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An Australian Government Initiative



Australian Low Rainfall Tree Improvement Group

*Metadata from measures of hardwood tree
improvement trials in Southern Australia*

RIRDC Publication No. 09/078





Australian Low Rainfall Tree Improvement Group: Metadata from measures of hardwood tree improvement trials in Southern Australia

Edited by David Bush, Tim Jackson, Joshua Driscoll and Chris Harwood

June 2009

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Foreword

This report contains important high level data summaries (metadata) taken from the measurement of 30 tree improvement trials established by partners of the Australian Low Rainfall Tree Improvement Group (ALRTIG). The report focuses on hardwood species that are suited to Australia's low rainfall sheep-wheat belt, an area that is of increasing interest to Australian society for a number of reasons including biodiversity, water security and potential for diversified agriculture including carbon sequestration and bioenergy production. ALRTIG's goal, since its formation in 1999, has been to develop and genetically improve tree species that are both well-adapted to this region, and that will produce commercially valuable products in tandem with environmental outcomes.

The report will be of value to scientists, resource planners and modellers and growers who are seeking scarce 'hard data' of sufficient reliability to guide plantation establishment in this area. The report also provides some insight into ALRTIG's capacity to produce genetically improved seed and other germplasm for this purpose, as many of the trials described are being developed into working seed orchards, a few of which have commenced production within the last two years.

This project has been jointly funded by JVAP and the ALRTIG partner organisations, CSIRO, Forest Products Commission WA, Primary Industries and Resources South Australia, Forests NSW, and Department of Primary Industries, Victoria.

This project was funded by the Joint Venture Agroforestry Program (JVAP), which is supported by three R&D Corporations - Rural Industries Research and Development Corporation (RIRDC), Land & Water Australia (L&WA), and Forest and Wood Products Research and Development Corporation¹ (FWPRDC). **The Murray-Darling Basin Commission (MDBC) also contributed to this project.** The R&D Corporations are funded principally by the Australian Government. **State and Australian Governments contribute funds to the MDBC.**

This report is an addition to RIRDC's diverse range of over 1800 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

Most of RIRDC's publications are available for viewing, downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation

¹ Now Forest & Wood Products Australia (FWPA)

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The data reported have been collected with the help and support of a large number of people who have put a huge amount of effort into planning, planting, maintaining, measuring and analysing the trials. We acknowledge these people, literally in the hundreds, for the effort they have put in, and a glance at the listed references in each part shows many of the people who have been involved in reporting. A few of the many people who have ‘worked behind the scenes’ that deserve specific recognition here include Andrew Callister, Adrian Agars, Bev Boyer, Brioni Brammall, Sally Collins, Amy Ho, Adrian Lynch, Tracee Perry, Dean Severino, Helen Smith, Clinton Tepper, Paul Turnbull, and Bob Wood. Our most sincere thanks go to the many landholders who have supported the project by hosting trials on their farms. Without this group of people this research would not have been possible.

Abbreviations

ALRTIG	Australian Low Rainfall Tree Improvement Group
ANOVA	Analysis of variance
ATSC	Australian Tree Seed Centre
BLUE	Best linear unbiased estimator
BLUP	Best linear unbiased predictor
CP	Controlled pollination
CSIRO	Commonwealth Scientific Industrial Research Organisation
CSO	Clonal Seed Orchard
DBH	Diameter at breast height
DEC	Department of Environment and Conservation (Western Australia)
DSE	Department of Sustainability and Environment (Victoria)
DPI	Department of Primary Industries (Victoria)
FNSW	Forests New South Wales
FPC	Forest Products Commission (Western Australia)
GxE	Genotype-by-environment interaction
JVAP	Joint Venture Agroforestry Program
MAI	Mean annual increment
MAR	Mean annual rainfall
OP	Open pollinated
PT	Progeny trial

REML	Restricted maximum likelihood
RIRDC	Rural Industries Research and Development Corporation
ROP	Region-of-provenance
SF	State Forest
SO	Seed orchard
SPA	Seed Production Area
SS	Seed stand
SSO	Seedling Seed Orchard

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Executive Summary

What the report is about

This report summarises early results from a total of 30 breeding trials implemented by the Australian Low Rainfall Tree Improvement Group (ALRTIG), established across the low-rainfall (400-650 mm mean annual rainfall) zone of southern Australia. The trials evaluated genetic variation in three important plantation eucalypt species: spotted gum (*Corymbia maculata*), sugar gum (*E. cladocalyx*) and swamp yate (*E. occidentalis*). The report provides information on survival, growth and stem form of the different seed sources tested (natural provenances, and seedlots from seed orchards and other planted stands) in the individual trials. Assessments made at ages ranging from two to six years are reported. For each species, the relative performance of the seed sources across different trial sites is given, showing the degree of GxE (genotype by environment interaction), which is important when choosing seedlots for planting and making decisions about breeding strategy.

Why the research is important

Prior information on growth rates of tree plantations in the low rainfall zone is very limited, so the data reported here will enable prospective growers to obtain a better idea of the performance that can be expected from well-managed plantations, and the degree of improvement obtainable from genetically improved seed sources over wild material.

Who is the report targeted at?

The report will be of interest to tree breeders, farm foresters, tree planting companies and policy makers who are considering plantation forestry in the wheat-sheep belt. It presents information on material under test in field trials, trial design and performance achieved that also suggest further research opportunities in a range of scientific disciplines including forest health, hydrology, tree physiology and wood science. The ALRTIG trials already support research projects in some of these areas.

Background

Spotted gum, sugar gum and swamp yate were identified by the ALRTIG partners as suitable for planting in the wheat-sheep zone of southern Australia and capable of producing commercial wood products. There is interest from farm foresters and forest plantation companies in planting these species for wood products and environmental services such as carbon sequestration, hydrological control and shelter for livestock. Breeding programs were initiated by ALRTIG in the late 1990s and genetically improved seed is now becoming available. The trials reported here were established as part of these breeding programs

The introductory section to this report provides background on ALRTIG's formation following a workshop in 1998, and the subsequent development of tree improvement plans for a small number of 'key species' suited to southern Australia's sheep-wheat belt. These strategies are not covered in depth in this document, rather a list of references to the relevant publications (freely downloadable in PDF format from RIRDC) is given. This section also lists the complete set of over 75 trials that have been established by ALRTIG since 1999, and suggests some possible further uses and development for the rich biological and ecological research opportunity that this resource represents.

The subsequent three Metadata Parts each focus on a separate species: *Eucalyptus occidentalis* (swamp yate), *E. cladocalyx* (sugar gum) and *Corymbia maculata* (spotted gum). Each part is self-contained with descriptions of the trial sites, genetic materials, trial establishment and management, traits measured and statistical methodology. This information is then followed by results including both

comprehensive data tables and statistical measures and graphical data representation. This is followed by general discussion of the implications of the results.

Aims/objectives

The overall purpose of ALRTIG is to develop improved planting material of key tree species suitable for planting in low-rainfall regions of southern Australia and make growers aware of its availability. The trial results reported here contribute to the breeding programs. This report makes public a large amount of information on the performance of three key eucalypt species in trials across the low rainfall region of southern Australia, and the levels of genetic variation among natural provenances and other seed sources from planted stands including seed production areas and seed orchards.

Methods used

Each individual trial reported here tests a range of genetic material of a single species. Individual *provenance-progeny trials* tested many (from 50 to 130) families from a number of different seed sources. A family or progeny is seedlings raised from seed collected from a single mother tree. These trials tested 4-5 replicates of small (4-5 tree) line plots of each family. The performance of each provenance, or other seed source such as a seed orchard, can be estimated as the average of the families originating from it. Assessments made at age 5-6 years are reported here. *Seed source trials* compared a small number (4-7) “best-bet” available seedlots including natural provenances and seedlots collected from planted stands such as seed orchards. Seed source trials used five replicates of large (e.g. 64-tree) plots, that will eventually provide reliable estimates of per-hectare wood production. These seed source trials were established at a later stage of the ALRTIG program and consequently were assessed at age 2-3 years for this report. All trials were assessed for survival and growth traits, and most trials were assessed for stem-form and branching traits. Statistical analysis was conducted to test the significance of differences between seed sources in each individual trial. For each species changes in relative performance of different seed sources across the different trials (GxE) were also examined.

Results/key findings

Survival to age 5-6 years in the provenance-progeny trials was generally good to excellent (over 80%) indicating that the species were well-adapted to most of the trial sites. Growth of all three species in the individual trials was slow to moderate. Estimates of mean annual wood volume increment in the provenance-progeny trials to age 5-6 years were generally less than $10 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$, and in most cases well below this figure, with the exception of one trial of *E. occidentalis* on an irrigated site at Boort, Vic, which grew at about $9.5 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$ to age 3.4 years.

Swamp yate: Overall survival exceeded 80% for 4 out of 6 provenance-progeny trials but was lower (between 50 and 60%) in two trials which experienced severe drought after planting. Rankings of seed sources in the provenance-progeny trials for height and stem diameter growth were relatively stable across the sites, with the Grass Patch, Ongerup and Red Lake provenances proving superior. These provenances also had superior stem form. Families from planted seed production areas were not superior. In three seed source trials, Grass Patch provenance performed as well as seedlots from planted seed stands in SA, and outperformed a seedlot from a planted stand near Boort, Vic.

Sugar gum: Survival to age 5-6 years in the provenance-progeny trials exceeded 80% at 5 out of 8 sites and exceeded 60% at the other three sites. Rankings of seed sources for height and stem diameter growth were stable across most sites. Progenies from four planted stands (a seed orchard at Kersbrook, SA, and plantations at Lismore and Wail (Vic) and Mt Burr (SA) outperformed those from natural provenances in the southern Flinders Ranges and Kangaroo Island, SA. They also had superior stem form. In the seed source trials, a seedlot from a provenance trial at Bundaleer (SA) and a natural provenance from Kangaroo Island performed poorly.

Spotted gum: Survival in four provenance-progeny trials in western Victoria was excellent, except at a dry, frosty site at Brynterion, Vic where it was only 51%. Progenies from Barclays seed orchard at Deniliquin, NSW and from Mumbula State Forest, Kioloa State Forest in NSW and Mottle Range, Vic, displayed good growth. In the seed source trials, seedlots of northern spotted gum (*C. citriodora* ssp. *variegata*) grew more slowly, particularly in their stem diameter, and displayed poorer survival than did the *C. maculata* seedlots tested. *C. maculata* seedlots from two planted stands (Barclays seed orchard and a provenance trial at Hamilton, Vic) outperformed the Bodalla natural provenance.

Implications for relevant stakeholders:

Prospective growers, and decision-makers influencing tree planting, can obtain information on performance of the species, genetic variation within each species, and the extent to which rankings of provenances and other seed sources are stable, across diverse dryland planting sites in southern Australia. Using the best seed source makes a very important contribution in determining the success of plantations, and the report will assist in selection of the best currently available seed sources of these species. The full implications of the results are outside the scope of the report.

Recommendations

Growers should use these results to help forecast plantation growth rates and choose appropriate seed sources. The significant differences in survival, growth and stem form among provenances and other seed sources demonstrated for all three species confirm the potential for ongoing genetic improvement in the ALRTIG breeding programs. Some seed orchards of sugar gum and spotted gum tested in these trials produced seedlots that outperformed natural provenances and can be recommended as a source of planting material.

Introduction to the metadata report

About ALRTIG

ALRTIG, the Australian Low Rainfall Tree Improvement Group, has a mission to produce genetically improved planting material for farm forestry in the low rainfall areas of southern Australia, and inform tree growers of its availability.

The ALRTIG concept was developed at a workshop organised during 1998 by the Joint Venture Agroforestry Program and the South Australian State forestry research organisations (Bush and Bulman 1999). Its membership includes tree improvement stakeholders from the southern States, each of whom were undertaking independent research programs of a modest scale prior to its formation. It was recognised that better progress could be made by pooling existing and future resources in a cooperative model. The concept of an ALRTIG was put forward and agreed to in principle. Following discussions between State and Commonwealth Government researchers, JVAP and representatives of the Department of Agriculture Fisheries and Forestry Natural Heritage Trust (a precursor to the Caring for Our Country program), a cooperative low rainfall tree improvement program was established in 1999. Some of the ALRTIG partners are detailed in Table 1, though there are many others (mainly private landholders) involved in the trial programs.

Table 1. Partners in ALRTIG

Organisation	State	Nature of Involvement
<i>Core partners</i>		
CSIRO Forest Biosciences ¹	Commonwealth	Coordination and implementation of program
Forests NSW ²	New South Wales	Implementation of program
Primary Industries and Resources (PIRSA) ³	South Australia	Implementation of program
Department of Primary Industries (DPI) and The University of Melbourne ⁴	Victoria	Implementation of program
Forest Products Commission (FPC) ⁵	Western Australia	Implementation of program
Joint Venture Agroforestry Program (JVAP)	Commonwealth	Funding body and program steering
<i>Other research partners</i>		
Private Forests Tasmania	Tasmania	<i>P. pinaster</i> yield trial partner
Department of Environment and Conservation (DEC) ⁴	Western Australia	Led short-rotation project
The Australian National University (ANU)	Commonwealth	Involved in short-rotation project
<i>Industry partners</i>		
Organisation	State	Nature of Involvement

G.R. Davis Pty Ltd	NSW	Short-rotation trial partner
Hancock Victorian Plantations Pty Ltd	Victoria	Brutian pine collaborator
Integrated Tree Cropping Ltd	Western Australia	Seed source trial partner
Treecorp Ltd	Victoria	Seed source trial partner
Woollybutt Pty Ltd	Victoria	Seed source trial partner

-
1. CSIRO Forest Biosciences was formerly known as CSIRO Division of Forestry and Forest Products and Ensis
 2. Forests New South Wales was formerly known as State Forests of New South Wales
 3. Responsibility for the ALRTIG program has shifted from ForestrySA to PIRSA, though both have been involved since 1999
 4. The Victorian Department of Natural Resources and Environment split into the Department of Primary Industries (DPI) and the Department of Sustainability and Environment (DSE) in 2002. DSE's interests were transferred to The University of Melbourne (UM), School of Forest and Ecosystem Science in 2004. ALRTIG works with both DPI and UM.
 5. The Forest Products Commission was split as a separate entity from Western Australia's Department of Conservation and Land Management which is now called Department of Environment and Conservation. ALRTIG works with both organisations

Tree Improvement Programs

ALRTIG has developed tree improvement programs in three areas: hardwoods, softwoods and short rotation woody crops. A small number of 'key species' was selected from a list of candidates for each area (Bush *et al.* 2001) based on pre-existing knowledge about adaptability, growth rates, biological information and existence of suitable genetic materials for a breeding program. Separate Technical Committees were formed for each of the three research areas, and the members jointly developed breeding strategies for the various key species in 2000. These strategies were published by RIRDC in three separate documents, (details are given in Table 2). The hardwoods strategies were updated in 2004 (Harwood *et al.* 2005).

Table 2. ALRTIG genetic improvement programs: summary of published information

Species	Authors	Reference
Hardwoods	(Harwood <i>et al.</i> 2001)	Compendium of hardwood breeding strategies
<i>E. occidentalis</i>	(Harwood 2001)	Genetic improvement strategy for <i>Eucalyptus occidentalis</i> in southern Australia
<i>E. camaldulensis</i>	(Harwood and Mazanec 2001)	Program for Genetic Improvement of <i>Eucalyptus camaldulensis</i> in Southern Australia
<i>E. cladocalyx</i>	(Harwood and Bulman 2001)	Genetic improvement strategy for <i>Eucalyptus cladocalyx</i> in southern Australia
Red ironbarks (<i>E. tricarpa</i> and <i>E. sideroxylon</i>)	(Stackpole and Harwood 2001)	Genetic improvement strategy for <i>Eucalyptus tricarpa</i> in southern Australia
Spotted gums (<i>Corymbia</i>)	(Mazanec and Harwood 2001)	Genetic improvement strategy for spotted gums in southern Australia
Update of hardwood strategies	(Harwood <i>et al.</i> 2005)	Update of Australian Low Rainfall Tree Improvement Group Breeding Strategies
Softwoods	(Boardman <i>et al.</i> 2002)	Compendium of softwood breeding strategies
<i>P. pinaster</i>	(Butcher 2002)	Genetic gain trial* strategy for <i>Pinus pinaster</i> in southern Australia
<i>P. brutia</i>	(Spencer and Boardman 2002)	Genetic Improvement Strategy for <i>Pinus brutia</i> in southern Australia
<i>P. radiata</i>	(Matheson <i>et al.</i> 2005)	A strategy to develop a low rainfall breed of <i>Pinus radiata</i>
Short rotation crops		
<i>E. horistes</i> and <i>E. polybractea</i>	(Bartle and Brennan 2002)	Mallee genotype/environment interaction

* The seed source trials are also known as genetic gain trials

Activities and trials

ALRTIG partners, in association with a large number of collaborators, have established a substantial planted resource since 2000. The planted resources can be categorised as follows:

- (i) Progeny trials - seedling seed orchards (PT-SSOs). These are planted trials that are designed to both test genetic materials (open-pollinated seedling progeny of individual trees) and form the breeding base population for recurrent breeding programs. Some of these trials are earmarked for later conversion to seed production.
- (ii) Genetic gain (seed source) trials established by ALRTIG that are designed to test the relative superiority of genetically improved materials across a range of sites.
- (iii) Clonal seed orchards. These are composed of grafted clones of individual trees selected for their demonstrated or likelihood of superiority
- (iv) Seed production areas and seed stands. These are planted stand of known genetic origin that were existent prior to 1999 that were identified by ALRTIG as relatively superior sources of seed prior to the ALRTIG seed orchards becoming productive.

Much of the detail of the composition of the various trials is described in some detail in the publications listed in Table 1. Additional information and some early results on some species can be found in Bush *et al.* (2007) and Harwood *et al.* (2007).

Overall ALRTIG has established 76 trials, details of which are summarised in Table 3.

About the metadata

Species

The metadata reported here are taken from 30 of ALRTIG's progeny trial and seed source (genetic gain) trial sites. The focus of this report is on three of the most prospective hardwood species, *Eucalyptus cladocalyx* (sugar gum), *E. occidentalis* (swamp yate) and *Corymbia maculata* (spotted gum). These species were selected because of the good range of ALRTIG trials throughout the sheep wheat belt available for analysis, and the growing commercial prospects of the species (particularly sugar gum and spotted gum).

Of course there are a number of excellent datasets that are not reported in this metadata report. In the case of the pines, it would be useful to carry out a metadata compilation in the future. Pines generally grow at a lower rate than eucalypts for the first few years, and the ALRTIG pine trials will be of a suitable size for assessment several years from now. The short rotation crops have already been harvested in some cases, and growth and oil traits are being assessed by DEC WA. The red ironbarks (*E. tricarpa*) have already been studied in some detail, particularly aspects of their leaf chemistry (Andrew *et al.* 2007). The *E. sideroxylon* trials, which were planted in 2002, are currently being assessed.

Traits

A wide variety of traits have been assessed for the trials reported here. These are of two main sorts: growth traits and form traits. In some cases other traits such as flowering, seed production and leaf characteristics have also been assessed. While height and diameter have been assessed using standard, uniform techniques, the form traits have been assessed using a variety of scores and measures that are standard measures in the institutes that have carried out the assessment. The benefit of this is that the ALRTIG trial data can be compared with

other trial data belonging to each organisation. A disadvantage is that cross-site comparisons in the ALRTIG trial series are complicated. There are various approaches to addressing this, such as transcribing scores from one system to another (e.g. compressing a 1-6 scale to a 1-4 scale) or conversion to standard deviation units. We have chosen not to take this approach in the metadata described here, as there are some problems with undertaking conversions (especially of data that is not normally distributed) that may be misleading to the reader. We have taken the view that it is better to present the metadata user with the untransformed metadata results, the underlying data of which could potentially be transformed as necessary in future. An exception to this is the simple case where transformation is a trivial matter of 'reversing' scores (e.g. converting from scored from 1-4 worst-to-best to 1-4 best-to-worst) or converting a 0-5 scale to a 1-6 scale where the six categories are identical.

Environmental data

Basic site summaries are presented for each of the sites, including an estimate of climatic parameters and a one-line description of the soil. For some sites, more detailed soil physical properties have been determined (see Table 3), and these data reside with the trial manager.

Genotype-by-environment interaction

As the trials have been established across a wide range of sites, they are well suited for assessment of genotype-by-environment interaction (GxE). Genotype-by-environment interaction refers to the differential performance of genetic groups, such as provenances, across sites. If for example Provenance A was the best of three provenances at Site 1, but ranked the lowest at Site 2, there would be provenance-by-site interaction. If one were to consider this result with the objective of choosing the best provenance to plant at untested Site 3, clearly the choice of Provenance A would be risky, unless it was evident that Site 3 was going to behave as Site 1 had done (perhaps, for example, Site 1 and 3 are free from frost and the poor performance at Site 2 was due to frost damage). If there is little or no GxE across a wide range of sites then selection of provenances for untested sites will be straightforward. Identification and characterisation of GxE where there are a large number of sites and genotypes is a complex science. If there are more than a few combinations of sites and genotypes there will nearly always be some rank changes amongst the genotypes, and the challenge is then to decide whether these are of a minor nature or will impact significantly on selection.

Potential uses for the trials and data

The majority of the trials here serve to generate genetic data to underpin breeding programs for the ALRTIG key species, some of the trials form the breeding populations of the target species and some are being developed to produce genetically improved seed. However this suite of trials is a large and well-designed resource that could potentially be tapped by a variety of other users. The value of the resource is amplified by the fact that very few well designed and documented forestry trials exist in the sheep-wheat belt, despite the growing interest in this area. Some potential uses include but are not limited to:

- Estimation of growth rates
- Carbon sequestration parameters (e.g. biomass partitioning, rate of storage)
- Collection and measurement of biological data on flowering, photosynthesis
- Genotype by environment interaction study

- Soil water and hydrology under plantation
- Biodiversity (insect, avian etc)

The metadata report is designed to show potential users the data that are available, and that could potentially be available with extra research.

Table 3. List of ALRTIG trials by location and type

Species	Type*	Planted	Location	State	Organisation†	Area	Soil	Status
<i>C. maculata</i>	PT-SSO	2001	Willow Tree	NSW	FNSW	1.0		POOR
<i>C. maculata</i>	PT-SSO	2001	Hensley Park	Vic.	DPI	1.0		METADATA
<i>C. maculata</i>	PT-SSO	2001	Balmoral	Vic.	DPI	1.0		METADATA
<i>C. maculata</i>	PT-SSO	2001	Buckley Swamp	Vic.	DPI	1.0		METADATA
<i>C. maculata</i>	PT-SSO	2001	Brynterion SF	Vic.	DPI	1.0		METADATA
<i>C. maculata</i>	PT-SSO	2002	Esperance	WA	FPC	1.0		OK
<i>E. cladocalyx</i>	Gain	2003	Kojonup	WA	ITC	1.2		OK
<i>E. cladocalyx</i>	Gain	2003	Wagga Area	NSW	FNSW	1.2		OK
<i>E. cladocalyx</i>	Gain	2001	Hamilton	SA	TREECORP	1.0		POOR
<i>E. cladocalyx</i>	Gain	2003	Bundaleer	SA	PIRSA	1.5		METADATA
<i>E. cladocalyx</i>	Gain	2003	Kangaroo Island	SA	PIRSA	1.3		METADATA
<i>E. cladocalyx</i>	Gain	2003	Lismore	Vic.	DPI/UM	1.2		METADATA
<i>E. cladocalyx</i>	Gain	2003	Craigieburn	Vic.	Woollybutt	1.2		METADATA
<i>E. cladocalyx</i>	Gain	2003	Tenterden	WA	FPC	1.2		OK
<i>E. cladocalyx</i>	Gain	2003	Rocky Gully	WA	ITC	1.2		METADATA
<i>E. cladocalyx</i>	PT	2001	Kojonup	WA	ITC	1.0		OK
<i>E. cladocalyx</i>	PT	2001	Wellstead	WA	ITC	1.0		OK
<i>E. cladocalyx</i>	PT	2001	Esperance	WA	ITC	1.0		OK
<i>E. cladocalyx</i>	PT-SSO	2001	Brucedale	NSW	FNSW	1.0		METADATA
<i>E. cladocalyx</i>	PT-SSO	2001	Corowa	NSW	CSIRO	1.5		METADATA
<i>E. cladocalyx</i>	PT-SSO	2001	Bordertown	SA	PIRSA	1.0		METADATA
<i>E. cladocalyx</i>	PT-SSO	2001	Avenue	SA	PIRSA	1.0		METADATA
<i>E. cladocalyx</i>	PT-SSO	2001	Western Flat	SA	PIRSA	1.0		FAILED
<i>E. cladocalyx</i>	PT-SSO	2001	Lismore	Vic.	DPI	1.0		METADATA
<i>E. cladocalyx</i>	PT-SSO	2001	Kalkee	Vic.	DPI	1.0		OK
<i>E. cladocalyx</i>	PT-SSO	2001	Esperance	WA	FPC	1.0	Yes	METADATA
<i>E. cladocalyx</i>	PT-SSO	2001	Moora	WA	FPC	2.4	Yes	METADATA
<i>E. horistes</i>	Gain/Gx	2001	West Wyalong	NSW	FNSW	0.5		OK
<i>E. horistes</i>	Gain/Gx	2001	Murray Bridge	SA	PIRSA	0.5		OK
<i>E. horistes</i>	Gain/Gx	2001	Bendigo	Vic.	DPI	0.5		OK
<i>E. horistes</i>	Gain/Gx	2001	Dowerin	WA	DEC WA	0.5		OK
<i>E. occidentalis</i>	Gain	2003	Wagga Area	NSW	FNSW	1.2		OK
<i>E. occidentalis</i>	Gain	2003	Marcollat	SA	PIRSA	1.2		METADATA
<i>E. occidentalis</i>	Gain	2003	Carew	SA	PIRSA	1.2		OK
<i>E. occidentalis</i>	Gain	2003	McKerrals	Vic.	Treecorp	1.2		POOR
<i>E. occidentalis</i>	Gain	2003	Tenterden	WA	FPC	1.2		OK
<i>E. occidentalis</i>	Gain	2003	Rocky Gully	WA	ITC	1.2		METADATA
<i>E. occidentalis</i>	PT	2001	Esperance	WA	FPC	1.9	Yes	METADATA
<i>E. occidentalis</i>	PT	2001	Moora	WA	FPC	1.7	Yes	OK
<i>E. occidentalis</i>	PT-SSO	2001	Narrandera	NSW	FNSW	2.3		METADATA
<i>E. occidentalis</i>	PT-SSO	2001	Marcollat	SA	PIRSA	1.8		METADATA
<i>E. occidentalis</i>	PT-SSO	2001	Boort	Vic.	DPI	1.9		METADATA
<i>E. occidentalis</i>	PT-SSO	2001	Dunkeld	Vic.	DPI	1.0		METADATA
<i>E. occidentalis</i>	PT-SSO	2002	Brynterion SF	Vic.	DPI	1.0		METADATA
<i>E. occidentalis</i>	PT-SSO	2002	Rupanyup	Vic.	DPI	1.0		OK
<i>E. polybractea</i>	Gain/Gx	2001	West Wyalong	NSW	FNSW	0.5		OK
<i>E. polybractea</i>	Gain/Gx	2001	Murray Bridge	SA	PIRSA	0.5		OK
<i>E. polybractea</i>	Gain/Gx	2001	Bendigo	Vic.	DPI	0.5		OK

