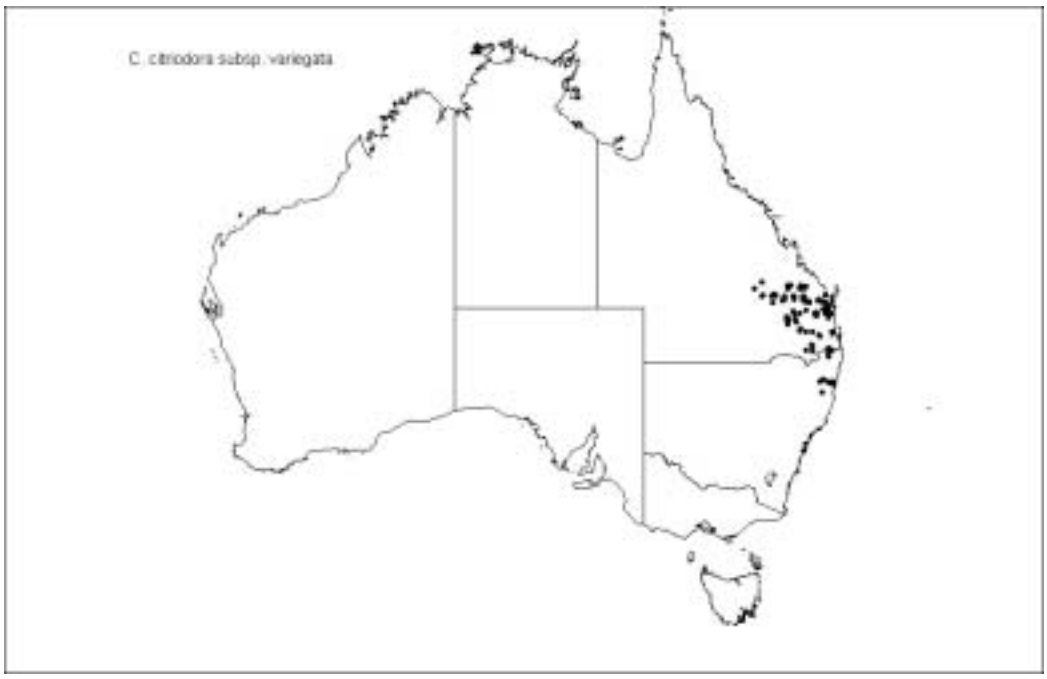

Fig. 4.22.1 Natural distribution of *C. citriodora* subsp. *variegata*

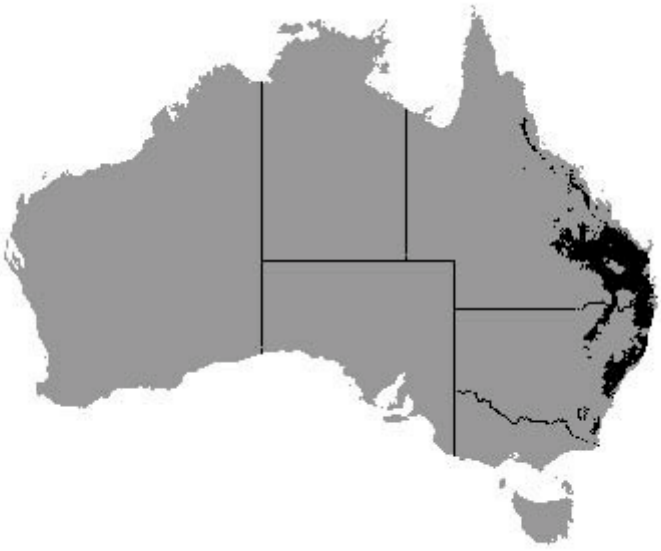

Fig. 4.22.2 Climatically suitable areas for *C. citriodora* subsp. *variegata* shown in black

4.23 *Corymbia henryi* (Blake) Hill & Johnson

Corymbia henryi is found naturally from Brisbane, Queensland to the south of Grafton at Glenreagh. This species and its close relatives are some of the most important commercial species in eastern Australia. Timber uses include construction, flooring, tool handles and (when preserved) poles (Cremer, 1990).

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	830 – 1745	830 – 1745
Rainfall regime	summer	summer
Dry season length	0 – 2 months	0 – 5 months
Mean max. temp. hot. mth. (°C)	26 – 31	26 – 31
Mean min. temp. cold. mth. (°C)	2 – 8	2 – 8
Mean annual temp. (°C)	15 – 20	15 – 20

Revisions to the climatic range of the natural distribution

The major revisions include the raising of the dry season length to five months with the inclusion of trials at Kwambonambi, JDM Keet and Frankfort in South Africa (Darrow, 1996). The upper limits of the mean minimum temperature of the coldest month and mean annual temperature was exceeded in a trial at Port Durnford in South Africa, but as this was only one occurrence the range was not changed. The lower limit for mean annual temperature was also exceeded at Frankfort in South Africa (Darrow ibid.), but as this was also only one occurrence the limits were not changed.

***Corymbia henryi* continued**

Fig. 4.23.1 Natural distribution of *C. henryi*

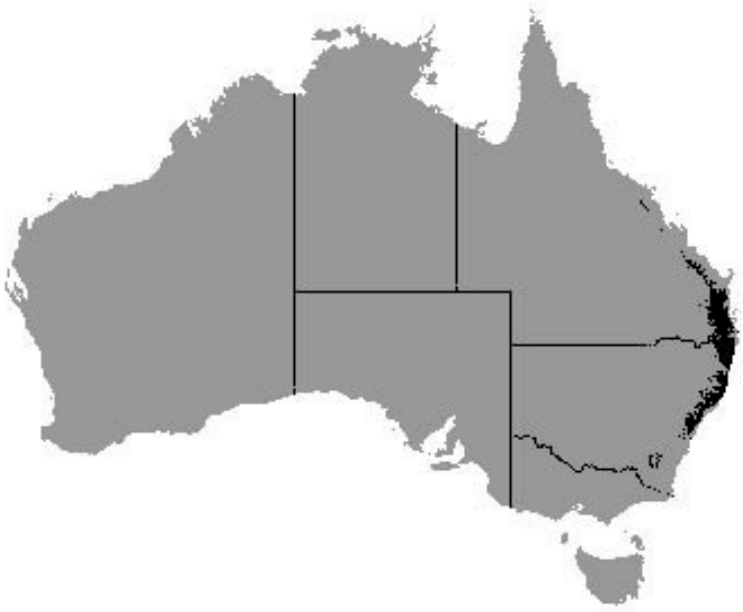

Fig. 4.23.2 Climatically suitable areas for *C. henryi* shown in black

4.24 *Corymbia maculata* Hook. (Spotted Gum)

The distribution of this species is mainly coastal, ranging from the Manning river in northern NSW to near Nowa Nowa in eastern Victoria. The timber uses are similar to those detailed in the *Corymbia henryi* section.

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	610 – 1490	580 – 1500
Rainfall regime	uniform/bimodal, summer	uniform/bimodal, summer
Dry season length	0 – 4 months	0 – 5 months
Mean max. temp. hot. mth. (°C)	20 – 32	20 – 32
Mean min. temp. cold. mth. (°C)	0 – 7	0 – 7
Mean annual temp. (°C)	10 – 19	10 – 19

Revisions to the climatic range of the natural distribution

The dry season length was increased to five months with the inclusion of trials in South Africa at Kwambonambi, JDM Keet and Frankfort (Darrow, 1985). Evidence is emerging from trials in Australia of the species' drought tolerance (Roger Arnold pers. comm.). The upper limit of the mean annual temperature of the coldest month was exceeded in a trial at Port Durnford in South Africa, but as this was only one occurrence this was not changed.