Species	Type*	Planted	Location	State	Organisation†	Area	Soil	Status
<i>E. polybractea</i>	Gain/Gx	2001	Wickepin	WA	DEC	0.5		OK
<i>E. sideroxylon</i>	PT-SSO	2002	Corowa	NSW	CSIRO	2.0		METADATA
<i>E. sideroxylon</i>	PT-SSO	2002	Melville Forest	NSW	DPI	1.0		OK
<i>E. tricarpa</i>	PT-SSO	2000	Walla Walla	NSW	FNSW	1.0		OK
<i>E. tricarpa</i>	PT-SSO	2000	Huntly	Vic.	DPI	1.0		OK
<i>E. tricarpa</i>	PT-SSO	2000	Lake Tyers	Vic.	DPI	1.0		OK
<i>E. tricarpa</i>	PT-SSO	2001	Esperance	WA	FPC	1.0		OK
<i>P. brutia</i>	CSO	2002	Weston Creek	ACT	CSIRO	2.0		POOR
<i>P. brutia</i>	CSO	2001	Bundaleer	SA	PIRSA	2.0		OK
<i>P. brutia</i>	CSO	2001	Manjimup	WA	FPC	2.0		OK
<i>P. brutia</i>	PT	2002	Back Yamma	NSW	FNSW	1.9		POOR
<i>P. brutia</i>	PT	2002	Bundaleer	SA	PIRSA	1.9		OK
<i>P. brutia</i>	PT	2002	Brookton	WA	FPC	1.9		OK
<i>P. pinaster</i>	Yield	2000	Lake Albert	NSW	FNSW	2.0	Yes	OK
<i>P. pinaster</i>	Yield	2000	Harefield	NSW	FNSW	2.0	Yes	OK
<i>P. pinaster</i>	Yield	2000	Tintinara	SA	PIRSA	2.0	Yes	OK
<i>P. pinaster</i>	Yield	2000	Carrick	TAS	PFT	1.9	Yes	POOR
<i>P. pinaster</i>	Yield	2000	Campbell Town	TAS	PFT	2.9	Yes	POOR
<i>P. pinaster</i>	Yield	2000	Kamarooka	Vic.	DPI	2.0	Yes	POOR
<i>P. pinaster</i>	Yield	2000	Cressy	Vic.	DPI	2.0	Yes	OK
<i>P. pinaster</i>	Yield	2000	Telopea Downs	Vic.	PIRSA	2.0	Yes	OK
<i>P. pinaster</i>	Yield	2000	Esperance	WA	FPC	2.2	Yes	OK
<i>P. pinaster</i>	Yield	2000	Marchagee	WA	FPC	1.3	Yes	OK
spotted gum	Gain	2003	Quirindi	NSW	FNSW	1.2		OK
spotted gum	Gain	2003	Bordertown	SA	PIRSA	1.2		METADATA
spotted gum	Gain	2003	Melville Forest	Vic.	DPI	1.2		METADATA
spotted gum	Gain	2003	Craigieburn	Vic.	Woollybutt	1.2		METADATA
spotted gum	Gain	2003	Tenterden	WA	FPC	1.2		OK
spotted gum	Gain	2003	Rocky Gully	WA	ITC	1.2		METADATA
Total						101	Ha	

*CSO=clonal seed orchard; Gain=seed source (genetic gain) trial; PT denotes progeny trial; SSO=seedling seed orchard; GxE=genotype-by-environment interaction trial; Yield=yield trial

†DEC=Department of Environment and Conservation; DPI=Department of Primary Industries; FPC=Forest Products Commission; ITC=Integrated Tree Cropping; PFT=Private Forests Tasmania; PIRSA=Department of Primary Industries South Australia; UM=University of Melbourne

Structure of the report

The report is structured as three separate reports. Each is designed to be self-contained, but the data tables and analysis have been carried out in a consistent format to aid comparison between species. The metadata reports are in three separate parts:

Metadata Part 1. *E. occidentalis*

Metadata Part 2. *E. cladocalyx*

Metadata part 3. *C. maculata*

Each Part contains site information such as location, basic climate and soil data, establishment and measurement dates and a description of each trait assessed. This is followed by a results section including both data tables with relevant statistical parameters and graphs. The former format will be useful to those who wish to transfer data and construct comparisons between species or with other data, while the graphical format is more readily accessible to those users who want to quickly gain an impression of the overall data and trends

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1 Metadata Part 1: *Eucalyptus occidentalis* provenance-progeny and seed source trials

J. Driscoll, D. Bush, T. Jackson, T. Butcher, D. Stackpole

1.1. Background

Eucalyptus occidentalis is a small-medium sized tree endemic to south-western Western Australia. It is mostly found within 150 km of the south coast (Boland *et al.* 1984). Commonly known as swamp yate and flat-topped yate, *E. occidentalis* has been extensively planted in many regions around the world due to its adaptability to dry temperate climates and saline soils. The species has been successfully introduced into southern Europe, North Africa and the Middle East, and has performed well in California, Mexico and Chile, and the drier regions of south-eastern Australia (Elliott and Byrne 2003). Planting has been mostly for firewood, shade, windbreaks and catchment afforestation rather than for industrial wood production, and is planted nowhere on a very large scale. Italy has the greatest area of plantations, with a total of over 10 000 ha in Calabria and Sicily (Harwood 2001).

Within its natural range *E. occidentalis* occurs in woodlands and is commonly found on clayey depressions, drainage lines and around the borders of freshwater and brackish lagoons (Elliott and Byrne 2003). The ground surface can be inundated with water in these environments for several months during winter and spring. *E. occidentalis* is adapted to survive in these environments, with some provenances having tolerance to soil salinity and waterlogging (Boland *et al.* 1984). In its natural range, *E. occidentalis* also occurs on alluvial flood plains containing sandy duplex soils and near granite rock outcrops (Elliott and Byrne 2003). The species has proved to be adaptable to a wide range of soil types in exotic plantings, including clays, well drained loess soils and sands (Elliott and Byrne 2003). Along with saline and waterlogged conditions, *E. occidentalis* also grows well on alkaline sites, tolerates dry sites with shallow soils and has a resistance to frost (Bush 2007). It displays excellent survival and moderate growth rates in arid, semi-arid and sub-humid winter rainfall climates that receive less than 450 mm mean annual rainfall (MAR) (Boland *et al.* 1984).

The timber of *E. occidentalis* is very hard, heavy, strong and durable with a basic density of 540-775 kg m⁻³ (Bush 2007). It has been used for poles, pilings, posts and heavy construction and has potential as a pulping species with Kraft pulp yields of 50%, although it has low pulp tearing resistance (Elliott and Byrne 2003). Blakemore (2004) concluded from a sawing trial that the advantages of its timber properties possibly make it suited to applications such as outdoor furniture and decking, as well as interior furniture and flooring.

The main problem with *E. occidentalis* is that it commonly displays poor stem form (low forking and heavy branching) thus reducing the production of economically usable wood (Harwood 2001).

1.2. Genetic improvement

ALRTIG's aim is to produce improved germplasm for a selection of 'key species' of trees suited to low rainfall environments. The targeted low rainfall plantation zone is defined as those areas that receive 400–600 mm per year of winter or uniform rainfall within the southern States: NSW, South Australia, Tasmania, Victoria and Western Australia.

E. occidentalis was selected as a candidate species for genetic improvement in 1999 because of its tolerance to waterlogging, drought and saline conditions and good growth rate relative to other woodland species, and availability of trial data and background information and genetic resources (Bush *et al.* 2001).

Breeding strategy

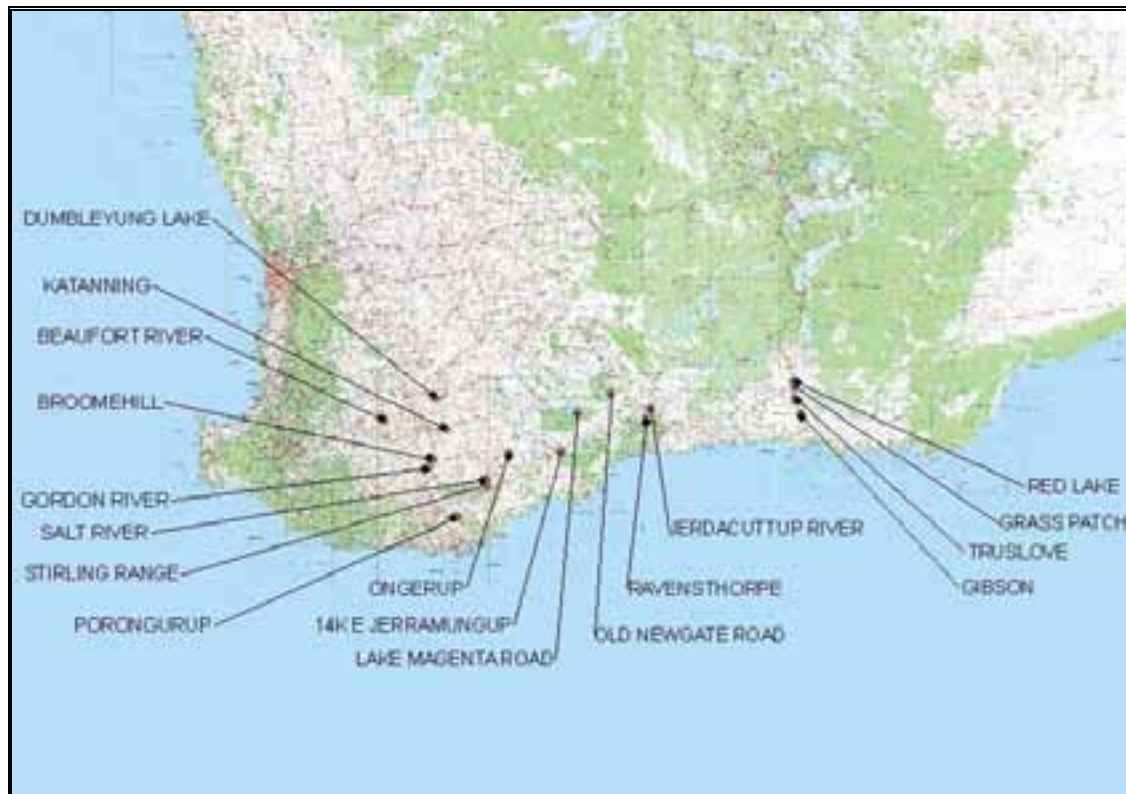
The improvement objective is to maximise the value of logs per hectare per year produced by plantations in the target planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles, posts and possibly pulpwood. The initial selection criteria are improved volume production, single straight stem, and tolerance to pests, diseases and salinity. Selection and breeding for improved wood properties may be appropriate from the second generation, once market prospects for different wood products become clearer, enabling important wood quality traits to be identified (Harwood 2001). Indications are that vegetative propagation of this species is relatively easy (Brammall and Harwood 2001) and this could be used to advantage both for breeding and deployment (Harwood *et al.* 2005).

Provenance information and interim seed sources

Provenance trials of *E. occidentalis* have been conducted in Europe, the Middle East, and Australia (Harwood 2001). Bulman *et al.* (1999) tested ten natural provenances at five sites in South Australia, with mean annual rainfalls in the range 360 to 500 mm. Results established that the Grass Patch and Ravensthorpe provenances were consistently good performers in terms of height and diameter growth, and also had the highest proportion of single-stemmed trees. Unpublished 2-year and 4-year results of four provenance trials in Italy indicate that Grass Patch, Ravensthorpe, Broomehill and Bremer Bay were the fastest-growing provenances of those tested (Harwood 2001). On saline sandy sites in the Gulf of Elat, Israel, the highest growth rate and resistance to salinity was displayed by a provenance collected north of Esperance (Zohar 1982).

Seed is available from the Department of Environment and Conservation (DEC) (Western Australia) who have collected seed from superior trees near Red Lake, 10 families at Jerramungup and intend to collect from additional trees from Swan Lagoon, the exact location of the Grass Patch collections (Harwood 2001). Primary Industries and Resources SA (PIRSA) has established seed production areas (SPAs) at Bundaleer (1992) and Redhill (1993) that contain trees from 8 provenances and have been thinned, from which seed is for sale. Prior to the ALRTIG trials, provenance trials have been established by CSIRO in 1998 at Shelford, Vic. and Wakool, NSW containing 90 families and Wikkepin and Gingin, WA by DEC, each containing 100 families (Harwood 2001).

Figure 1: Locations of natural provenances of *E. occidentalis* in SW Western Australia used in the ALRTIG study



Breeding population

Provenance-progeny trials

ALRTIG established a main breeding population as eight provenance-progeny trials at carefully selected sites in WA, SA, Vic. and NSW in 2001 and 2002. These trials incorporate 123 families from (i) randomly sampled mother trees representative of good provenances and (ii) superior trees in field trials and planted stands of these provenances. The trials will serve the dual purposes of supplying data on variation and estimates of genetic parameters of target traits, and supplying genetically improved seed.

Some of the sites are being converted by selective thinning to seedling seed orchards (SSOs), which will supply genetically improved seed for plantations and for the next generation of the main breeding population. One of the trial sites at Marcollat, SA is capable of producing limited quantities of seed as the poorest 2 of 5 trees per family have been rogued.

Results from assessment completed at six of the provenance-progeny trial sites are included in this report.

Details of the seedlots included in the provenance-progeny trials are summarized in Table 1.1. They are comprised of 123 families from 21 seed sources. The seed sources were of two main sorts: wild provenance collections, with families selected at random, and collections from planted stands, with families phenotypically selected as candidate plus trees. The wild families were drawn from *E. occidentalis* natural range in south-western Western Australia (see Figure 1.1). Not all of the families in this series of trials were included at all of the sites; however there is sufficient overlap for robust joint analysis.

Table 1.1. Seedlots (open-pollinated families) included in the progeny trials

Seed source	ATSC seedlot no.	State	Esperance WA	Marcollat SA	Narrandera NSW	Dunkeld Vic	Brynterion SF Vic	Boort Vic
14 km E Jerramungup	19412	WA	18	18	18	18	18	17
Beaufort River	19922	WA	5	5	5	5	5	5
Broomehill	13634	WA	4	4	5	4	3	4
Bundaleer SPA	-	SA	11	10	11	10	9	11
Dumbleyung Lake	15395	WA	9	9	9	8	7	9
Gibson	13646	WA	2	2	2	2	1	2
Gordon	15390	WA	2	2	1	1	1	2
River Grass Patch	99052	WA	6	6	6	6	5	5
Jerdacuttup	-	WA	1	1	1	1	1	1
Jerdacuttup River	19925	WA	4	3	3	3	2	3
Katanning Lake	15377	WA	8	8	8	8	6	8
Magenta Rd	19923	WA	2	2	2	2	2	2
Old Newgate Rd	19924	WA	3	3	3	3	3	3
Ongerup	20222	WA	5	5	5	5	5	5
Porongorup	13636	WA	1	1	1	1	1	1
Ravensthorpe	13642	WA	2	1	2	1	1	1
Red Lake	99050	WA	12	12	11	12	11	12
Red Hill SPA	-	SA	15	15	15	15	11	14
Salt River	15389	WA	2	2	2	-	1	2
Stirling Range	13637	WA	1	1	1	1	1	1
Truslove	15416	WA	9	8	9	8	5	8
Total No. provenances/seed sources			21	21	21	21	21	20
Total No. families			120	120	122	120	120	114

Seed source trials

Seed source trials test whether or not genetically improved materials perform significantly better than unimproved controls, and as such, are a special case of genetic gain trial. A series of *E. occidentalis* seed source trials were established in winter 2003 across 6 sites. The seedlots were chosen to contrast seed sources that ALRTIG had promoted as ‘best-bets’ on the basis of early data collation from partners’ trial data gathered prior to 1999 with wild provenance material.

Results from assessment completed at three of the seed source trial sites are included in this report.

1.3 Genetic resources

The seed sources are given in Table 1.2. One wild seed source, Grass Patch was selected based on the basis of its good performance in earlier studies (Harwood 2001). Seed was also included from two SA SPAs located at Red Hill (saline) and Bundaleer (non-saline) that both contain eight provenances and a planted stand at Boort, Vic.

Table 1.2. Seedlots included in the seed source trials.

Seed source	State	ATSC seedlot or other seedlot information	Rocky Gully WA	Marcoll at SA	Carew SA
Bundaleer SPA bulk	SA	Seed supplied by PIRSA	Yes	Yes	Yes
Bundaleer SPA plus tree bulk	SA	Seed supplied by PIRSA	Yes	Yes	Yes
Grass Patch	WA	99052	Yes	Yes	Yes
Red Hill SPA plus tree bulk	SA	Seed supplied by PIRSA	No	Yes	Yes
Yando River Rd Boort	Vic	Seed supplied by DPI (Vic)	Yes	Yes	Yes
Total No. provenances/seed sources			4	5	5
Total No. replicates			5	5	5

1.4 Sites, trial designs and establishment

Sites for both the provenance-progeny trials and the seed source trials were selected to be representative of the species' perceived target planting zone in the 350-750 mm MAR winter/uniform rainfall zone. Where possible trials were located in lower parts of the landscape where restricted drainage and saline soils are prevalent. Summarised details are given in Table 1.3.

Table 1.3. Summary of site locations, MAR and soil descriptions

Site Location	State	Lat.	Long	Alt (m)	MAR (mm) 30 yr av. 2001-07		Soil	Comments
<i>Progeny trials</i>								
Esperance	WA	33.84	121.89	20	571	580	Sand over heavy clay <1 m	Flat, low lying, saline, restricted drainage Restricted drainage Restricted drainage.
Marcollat	SA	36.63	140.29	50	499	458	Alkaline (pH 9) sand over clay <1 m	
Dunkeld	Vic	37.65	142.34	250	642	588	Clay loam over clay <1 m	
Brynterion	Vic	33.75	142.56	150	411	349	Grey clay, alluvial sediments	
Boort	Vic	36.11	143.78	90	362	326	Brownish grey clay, alluvial sediments	Irrigated site
Narrandera	NSW	34.74	146.56	200	463	379	Grey medium clay over sandy light-medium clay	Upper horizon is hard-setting.
<i>Seed source trials</i>								
Marcollat	SA	36.63	140.29	50	499	458	Alkaline (pH 9) sand over clay <1 m	Flat, low lying, saline, restricted drainage.
Carew	SA	36.36	140.48	55	447	402	Acidic (pH 6.5) loam over dark clay <1 m	Flat, restricted drainage
Rocky Gully	WA	34.51	117.01	220	678	-	Shallow granitic	Flat, low lying, restricted drainage.

Note: Latitude/Longitudes/Altitude are estimates. For most sites they were estimated from maps. MAR statistics were obtained from BOM and are from the closest weather station to trial sites. Esperance Aerodrome 009542 (Esperance); Padthaway-Marcollat 026017 (Marcollat); Dunkeld 089011 (Dunkeld); Horsham 079082 (Brynterion SF); Boort 080002 (Boort); Narrandera Golf Club 074221 (Narrandera); Keith 025507 (Carew); Rocky Gully 009964 (Rocky Gully).

The provenance-progeny trials were established in winter or spring of 2001 (see Table 1.4). Each family (Table 1.1) was represented by 20 progeny arranged in either 4 randomized complete block replicates of 5-tree line-plots or 5 replicates of 4-tree line-plots. The provenance-progeny trials were mostly resolvable incomplete block types, with incomplete blocks in a two-dimensional row-column arrangement where possible. Initial trial stocking was 1250 stems per hectare (SPH) (4 m x 2 m spacing) at all sites except Dunkeld, Vic 1000 SPH (4 m x 2.5 m) and Boort, Vic. 1428 SPH (3.5 m x 2 m). Buffers were planted at all sites except at Boort, Vic. Buffer usually consisted of two planted rows and two to five trees at the end of trial rows.

The seed source trials were established in 5 replicates of 64 tree plots in winter or spring 2003. The common design was randomized complete blocks (RCB) with incomplete block structures superimposed in some cases (resolvable ICB). The seed source trials were established at 1000 SPH (4 m x 2.5 m) at Marcollat, SA and Carew, SA and 800 SPH (5 m x

2.5 m) at Rocky Gully. Buffers were planted at all sites. Buffer usually consisted of two planted rows and two to five trees at the end of trial rows.

1.5 Measurements

The provenance-progeny trials were measured at approximately five years, and the seed source trials at three years (see Table 1.4). Various traits were measured at each of the trial sites as summarised in Table 1.4. Survival was calculated for each trial along with stem volume and stem count where possible.

Table 1.4. Traits assessed at each of the trial sites

Site Location	Date Planted	Date measured	Stocking est. (SPH)	Height	DBH/B	Axis persist.	Stem straight.	Branch weight	Other
<i>Progeny Trials</i>									
Esperance WA	07/2001	02/2006	1250		Yes	Yes	Yes		Commercial bole length, Dominance, Malformation, Crown class
Marcollat SA	8/2001	09/2006	1250 Rogued to 750 (2005)	Yes	Yes	Yes	Yes	Yes	
Dunkeld Vic	11/2001	11/2006	1000	Yes	Yes	Yes	Yes		
Brynterion SF Vic	10/2001	05/2007	1250	Yes	Yes				
Boort Vic	08/2001	01/2005	1428		Yes	Yes		Yes	Form
Narrandera	09/2001	04/2004	1250	Yes					
<i>Seed source trials</i>									
Marcollat SA	07/2003	11/2006	1000	Yes	Yes				
Carew SA	08/2003	11/2006	1000	Yes	Yes				
Rocky Gully WA	07/2003	11/2006	800	Yes					

Notes on each of the traits are as follows:

Survival

Survival was calculated and analysed on the basis of plot mean survival. There is likely to be a downward bias on survival as assessed by this method at the Esperance site, because runts were not assessed (and indeed they are not likely to survive in the long term). Runts were assessed and counted as survivors at the other sites.

Growth traits

Height

Taken as the height from ground level to the highest point of the crown.

Diameter at breast height, over bark (DBHOB)

Where more than one stem was found at breast height, and where secondary stems were more than half the diameter of the largest stem, the diameters of the other stems were also taken. Equivalent diameter was calculated as the geometric mean of the stems:

$$\text{Equivalent DBH} = \sqrt{\text{Stem}_1^2 + \text{Stem}_2^2 \dots \text{Stem}_n^2}$$

Stem volume

Individual stem volumes for those sites where both DBH and height were measured was estimated as:

$$\text{Volume} = 1/3 \pi \times (\text{Equivalent DBH}/2)^2 \times \text{height}$$

It was also possible to estimate the height for each tree, for the purpose of volume estimation, at Esperance, Boort and Narrandera by deriving a simple regression relationship between height and DBH for Marcollat and Dunkeld.

Commercial bole length

Bole length rather than height was assessed at Esperance, WA. This trait is an estimate of commercial bole length that can be achieved with moderate form pruning.

Dominance

Trees at Esperance, WA were classified as follows:

0. missing tree
1. dead tree
2. runt
3. sub-dominant
4. co-dominant
5. dominant

No further assessments were carried out on trees scored as 0,1 or 2.

Form traits

Axis persistence

Axis persistence is a measure of forking, where a fork is defined as being greater than half the thickness of the stem at the point of union, and having apically dominant tendency. This trait was assessed differently between trial sites.

Esperance, WA; Dunkeld, Vic

1 = lowest fork occurs in lowest quarter of tree

2 = lowest fork in first half of tree

3 = lowest fork in third quarter of tree

4 = lowest fork in highest quarter of tree

5 = no forks

Marcollat, SA

1 = lowest fork at base

2 = lowest fork occurs in lowest quarter of tree

3 = lowest fork in first half of tree

4 = lowest fork in third quarter of tree

5 = lowest fork in highest quarter of tree

6 = no forks

Boort, Vic.

0 = no forks

1 = forking of any sort above 1.3 m

2 = two stems at 1.3 m

3 = three stems at 1.3 m

Malformation

Malformation is an assessment that incorporates branching, forking, stem bends and damage to give an overall malformation score. This trait was assessed at Esperance, WA.

6 - Normal stem, no malformation.

5 - Minor - single ramicorn, no forks, no kink, insignificant.

4 - No damage, minor fork (high), few ramis or basket; major kink.

3 - Damage, numerous ramis or basket; major kink.

2 - Basket, lost top and basket leaders; major fork.

1 - Forks - multiple.

Form

Form is an assessment that incorporates branching, forking, stem bends and damage to give an overall form score. This trait was assessed at Boort, Vic.

1 = excellent

2 = satisfactory

3 = poor

4 = firewood

5 = atrocious

Stem straightness

Stem straightness was measured on a scale of 1-4 (worst-best) at Dunkeld, Vic. and on a scale of 1-6 (worst-best) (normally distributed) at Esperance, WA.

At Marcollat, the number of slight bends (defined as a deviation from the stem main axis of half to equal the diameter of the stem at that point) and large bends (a major deviation being greater than a full stem width) in the first 4 m of stem was counted.

The scores were weighted and combined to make a single stem straightness score:

Stem straightness score = no. slight bends + 2 x no. large bends

Crown Class

Crown class is an assessment that assesses branch size and angle to give an overall crown class score. It was assessed on a scale of 1-6 (poor-best) with the aim of a normal distribution of data. This trait was assessed at Esperance, WA.

Branch weight

A measurement of branch size, both heaviness (diameter) and frequency (number). This trait was assessed differently between trial sites.

Marcollat, SA

The number of heavy branches (defined as those between 25 and 50% of the stem diameter at the point of intersection) and very heavy branches (greater than 50%, but lacking apical tendency and so not also scored as a fork) in the first 4 m of stem was counted.

The scores were combined to make a single branch score:

Branch weight score = no. heavy branches + 2 x no. very heavy branches

Boort, Vic.

The number of branches deemed to be of significant weight to affect a potential commercial bole were counted in the lower, middle and top thirds of each tree.

The scores were combined to make a single branch score:

Branch weight score = 3 x no. branches in lower third + 2 x no. branches in mid third + no. branches in top third

1.6 Data analysis

Trial data from each progeny trial site was screened for errors and outliers and analysed separately. The trials were analysed for each trait using an individual tree model with genetic groups corresponding to the provenances detailed in Table 1.1 implemented with ASREML software (Gilmour *et al.* 2006). This procedure gives Best Linear Unbiased Estimators (BLUEs - an adjusted mean value) for the provenances and Best Linear Unbiased Predictors (BLUPs - an adjusted mean often used for genetic ranking) for each mother and each individual tree. This report considers the more generally useful provenance estimates, while the BLUPs are being used to guide selection and thinning and for calculation of more complex genetic parameters.

Site and provenance means have been reported with average standard errors of difference between the means. Chi-squared probabilities on Wald tests for equality of treatment means are given for provenances and families-within-provenances. Probabilities $0.05 < p < 0.001$ are considered to be 'weakly' significant, whereas $p < 0.001$ are considered to be 'highly' significant. This is because the chi-square distribution used with Wald tests is an asymptotic approximation (i.e. for large samples) and underestimates the probabilities in other cases (Payne *et al.* 2007).

A preliminary analysis of GxE (genotype-by-environment interaction) was carried out at the provenance level for those traits where it was possible. The objective was simply to provide an indication of whether there is likely to be significant GxE and to generate a set of cross-site means, not to characterise the GxE in detail. There are a number of ways that this can be done (see for example White *et al.* 2007). We have chosen a mixed modelling approach with sites treated as fixed effects and provenances and the interaction of provenances and sites treated as random effects (see also White *et al.* 2007 for an explanation of the difference between fixed and random effects). This gives (1) a set of BLUP means for provenances taken across the sites, and, (2) variance components for the provenance and provenance-by-site interaction.

Shelbourne (1972) suggests that, as a rule of thumb, when the provenance-by-site interaction variance is more than 50% of the provenance variance, the level of GxE is likely to be of concern in making selections. The GxE analyses were carried out using the ASREML software described above. More sophisticated GxE analyses could include fitting of a more comprehensive model to account for heterogeneous residual (error) variances at each site, and such analyses are recommended if more detailed information on GxE is required. It should be noted that some of the provenances were represented by different numbers of families at the different sites (Table 1.1). This introduces a certain degree of error into the assessment of GxE - the material representing these provenances tested at the different sites is not identical.

The seed source trials with incomplete block structures were analysed using a mixed-model reml procedure, with replicate and seedlot effects treated as fixed, and incomplete blocks as random. Trials without incomplete blocks were analysed using fixed-effects ANOVA. These analyses were implemented with Genstat software.

1.7 Results

Results are presented in the following sections:

Section A - progeny trials

Section B – seed source trials

In Section A, the traits have been placed into groups: survival, growth, form and other. Both tables and graphs of means at each site for each trait along with statistical data can be found in Appendix 1. Table 5 gives the results of the provenance-by-site interaction analysis described in Section 1.5. Interaction components were identified for all traits and in the case of stem volume and survival, interaction components were a significant proportion (>50%) of the genotype component, which Shelbourne (1972) suggests is the approximate point where GxE is of practical significance. Where the ratio of genotype to interaction components is less than 50%, it is appropriate to examine cross-site means.