***Corymbia maculata* continued**

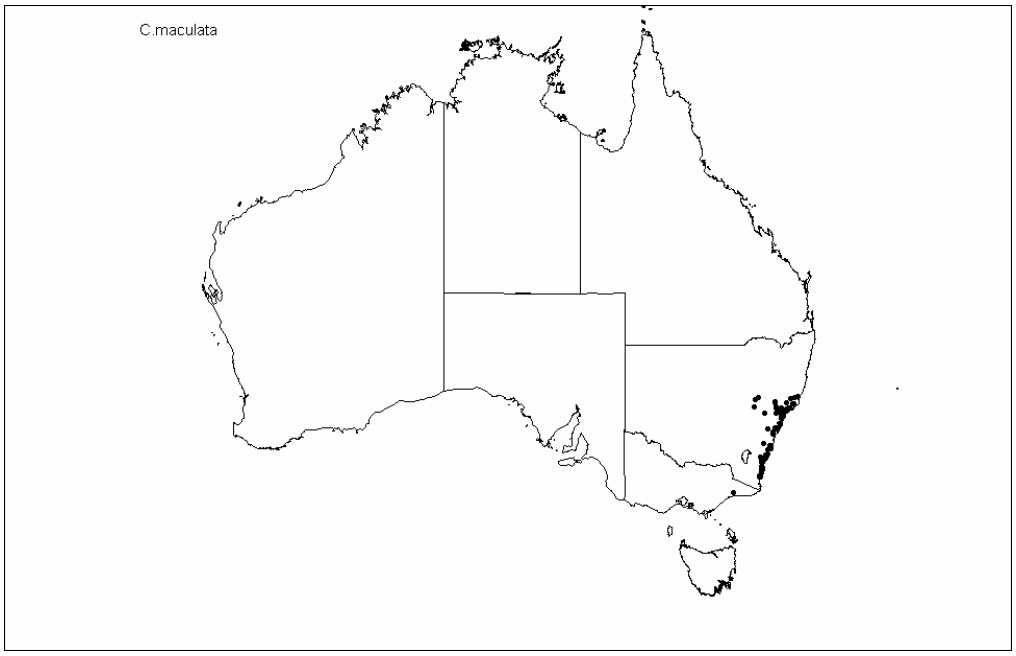

Fig. 4.24.1 Natural distribution of *C. maculata*

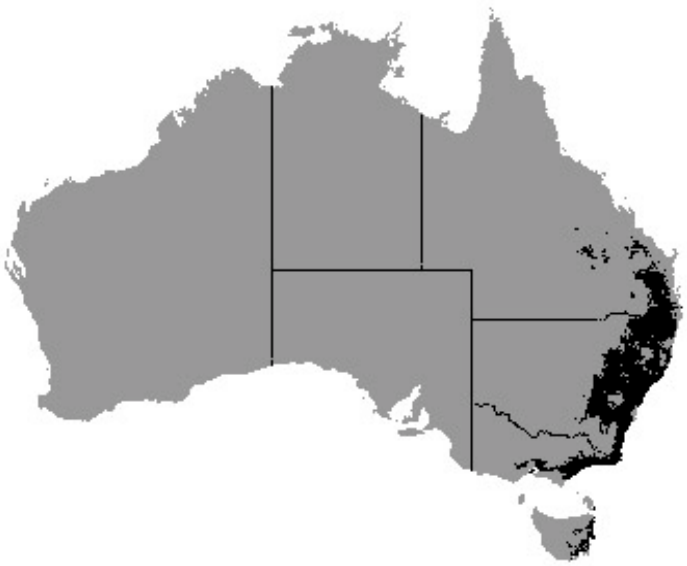

Fig. 4.24.2 Climatically suitable areas for *C. maculata* shown in black

4.25 *Grevillea robusta* Cunn. ex R. Br. (Silky Oak)

Silky oak has a limited distribution based in Northern Rivers region of NSW and south-eastern Queensland. The species is very adaptable and is widely grown overseas as a shade tree for coffee and tea plantations. The species has an attractive wood suitable for cabinet work (Cremer, 1990).

Climatic requirements (natural distribution)		**Climatic requirements (revised)**
Mean annual rainfall (mm)	740 – 2160	700 – 2400
Rainfall regime	Summer	Uniform, winter, summer
Dry season length	0 – 2 months	0 – 7 months
Mean max. temp. hot. mth. (°C)	27 – 31	25 – 38
Mean min. temp. cold. mth. (°C)	0 – 11	0 – 16
Mean annual temp. (°C)	13 – 21	13 – 24

Revisions to the climatic range of the natural distribution

The climatic requirements for the species has been revised from descriptions originally published in (Harwood and Booth, 1992) and (Harwood, 1998). The species has a restricted range yet is renowned for its climatic tolerance. The lower and upper limits for mean annual rainfall have been set to 700mm and 2400mm with the inclusion of trials in Yavello, Ethiopia (Haugen, 1989), Dehra Dun, India (Bahuguna and Dhawan, 1990) and Malava, Kenya (Kalinganire *et al.*, 1996). The inclusion of data from trials at Kabanyolo in Uganda (Okorio *et al.*, 1994) and near La Tontarla in New Caledonia (Ehrhart and Sarraich, 1997) also extend the upper range for the mean minimum temperature of the coldest month from 11ºC to 16°C. Best growth is achieved at sites where the mean annual temperature is between 15ºC and 18ºC and the mean rainfall is between 1000 - 2000mm (Harwood and Booth, 1992). The species can tolerate colder temperatures, particularly as the tree grows older, but will suffer damage if growing as seedlings or young saplings in environments where the temperature drops below -5ºC (Harwood and Booth, 1992). Commercial plantations outside Australia all tend to have mean minimum temperatures of the coldest month above 6^{o}C.

***Grevillea robusta* continued**

Fig. 4.25.1 Natural distribution of *G. robusta*

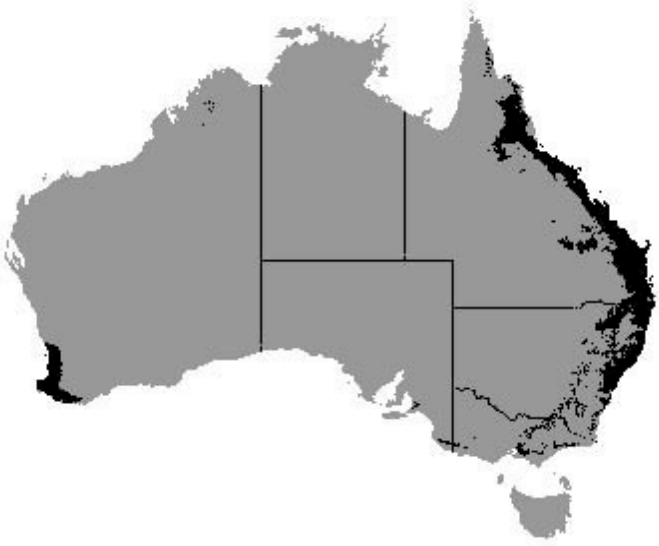

Fig. 4.25.2 Climatically suitable areas for *G. robusta* shown in black

4.26 *Pinus pinaster* Aiton (Maritime pine)

The natural distribution of *Pinus pinaster* (maritime pine) includes parts of southern France, Corsica, Sardinia, Italy, Portugal, Spain, Morocco and Tunisia (CAB International, 2000). The species is of major importance in Europe with about two million hectares of plantations in France. It was one of the successful species to emerge from extensive species evaluation trials carried out in Australia about one hundred years ago (Lewis *et al.*, 1976). In the past it has been used on Australian sites, especially in South Australia and Western Australia, which were considered too poor for *Pinus radiata.* In 1994 it was estimated there were approximately 29,000 ha of *P. pinaster* plantations (National Forest Inventory, 1997).

In recent years the Department of Conservation and Land Management (CALM) in Western Australia (WA) has put considerable effort into genetic improvement of the species. In 1997, CALM announced a major plan to establish 150,000 ha of the species in WA over the next decade concentrating on the 400-600 mm rainfall zones. Farmers were invited to participate in share-cropping schemes. Trees are being grown on 30-40 year rotations with at least two thinnings to produce a range of products including pulpwood, wood panels and sawlogs. Like CALM's blue gum projects, the plantations are also aimed at providing environmental benefits by lowering water tables and helping to control salinity problems. However, recent information suggests that the maritime pine scheme may be wound down.

Three descriptions of the climatic requirements of *P. pinaster* are tabulated and mapped below. The first is the description of climatic requirements included in the Forestry Compendium Global Module (CABI 2000) CD-ROM prepared by CAB International. This was described by researchers in Portugal and appears to be based largely on conditions experienced at European plantations.

The second description was prepared for this report by analysing climatic conditions at long established *P. pinaster* plantations in Australia. The following locations have significant plantations of *P. pinaster* which have been established for many years (Booth, 1984): South Australia – Caroline, Penola, Comaum, Cave Range, Mt Gambier, Mt Burr, Tantanoola, Kongorong, Kuitpo, Mt Crawford; Western Australia – Yanchep, Pinjar, Gnangara, Myalup, Vasse. At virtually all these locations *P. pinaster* was planted as a minor species at selected sites within areas where *P. radiata* was the dominant plantation species. The 'pre-1984' description below is based on a climatic analysis of these locations.