Table 1.5. Variance components and ratios for provenance and site-by-provenance for each trait. Variance component ratios over 50% (shown in bold typeface) indicate GxE that is likely to be of practical significance for selection

Variance components			
Trait	Provenance	Site-by-provenance (SxP)	Ratio of P to SxP
Survival	~0	0.024	Large
Equivalent DBH	0.220	0.081	37%
Height	0.081	0.018	22%
Stem volume	0.09	1.25	1350%
Stem count	4.46	0.04	1%
Axis persistence	0.093	0.002	2%

A. Provenance-progeny trials

Survival (Appendix 1.1)

Survival at four of the six trials sites; Esperance, WA, Marcollat, SA, Dunkeld, Vic. and Boort, Vic. has been good averaging greater than 80% (Appendix 1.1). Survival at Narrandera, NSW (54%) and Brynterion SF, Vic. (58%) has been poor due to successive drought years at the Narrandera trial site after establishment (2001: 312 mm; 2002: 356 mm)(BOM site no. 074221) and a second year drought year at the Brynterion SF trial site (2002: 231 mm)(BOM site no. 079082).

There was a significant difference between provenances ($p=0.03$) and strongly significant difference between families-within-provenances ($p<0.001$) at Dunkeld (Appendix 1.1). Beaufort River, Kattanning and Old Newgate Road had significantly lower survival than the other 18 provenances, but all still achieved at least 80% survival (Appendix 1.1).

A strong significant difference between provenances was also identified at Narrandera. Jerdacuttup provenance had significantly higher survival than all other provenances trialed at the site. Gordon River survival was significantly lower than the other 20 provenances (Appendix 1.1) However, both Jerdacuttup and Gordon River are represented by only 1 family (Table 1.1), so provenance estimates should be viewed cautiously.

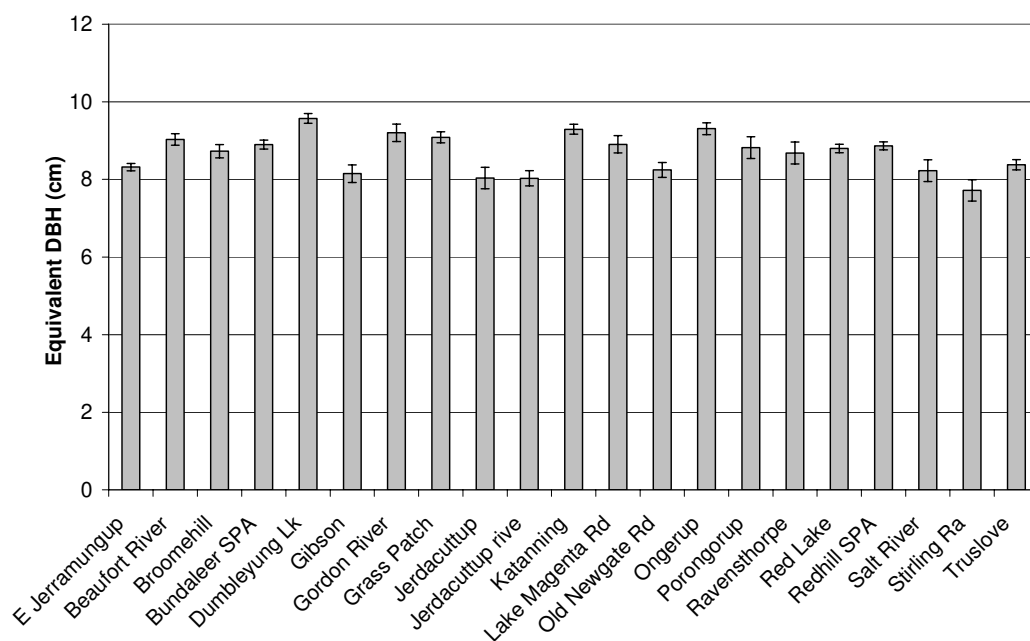
There are no strong survival patterns evident across sites, with a high site-by-provenance variance component and a provenance component approaching zero identified in the GxE analysis (Table 1.5).

Productivity traits

Equivalent DBH (Appendix 1.2a)

There were highly significant differences ($p < 0.001$) between provenance for equivalent DBH at Esperance, Marcollat, Dunkeld, and Boort. There were also highly significant differences for families-within-provenances at Esperance, Dunkeld, and Boort but not Marcollat or Brynterion (Appendix 1.2a). There was relatively little site-by-provenance interaction as indicated by the ratio of genotype and interaction variance components (Table 1.5). Across trial sites, Dumbleyung Lake, Grass Patch, Beaufort River, Katanning and Ongerup provenances had consistently highly ranked equivalent DBH. Consistently poor equivalent DBH was recorded for Stirling Range, Jerdacuttup, Jerdacuttup River and Gibson (Figure 1.2).

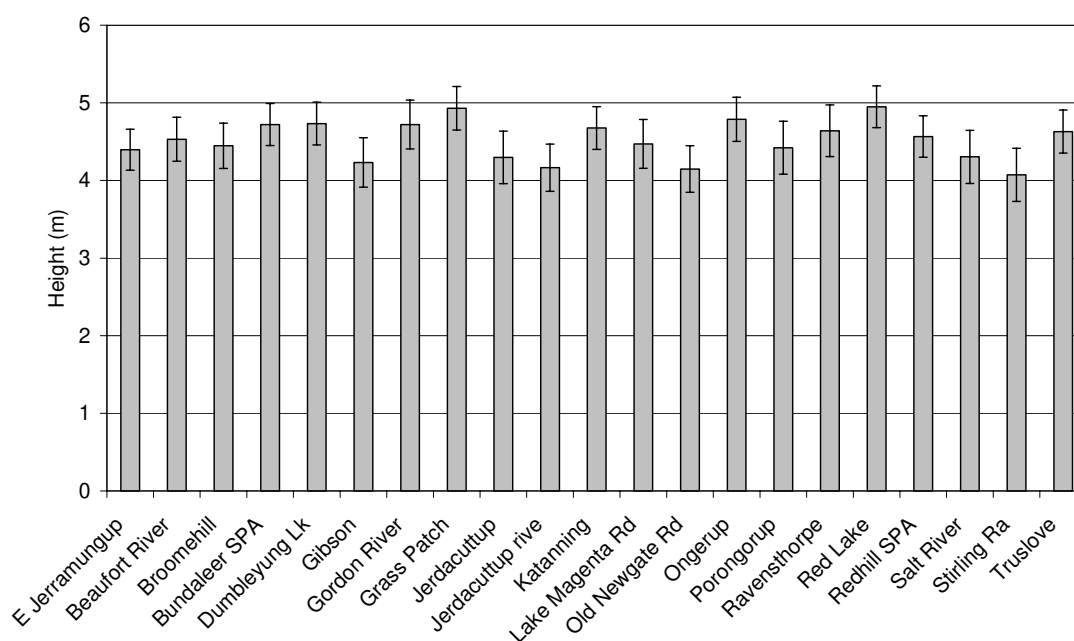
Figure 1.2. Cross-site means: equivalent DBH (cm) (bars indicate average standard error of difference)



Height (Appendix 1.2b)

Highly significant differences ($p < 0.001$) were identified between provenances for height at Marcollat, Dunkeld and Narrandera (Appendix 1.2b). There were highly significant differences for families-within-provenances at Dunkeld and Brynterion SF ($p < 0.001$) and a significant difference ($p = 0.01$) at Narrandera. Site-by-provenance interaction was not marked (Table 1.5). At the Marcollat and Dunkeld trial sites, Gordon River, Ongerup and Red Lake were the tallest trees (Appendix 1.2d-e). Red Lake was also one of the tallest provenances at Narrandera. Consistently poor provenances include Jerdacuttup River, Gibson and Stirling Range (Appendix 1.2b). Grass Patch, Ongerup and Red Lake were the best cross-site performers (Figure 1.3).

Figure 1.3. Cross-site means: height (m) (bars indicate average standard error of difference)



Height and DBH relationship

A regression relationship between height and DBH was determined using data from Marcollat, Dunkeld and Brynterion where both traits were measured. The equation of the regression line was:

$$\text{Height (m)} = 1.5693 + 0.58033 \times \text{DBH (cm)}$$

This model accounts for 84.6% of the phenotypic height variance, so is quite suitable for estimating heights from the measured diameters at Esperance and Boort for the purpose of gauging comparative growth between the sites, though not necessarily for ranking provenances.

Volume (Appendix 1.3)

Highly significant differences ($p < 0.001$) were identified between provenance and for families-within-provenances at Marcollat and Dunkeld. There was a significant difference within provenances ($p = 0.04$) at Brynterion SF (Appendix 1.3a). High volume provenances at Marcollat and Dunkeld include Ongerup, Gordon River and Dumbleyung Lake. (Appendix 1.3a-c). Other good volume performers at Marcollat were Broomehill, Katanning, Beaufort River and Grass Patch. Jerdacuttup River and 14 km E Jerramungup had poor volume production at both Marcollat and Dunkeld (Appendix 1.3b-c). Porongorup had significantly better volume than all other provenances at Dunkeld. In contrast to its performance at Dunkeld, Porongorup was a low volume provenance at Brynterion SF, although at this site there were no significant differences between provenances ($p = 0.062$). There was a large site-by-provenance interaction component for this trait indicating significant GxE (Table 1.5).

Commercial Bole Length (Appendix 1.4)

Commercial bole length is a trait that combines growth and form parameters. It was assessed only at the Esperance trial site. Significant differences ($p < 0.001$) were identified between provenance and for families-within-provenances (Appendix 1.4a). The greatest commercial

bole lengths were produced by Grass Patch, Red Lake and Ongerup. Stirling Range produced the shortest commercial bole length (Appendix 1.4a-b).

Dominance (Appendix 1.5)

Dominance identifies trees competition status within a stand. It was assessed only at the Esperance trial site. Significant differences were identified between provenance ($p=0.001$) and weakly for families-within-provenances ($p=0.019$) (Appendix 1.5a). Grass Patch and Red Lake had a higher proportion of dominant trees. Gibson and Salt River were the least dominant (Appendix 1.5b).

Productivity

MAI was calculated for each trial site except Narrandera by dividing the standing volume by trial area and trial age. Height was calculated using the regression relationship between height and DBH to determine volume and MAI at the Esperance and Boort sites. Boort has achieved a relatively high growth rate of $9.5 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ at 3.4 years. This site has been irrigated and is not representative of potential dryland forestry plantations of this species. Of the other sites Marcollat achieved the best growth rate of $3.74 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ at 5.08 years. This site was thinned to 750 SPH in 2005 and may not yet have fully recovered. Dunkeld has the lowest MAI of $0.68 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ at 5 years (Table 1.6). The result at Dunkeld is surprising, because this species was expected to be well-suited to the site. Early waterlogging at the site is a possible cause, though *E. occidentalis* is normally considered to be well-adapted to this condition.

Table 1.6. Provenance MAI estimates

	Esperance, WA ♦	Marcollat, SA	Dunkeld, Vic.	Brynterion, Vic.	Boort, Vic. ♦ ●
Age (yrs)	4.58	5.08	5.00	5.58	3.42
Volume (m^3)	11.15	36.54	8.15	17.80	61.47
Area (ha)	1.92	1.92	2.40	1.92	1.4
MAI ($\text{m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$)	1.3	3.7	0.7	1.7	9.45

♦ Modelled height from a height to DBH regression from the Marcollat and Dunkeld sites were used to calculate individual tree volumes.

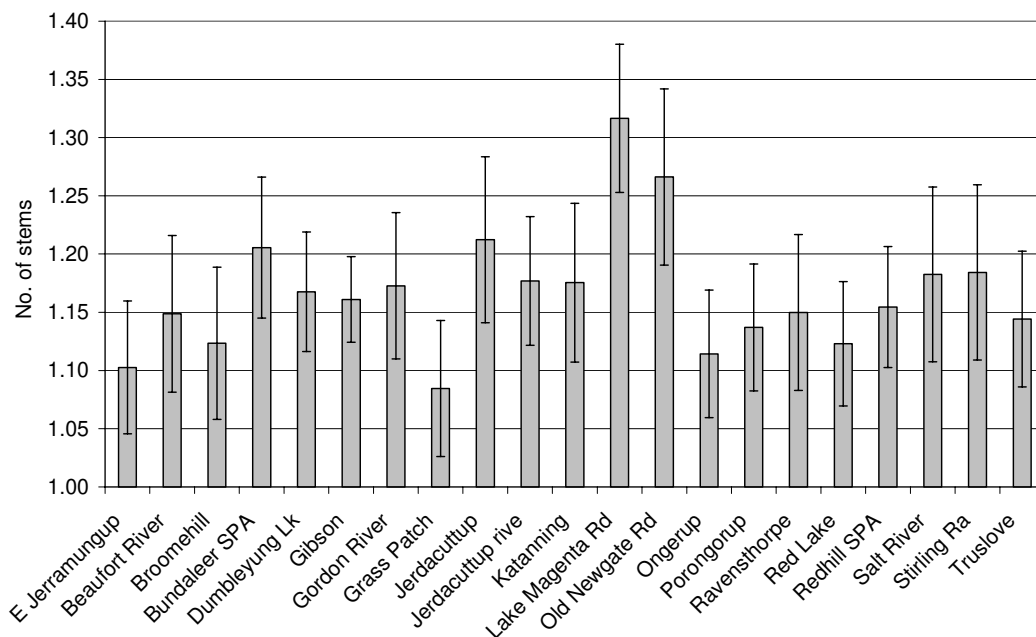
● A one row, one tree buffer was removed for productivity calculations to reduce edge effects.

Form traits

Number of Stems (Appendix 1.6)

There were highly significant differences ($p<0.001$) between provenances for stem count at all sites. There were highly significant differences for families-within-provenances at Esperance and Brynterion SF ($p<0.001$) and a significant difference ($p=0.003$) at Boort (Appendix 1.6a-c). There was a proportionately low site-by-provenance interaction component (Table 1.5) indicating relatively little GxE. Provenances that performed well include east Jerramungup, Grass Patch and Ongerup (Figure 1.4). The most multi-stemmed provenances were Lake Magenta Road and Old Newgate Road.

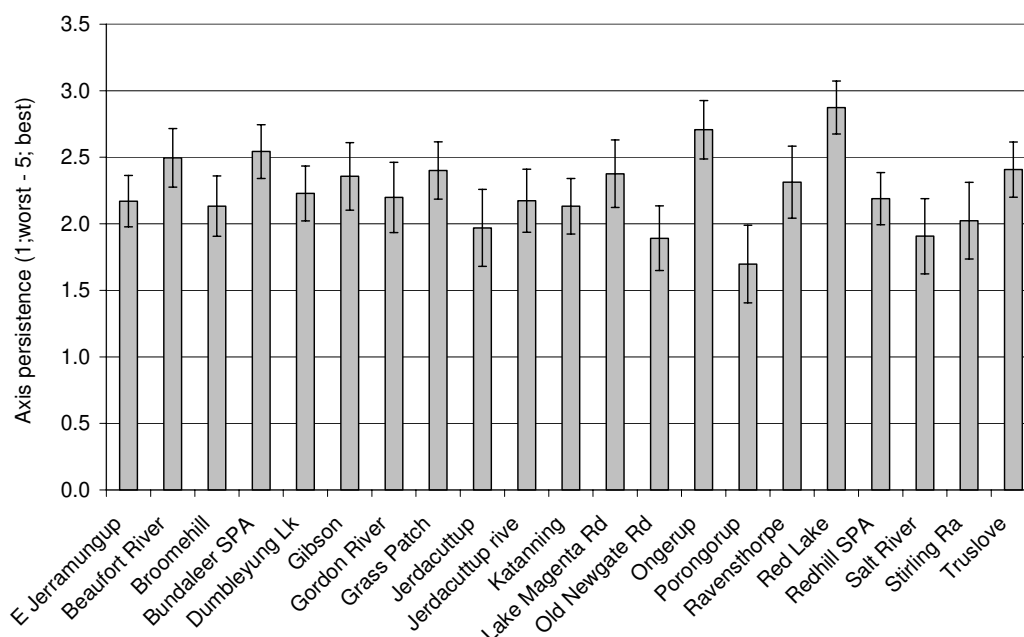
Figure 1.4. Cross-site BLUP means: stem count – (bars indicate average standard error of difference)



Axis Persistence (Appendix 1.7)

There were highly significant differences ($p < 0.001$) between provenances and families-within-provenances for axis persistence at Esperance, Marcollat, Dunkeld and Boort except for within provenances at Dunkeld where there was a significant difference ($p = 0.01$) (Appendix 1.7a-e). For the cross-site analysis, scores for Esperance, Dunkeld and Marcollat were rescaled to the 1-5 system used at Esperance (see Section 1.4) by converting forks at the base and in the first quarter of the stem to a score of 1. The Boort scores were omitted because they could not be readily scaled, but they are compared qualitatively. The analysis indicated a negligible site-by-provenance interaction component relative to the provenance component (Table 1.5) indicating low levels of GxE. The provenances with the lowest frequency of forks (or high forks) consistently across sites were Red Lake, Ongerup and Bundaleer SPA (Figure 1.4).

Figure 1.5. Cross-site BLUP means: axis persistence (bars indicate average standard error of difference). Scores were rescaled: 1-5 (worst-best)



Malformation and Form (Appendix 1.8)

Malformation and form are traits that incorporate branching, forking, stem bends and damage to give an overall form score. Malformation was assessed at Esperance and form was assessed at Boort.

There were highly significant differences ($p < 0.001$) between provenance and for families within provenances for malformation at Esperance and form at Boort (Appendix 1.8a). Ongerup was the only provenance that ranked highly at both Esperance and Boort. The provenances with high tendency for poor form consistently across both sites were Jerdacuttup, Salt River and Old Newgate Rd. At Esperance, Red Lake had significantly better form than all other provenances trialled. At Boort, Red Lake ranked in the second quartile. Dumbleyung Lake and Lake Magenta Rd had the best form at Boort. Conversely, Dumbleyung Lake ranked in the bottom quartile at Esperance. Lake Magenta Rd at Esperance only achieved a mid table malformation ranking. Another contrasting result is Gibson, which ranked highly for malformation at Esperance, but at Boort was significantly worse than all other provenances (Appendix 1.8b). Both Lake Magenta Rd and Gibson are represented by only two families (Table 1.1), so provenance estimates should be viewed cautiously.

Stem Straightness (Appendix 1.9)

There were highly significant differences ($p < 0.001$) between provenances and families-within-provenances for stem straightness at the three trial sites of Esperance, Marcollat and Dunkeld (Appendix 1.9a). The straightest provenances consistently across sites were Ongerup, Dumbleyung Lake and Bundaleer SPA. Red Lake, Grass Patch and Broomehill ranked highly for stem straightness at Esperance and Dunkeld but both only achieved a mid-table ranking at Marcollat. Broomehill ranked highly for stem straightness at Marcollat and Dunkeld, but achieved only a mid-table ranking at Esperance. The consistently crooked provenances were Gibson, Salt River and Jerdacuttup. Old Newgate Rd performed poorly at Marcollat and Dunkeld, but achieved a mid-table ranking at Esperance.

Crown Class & Branch Weight (Appendix 1.10)

Crown class is a trait that incorporates branch size and angle, and so has been grouped with branch weight, as they are similar assessments.

There was a significant difference ($p=0.03$) between provenances and a highly significant difference ($p<0.001$) between families-within-provenances for crown class at Esperance. There were highly significant differences ($p<0.001$) between provenance and for families-within-provenances for branch weight at Marcollat and Boort (Appendix 1.10a). Stirling Range, Lake Magenta Rd and Bundaleer SPA ranked highly for crown class and branch weight across all three sites. Ravensthorpe rated highly for branch weight at Marcollat and Boort. Old Newgate Rd and Salt River had the lowest crown class and branch weight ranking at each site. Porongorup ranked poorly for branch weight at Marcollat and Boort, but was ranked in the second quartile at Esperance. Broomehill and Redhill SPA had the lowest crown class at Esperance and branch weight at Marcollat, but achieved a mid-table ranking at Boort (Appendix 1.10b-c).

B. Seed source trials (Appendix 1.11)

Equivalent DBH

DBH was measured at Carew and Marcollat. There was a highly significant difference between seed sources at Marcollat ($p<0.001$) but no significant difference at Carew (Appendix 1.11a). Redhill SPA plus tree bulk seedlot had the greatest equivalent DBH at both Carew and Marcollat. Yando River Road had the poorest equivalent DBH at both sites and is significantly lower than all other seedlots at Marcollat (Appendix 1.11b).

Height

There was a highly significant difference between seed sources at Rocky Gully ($p<0.001$) and significant differences at Carew ($p=0.002$) and Marcollat ($p=0.003$) for height. Yando River Road was the shortest seed source at all sites. It was smallest at Carew and Marcollat and second lowest at Rocky Gully. Bundaleer SPA plus trees also ranked poorly for height, being significantly shorter than all other seedlots at Rocky Gully and significantly shorter than the wild provenance of Grass Patch and Redhill SPA plus tree bulk at Carew (Appendix 1.11c). The Rocky Gully trial site has performed poorly with a mean height of 2.34 m compared to Marcollat (3.9 m) and Carew (4.4 m) when all sites were assessed at age of 3.3 years.

Number of Stems

Analysis of the number of stems per tree was undertaken at Carew and Marcollat. There was a highly significant difference between seed sources at both sites ($p<0.001$). Yando River Road had a higher tendency to produce multiple stems at both Carew and Marcollat than the other seed sources. At Carew, Yando River Road has significantly greater number of stems than the rest of the seedlots. Redhill SPA plus tree bulk also performed poorly at Marcollat having significantly greater number of stems than Bundaleer SPA plus tree bulk, Bundaleer SPA bulk and the wild provenance, Grass Patch.

1.8 Discussion

The ALRTIG *E. occidentalis* progeny-provenance trials tested 122 families of 21 provenances and have identified high and low performing provenances in growth traits, form traits and all-round performance across differing site environments. One provenance that

performed well across all traits, both growth and form, was Ongerup. Other good all-round performers were Red Lake and Grass Patch that were highly ranked across seven (Red Lake) and six (Grass Patch) out of the 10 traits assessed. This reinforces the previous finding that Grass Patch performs well compared to other provenances (Harwood 2001; Bulman *et al.* 1999). Red Lake is a neighbouring provenance to Grass Patch (see Figure 1 and Table 3) and may presumably be genetically similar. Dumbleyung Lake and Gordon River were other provenances that performed well in growth traits. Bundaleer SPA was one of highest performing provenances for all form traits except malformation/form.

When examining the poorer performers, only Jerdacuttup was in the lowest ranked group for growth (equivalent DBH, volume) and form traits (malformation/form, stem straightness). Along with Jerdacuttup, poor growth trait provenances were Stirling Range (Equivalent DBH, height, bole length) and Gibson (equivalent DBH, height). Across all form traits, Old Newgate Road was amongst the lowest ranked groups. Salt River was amongst the lowest performing provenances for all form traits except number of stems.

The SPA progeny trialled at all trial sites contained parentage from eight better-performing provenances, including Grass Patch, identified from previous trials (Harwood 2001). Roguing in the SPAs on the basis of both growth and form traits, which removed 50% (Bundaleer SPA) and 33% (Redhill SPA) of the poorer trees (Harwood 2001) should also have ensured that the performance of the SPA seedlots was amongst the best. This was not generally the case, though Bundaleer SPA did rank well for the form traits. Although both SPAs include individuals from Grass Patch they do not include other highly ranked provenances identified in the trial such as Ongerup, Red Lake, Dumbleyung Lake and Gordon River (Bulman *et al.* 1999) and therefore were not planted with the best genetic material available. Another explanation may be inbreeding. The SPAs had an adequate layout and genetic diversity to mitigate against neighbourhood inbreeding, though poor flowering in the year the seedlots were harvested may have led to a high proportion of selfing. In regards to the poor performance of Redhill SPA, its harsh saline conditions may have led to the production of material suitable for saline sites and of the trial sites only Marcollat is exposed to a saline watertable (Table 1.3).

From the seed source trial results Yando River Road was the poorest performer for equivalent DBH, height and number of stems. Yando River Road is a seed stand of unknown genetic origin. The good performance of the (wild) Grass Patch in comparison to the improved seed sources echoes the results of the SPA seedlots in the provenance-progeny trials and shows they are poorer than the best wild provenances. Moreover, the plus tree bulk appears to be inferior to the general bulk. This result is contrary to that found in *E. cladocalyx*, where the SPA seedlots have performed very well. One common cause of poor performance of seed orchard progeny is inbreeding caused by selfing and/or neighbourhood inbreeding (mating with near relatives) in the seed orchards. However outcrossing rates in the Bundaleer SPA have been studied, and found to be higher than usual for wild eucalypt populations (Byrne 2004). It is more likely the case that the SPAs, which were based on range-wide provenance collections, still have too many trees that perform well below the average of the better provenances such as Grass Patch. The intensity of selection during thinning of the SPAs was not great, and may not have been sufficient to counter the poorer initial genetic merit of the SPAs.

1.9 References

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Appendix 1: *E. occidentalis* metadata tables

Table A1.1. Survival (%) at six provenance-progeny trial sites

Provenance	Esperance WA	Marcollat SA ♣	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E Jerramungup	87	86	93	57	95	55
Beaufort River	84	90	83	61	99	60
Broomehill	76	77	96	55	93	58
Bundaleer SPA	88	86	92	53	98	57
Dumbleyung Lake	81	84	92	52	95	50
Gibson	86	75	95	61	100	59
Gordon River	85	81	100	69	97	21
Grass Patch	94	87	90	53	97	55
Jerdacuttup	91	89	100	48	100	77
Jerdacuttup river	84	78	88	49	93	43
Katanning	85	86	84	59	91	55
Lake Magenta Rd	82	93	90	54	90	47
Old Newgate Rd	80	73	80	53	97	63
Ongerup	88	73	90	51	94	48
Porongorup	76	74	85	65	90	52
Ravensthorpe	87	79	95	67	95	60
Red Lake	87	74	89	54	95	56
Red Hill SPA	89	83	94	58	95	53
Salt River	83	65	*	69	93	50
Stirling Range	85	80	95	77	95	48
Truslove	89	77	91	58	94	59
s.e.d.	6	9	7	12	4	10
Site mean	85	80	91	58	95	54
Probability (prov)	0.10	0.10	0.03	0.94	0.47	<0.001
Probability (prov.mum)	0.13	0.83	<0.001	0.42	0.47	0.48

♣ Marcollat SA survival data is from a measurement at P+4 years after which time the trial was thinned. Other survival data calculated from assessment indicated in Table 4.