The third 'revised' description was extended to include drier locations of the type being targeted by the CALM maritime pine plan. This was achieved by revising the 'pre-1984' description and lowering its lower limit of mean annual rainfall and increasing the dry season length to eight months (most of the 400-600 mm rainfall zone in WA has a 6-8 month dry season). The lower limit of the mean minimum temperature of the coldest month was lowered also to match the CABI (2000) lower limit. The lower limits for mean maximum temperature of the hottest month and mean annual temperature were not changed to match the CABI (2000) description as these changes do not significantly affect the suitable areas mapped in Australia.

***Pinus pinaster* continued**

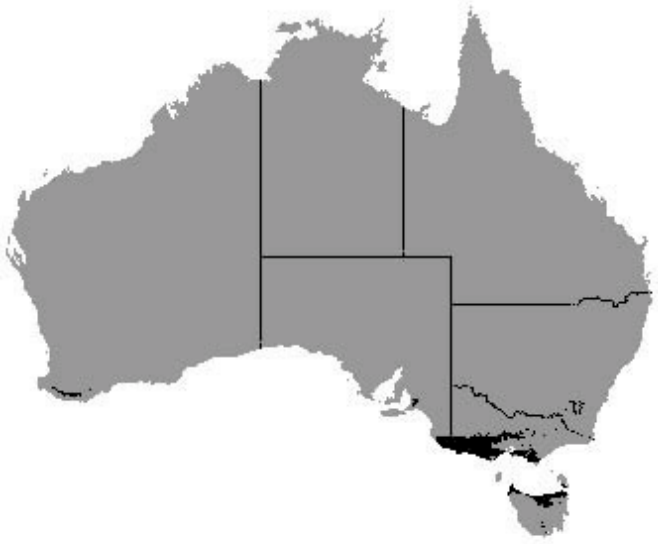

Fig. 4.26.1 Climatically suitable areas for *P. pinaster* (based on CABI 2000) shown in black

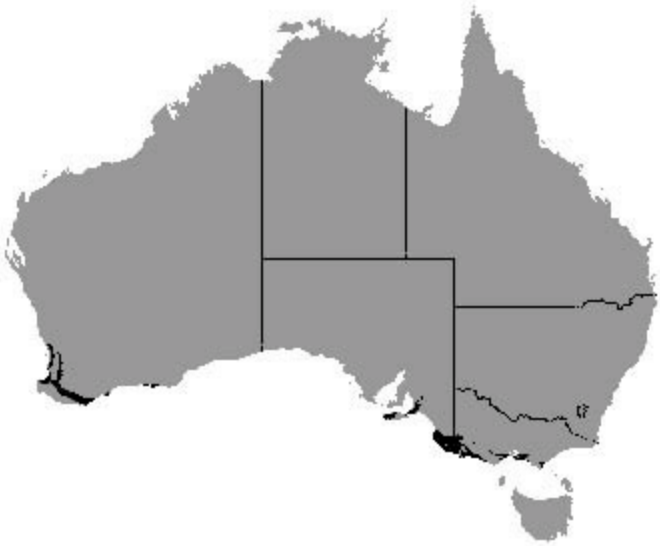

Fig. 4.26.2 Climatically suitable areas for *P. pinaster* (based on analysis of pre-1984 plantations) shown in black

***Pinus pinaster* continued**

Climatic requirements	**CABI(2000)**	**(Pre-1984)**	**(revised)**
Mean annual rainfall (mm)	400 – 1200	600 – 950	400[A] – 1200
Rainfall regime	winter	winter	winter, uniform
Dry season length (months)	0 – 4	0 – 5	0 – 8
Mean max. temp. hot. mth. (°C)	15 – 26	22 – 31	22 – 31
Mean min. temp. cold. mth. (°C)	0 – 6	4 – 8	0 – 8
Mean annual temp. (°C)	10 – 23	13 – 18	13 – 18

[A] Particular care should be taken when planting the species in low rainfall environments to ensure that local conditions are suitable and appropriate planting densities are used.

The CABI (2000) description includes low rainfall (ie 400-600 mm) zones, but indicates a requirement for relatively short dry seasons (ie 0-4 consecutive months with less than 40 mm of rainfall). Such areas are fairly common in Spain and North Africa, and significant areas exist in Victoria, but such dry areas in Western Australia have a much longer dry season. However, it should be remembered that trees planted in the 400-600 mm rainfall zone of WA may have access to groundwater.