Table A1.2a. Provenance means: equivalent DBH (mm)

Provenance	Esperance WA	Marcollat SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E	54.3	101.7	50.2	82.2	105.0	*
Jerramungup						
Beaufort River	59.3	115.2	48.8	86.7	113.2	*
Broomehill	50.0	117.7	54.2	72.9	104.2	*
Bundaleer SPA	58.9	106.8	55.2	81.9	109.5	*
Dumbleyung	61.2	116.8	56.3	89.0	119.7	*
Lake						
Gibson	49.0	98.2	52.1	80.5	95.5	*
Gordon River	57.6	114.3	58.3	95.1	109.8	*
Grass Patch	69.6	110.1	52.1	89.2	113.7	*
Jerdacuttup	57.0	87.0	54.9	70.6	97.3	*
Jerdacuttup	49.0	90.3	47.4	75.6	98.9	*
river						
Katanning	59.2	112.4	53.5	93.8	113.2	*
Lake Magenta	60.6	107.1	52.3	92.5	108.0	*
Rd						
Old Newgate Rd	56.9	101.8	50.7	77.0	98.5	*
Ongerup	60.8	116.0	57.7	82.5	117.5	*
Porongorup	54.0	101.4	66.2	83.7	107.5	*
Ravensthorpe	51.9	105.9	59.8	86.1	100.6	*
Red Lake	62.4	105.1	56.2	78.6	111.1	*
Red Hill SPA	60.7	109.7	53.8	83.2	108.3	*
Salt River	52.8	106.8	0.0	55.5	103.2	*
Stirling Range	46.7	103.7	45.1	51.9	93.2	*
Truslove	58.3	99.8	51.4	80.7	102.5	*
s.e.d.	3.5	6.4	4.2	12.53	6.9	10.4
Site mean	56.7	106.1	53.8	82.57	106.2	53.6
Probability	<0.001	<0.001	<0.001	0.370	<0.001	<0.001
(prov)					1	
Probability	<0.001	0.01	<0.001	0.630	<0.001	<0.001
(prov.mum)					1	

Table A1.2b. Provenance means: height (m)

Provenance	Esperance WA	Marcollata SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E Jerramungup	*	7.8	4.1	6.4	*	3.2
Beaufort River	*	8.3	4.0	6.3	*	3.4
Broomehill	*	8.4	4.3	5.7	*	3.0
Bundaleer SPA	*	8.4	4.5	6.5	*	3.5
Dumbleyung Lake	*	8.3	4.5	6.4	*	3.6
Gibson	*	7.4	4.0	5.9	*	3.0
Gordon River	*	8.6	4.7	7.1	*	3.1
Grass Patch	*	8.8	4.4	6.8	*	3.8
Jerdacuttup	*	7.0	4.5	5.8	*	3.1
Jerdacuttup river	*	7.5	3.9	6.0	*	2.7
Katanning	*	8.4	4.2	6.8	*	3.4
Lake Magenta Rd	*	8.0	4.1	6.8	*	3.1
Old Newgate Rd	*	7.2	4.0	5.6	*	2.9
Ongerup	*	8.5	4.8	6.3	*	3.4
Porongorup	*	7.7	4.5	6.0	*	2.8
Ravensthorpe	*	8.3	4.6	6.6	*	3.2
Red Lake	*	8.5	4.9	6.6	*	3.9
Red Hill SPA	*	8.1	4.3	6.3	*	3.5
Salt River	*	7.9	0.0	5.3	*	3.1
Stirling Range	*	7.7	3.8	4.4	*	3.2
Truslove	*	8.1	4.3	6.7	*	3.5
s.e.d.	*	0.33	0.27	0.7	*	0.26
Site mean	*	8.0	4.3	6.2	*	3.3
Probability (prov)	*	<0.001	<0.001	0.129	*	<0.001
Probability (prov.mum)	*	0.06	<0.001	<0.001	*	0.01

Figure A1.2a. Provenance means at Esperance WA: equivalent DBH (mm) (bars indicate average standard errors of difference; solid line illustrates the site mean)

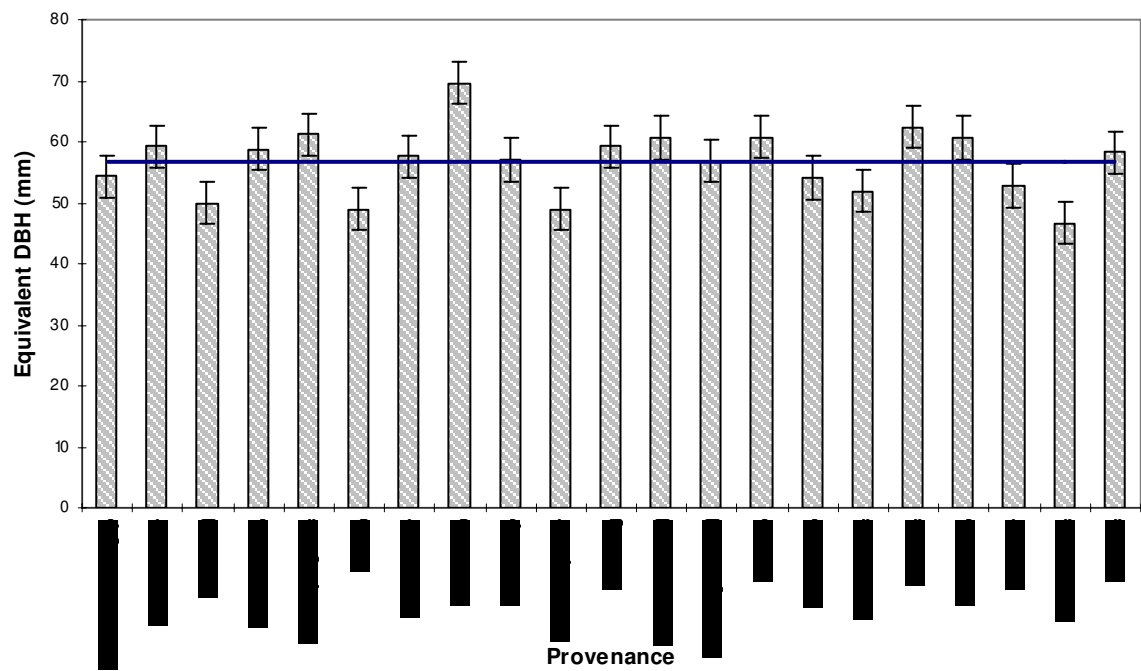


Figure A1.2b. Provenance means at Marcollat SA: equivalent DBH (mm) and height (dm) (bars indicate average standard errors of difference)

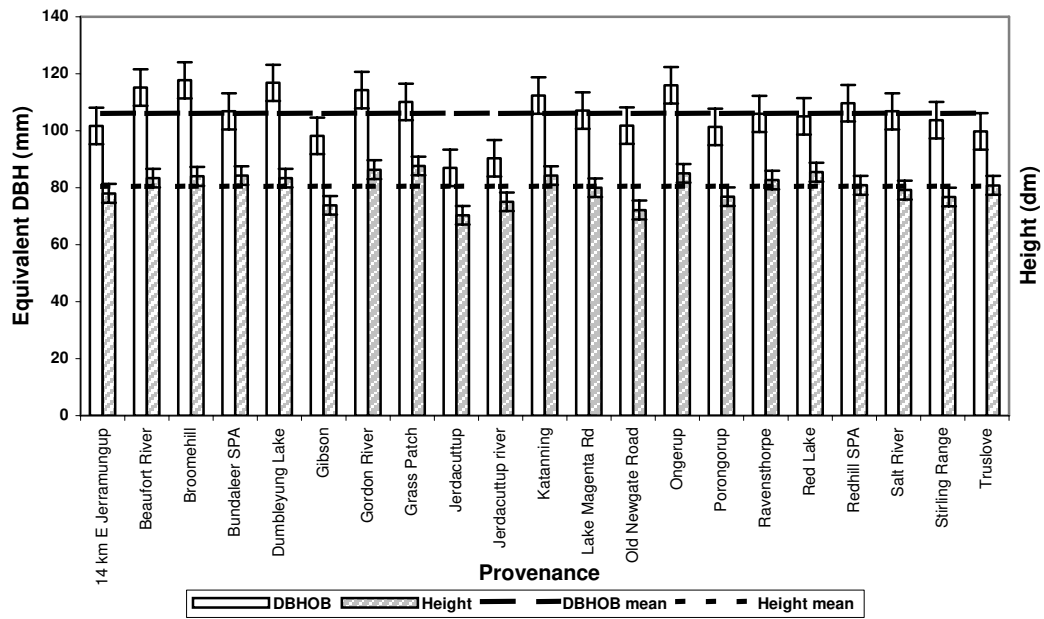


Figure A1.2c. Provenance means at Dunkeld Vic.: equivalent DBH (mm) and height (dm) (bars indicate average standard errors of difference)

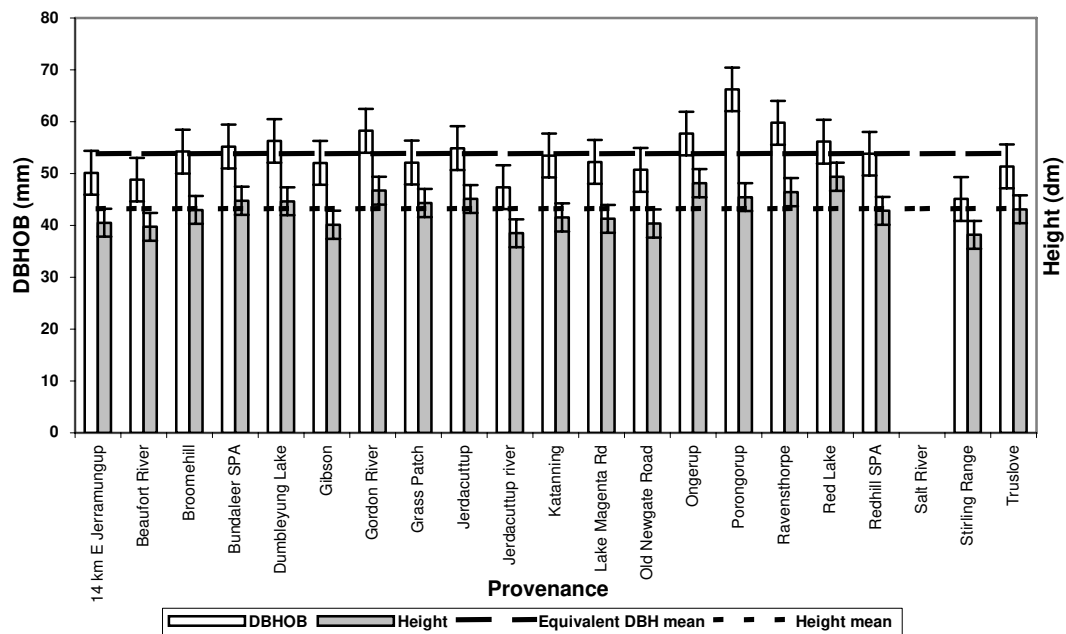


Table A1.3. Provenance means: volume (m³)

Provenance	Esperance WA	Marcollat SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E	*	0.0230	0.0032	0.0163	*	*
Jerramungup						
Beaufort River	*	0.0313	0.0033	0.0193	*	*
Broomehill	*	0.0321	0.0039	0.0160	*	*
Bundaleer SPA	*	0.0265	0.0043	0.0162	*	*
Dumbleyung Lake	*	0.0321	0.0045	0.0206	*	*
Gibson	*	0.0206	0.0033	0.0137	*	*
Gordon River	*	0.0319	0.0047	0.0195	*	*
Grass Patch	*	0.0295	0.0038	0.0219	*	*
Jerdacuttup	*	0.0162	0.0043	0.0125	*	*
Jerdacuttup river	*	0.0169	0.0028	0.0140	*	*
Katanning	*	0.0317	0.0041	0.0238	*	*
Lake Magenta Rd	*	0.0255	0.0037	0.0229	*	*
Old Newgate Rd	*	0.0231	0.0031	0.0157	*	*
Ongerup	*	0.0318	0.0049	0.0180	*	*
Porongorup	*	0.0217	0.0059	0.0129	*	*
Ravensthorpe	*	0.0252	0.0044	0.0194	*	*
Red Lake	*	0.0275	0.0049	0.0165	*	*
Red Hill SPA	*	0.0280	0.0039	0.0172	*	*
Salt River	*	0.0270	0.0000	0.0090	*	*
Stirling Range	*	0.0253	0.0033	0.0080	*	*
Truslove	*	0.0227	0.0036	0.0149	*	*
s.e.d.	*	0.0036	0.0007	0.0052	*	*
Site mean	*	0.0262	0.0040	0.0166	*	*
Probability (prov)	*	<0.001	<0.001	0.062	*	*
Probability (prov.mum)	*	<0.001	<0.001	0.040	*	*

Figure A1.3a. Provenance means at Marcollat SA: volume (m³) (bars indicate average standard errors of difference; solid line illustrates the site mean)

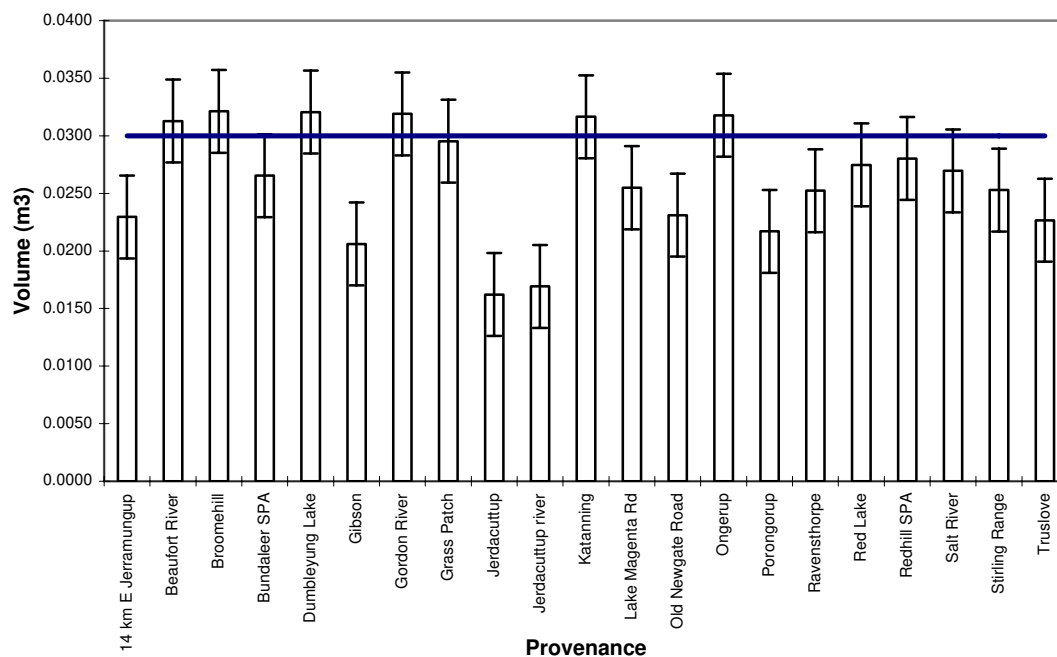


Figure A1.3b. Provenance means at Dunkeld Vic: volume (m³) (bars indicate average standard errors of difference; solid line illustrates the site mean)

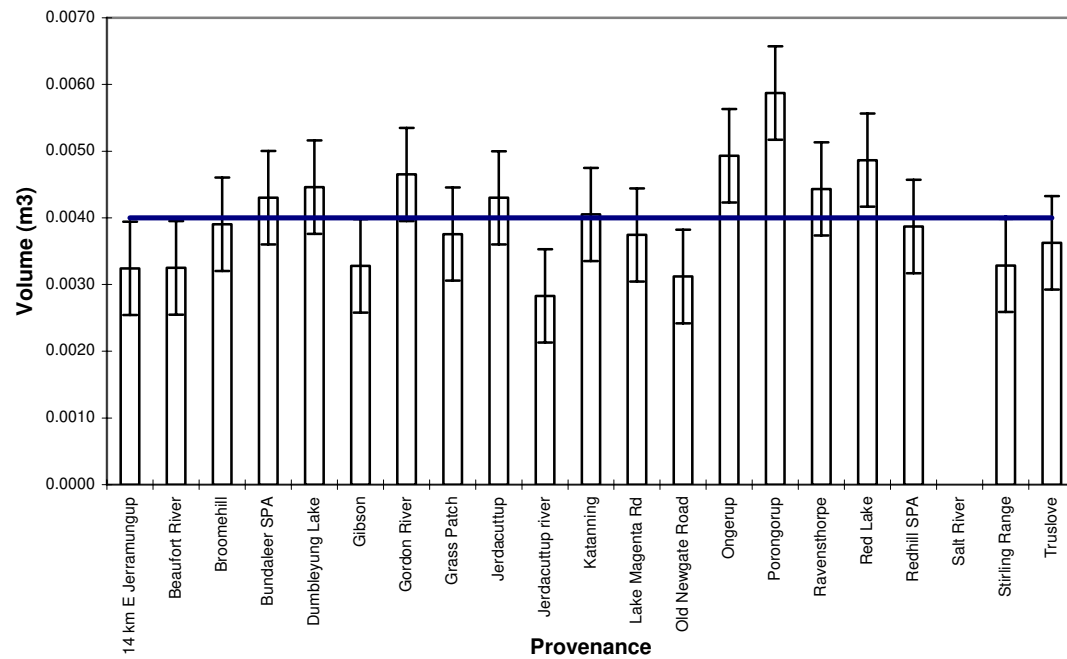


Table A1.4. Provenance means: commercial bole length (m)

Provenance	Esperance WA	Marcollat SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E	1.11	*	*	*	*	*
Jerramungup						
Beaufort River	1.50	*	*	*	*	*
Broomehill	1.09	*	*	*	*	*
Bundaleer SPA	1.47	*	*	*	*	*
Dumbleyung	1.55	*	*	*	*	*
Lake						
Gibson	0.87	*	*	*	*	*
Gordon River	1.16	*	*	*	*	*
Grass Patch	1.86	*	*	*	*	*
Jerdacuttup	1.09	*	*	*	*	*
Jerdacuttup river	0.76	*	*	*	*	*
Katanning	1.20	*	*	*	*	*
Lake Magenta Rd	1.47	*	*	*	*	*
Old Newgate Rd	0.99	*	*	*	*	*
Ongerup	1.64	*	*	*	*	*
Porongorup	1.00	*	*	*	*	*
Ravensthorpe	0.88	*	*	*	*	*
Red Lake	1.79	*	*	*	*	*
Red Hill SPA	1.35	*	*	*	*	*
Salt River	0.73	*	*	*	*	*
Stirling Range	0.51	*	*	*	*	*
Truslove	1.23	*	*	*	*	*
s.e.d.	0.2	*	*	*	*	*
Site mean	1.20	*	*	*	*	*
Probability (prov)	<0.001	*	*	*	*	*
Probability (prov.mum)	<0.001	*	*	*	*	*

Figure A1.4. Provenance means at Esperance WA: commercial bole length (m) (bars indicate average standard errors of difference; solid line illustrates the site mean)

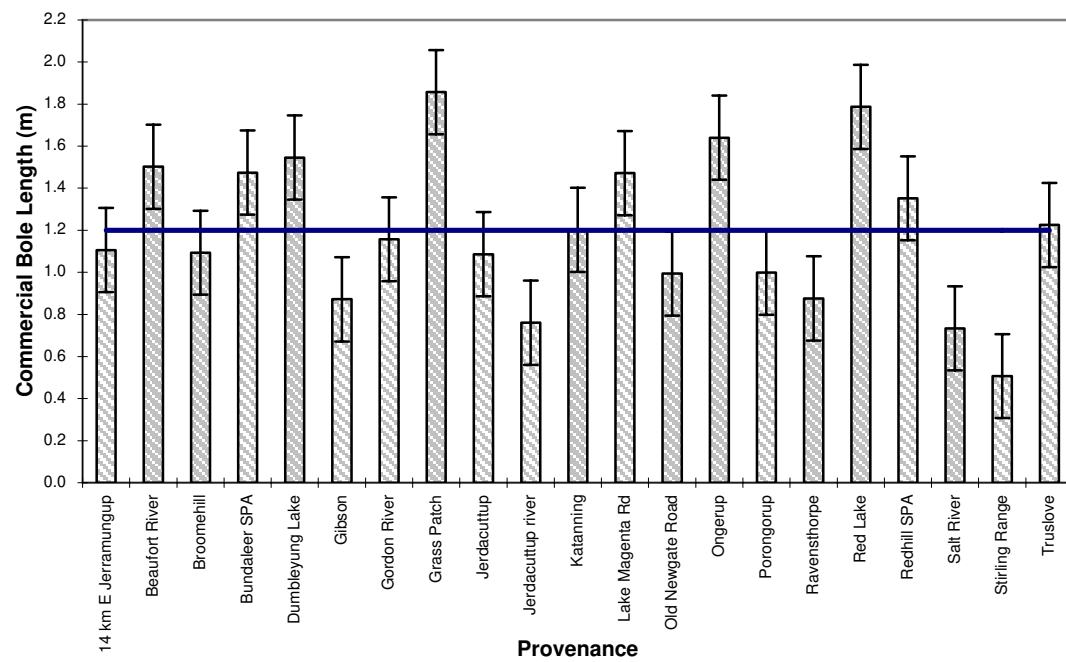


Table A1.5. Provenance means: dominance

Provenance	Esperance WA	Marcollat SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E	1.11	*	*	*	*	*
Jerramungup						
Beaufort River	1.50	*	*	*	*	*
Broomehill	1.09	*	*	*	*	*
Bundaleer SPA	1.47	*	*	*	*	*
Dumbleyung	1.55	*	*	*	*	*
Lake						
Gibson	0.87	*	*	*	*	*
Gordon River	1.16	*	*	*	*	*
Grass Patch	1.86	*	*	*	*	*
Jerdacuttup	1.09	*	*	*	*	*
Jerdacuttup river	0.76	*	*	*	*	*
Katanning	1.20	*	*	*	*	*
Lake Magenta Rd	1.47	*	*	*	*	*
Old Newgate Rd	0.99	*	*	*	*	*
Ongerup	1.64	*	*	*	*	*
Porongorup	1.00	*	*	*	*	*
Ravensthorpe	0.88	*	*	*	*	*
Red Lake	1.79	*	*	*	*	*
Red Hill SPA	1.35	*	*	*	*	*
Salt River	0.73	*	*	*	*	*
Stirling Range	0.51	*	*	*	*	*
Truslove	1.23	*	*	*	*	*
s.e.d.	0.2	*	*	*	*	*
Site mean	1.20	*	*	*	*	*
Probability (prov)	<0.001	*	*	*	*	*
Probability (prov.mum)	<0.001	*	*	*	*	*

Figure A1.5. Provenance means at Esperance WA: dominance (bars indicate average standard errors of difference; solid line illustrates the site mean)

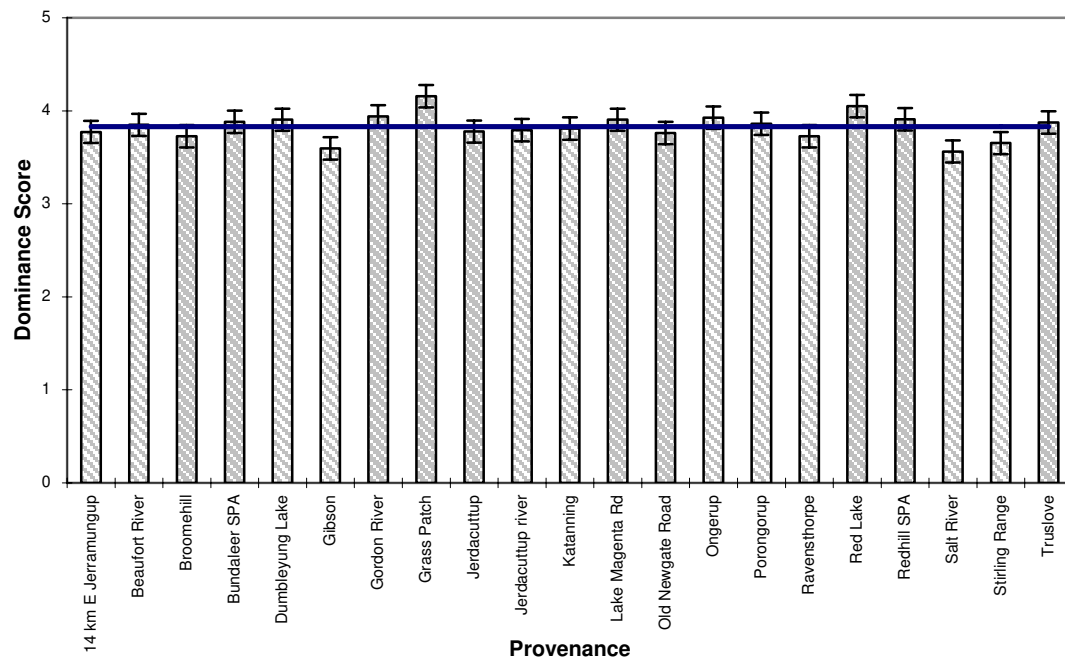


Table A1.6. Provenance means: number of stems

Provenance	Esperance WA	Marcollat SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E Jerramungup	1.22	1.22	*	1.29	1.08	*
Beaufort River	1.18	1.15	*	1.25	1.09	*
Broomehill	1.19	1.29	*	1.15	1.15	*
Bundaleer SPA	1.18	1.12	*	1.13	1.05	*
Dumbleyung Lake	1.18	1.11	*	1.32	1.09	*
Gibson	1.21	1.18	*	1.41	1.07	*
Gordon River	1.18	1.15	*	1.14	1.04	*
Grass Patch	1.11	1.12	*	1.18	1.06	*
Jerdacuttup	1.47	1.09	*	1.49	1.04	*
Jerdacuttup river	1.23	1.15	*	1.17	1.14	*
Katanning	1.24	1.14	*	1.43	1.14	*
Lake Magenta Rd	1.21	1.16	*	1.09	1.05	*
Old Newgate Rd	1.39	1.51	*	1.19	1.22	*
Ongerup	1.12	1.06	*	1.18	1.03	*
Porongorup	1.26	1.47	*	1.49	1.33	*
Ravensthorpe	1.31	1.34	*	1.67	1.04	*
Red Lake	1.03	1.06	*	1.14	1.01	*
Red Hill SPA	1.20	1.18	*	1.30	1.10	*
Salt River	1.33	1.15	*	1.12	1.06	*
Stirling Range	1.17	1.37	*	1.43	1.11	*
Truslove	1.13	1.15	*	1.17	1.07	*
s.e.d.	0.90	0.11	*	0.17	0.05	*
Site mean	1.22	1.20	*	1.27	1.09	*
Probability (prov)	<0.001	<0.001	*	<0.001	<0.001	*
Probability (prov.mum)	<0.001	0.189	*	<0.001	0.003	*

Figure A1.6a. Provenance means at Esperance WA and Marcollat SA: number of stems
(bars indicate average standard errors of difference)

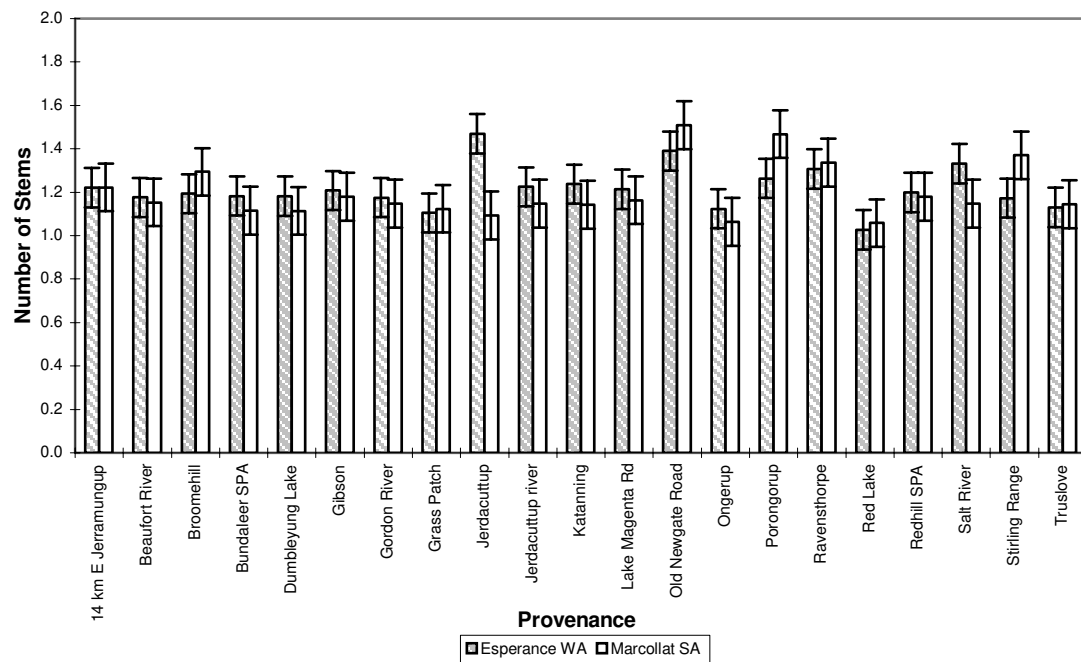


Figure A1.6b. Provenance means at Brynterion Vic. and Boort VIC: number of stems
(bars indicate average standard errors of difference)

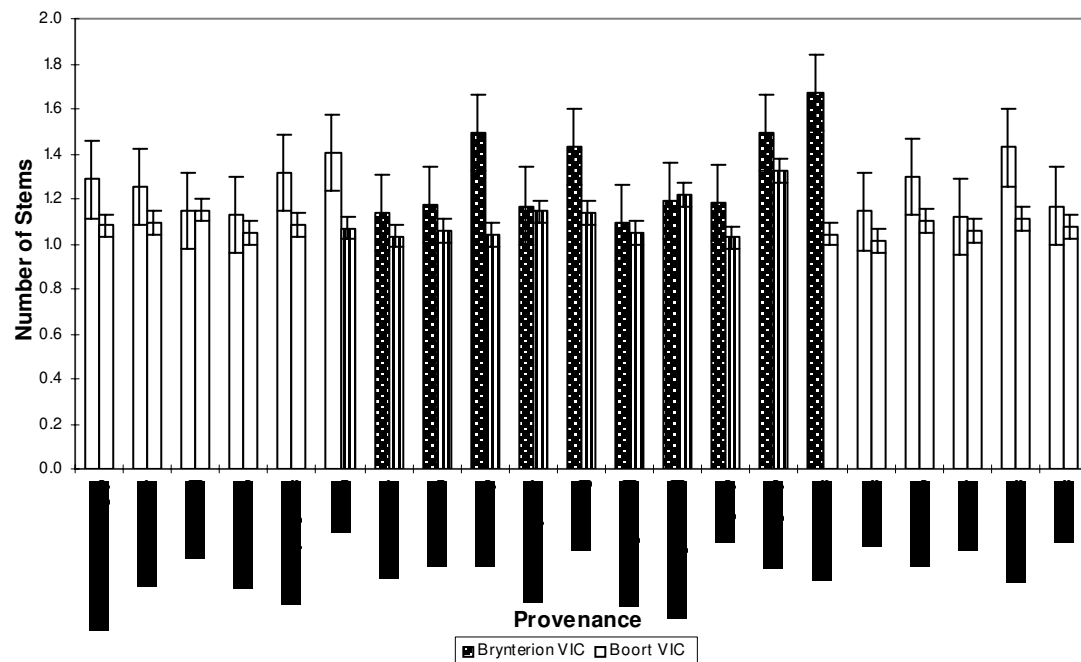


Table A1.7. Provenance means: axis persistence

Provenance	Esperance WA	Marcollata SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E	3.2	4.2	2.1	*	0.8	*
Jerramungup						
Beaufort River	3.5	4.7	2.3	*	0.8	*
Broomehill	3.2	3.8	2.2	*	0.8	*
Bundaleer SPA	3.5	4.7	2.5	*	0.7	*
Dumbleyung	3.1	4.3	2.4	*	0.9	*
Lake						
Gibson	3.4	4.5	2.2	*	0.9	*
Gordon River	2.9	4.5	2.4	*	0.7	*
Grass Patch	3.4	4.4	2.4	*	0.9	*
Jerdacuttup	2.0	4.0	2.3	*	0.8	*
Jerdacuttup	3.3	4.2	2.0	*	0.9	*
river						
Katanning	3.0	4.4	2.1	*	1.0	*
Lake Magenta	3.2	4.8	2.5	*	0.6	*
Rd						
Old Newgate Rd	2.8	3.3	2.1	*	1.0	*
Ongerup	3.7	5.0	2.6	*	0.6	*
Porongorup	2.3	2.9	1.8	*	1.3	*
Ravensthorpe	3.2	4.3	2.6	*	0.7	*
Red Lake	4.0	4.9	2.8	*	0.7	*
Red Hill SPA	3.2	4.1	2.3	*	0.9	*
Salt River	2.5	4.1	0.0	*	0.9	*
Stirling Range	2.6	3.4	2.5	*	0.7	*
Truslove	3.5	4.3	2.4	*	0.8	*
s.e.d.	0.3	0.5	0.17	*	0.1	*
Site mean	3.1	4.2	2.3	*	0.8	*
Probability	<0.001	<0.001	<0.001	*	<0.00	*
(prov)					1	
Probability	<0.001	<0.001	0.01	*	<0.00	*
(prov.mum)					1	

Figure A1.7a. Provenance means at Esperance WA: axis persistence (bars indicate average standard errors of difference; solid line illustrates the site mean)

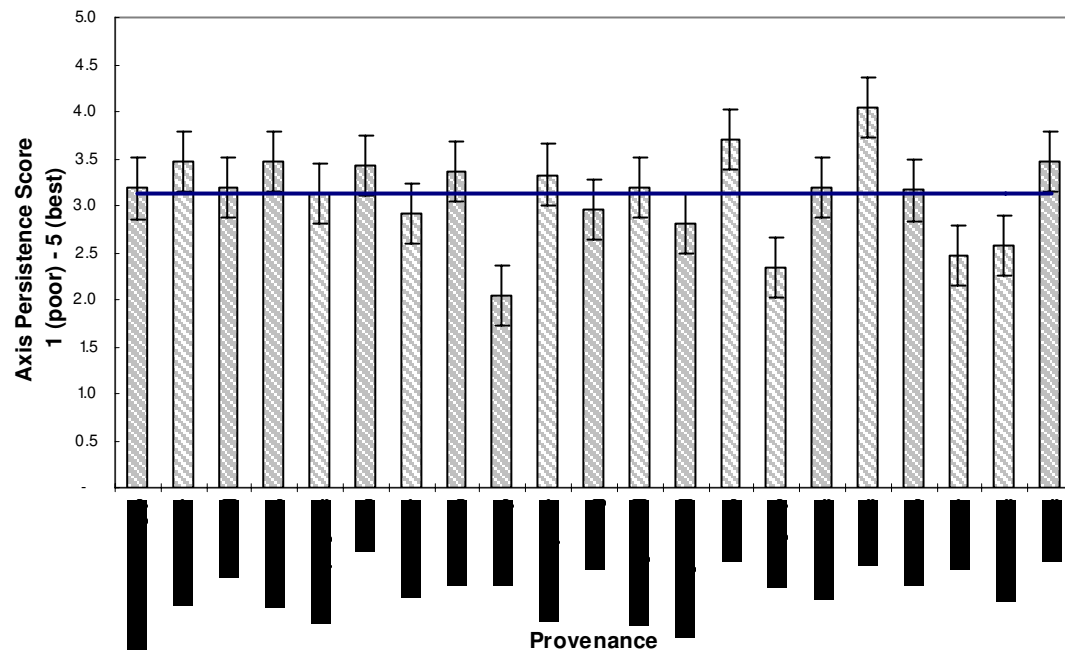


Figure A1.7b. Provenance means at Marcollat SA: axis persistence (bars indicate average standard errors of difference; solid line illustrates the site mean)

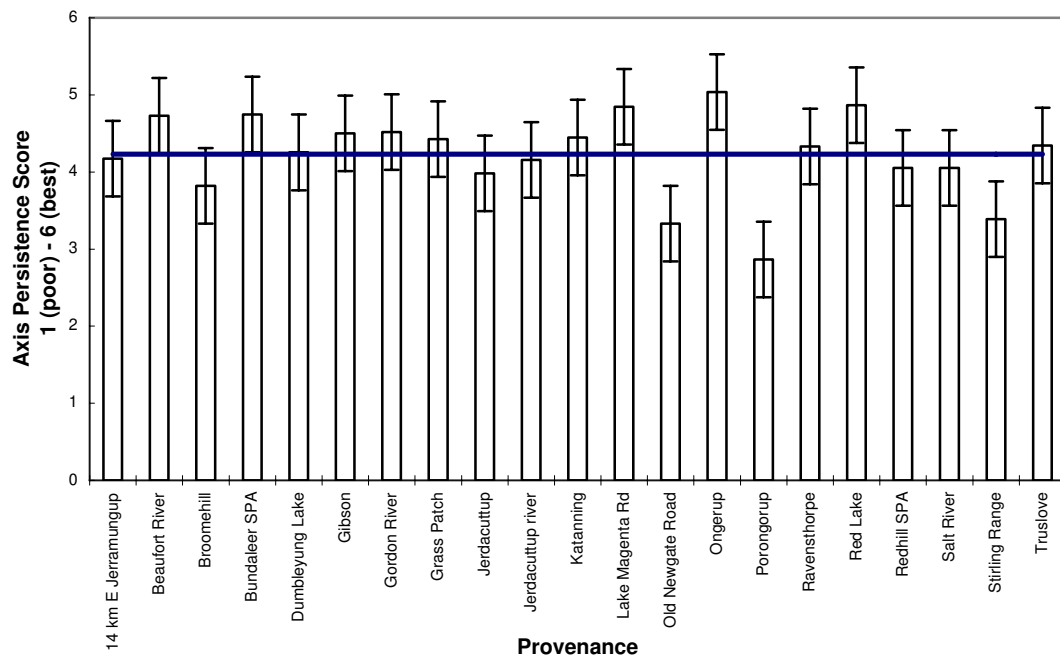


Figure A1.7c. Provenance means at Dunkeld Vi.: axis persistence (bars indicate average standard errors of difference; solid line illustrates the site mean)

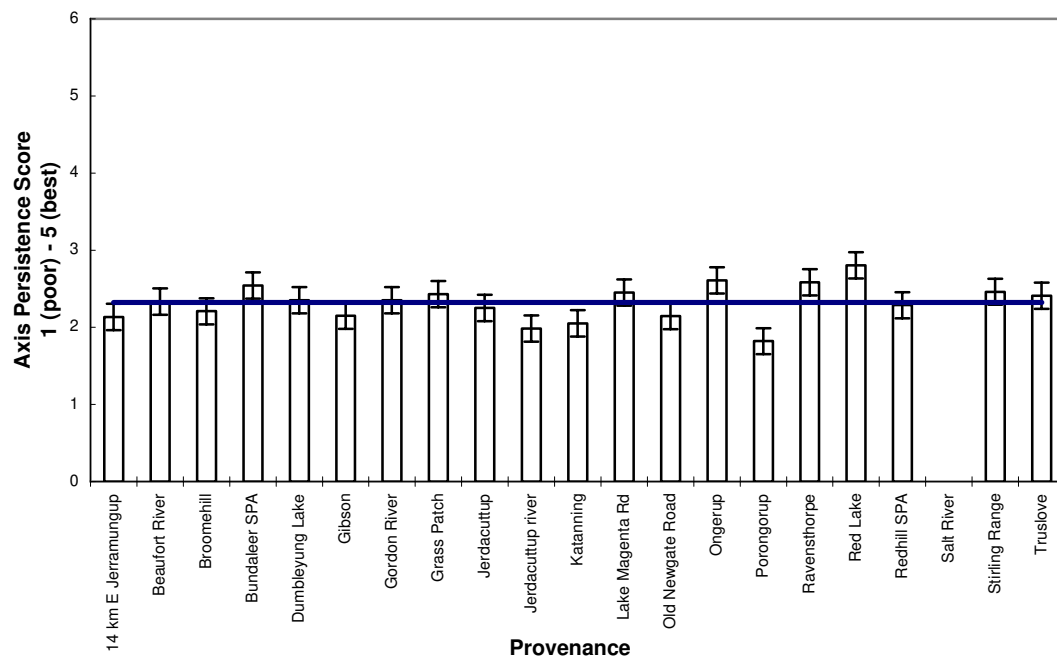


Figure A1.7d. Provenance means at Boort Vic: axis persistence (bars indicate average standard errors of difference; solid line illustrates the site mean)

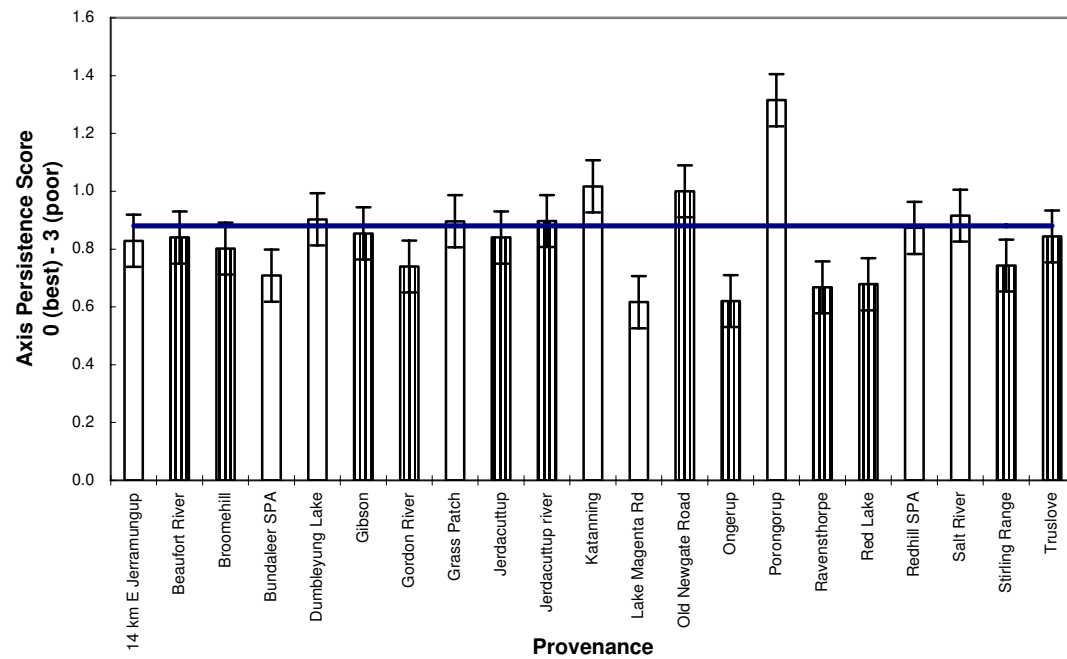


Table A1.8. Provenance means: malformation (Esperance WA); form (Boort Vic.)

Provenance	Esperance WA	Marcollata SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E	3.07	*	*	*	3.00	*
Jerramungup						
Beaufort River	3.08	*	*	*	2.44	*
Broomehill	3.05	*	*	*	2.38	*
Bundaleer SPA	3.39	*	*	*	2.45	*
Dumbleyung	2.71	*	*	*	2.01	*
Lake						
Gibson	3.49	*	*	*	3.47	*
Gordon River	3.02	*	*	*	2.67	*
Grass Patch	3.15	*	*	*	2.63	*
Jerdacuttup	1.86	*	*	*	3.07	*
Jerdacuttup	3.37	*	*	*	3.03	*
river						
Katanning	2.84	*	*	*	2.65	*
Lake Magenta	3.05	*	*	*	2.24	*
Rd						
Old Newgate Rd	2.78	*	*	*	3.03	*
Ongerup	3.42	*	*	*	2.31	*
Porongorup	2.07	*	*	*	2.70	*
Ravensthorpe	3.23	*	*	*	2.45	*
Red Lake	4.09	*	*	*	2.43	*
Red Hill SPA	3.07	*	*	*	2.62	*
Salt River	2.25	*	*	*	3.14	*
Stirling Range	3.04	*	*	*	2.31	*
Truslove	3.40	*	*	*	3.06	*
s.e.d.	0.36	*	*	*	0.16	*
Site mean	3.02	*	*	*	2.67	*
Probability	<0.001	*	*	*	<0.00	*
(prov)					1	
Probability	<0.001	*	*	*	<0.00	*
(prov.mum)					1	

Figure A1.8. Provenance means at Esperance WA: malformation; Boort Vic.: form (bars indicate average standard errors of difference)

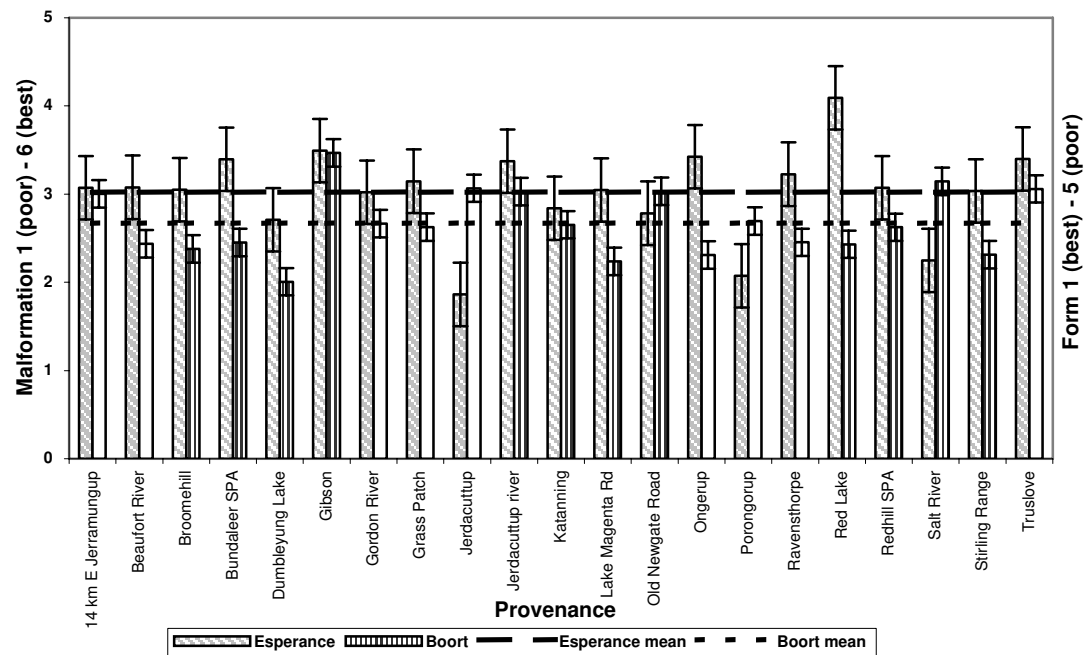


Table A1.9. Provenance means: stem straightness

Provenance	Esperance WA	Marcollat SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E	2.9	7.5	2.1	*	*	*
Jerramungup						
Beaufort River	3.4	5.7	2.4	*	*	*
Broomehill	3.2	5.1	2.5	*	*	*
Bundaleer SPA	3.4	5.3	2.4	*	*	*
Dumbleyung	3.5	4.7	2.7	*	*	*
Lake						
Gibson	2.2	8.3	1.9	*	*	*
Gordon River	3.0	6.9	2.1	*	*	*
Grass Patch	3.7	5.7	2.5	*	*	*
Jerdacuttup	2.5	7.5	2.0	*	*	*
Jerdacuttup river	2.7	6.7	2.0	*	*	*
Katanning	3.2	6.4	2.2	*	*	*
Lake Magenta Rd	3.4	5.6	2.3	*	*	*
Old Newgate Rd	2.9	7.3	1.9	*	*	*
Ongerup	3.8	4.8	2.8	*	*	*
Porongorup	2.8	6.5	1.9	*	*	*
Ravensthorpe	2.7	6.6	2.3	*	*	*
Red Lake	3.6	5.7	2.5	*	*	*
Red Hill SPA	3.3	5.7	2.3	*	*	*
Salt River	2.6	7.6	0.0	*	*	*
Stirling Range	2.4	5.2	2.2	*	*	*
Truslove	2.9	7.1	2.1	*	*	*
s.e.d.	0.22	0.82	0.15	*	*	*
Site mean	3.05	6.29	2.25	*	*	*
Probability (prov)	<0.001	<0.001	<0.001	*	*	*
Probability (prov.mum)	<0.001	<0.001	<0.001	*	*	*

Figure A1.9a. Provenance means at Esperance WA and Boort Vic.: stem straightness (bars indicate average standard errors of difference)

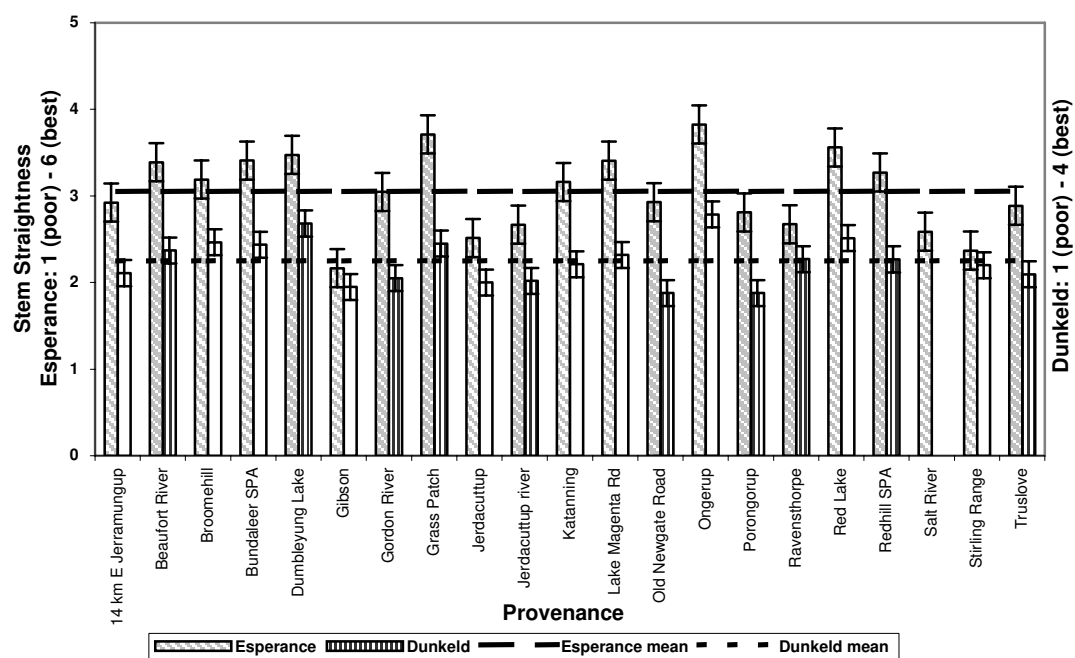


Figure A1.9b. Provenance means at Marcollat SA: stem straightness (bars indicate average standard errors of difference; solid line illustrates the site mean)

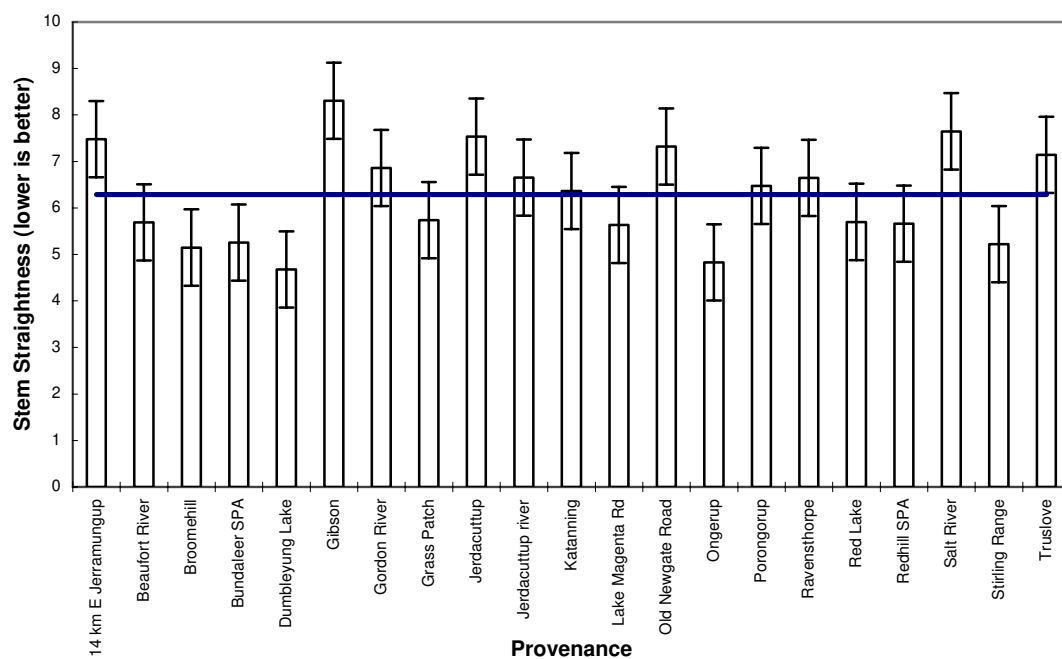


Table A1.10. Provenance means: crown class (Esperance WA); branch weight (Marcollat SA and Boort Vic)

Provenance	Esperance WA	Marcollat SA	Dunkeld Vic.	Brynterion SF Vic.	Boort Vic.	Narrandera NSW
14 km E	3.2	2.6	*	*	1.7	*
Jerramungup						
Beaufort River	3.0	2.5	*	*	1.8	*
Broomehill	2.9	2.9	*	*	1.8	*
Bundaleer SPA	3.4	1.8	*	*	1.5	*
Dumbleyung	3.0	2.5	*	*	1.9	*
Lake						
Gibson	3.0	2.3	*	*	2.2	*
Gordon River	2.8	2.9	*	*	1.5	*
Grass Patch	3.3	2.5	*	*	1.7	*
Jerdacuttup	3.6	3.2	*	*	1.9	*
Jerdacuttup river	3.1	2.7	*	*	2.1	*
Katanning	2.8	2.8	*	*	2.0	*
Lake Magenta Rd	3.4	2.2	*	*	1.2	*
Old Newgate Rd	2.9	3.7	*	*	2.1	*
Ongerup	3.0	2.6	*	*	1.3	*
Porongorup	3.1	3.4	*	*	3.3	*
Ravensthorpe	3.1	1.6	*	*	1.1	*
Red Lake	3.0	2.3	*	*	1.3	*
Red Hill SPA	2.9	2.9	*	*	1.6	*
Salt River	3.0	3.1	*	*	2.2	*
Stirling Range	3.4	1.7	*	*	1.6	*
Truslove	3.0	2.2	*	*	1.8	*
s.e.d.	0.29	0.51	*	*	0.27	*
Site mean	3.09	2.59	*	*	1.77	*
Probability (prov)	0.03	<0.001	*	*	<0.001	*
Probability (prov.mum)	<0.001	<0.001	*	*	<0.001	*

Figure A1.10a. Provenance means at Esperance WA: crown class (bars indicate average standard errors of difference; solid line illustrates the site mean)

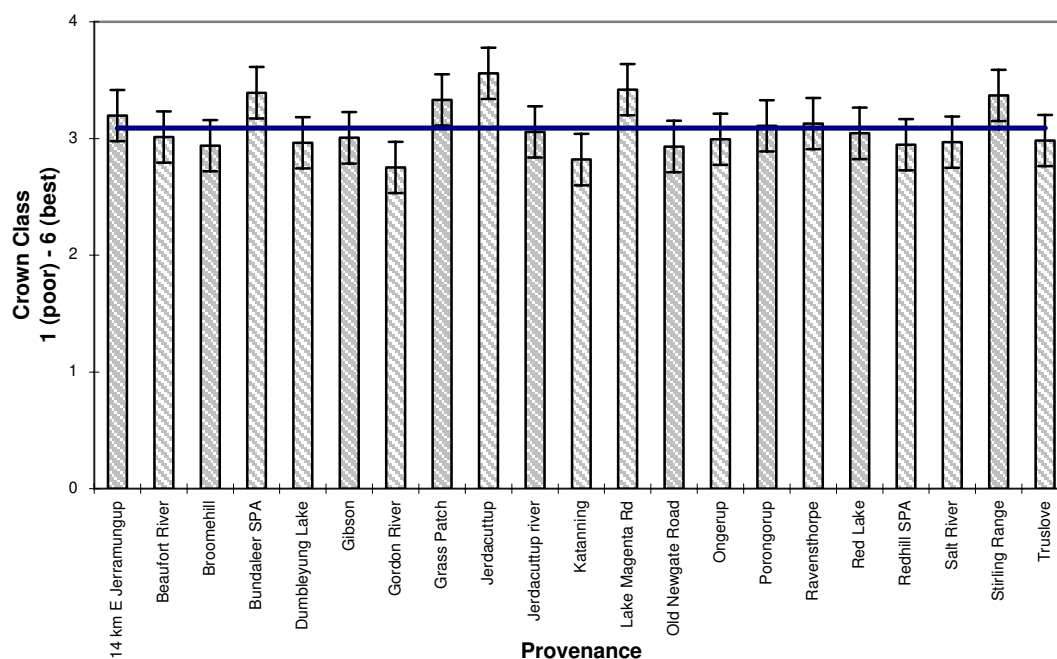


Figure A1.10b. Provenance means at Marcollat SA and Boort Vic.: branch weight (bars indicate average standard errors of difference)

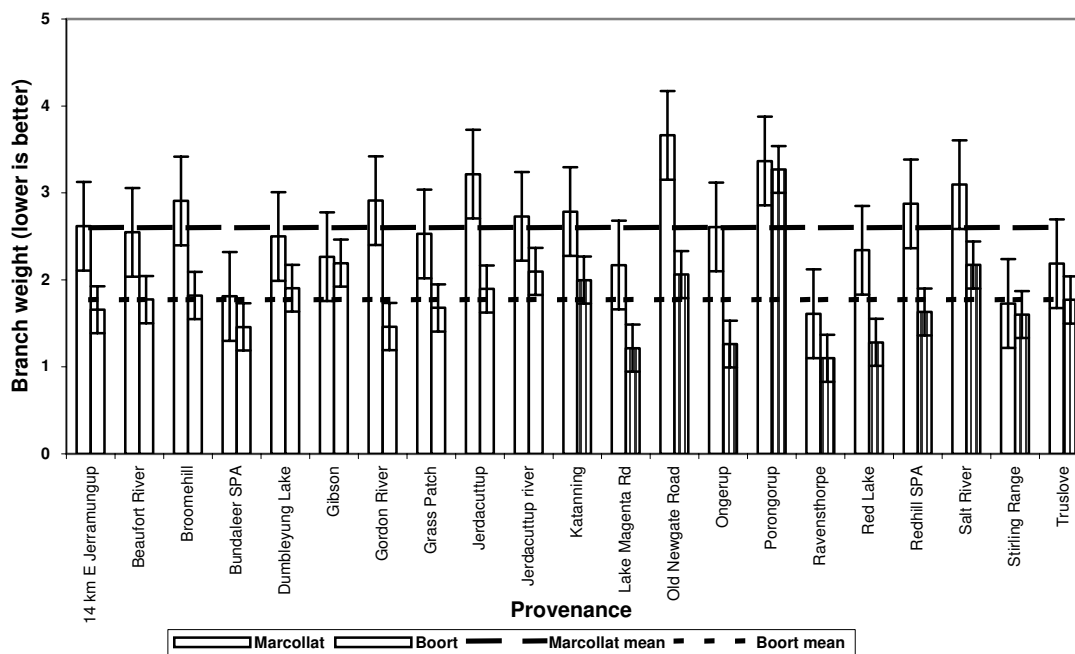


Table A1.11. Summary of seed source trial results

Trait	Rocky Gully, WA	Carew, SA	Marcollat, SA
DBH (mm)			
Bundaleer SPA + trees	*	59.1	52.92
bulk			
Bundaleer SPA bulk	*	62.47	54.57
Grass Patch WA (control)	*	66.09	54.8
(5 trees)			
Red Hill SPA + tree bulk	*	68.72	62.42
Yando River Road	*	57.35	42.38
s.e.d	*	4.96	3.884
Probability	*	0.122	<0.001
Height (m)			
Bundaleer SPA + trees	2.169	4.246	3.815
bulk			
Bundaleer SPA bulk	2.598	4.348	4.015
Grass Patch WA (control)	2.570	4.757	4.103
(5 trees)			
Red Hill SPA + tree bulk	*	4.638	4.171
Yando River Road	2.039	3.937	3.307
s.e.d	0.1179	0.2268	0.2445
Probability	<0.001	0.002	0.003
Number of stems			
Bundaleer SPA + trees	*	1.10	1.115
bulk			
Bundaleer SPA bulk	*	1.12	1.123
Grass Patch WA (control)	*	1.07	1.105
(5 trees)			
Red Hill SPA + tree bulk	*	1.10	1.248
Yando River Road	*	1.17	1.22
s.e.d	*	0.02	0.04429
Probability	*	<0.001	<0.001

□ DBH is equivalent DBH (i.e. geometric mean of individual stems).