The pre-1984 description indicates that *P. pinaster* plantations in the past have been planted in areas with moderate levels of rainfall. It also shows that mean maximum temperatures of the hottest month are considerably warmer in Australia than those found at *P. pinaster* sites in Europe.

The revised description includes 400 mm as the lower rainfall limit, but plantations in WA are being established mainly in the 500-600 mm zone of the 400-600 mm rainfall belt (R. Harper pers. comm.). Plantations tend to be south of Moora, which is about 130 km north of Perth. There is a significant evaporation gradient from south to north in WA, with the evaporation/precipitation ratio being about 50 % greater in northern areas of the 500-600 mm zone than in the southern areas.

The revised description also includes uniform rainfall areas, such as those in New South Wales where the suitability of *P. pinaster* is currently under evaluation. The evaporation/precipitation ratio is about 30% higher in northern parts of the 500-600 mm rainfall zone of New South Wales in comparison to southern areas. Preferred low rainfall areas for *P. pinaster* may be in southern areas of NSW with annual precipitation above 500 mm, similar to WA. *P. pinaster* has recently been planted in dryland salinity demonstration trials being run by State Forests of NSW. The latest results from these trials should be considered before planting the species at sites in New South Wales.

***Pinus pinaster* continued**

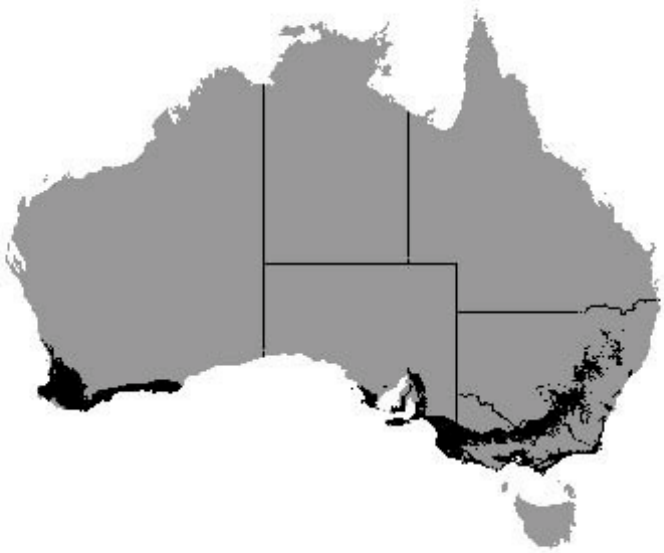

Fig. 4.26.2 Climatically suitable areas for *P. pinaster* (based on pre-1984 plantations and current trial developments) shown in black

4.27 *Pinus radiata* D. Don (Radiata pine)

Pinus radiata (Radiata or Monterey Pine) is found naturally in three small areas south of San Francisco and on two small islands off the Baja Peninsula. The total area of natural stands is only around 7000 ha, but the species is now the most extensively planted exotic softwood in the temperate zone with about four million hectares of plantations worldwide. *P. radiata* dominates commercial plantations in Australia accounting for about 642,000 ha or about 60 per cent of the total area as of 1994 (National Forest Inventory, 1997). It is typically grown in rotations of about 30 years with one or two thinnings. The thinning operations produce pulpwood and poles, whilst the final harvest produces timber suitable for uses such as house framing and relatively low cost furniture.

We have previously presented a description of the climatic requirements of the species based on an analysis of climatic conditions at 71 plantations across Australia, which then represented about 90% of Austrlia's radiata pine estate (Booth and Jovanovic, 1991; see below). For the present study this description was checked by comparing the description with climatic conditions estimated using the locations of 33 plantations (Turvey *et al.*, 1990). Twenty one of the locations were included in both datasets and 30 of the 33 locations were within the mean annual rainfall range of the 1991 description. Two locations (Strahan and Oonah) in Tasmania had slightly higher rainfalls (1742 and 1763 mm), whilst one location Comaum (South Australia) was estimated to have a slightly lower rainfall (635 mm). The upper range was modified to include the Tasmanian sites, but the existing lower limit was retained as this is commonly considered to be appropriate for *P. radiata*. Though one location had a summer rainfall season, *P. radiata* is generally better suited to winter/uniform rainfall environments, so this seasonality requirement was retained. Of the locations 27 of the 33 had no dry season (i.e. consecutive months with less than 40mm rainfall) and all locations had a dry season length of four months or less. However, all the 33 locations came from eastern Australia and it was pointed out to us that *P. radiata* is grown in the Busselton area of Western Australia (R. Harper, pers. comm.). As the average dry season length in this area is five months the description was modified. Only one location (Oonah, Tasmania; 18^{o}C) had a mean maximum temperature of the hottest month outside the 1991 range, but the revised description was modified to include this location. All the 33 locations fell within the mean minimum temperature of the coldest month range. Five locations had mean annual temperatures below the lower limit of the 1991 description (i.e. 11^{o}C). These were Sunny Corner, NSW (10^{o}C); Hampton, NSW (10^{o}C); Myrtle Grove, Tasmania (10^{o}C); Oonah, Tasmania (9^{o}C); and Tower Hill, Tasmania (10^{o}C).

	Climatic requirements (Booth & Jovanovic 1991)	**Climatic requirements (revised)**
Mean annual rainfall (mm)	650 – 1600	650 – 1800
Rainfall regime	uniform, winter	uniform, winter
Dry season length	0 – 4 months	0 – 5 months
Mean max. temp. hot. mth. (°C)	20 – 30	18 – 30
Mean min. temp. cold. mth. (°C)	-2 – 12	-2 – 12
Mean annual temp. (°C)	11 – 18	10 – 18

***P. radiata* continued**

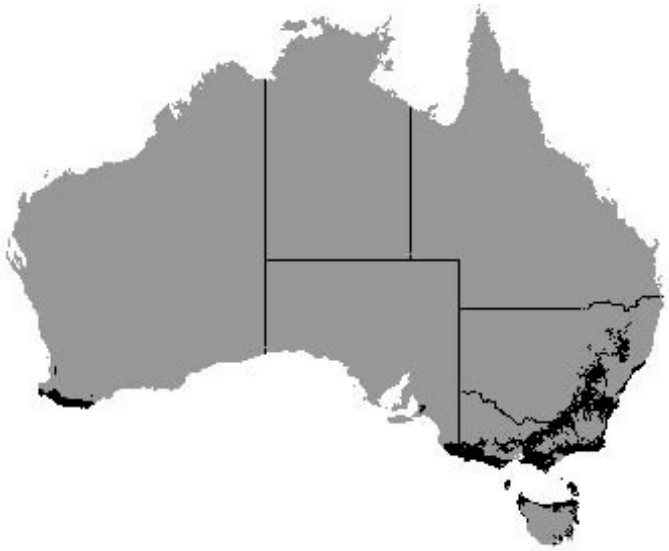

Fig. 4.27.1 Climatically suitable areas for *P. radiata* (based on description in Booth and Jovanovic 1991) shown in black

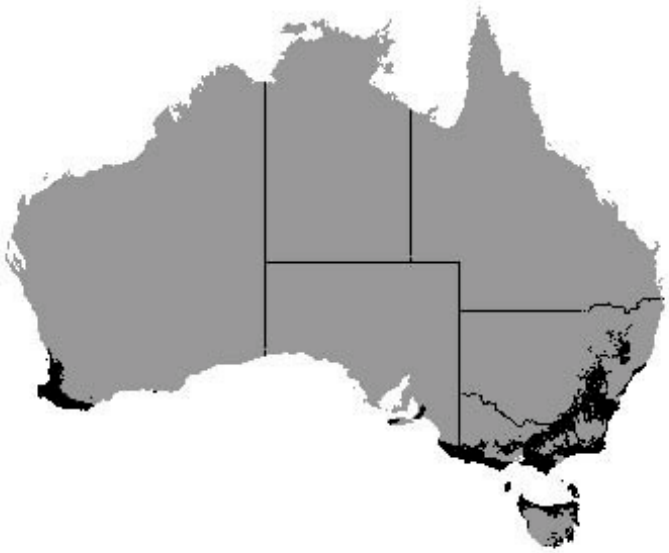

Fig. 4.27.2 Climatically suitable areas for *P. radiata* (based on slightly revised description produced for this report) shown in black. Note increased suitable area in Western Australia.

6. References

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