Figure A1.11a. Seed source means at Marcollat SA and Carew SA: equivalent DBH (bars indicate average standard errors of difference)

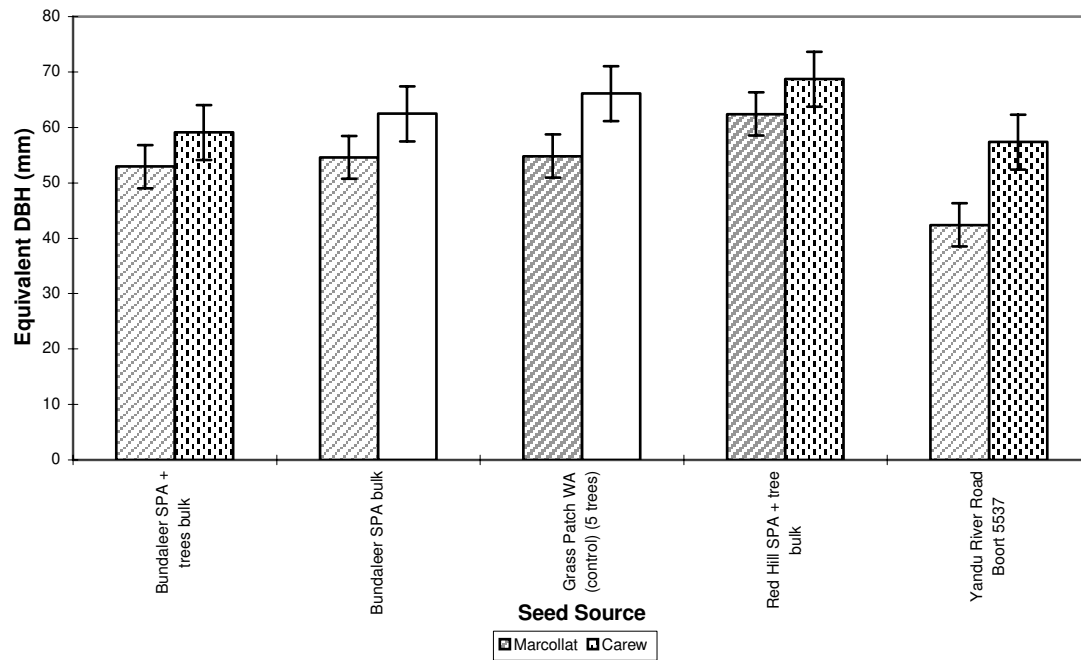


Figure A1.11b. Seed source means at Rocky Gully WA, Marcollat SA and Carew SA: height (bars indicate average standard errors of difference)

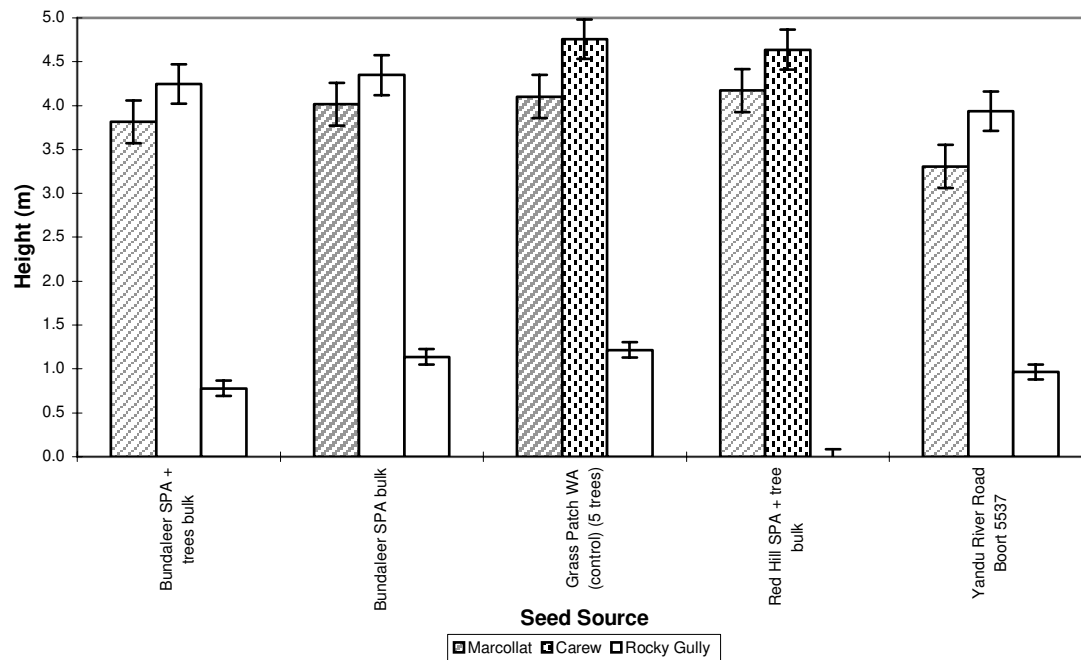
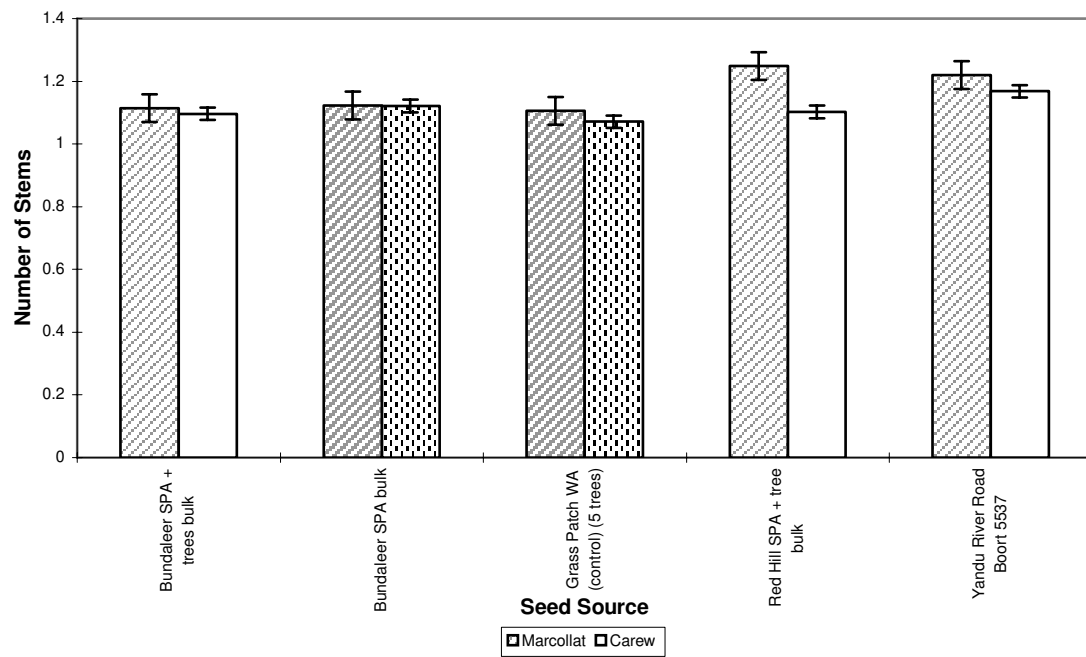


Figure A1.11c. Seed source means at Marcollat SA and Carew SA: number of stems
(bars indicate average standard errors of difference)



2 Metadata Part 2: *Eucalyptus cladocalyx* provenance-progeny and seed source trials

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2.1. Background

Eucalyptus cladocalyx (sugar gum) is endemic to South Australia. It occurs in three disjunct regions: Kangaroo Island, and the South Flinders Ranges, where it occurs as a medium-to-tall tree, and; the Eyre Peninsula where it occurs as small, spreading tree with a short, woodland habit. The forest tree form attains moderate growth rates, coupled with acceptable stem and branch characteristics, in Mediterranean or temperate climates that receive relatively little rainfall. It is very adaptable, performing well on thin or stony soils as long as they are well drained in climates that are free from heavy frosts. It can be successfully established from seedling stock or by direct seeding. It coppices vigorously. The timber is strong, hard and dense and produces poles and timber useful for general and heavy construction. It is naturally durable and suited to applications such as fence posts. It also makes excellent firewood. More recently, it has gained popularity as a cabinet timber and is used for decking and flooring. Its usefulness was identified soon after forestry commenced in South Australia in the 1870s, and seed from the largest, South Flinders Ranges population was extensively distributed to the other Australian colonies and the British Empire. It was planted quite extensively as windbreaks in South Australia and western Victoria up until circa 1940 (Andrew Lang, SmartTimbers Lismore, pers. comm.). Its suitability as a species for plantation forestry on drier sites in southern Australia has recently been reaffirmed, and a cooperative breeding program commenced in 1999, following provenance testing in Victoria and South Australia during the early 1990s.

2.2. Genetic improvement

Sugar gum was selected by ALRTIG as a candidate species for genetic improvement in 1999 because of its demonstrated adaptation to Mediterranean climates, environmental plasticity with respect to soil and environmental stress, good growth rate relative to other woodland species, and availability of background information, trial data and genetic resources.

Breeding strategy

The improvement objective is to maximise the value of logs produced by plantations in the target planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles and posts. The initial selection criteria were rapid growth, single straight stem, and resistance to pests and diseases. Selection and breeding for improved wood properties has commenced with a study on the genetic variation of traits relating to natural durability for in-ground use including some basic wood properties of young-aged material such as basic density and heartwood-sapwood ratios (RIRDC project CSF67A).

Provenance information and interim seed sources

An initial objective of the ALRTIG program was to pool trial data from the partner State organisations to identify the best seed sources for inclusion in breeding programs. Some

plantings were also developed as seed stands to produce seed in the interim prior to the program's own seed orchards bearing crops. Superior natural provenances of the species (Wirrabara in the South Flinders Ranges and Flinders Chase, Kangaroo Island) displaying rapid growth and acceptable stem-form were identified from the results of provenance trials at six sites in South Australia. Two trials in Victoria demonstrated that the local landrace (Lismore) was superior to any wild source. Further seed collections were made from outstanding trees in these places as an interim source of superior seed, while seed from a multi-provenance seed production area established in South Australia in 1992 is now available. A 30-year-old second-generation plantation at Wail, western Victoria, established from superior trees of first-generation plantations at Wail, originally derived from the South Flinders Range population, was converted into another interim seed production area by selective thinning in 2001.

Breeding population

ALRTIG established a main breeding population as seven provenance-progeny trials at carefully selected sites in NSW, SA, Vic. and WA. These trials incorporate 139 families from (i) randomly sampled wild mother trees from good provenances and (ii) superior trees in field trials and planted stands of these provenances. The trials will serve the dual purposes of supplying data on variation and estimates of genetic parameters of target traits, and supplying genetically improved seed.

Some of the sites are being converted by selective thinning to seedling seed orchards (SSOs), which will supply genetically improved seed for plantations and for the next generation of the main breeding population. These trials are termed progeny trial – seedling seed orchards (PT-SSOs). The first of these started producing limited quantities of seed in 2006 after the poorest 2 of 5 trees per family were rogued. One site in WA and one in Victoria are still unthinned, and these may be used for further data collection and possibly selection of scions for a clonal seed orchard. FNSW grafted clonal selections from the top 30 trees in the Wagga Wagga progeny trial during 2006.

Seed source trials

Seed source trials test whether or not genetically improved materials perform significantly better than unimproved controls, using experimental designs that test a small number of bulk seedlots using large treatment plots and good replication to enable precise ranking of seedlot performance and good estimates of stand volume production. A series of *E. cladocalyx* seed source trials were established in winter 2003 across 5 sites in the target planting zone (Table 2). The trials at Rocky Gully (WA) and Craigieburn (Vic.) were established, managed and measured by Integrated Tree Cropping Ltd and Woollybutt Pty Ltd respectively. Each trial was established using local best practice management and silviculture. The trial seedlots were chosen to contrast seed sources that ALRTIG had promoted as 'best-bets' on the basis of early data collation from partners' trial data gathered prior to 1999 with wild provenance material.

2.3. Genetic resources

Details of the seedlots included in the progeny trials are summarised in Table 2.1a. They include 139 families from 13 seed sources, and have been grouped in three 'regions-of-provenance'. This grouping is made on the basis of a molecular genetic study of *E. cladocalyx* populations, which delineates three regions-of-provenance (ROP) for the species, namely Kangaroo Island, South Flinders Ranges and the Eyre Peninsula (McDonald *et al.* 2003). This grouping (with material from planted stands forming a separate group) has been previously

adopted by Bush *et al.* (2007) and Callister *et al.* (2007). The seed sources were of two main sorts: wild provenance collections, with families selected at random, and collections from planted stands, with families phenotypically selected as candidate plus trees. The wild families were drawn from provenances on Kangaroo Island and the South Flinders Ranges only: Eyre Peninsula families were not included on the basis of demonstrated poor performance in ALRTIG partners' provenance trials (Harwood and Bulman 2001). Not all of the families in this series of trials were included at all of the sites; however there is sufficient overlap for robust joint analysis.

Table 2.1a. Seedlots (open-pollinated families) included in the progeny trials

Seed source	ATSC seedlot no.	Moora	Esperance	Avenue	Bordertown	Hamilton	Lismore	Corowa	Wagga	Sites
Kangaroo Island										
American River	20265	6	4	4	6	4	6	5	6	6
Cygnat River	20266	5	1	3	7	3	5	2	4	7
Flinders Chase	16022	3	-	2	7	2	4	3	3	9
Flinders Chase 2	19717	9	7	5	11	8	9	9	9	12
Flinders Chase 3	20267	12	7	5	12	11	12	9	11	12
S. Flinders Range										
Mt. Remarkable	20388	16	15	12	16	16	16	16	14	16
Wilmington	19348	7	6	1	8	4	7	-	7	9
Wirrabara State For.	20268	15	10	5	17	10	16	4	13	17
Wirrabara State For. (2)	20414	6	5	5	6	5	6	6	6	6
S. Wilmington PO SA	16089	7	-	2	9	5	7	2	6	10
Planted stands										
Wail, Vic.	-	3	-	-	5	3	3	3	2	5
Kersbrook SPA, SA	-	15	-	10	15	13	15	15	15	15
Lismore, Vic.	21042	4	3	1	3	1	3	1	3	4
Majorca, Vic.	21043	5	3	4	5	5	5	5	5	5
Mt Burr, SA	-	5	-	5	5	5	5	4	5	5
Total seed sources		11	10	10	11	11	11	10	11	11
Total families (all sites)		118	61	64	133	96	119	84	109	139

The seed sources are given in Table 2.1b. Two wild seed sources, Wirrabara (South Flinders Ranges) and Flinders Chase (Kangaroo Island) were selected on the basis of their good performance in earlier studies (Bulman and Harwood 1999 and Harris 2000). Some seed was included from an unthinned range-wide provenance trial at Bundaleer, S.A. Seed from two thinned stands in S.A. at Leighton and Keyneton, as well as phenotypically selected trees from Lismore, Vic. were also included. It is highly likely that the stands at Leighton, Keyneton and Lismore are derivative of seed collected from the South Flinders Range population. The Kersbrook seed production area was established in 1992 by PIRSA, and originally contained individuals from across the *E. cladocalyx* range, including the Eyre Pa., but it has been fully thinned to leave only the best trees (including none from Eyre Pa.).

Table 2.1b. Seedlots included in the seed source trials

Seedlot	ATSC seedlot or other information	Description
Kersbrook SPA	Seed supplied by ForestrySA	Bulk seed from selectively thinned seed production area
Lismore	Seed supplied by ERA nursery	Seed from phenotypically selected trees in Lismore area of W. Victoria
Keyneton seed stand	Seed supplied by State Flora nursery, Murray Bridge	Bulk seed from a thinned plantation in SA,
Wirrabara (wild)	20268 (3 trees), 20389 (5 trees), 20414 (2 trees)	Bulk of 10 wild trees from Wirrabara, SA
Leighton seed stand	Seed supplied by ForestrySA	Bulk seed from a thinned plantation (planted 1911) in SA
Flinders Chase (wild)	20267	Bulk of 9 wild families from Kangaroo Island (KI), SA
Bundaleer provenance trial	Seed supplied by ForestrySA	Seed from trees in a provenance trial including Eyre Pa. S. Flinders Ra. and Kangaroo Is. material

2.4. Sites, trial designs and establishment

Sites for the both the provenance-progeny trials and the seed source trials were selected to be representative of the species' perceived target planting zone in Australia's southern wheat-sheep agricultural area. This zone is characterised by low mean annual rainfall and high evaporation relative to areas where plantation forestry has traditionally been established. Sites were selected with adequate drainage and freedom from heavy frost. Summarised details are given in Table 2.2. The sites are grouped as primary sites, which have most of the families included, and secondary sites, which have a subset of families.

The provenance-progeny trials were established in winter or spring of 2001 (see Table 2.3). Each family (Table 1a) was represented by 20 progeny arranged in either 4 randomized complete block replicates of 5-tree line-plots or 5 replicates of 4-tree line-plots. The site at Avenue, S.A. was established as 3 replicates of 5-tree plots. The progeny trials were mostly resolvable incomplete block types, with incomplete blocks in a two-dimensional row-column arrangement where possible. Initial trial stocking was 1250 stems per hectare (4 m x 2 m spacing) at all sites except Moora and Corowa, which were 1333 sph (3 x 2.5 m) and 1111 sph (4.5 m x 2 m) respectively.

The seed source trials were established in 5-8 replicates of 40-64 tree plots in winter or spring 2003. The common design was randomized complete blocks (RCB) with incomplete block structures superimposed in some cases (resolvable ICB). Spacing was 4 x 2.5 m.

Table 2.2. Summary of site locations, soils and climate for the progeny and seed source trials

Site name	State	Lat.	Long.	Alt.	MAR	Evap.	Geology and/or soil
<i>Progeny trial - primary sites</i>							
Moora	WA	-30.87	115.97	200	460		Sand over sandy clay loam
Bordertown	SA	-36.25	140.57	30	460		Sand over clay
Hamilton	Vic.	-36.36	142.12	205	685	1298	Duplex clay loam over clay
Lismore	Vic.	-37.85	143.5	200	600		Buckshot gravel, clay-loam
Wagga Wagga	NSW	-34.99	147.48	210	570	1860	Red clay-loam to sandy clay loam
<i>Progeny trial - secondary sites</i>							
Esperance	WA	-33.48	122.02	25	620	1720	Deep yellow sand
Avenue	SA	-36.77	140.2				Sandy loam
Corowa	NSW	-35.98	146.38	175	540	1570	Alluvial loam
<i>Seed source trials</i>							
Rocky Gully	WA	-34.5	117.93		835		Shallow granitic
Kangaroo Is.	SA	-35.72	137.32	95	612	1460	Loamy sand over sandstone
Bundaleer	SA	-33.32	138.55	460	580	1600	Medium clay/loam
Lismore	Vic.	-37.75	143.5	200	600		Buckshot gravel, clay-loam
Craigieburn	Vic.	-37.58	144.93	230	600		Duplex, basalt

The progeny and seed source trials were prepared using best local management practice at each site. Typically this involved cultivation (shallow or deep ripping with or without mounding) and weed control, either using chemicals in the eastern States or by scalping in WA. Second year weed control was applied at most sites as necessary. Detailed soil data were collected at the two Western Australian sites.

The trials at Avenue and Bordertown were thinned prior to the measures reported here. Avenue was thinned in December 2004 (3 of 5 stems removed per family plot) and Bordertown was thinned in June 2004 (2 of 5 stems removed per family plot).

2.5. Measurements

The provenance-progeny trials were measured at circa five years, and the seed source trials at three years (see Table 3). The Bordertown progeny trial was also measured at three years (see Bush *et al.* 2005). Various traits were measured at each of the trial sites as summarised in Table 2.3. Survival was also calculated for each trial and mean annual stem volume increment estimates were possible.

Table 2.3. Traits measured at each of the trial sites

Site	Date planted	Other measure	Date measured	Height	DBH	Axis persist.	Branch weight	Stem straight	Form	Other
<i>Progeny trials</i>										
Moora	July 2001	*	Oct. 2005	*	Yes	*	*	Yes	Yes	Bole length, dominance, crown
Esperance	July 2001	*	Mar. 2006	*	Yes	Yes	*	Yes	Yes	Bole length, dominance, crown
Avenue	Aug. 2001	July 02	Feb. 2007	Yes	Yes†	Yes	*	*	*	*
Bordertown	Aug. 2001	Jul. 02; 2003	Oct. 2005, Feb. 2007‡	Yes	Yes†	Yes	Yes	Yes	*	*
Hamilton	Sept. 2001	*	May-June 2005	Yes	Yes†	Yes	Yes	Yes	*	Erectness
Lismore	Aug. 2001	Nov. 05	Oct.-Nov. 2006	Yes	Yes†	Yes	Yes	Yes	*	Leaf shed
Corowa	Sept. 2001	*	Feb. 2006	Yes	Yes	Yes	*	*	*	*
Wagga		*	Nov. 2006	Yes	Yes	Yes	*	*	Yes	Tree health
<i>Seed source trials</i>										
Bundaleer	July 2003	*	Sep. 2006	Yes	Yes	*	*	*	*	*
Rocky Gully	July 2003	Jan. 05	Nov. 2006	Yes	Yes	Yes	*	*	Yes	*
Kangaroo Island	July 2003	*	*	Yes	Yes	*	*	*	*	*
Craigieburn	Sep. 2003	Jan. 05	Sep. 2006	Yes	Yes	Yes	*	*	*	*
Lismore	Sep. 2003	*	Jan. 2006	Yes	*	*	*	*	*	*

† At these sites DBH of individual stems was recorded where present. This gives an extra trait – stem count.

‡ Branch weight and stem straightness were recorded in the 2007 assessment, other traits in 2005

Notes on each of the traits follow:

Survival

Survival was calculated and analysed on the basis of plot mean survival.

Health

Tree health was assessed at the Wagga Wagga site in NSW. Trees were assigned a score of 1-5 with 1 being assigned to a dead tree and 5 to a perfectly healthy tree.

Growth traits

Height

Taken as the height from ground level to the highest point of the crown.

Diameter at breast height

Where more than one stem was found at breast height, and where secondary stems were more than half the diameter of the largest stem, the diameters of the other stems were also taken. Equivalent diameter was calculated as the geometric mean of the stems:

$$\text{EquivalentDBH} = \sqrt[3]{\text{Stem}_1^2 + \text{Stem}_2^2 \dots \text{Stem}_n^2}$$

Stem volume

Individual stem volumes for those sites where both DBH and height were measured was estimated as:

$$\text{Volume} = 1/3 \times \pi \times (\text{EquivalentDBH}/2)^2 \times \text{height}$$

It was also possible to estimate the height for each tree, for the purpose of volume estimation, at Esperance and Moora by deriving a simple regression relationship between height and diameter for the other sites.

Bole length

Bole length rather than height was calculated at Esperance and Moora. This trait is an estimate of commercial bole length that can be achieved with moderate form pruning.

Dominance

Trees at Esperance were classified as follows:

0. missing tree (no further assessment)
1. dead tree (no further assessment)
2. runt (no further assessment)
3. sub-dominant
4. co-dominant
5. dominant

Form traits

Axis persistence

Axis persistence is a measure of forking, where a fork is defined as being greater than half the thickness of the stem at the point of union, and having apically dominant tendency, scored as follows:

1= lowest fork at base

2=lowest fork occurs in lowest quarter of tree

3= lowest fork in first half of tree

4= lowest fork in third quarter of tree

5=lowest fork in highest quarter of tree

6=no forks

Branch weight

At Hamilton, branch weight was scored as the number of branches with $D > 1/4$ of stem diameter at that height (including non-basal forks) to 4 m or to $D = 2$ cm, whichever comes first.

At Bordertown, the number of heavy and very heavy branches in the first 4 m of stem was counted, with heavy branches defined as those between 25 and 50% of the stem diameter at the point of intersection, and very heavy greater than 50% (but lacking apical tendency and so not also scored as a fork). Large and small bends were counted and recorded separately. The scores were combined to make a single branch score:

Branch score = sum heavy branches + sum(very heavy branches *2)

At Lismore branching was scored from 1 (heavy branching) to 4 (light branching).

Stem straightness

Stem straightness was measured on a scale of 1-4 (worst-best) at Hamilton and Lismore, and on a scale of 1-6 (worst-best) (normally distributed) at Esperance and Moora. At Bordertown, the number of minor and severe bends in the first 4 m of stem was counted, with minor bends defined as a deviation from the stem main axis of half to equal the diameter of the stem at that point, and a major deviation being greater than a full deviation. Large and small bends were counted and recorded separately. The scores were combined to make a single straightness score by

Stem straightness score = sum small bends + sum(large bends *2)

Stem erectness

Stem erectness – score of 1, 2 or 3 corresponding to not vertical (>15 degrees), almost vertical (~5-10 degree lean) or vertical (no lean), respectively.

Form

At Wagga Wagga form was assessed on a scale of 1 to 6 (worst-best) with assessors aiming for a normal distribution of scores. The scores were assigned on the basis of stem, branch and crown defects that would impact on the production of a sawlog. At Rocky Gully, form was assessed on the basis of defects that would lead to commercial log downgrade, scored from 1 for highly defective tree, to 6 for a defect-free stem. At Esperance form was scored using a 1-6 scale as follows:

6 - no malformation, single stem

5 - insignificant, ramicorns

- 4 - minor forks or large ramicones
- 3 - forks and/or baskets
- 2 - major forks
- 1 – shrubby and/or multiple stems

Crown

Crown was assessed at Moora and Esperance. This trait incorporates various form-related traits as well as branch size and angle. It is assessed on a scale of 1-6 (worst-best).

Leaf shed

Leafshed from 1 (few leaves shed) to 4 (many leaves shed)

Buds and fruiting

Observations made on either presence/absence of flower buds and immature or mature fruit (at Corowa) or percentage of the crown that contains buds or fruit (Bordertown).

2.6. Data analysis

Trial data from each progeny trial site was screened for errors and outliers and analysed separately. The trials were analysed for each trait using an individual tree model with genetic groups corresponding to the provenances detailed in Table 2a implemented with ASREML software (Gilmour *et al.* 2006). This procedure gives Best Linear Unbiased Estimators (BLUEs - an adjusted mean value) for the provenances and Best Linear Unbiased Predictors (BLUPs – an adjusted mean often used for genetic ranking) for each mother and each individual tree. This report considers the provenance estimates, while the BLUPs are being used to guide selection and thinning and for calculation of more complex genetic parameters. Preliminary assessment of the data showed that the region-of-provenance groupings of provenances provides a useful way of examining the data, and this genetic grouping was also analysed in separate model runs as a fixed effect. Site, provenance and region-of-provenance means have been reported for each site, with standard errors of difference and chi-squared probabilities on Wald tests that the treatments are equal for provenances and families-within-provenances. Probabilities $0.05 < p < 0.001$ are considered to be ‘weakly’ significant, whereas $p < 0.001$ are considered to be ‘highly’ significant. This is because the chi-square distribution used with Wald tests is an asymptotic approximation (i.e. for large samples) and underestimates the probabilities in other cases (Payne *et al.* 2007).

In this metadata summary we have carried out a preliminary analysis of GxE at the provenance level. Our objective is simply to provide an indication of whether there is likely to be significant GxE, not to characterise the GxE in detail. There are a number of ways that this can be done (see for example White *et al.* 2007). We have chosen a mixed modelling approach with sites treated as fixed effects and provenances and the interaction of provenances and sites treated as random effects (see also White *et al.* 2007 for an explanation of the difference between fixed and random effects). This gives (1) a set of BLUP means for provenances taken across the sites, and, (2) variance components for the provenance and provenance-by-site interaction. Shelbourne (1972) suggests that when the provenance-by-site interaction variance is more than 50% of the provenance variance, the level of GxE is likely to be of concern in making selections. The GxE analyses were carried out using the ASREML software described above. More complex GxE analyses could include fitting of a more sophisticated model to account for disparate residual (error) variances at each site, and such analyses are recommended if more detailed information on GxE is required. It should be noted that some of the provenances were represented by different numbers of families at the

different sites (Table 2.1a). This introduces a certain degree of error into the assessment of GxE at the provenance-by-site level: the material representing the provenances tested at the different sites is not identical.

The seed source trials with incomplete block structures were analysed using a mixed-model REML procedure, with replicate and seedlot effects treated as fixed, and incomplete blocks as random. Trials without incomplete blocks were analysed using fixed-effects ANOVA. These analyses were implemented with Genstat software (Payne *et al.* 2007).

2.7. Results

Results are presented in the following sections:

Section A - progeny trials

Section B – seed source trials

In Section A, the traits have been placed into groups: survival and health; growth; form, and; other. Both tables and graphs of means at each site for each trait along with statistical data can be found in Appendix 2. Table 2.4 gives the results of the provenance-by-site interaction analysis described in Section 2.6. Interaction components were identified for all traits except bole length (site-by-ROP) and in some cases interaction components were a significant proportion (>50%) of the provenance component, which Shelbourne (1972) suggests is the approximate point where GxE is of practical significance. Where the ratio of genotype to interaction components is less than 50%, it is also appropriate to examine cross-site means.

Table 2.4. Variance components and ratios for site-by-provenance and site-by-ROP for each trait. Variance component ratios over 50% (shown in bold typeface) indicate GxE that is likely to be of practical significance for selection

Trait	Variance components			Variance components		
	Provenance	Site-by-provenance (SxP)	Ratio of P to SxP	ROP	Site-by-ROP (SxROP)	Ratio of ROP to SxROP
Survival	0.005	0.025	534%	0.004	0.029	718%
Equivalent DBH	23.9	5.3	22%	22.6	7.1	32%
Height	994	242	24%	853	361	42%
Bole length	0.023	0.011	47%	0.030	0.000	0%
Stem volume	0.016	0.287	1784%	0.015	0.287	1872%
Dominance	0.009	0.008	93%	0.010	0.001	12%
Stem count	0.002	0.001	74%	0.003	0.001	37%
Axis persistence	0.160	0.037	23%	0.249	0.039	16%
Stem straightness	Not determined			Not determined		
Branch weight	0.039	0.029	75%	0.067	0.033	49%
Form	0.076	0.006	7%	0.144	0.002	1%
Crown	0.117	0.021	18%	0.194	0.033	17%

2.7A. Progeny trials

Survival and tree health (Appendix 2.1)

Overall survival in the trial series was good ranging from 67-95%, with Esperance, Avenue and Moora having overall survival of circa 70% and the rest over 80%. Avenue and Bordertown had been thinned prior to this series of measures; though Bordertown had been measured at age three after which time it was thinned to prevent drought stress. Significant differences in survival were found between families-within-provenances at all sites and between provenances at all sites except Corowa and Lismore. There are significant indications of site-by-provenance and site-by-ROP interaction with numerous genotype rank changes across sites and high genotype to site-by-genotype interaction variance components (Table 2.4).

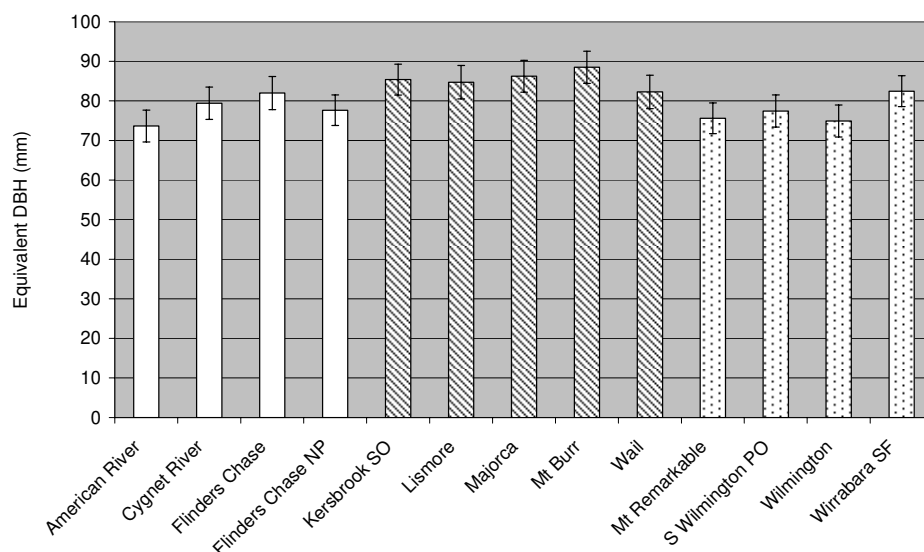
Health of individual trees was recorded at Wagga Wagga where ongoing mortality is perhaps due to the interaction of drought stress and stem borers. There were significant differences between provenances and families-within-provenances (Appendix 2.2), the Kangaroo Island provenances having lower mean health scores than either of the South Flinders Ranges or planted stand groupings.

Growth traits

Equivalent DBH (Appendix 2.3)

There were highly significant differences ($p < 0.001$) between provenances and families-within-provenances for this trait at all sites. The planted stand group of seed sources ranked consistently well, especially Mt Burr which was the best provenance at five sites. The American River provenance performed consistently poorly across sites, having the lowest mean DBH at five of the eight sites. DBH at Avenue is particularly outstanding, though this is probably due to its later date of measurement and response to thinning in December 2004. The degree of site-by-provenance interaction was low, and the cross-site trait means are shown in Figure 2.1.

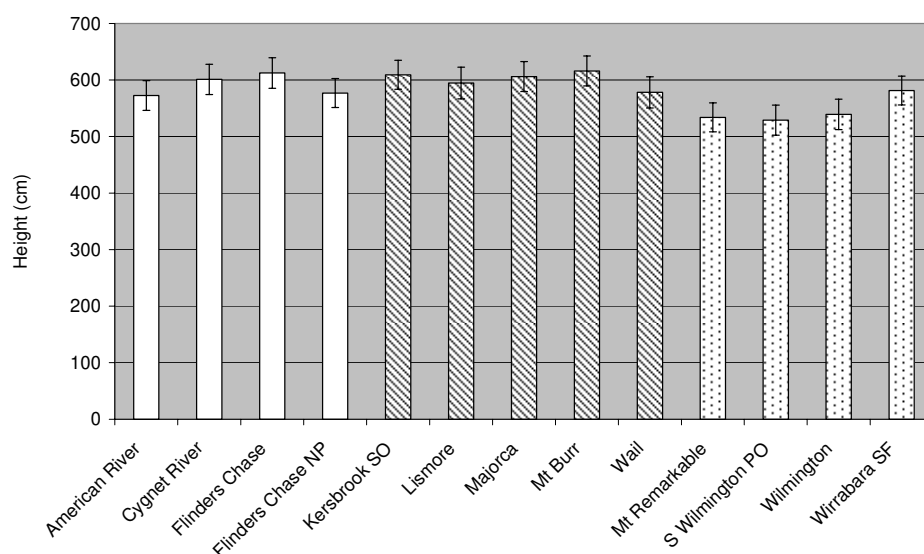
Figure 2.1. Cross-site means for equivalent DBH. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted stand



Height (Appendix 2.4)

There were highly significant differences ($p < 0.001$) between regions-of-provenance, provenances and families-within-provenances for this trait at the six sites where it was measured. Indications are that GxE (provenance-by-site) interaction is of little practical significance (Table 2.4) and the cross site means are shown in Figure 2.2. The planted stand and Kangaroo Island provenances were generally taller than the S. Flinders Range Provenances. Planted stand material performed particularly well at Wagga Wagga (which had the lowest mean height growth of the sites).

Figure 2. Cross-site means for Height. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted stand



Height and diameter relationship

A regression relationship between height and diameter was fitted using data from the six sites where both traits were measured. The equation of the regression line was:

$$\text{Height (m)} = 2.58 + 4.27 \times \text{DBH}$$

This model accounts for 72% of the phenotypic height variance, so is quite suitable for estimating heights from the measured diameters at the Western Australian sites for the purpose of gauging comparative growth between the sites, though not necessarily for ranking provenances. It should be noted that the WA trials were established at two different stocking levels from the eastern trials, which may cause somewhat different HT-DBH relationships in them.

Bole length (Appendix 2.5)

Bole length is a trait that combines growth and form parameters. It was assessed at the Western Australian sites only. There were significant differences between families-within-provenances at both sites, but between provenances at Moora only. Kangaroo Is. provenances have the shortest bole lengths at both sites. This latter finding accords with the fact that form traits are generally poorer in material of Kangaroo Island origin (see later) and heavy branches, double leaders, ramcorns and stem defects are presumably limiting log lengths.

Stem volume (Appendix 2.6)

Stem volume was calculated as conic volume from height and DBH measures for all sites except Moora and Esperance where it was estimated on the basis of the regression relationship as previously described. This procedure of course gives the same ranking of genetic groups as determined for DBH for the two WA sites: the benefit is an approximation of the stem volume growth which in turn can be used to estimate MAI (see later). There were significant differences ($p < 0.004$) between regions-of-provenance, provenances and families-within-provenances for this trait at the six sites where it was calculated from direct measures, and the two sites where it was estimated. The vigour of the planted stand provenances is higher at all sites. Though strong GxE is indicated by the variance component ratios (Table 2.4) this is mainly due to so-called *scale-change* GxE. There is a large difference in estimated

stem volume from site to site, even though the provenance and region-of-provenance rankings don't change appreciably. Scale-change GxE is considered to be of low practical significance (White *et al.* 2007).

Productivity

Progeny trials are not ideally suited to the purpose of mean annual increment estimation, due to the effects of uneven competition. Nevertheless an indication of growth productivity can be taken. Table 5 gives an approximate MAI for each site which was simply derived by dividing the standing volume by the area of plantation and the age to date of measurement. The following should be borne in mind: (1) estimates of volume at the WA sites are on the basis of height estimates derived by regression of height and DBH parameters in the eastern States; (2) Bordertown and Avenue had been thinned in mid and late 2004 respectively, and the stands may not have fully re-captured the site resources, resulting in lower MAI at the time of measurement.

Estimated MAI based on the relative volume growth rates of the three region-of-provenance groupings are also given, however the higher growth rates associated with the planted stand materials may or may not be obtainable in a plantation situation because of competition and limited water resources. The growth rates indicated by this round of measurements are clearly modest. It should be noted that Avenue and Bordertown had been thinned, and it is likely that annual increments will increase in the next few year substantially increasing MAI perhaps to a level similar to Hamilton, which has similar mean height and DBH. An older *E. cladocalyx* progeny trial established by CSIRO at Benalla, Victoria was measured at age 9 (with no thinning having been undertaken) and at that time had an MAI of 5.9 based on standing volume, despite having around 30% of Eyre Pa. families. The Benalla site does not have especially deep soils or high rainfall (perhaps comparable to Wagga Wagga), suggesting that MAI may not have peaked in the ALRTIG trial series, and/or that very dry conditions in the time after establishment have negatively impacted growth rates. Drought has certainly led to low growth rates and mortality at the Wagga Wagga site, where trees were visibly stressed at an inspection in November 2006.

Table 2.5. Productivity as indicated by stem volume mean annual increment (MAI) (m³/ha/year) and projected MAI

Site	Age	Standing volume		Projected MAI	
		MAI	Planted stands	S. Flinders	Kangaroo Island
Moora	4.22	1.5	1.9	1.5	1.3
Esperance	4.62	1.8	1.6	2.1	1.7
Avenue	5.55	1.6	1.9	1.2	1.7
Bordertown	4.22	2.1	3.9	3.0	3.3
Hamilton	3.75	4.4	5.0	3.9	4.6
Lismore	4.24	2.3	2.6	2.2	2.2
Corowa	4.41	1.9	2.3	1.8	1.7
Wagga	5.18	0.6	0.8	0.6	0.5

Dominance (Appendix 2.7)

There was a significant difference between provenances and families-within-provenances at both Esperance and Moora. At Moora, the planted stand seedlots were significantly more dominant than any of the wild provenances. At Esperance, a different pattern is evident, with Cygnet River and Majorca notably dominant. This difference is supported by the proportionately high site-by-provenance interaction component (Table 2.4).

Form traits

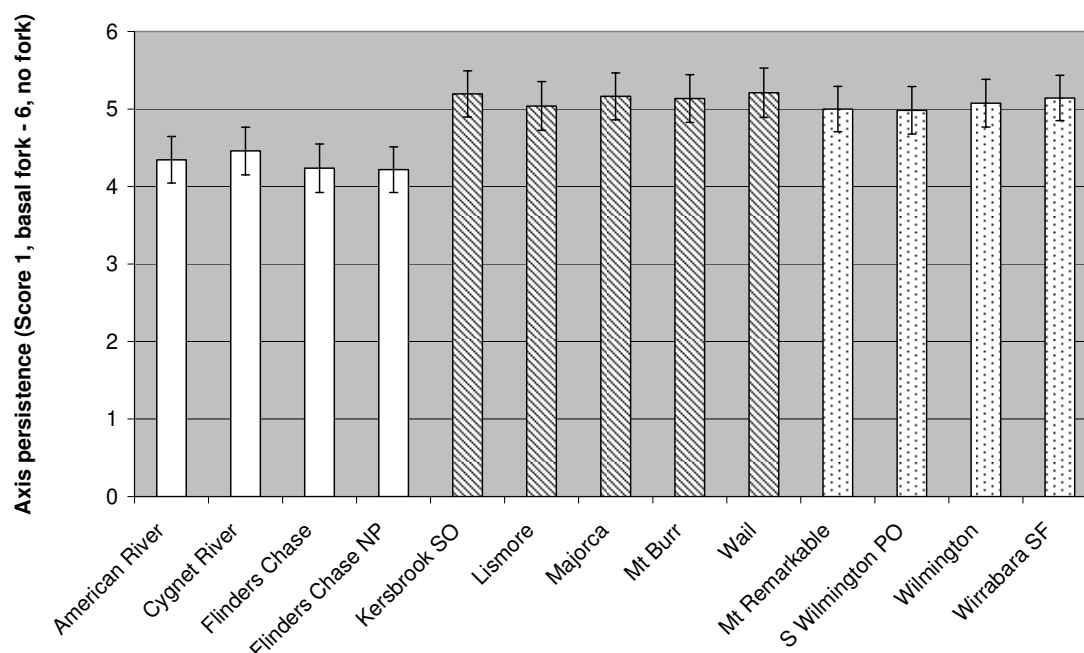
Stem count (Appendix 2.8)

Stem count data is available for five sites, though at Avenue the data had been collected after a selective thinning, with multi-stemmed trees having been culled preferentially. Consequently, there is no significant difference between provenances, though families-within-provenances are significantly different at the 0.007 level there. This difference is due to only a few families in the Flinders Chase NP provenance that still have a number of multi-stemmed trees. A further consequence is the indication of high site-by-provenance interaction (Table 2.4). There are highly significant differences between provenances and families-within-provenances at Bordertown and Hamilton, though the differences are more marked at Bordertown, where Kangaroo Island provenances have a more multistemmed tendency than the planted stand and South Flinders Ranges ones. Lismore and Majorca trees were almost exclusively single-stemmed.

Axis persistence (Appendix 2.9)

There were highly significant ($p < 0.001$) differences between provenances at each of the seven sites where the trait was measured. A consistent trend across sites is that the Kangaroo Island provenances had significantly more forks than both the planted and S. Flinders families (Figure 3) and indications are that there is little GxE for this trait (Table 2.4). There were also highly significant differences between families-within-provenances, except at Avenue and Esperance ($p = 0.033$, $p = 0.012$, both weakly significant, respectively).

Figure 2.3. Cross-site means for axis persistence. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted stand



Stem straightness (Appendix 2.10)

While there were significant differences between families at the four sites where the trait was measured (Esperance, Moora, Bordertown, Hamilton, Lismore), there was no significant difference between provenances or regions-of-provenance at Esperance and Wald tests indicated only a weakly significant probability ($p=0.05$) of provenance mean inequality at Lismore. Stand-out provenances across sites are Kersbrook SPA and Mt Burr, whereas Kangaroo Island provenances were significantly less straight. Cross site analysis for determination of whether GxE exists was not undertaken because of the quite disparate methods used to assess this trait.

Branch weight (Appendix 2.11)

There were significant differences between provenances and families-within-provenances at the three sites where branch weight was assessed. At Bordertown and Hamilton, the Kangaroo Island region-of-provenance had significantly heavier branching than both the planted and S. Flinders Range material. At Lismore, where branching was assigned a four-point score (a lower score indicating heavier branching) there is no significant difference between regions-of-provenance, with Wail and Lismore being lighter branched, while Kersbrook SPA and Wilmington are heavier. Though there are indications of significant GxE for this trait (Table 2.4) this is likely to be due at least in part to the quite different methods used to score branch weight. More detailed analysis of this trait should include rescaling of data and/or use of a more sophisticated GxE model.

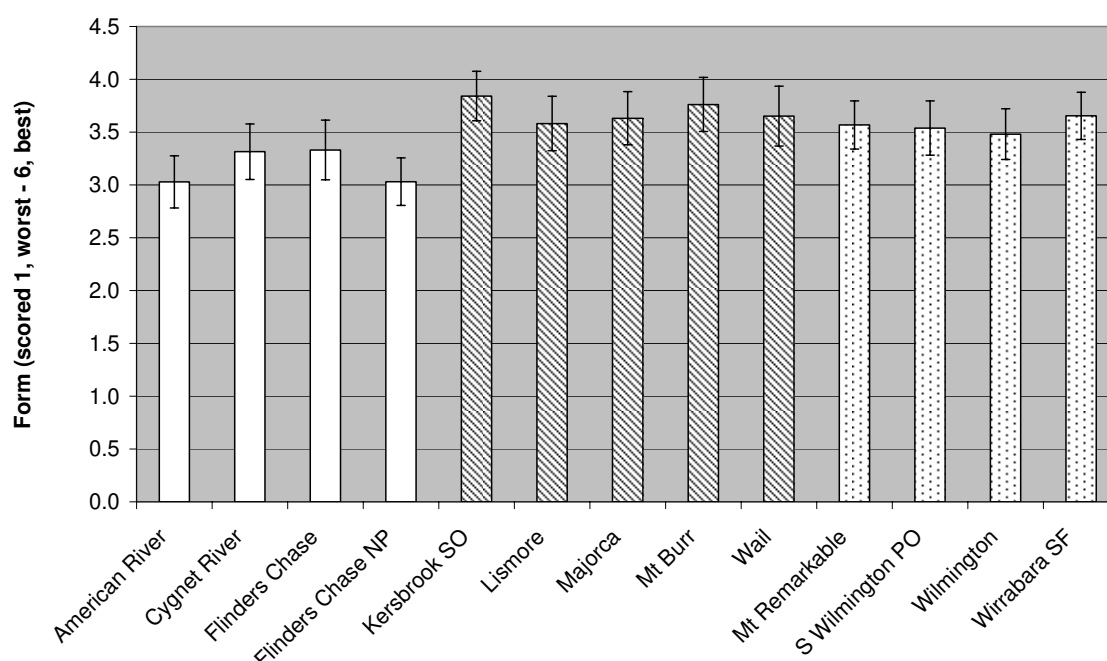
Stem erectness (Appendix 2.12)

Stem erectness was measured at the Hamilton site, where a number of leaning trees were noted by the assessors. Though the cause of lean is often wind, underlying traits such as poor root development, large sail (leaf) area etc. can lead to genetic differences, which were indicated here at both the provenance and family-within-provenance levels ($P<0.001$). The Kangaroo Island provenances generally had a higher proportion of leaning trees than either the S. Flinders Range or planted stand provenances.

Form (Appendix 2.13)

Form was assessed at the two Western Australian sites and at Wagga Wagga, NSW. A scale of 1-6 (worst- best) was used at all sites, though the Wagga Wagga assessment included branching characteristics included in the *Crown* trait that was assessed separately in WA. Scores are assigned in the WA system on the basis of various types of malformation, not including branch characteristics. It is therefore not possible to directly compare the absolute scores between the eastern and western sites. Despite these minor differences, there was only a minor amount of GxE (Table 2.4) and cross-site means are shown in Figure 2.4. The Kangaroo Island provenances have generally poor form relative to the planted stand and S. Flinders Range materials.

Figure 2.4. Cross-site means for form. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted stand



Crown (Appendix 2.14)

This form-related trait was scored separately from *Form* at the Western Australian sites. It includes branch size and angle. There were highly significant differences between provenances and families-within-provenances, and only a minor amount of GxE is indicated (Table 2.4). At the region-of-provenance level, it is evident that Kangaroo Island is inferior to S. Flinders, while the planted stand materials are clearly better than the wild material.

Other traits

Leaf-shed (Appendix 2.15)

Leaf-shed was measured at Lismore only. There were significant differences between provenances and families-within-provenances. The wild provenances, particularly Kangaroo Island ones, have tended to retain their leaves to a greater extent than the planted stand provenances. It is interesting to note that Mt Burr and Lismore, the tallest provenances (both planted stands) are quite different with respect to this trait, despite having nearly the same average height (5.6 and 5.7 m respectively).

2.7 B. Seed source trials

Growth and survival (Appendix 2.16)

Survival ranged between 67% at Kangaroo Island and 98% at Rocky Gully (Appendix 2.16a) with a grand mean (across sites) of 84%. Survival at Kangaroo Island was impacted by stock entry to the trial and marsupial browsing at the seedling stage. There are no significant differences between seedlots at any of the sites.

Height (Figure 2.5) and diameter (Appendix 2.16b-c) were variable between the sites. Rocky Gully, which receives the highest mean annual rainfall, had markedly higher DBH growth than the other sites. Kersbrook and Lismore grew particularly well (where present), whereas the Bundaleer provenance trial seed source was the poorest or in the poorest group at all sites for both traits.

Form traits

Though there are significant differences between seedlots for the stem count trait (Appendix 2.16d) multiple stems are not a serious problem in any provenance. Keyneton seed stand (a thinned plantation of *S. Flinders* origin) has a slightly higher proportion of multistemmed trees than the others. There are significant differences in axis persistence between seedlots (Figure 2.6) at the two sites where it was scored. The Bundaleer provenance trial and Kangaroo Island wild seed sources are significantly inferior to the other seed sources at both sites. Form, which was scored at Rocky Gully was clearly best in the Kersbrook SPA seedlot, with Keyneton, Leighton, Wirrabara and Lismore forming a middle group, and Flinders Chase and Bundaleer provenance trial being poorest.

Overall, these seed source trials demonstrate that Kersbrook SPA is the best all-round seed source for combined growth and form traits. The Lismore seed source was next-best, though the seed used here was from phenotypically selected trees: there is no guarantee that all seed from this general location will perform as well. Seed from Bundaleer provenance trial was the worst performer, being in the lowest ranking group for height, diameter and stem form at all sites. Some pollen parents contributing to this seed source may have been trees of the poorly-performing Eyre Peninsula origin (see Harwood and Bulman 2001).

Figure 2.5. Height (cm) at five seed source trial sites: Rocky Gully, WA; Craigieburn, Vic.; Kangaroo Is. SA; Bundaleer, SA and Lismore, Vic.

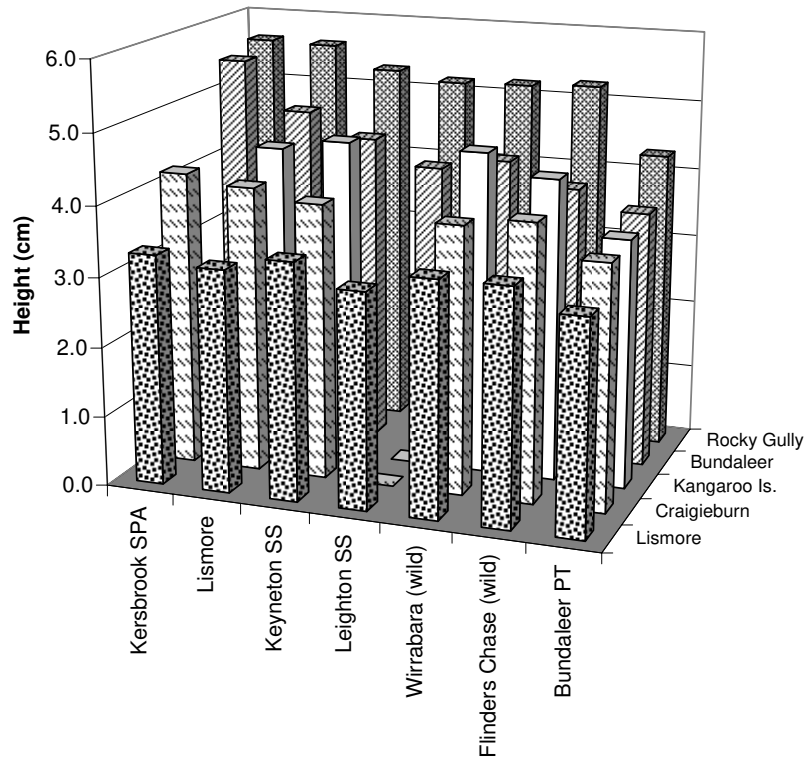
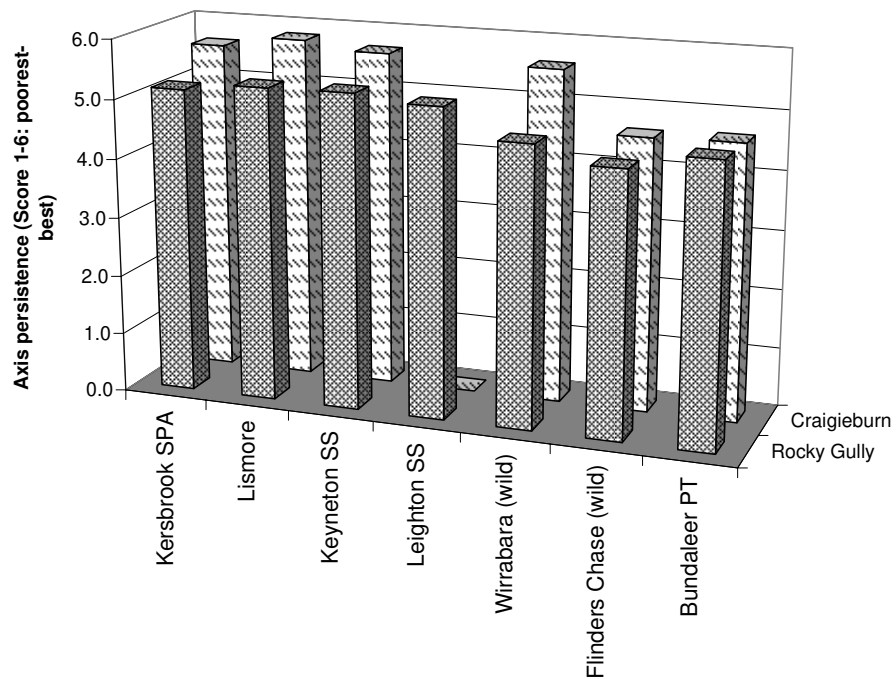


Figure 2.6. Axis persistence (scored 1-6: 1=fork at ground level; 2,3,4,5=forks in 1st, 2nd, 3rd and top quarters of crown, 6=no forks) at two seed source trial sites: Rocky Gully, WA and Craigieburn, Vic.



2.8. Discussion

This series of *E. cladocalyx* progeny trials has shown some important differences in response of the various provenances for a number of traits. The species has proven to be adaptable to a wide range of sites, with very good to excellent survival, despite below average rainfall in the years since planting at the majority of the sites. Drought stress, visible as mortality and poor growth, is only strongly evident at the Wagga Wagga site. It should be remembered that the progeny trials were established at higher rates of stocking than plantations in the sheep-wheat belt would normally be, to fulfil spacing requirements for seed production purposes. Early thinning may have been prudent at Wagga Wagga.

The data for most traits provide strong support for the region-of-provenance grouping indicated by the McDonald *et al.* (2003) study on the population genetics of the species. Taking the growth traits, there is a general trend that the planted stand grouping, which was comprised of phenotypically superior trees from planted stands, has outperformed the wild provenances. Kangaroo Island provenances tend to be slightly more vigorous (taller and of greater girth) than those of the South Flinders Range, though Wirrabara State Forest families have performed very well for both of these growth traits.

Volume MAI estimates for the sites are low-moderate, (0.6-4.4) as expected for the sheep-wheat belt. The growth rates attained are in accord with others for this species, and comparable to other species in this trial series (for example sugar gum has an MAI of 4.4 and spotted gum 5.0 at Buckley Swamp; sugar gum 1.76 and swamp yate 1.27 at Esperance).

As for the growth traits, there are clear trends across sites and regions-of-provenance for the form traits. A common finding is that the Kangaroo Island provenances have performed poorly. Kangaroo Island region-of-provenance has more stems, less axis persistence, heavier branching, a tendency to lean, and in the 'compound' form traits, worse overall form and shorter commercial bole length. The differences between the planted stand and South Flinders Range Groups are not pronounced at the region-of-provenance level, though when individual provenances are examined at individual sites, the best performers are most often from the planted stand group, but this is not necessarily consistent across sites for any trait.

The preliminary analysis of GxE for the data set has indicated that there is little interaction of practical importance for the growth traits at the provenance level. This finding should be further investigated by more detailed analysis of GxE at the family level, and investigation of provenance and family stability. Cross-site analysis of some of the form traits is made more complex by the various ways that some traits have been scored, and often assessment has been undertaken at only a small subset of sites. However for axis persistence, which was scored in a uniform way across seven of the eight sites, the interaction variance component was small at the provenance and ROP levels. GxE is probably not a major impediment to provenance selection in the sheep-wheat belt for this trait.

The seed source trials have demonstrated the superiority of the Kersbrook seed production area and phenotypically selected seed sources from the western Victorian planted stands over wild seed sources for both growth and form traits. The finding that the Kangaroo Island provenance has inferior stem form reinforces the result from the progeny trials.

2.9. References

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	Provenance	Moora	Esperance	Avenue‡	Bordertown†	Hamilton	Lismore	Corowaa	Wagga
Kangaroo Island	American River	0.71	0.76	0.66	0.98	0.98	0.97	0.81	0.78
	Cygnets River	0.73	0.85	0.86	0.92	0.95	0.89	0.83	0.69
	Flinders Chase	0.61	*	0.54	0.88	0.75	0.91	0.81	0.77
	Flinders Chase NP	0.66	0.72	0.70	0.91	0.96	0.94	0.83	0.64
Planted stands	Kersbrook SO	0.86	*	0.74	0.95	0.98	0.91	0.85	0.88
	Lismore	0.84	0.62	0.75	1.00	0.95	0.95	0.97	0.95
	Majorca	0.67	0.75	0.63	0.95	0.92	0.86	0.89	0.88
	Mt Burr	0.86	*	0.61	0.86	0.99	0.97	0.89	0.88
South Flinders	Wail	0.65	0.63	0.58	0.96	0.95	0.90	0.95	0.82
	Mt Remarkable	0.86	*	*	0.81	0.98	0.95	0.80	0.93
	S Wilmington PO	0.63	*	0.60	0.90	0.94	0.93	0.83	0.89

•	Wilmington	•	0.74	•	0.68	•	0.92	•	0.96	•	0.98	•	0.93	•		•	0.89
•	Wirrabara SF	•	0.82	•	0.70	•	0.71	•	0.91	•	0.97	•	0.88	•	0.83	•	0.87
•	<i>Std. error of difference</i>	•	<i>0.74</i>	•	<i>0.08</i>	•	<i>0.69</i>	•	<i>0.92</i>	•	<i>0.95</i>	•	<i>0.92</i>	•	<i>0.86</i>	•	<i>0.84</i>
•	<i>Significance (provenance)</i>	•	<i><0.001</i>	•	<i>0.028</i>	•	<i>0.028</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i>0.082</i>	•	<i>0.529</i>	•	<i><0.001</i>
•	<i>Family-within- provenance</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i>0.003</i>	•	<i><0.001</i>	•	<i>0.022</i>

† Bordertown survival data is from a measurement at P+3 years after which time the trial was thinned

‡ Avenue survival data is from a measurement at P+1 year. The trial was thinned at P+3 years.

Figure A2.1. Region of provenance means –survival (proportion). Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted stand

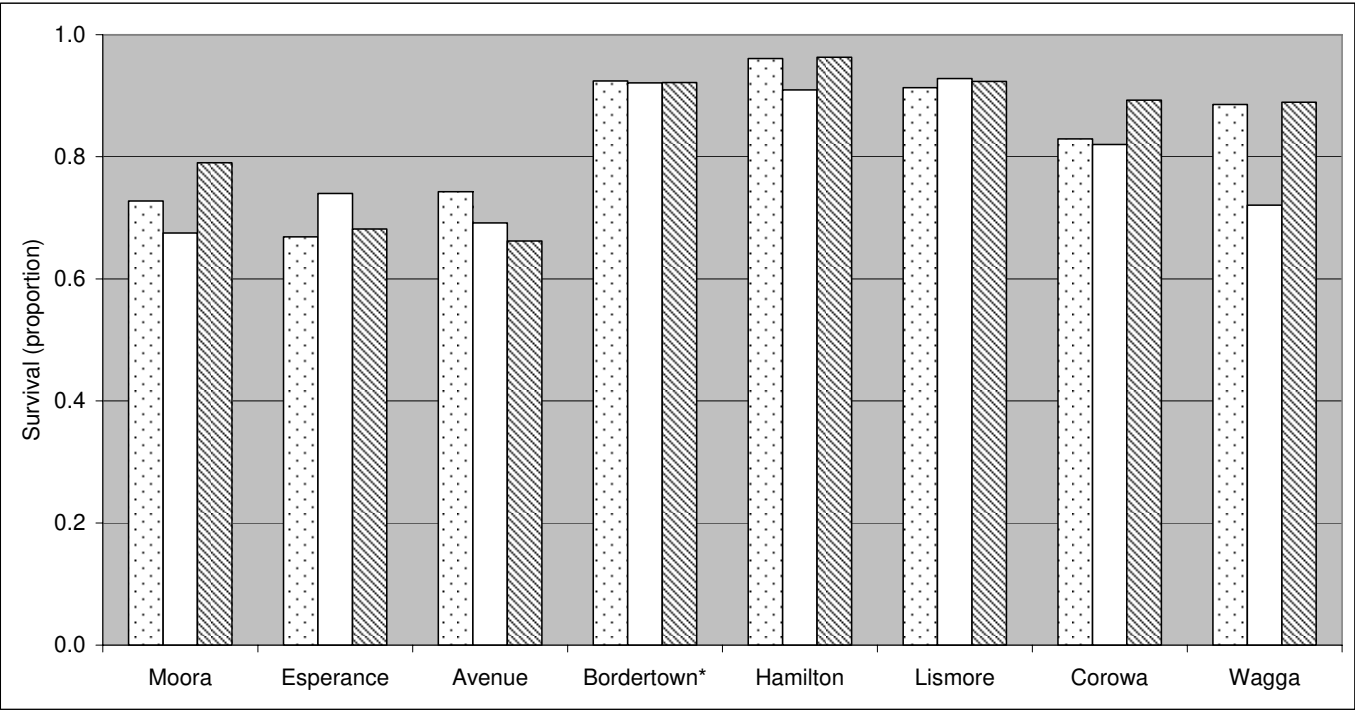


Table A2.2. Provenance means: health of trees at Wagga Wagga, NSW (scale of 1-5: 1=dead – 5=perfectly healthy)

	Provenance	Mo ora	Espera nce	Avenue	Bordertown	Hamilton	Lis more	Cor owa	Wagga
Kangaroo Island	American River	*	*	*	*	*	*	*	4.21
	Cygnnet River	*	*	*	*	*	*	*	3.87
	Flinders Chase	*	*	*	*	*	*	*	4.15
	Flinders Chase NP	*	*	*	*	*	*	*	4.24
Planted stands	Kersbrook SO	*	*	*	*	*	*	*	4.69
	Lismore	*	*	*	*	*	*	*	4.58
	Majorca	*	*	*	*	*	*	*	4.68
	Mt Burr	*	*	*	*	*	*	*	4.62
	Wail	*	*	*	*	*	*	*	4.65
South Flinders	Mt Remarkable	*	*	*	*	*	*	*	4.80
	S Wilmington PO	*	*	*	*	*	*	*	4.68
	Wilmington	*	*	*	*	*	*	*	4.87

• Wirrabara SF	• *	• *	• *	• *	• *	• *	• *	• *	• *	4.71
• <i>Std. error of difference</i>	• *	• *	• *	• *	• *	• *	• *	• *	• *	0.14
• <i>Significance (provenance)</i>	• *	• *	• *	• *	• *	• *	• *	• *	• *	<0.001
• <i>Family-within- provenance</i>	• *	• *	• *	• *	• *	• *	• *	• *	• *	0.003

Figure A2.2. Provenance means – health scored from 1-5 at Wagga Wagga (error bars indicate average standard error of difference). Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted stand

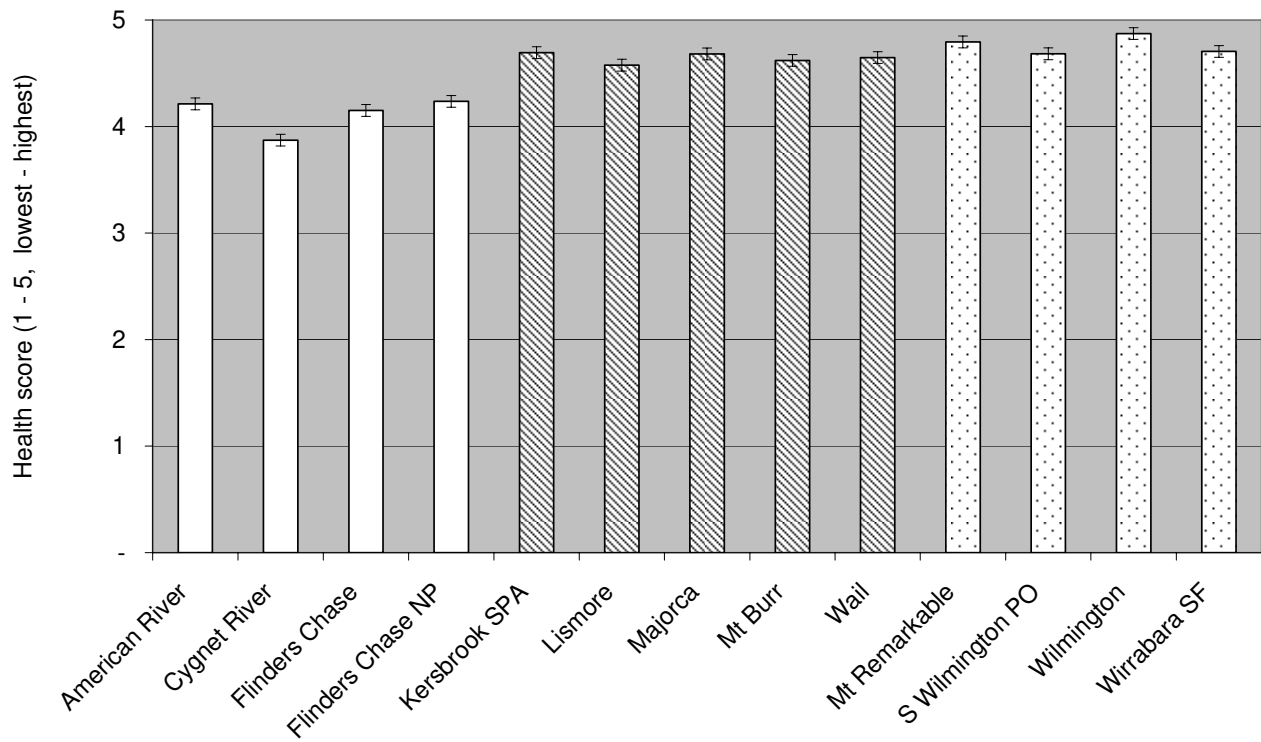


Table A2.3. Provenance means: equivalent dbh (mm)

	Provenance	Moora	Esperance	Avenue	Bordertown	Hamilton	Lismore	Corowa	Wagga
Kangaroo Island	American River	47	59	89	76	85	67	61	35
	Cygnets River	54	69	101	82	88	70	66	43
	Flinders Chase	56	*	91	84	93	76	77	46
	Flinders Chase NP	55	63	92	80	90	69	62	41
Planted stands	Kersbrook SO	65	*	92	88	92	77	76	53
	Lismore	65	72	88	89	88	79	75	50
	Majorca	58	73	106	91	94	78	75	51
	Mt Burr	62	*	101	93	94	82	79	57
	Wail	57	*	*	88	92	69	66	58
South Flinders	Mt Remarkable	57	57	73	78	82	69	65	48
	S Wilmington PO	56	*	78	81	84	72	69	44
	Wilmington	54	56	100	77	78	67	*	44
	Wirrabara SF	59	68	91	87	88	74	74	50

•

• <i>Std. error of difference</i>	• 4.5	• 4.1	• 11.5	• 3.55	• 4.7	• 4.8	• 6.9	• 3.1
• <i>Significance (provenance)</i>	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001
• <i>Family-within-provenance</i>	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001

Figure A2.3. Region-of-provenance means - equivalent dbh (mm) (bars indicate average standard errors of difference) Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

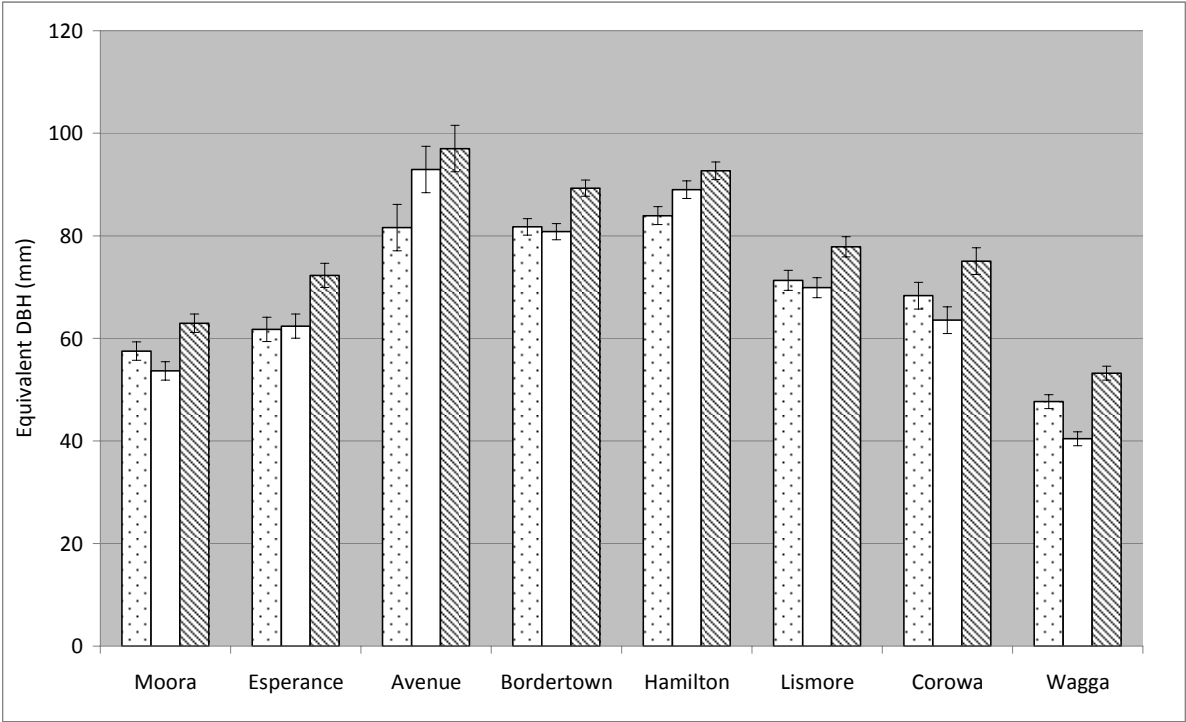


Table A2.4. Provenance means: height (m)

	Provenance		Mo ora		Espera nce		Avenu e		Bordertown		Hamilton		Lismor e		Corow a		Wagga	
Kangaroo Island	American River	•	*	•	*	•	7.5	•	6.3		•	6.5	•	5.3	•	5.7	•	3.9
	Cygnnet River	•	*	•	*	•	8.2	•	6.5		•	6.5	•	5.3	•	6.3	•	4.4
	Flinders Chase	•	*	•	*	•	7.8	•	6.6		•	6.4	•	5.6	•	6.4	•	4.7
	Flinders Chase NP	•	*	•	*	•	7.5	•	6.2		•	6.4	•	5.3	•	5.8	•	4.2
Planted stands	Kersbrook SO	•	*	•	*	•	7.6	•	6.3		•	6.6	•	5.6	•	6.4	•	4.9
	Lismore	•	*	•	*	•	7.2	•	6.3		•	6.2	•	5.7	•	6.3	•	4.6
	Majorca	•	*	•	*	•	8.3	•	6.4		•	6.6	•	5.4	•	6.2	•	4.6
	Mt Burr	•	*	•	*	•	7.8	•	6.6		•	6.5	•	5.6	•	6.5	•	5.0
	Wail	•	*	•	*	•	*	•	6.1		•	6.3	•	5.1	•	5.8	•	4.9
South Flinders	Mt Remarkable	•	*	•	*	•	6.1	•	5.6		•	6.0	•	5.0	•	5.5	•	4.4
	S Wilmington PO	•	*	•	*	•	6.2	•	5.6		•	5.8	•	4.9	•	5.7	•	3.9
	Wilmington	•	*	•	*	•	7.3	•	5.7		•	5.8	•	4.8	•	*	•	4.1

• Wirrabara SF	• *	• *	• 7.3	• 6.1	• 6.3	• 5.3	• 6.1	• 4.6
• <i>Std. error of difference</i>	• *	• *	• 0.77	• 0.24	• 0.28	• 0.26	• 0.44	• 0.29
• <i>Significance (provenance)</i>	• *	• *	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001
• <i>Family-within- provenance</i>	• *	• *	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001

Figure A2.4. Region-of-provenance means - height (m) (bars indicate average standard errors of difference). Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

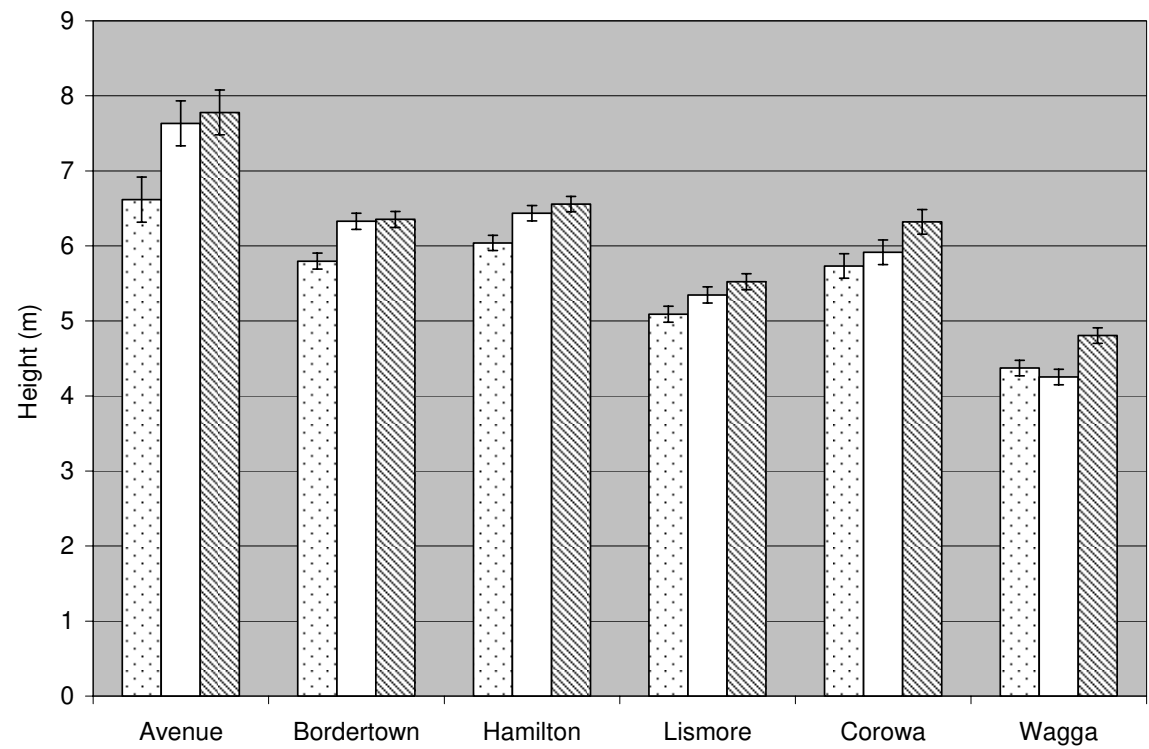


Table A2.5. Provenance means: bole length (m) at two Western Australian sites

	Provenance	Moora	Esperance	Avenue	Bordertown	Hamilton	Lismore	Corowa	Wagga
Kangaroo Island	American River	1.3	1.5	*	*	*	*	*	*
	Cygnnet River	1.7	2.5	*	*	*	*	*	*
	Flinders Chase	1.9	*	*	*	*	*	*	*
	Flinders Chase NP	1.8	1.5	*	*	*	*	*	*
	Kersbrook SO	2.1	*	*	*	*	*	*	*
	Lismore	2.1	1.9	*	*	*	*	*	*
	Majorca	1.9	2.0	*	*	*	*	*	*
	Mt Burr	2.1	*	*	*	*	*	*	*
	Wail	1.8	*	*	*	*	*	*	*
	Mt Remarkable	1.7	1.7	*	*	*	*	*	*
South Flinders	S Wilmington PO	1.8	*	*	*	*	*	*	*
	Wilmington	1.6	1.4	*	*	*	*	*	*

• Wirrabara SF	• 2.0	• 1.8	• *	• *	• *	• *	• *
• <i>Std. error of difference</i>	• 0.2	• 0.2	• *	• *	• *	• *	• *
• <i>Significance (provenance)</i>	• <0.001	• 0.212	• *	• *	• *	• *	• *
• <i>Family-within- provenance</i>	• 0.003	• 0.009	• *	• *	• *	• *	• *

Figure A2.5. Region-of-provenance means – bole length (m) (bars indicate average standard errors of difference). Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

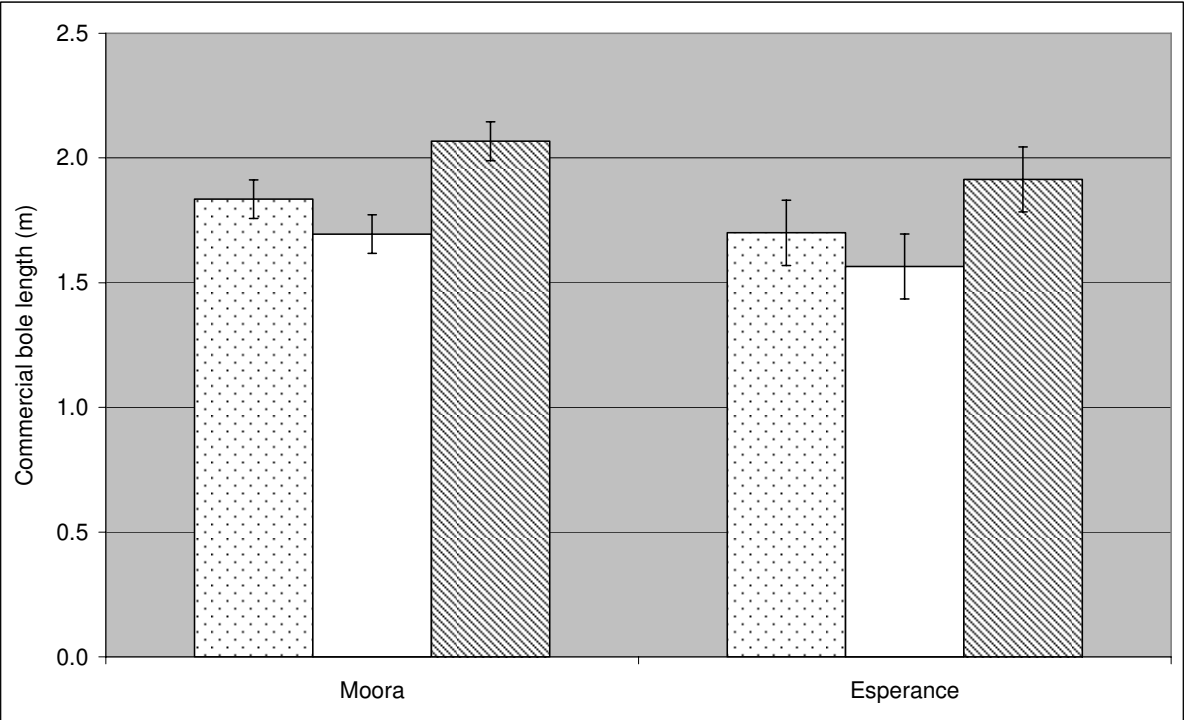


Table A2.6. Provenance means: stem volume (x 10⁻³ m³)

		Provenance		Moora †	Esperanc e†	Avenue	Bordertown		Hamilton		Lismor e		Corow a		Wagga
Kangaroo Island		American River		3.27	2.73	17.78	10.37		12.99		9.74		6.88		1.54
		Cygnnet River		4.57	4.26	24.20	13.22		14.07		10.88		8.62		2.44
		Flinders Chase		4.80	*	19.19	13.49		15.51		12.74		12.38		3.19
		Flinders Chase NP		4.77	3.70	19.95	11.5		14.69		10.76		7.86		2.34
Planted stands		Kersbrook SO		7.08	*	19.75	14		15.58		12.97		11.37		4.07
		Lismore		6.86	4.83	17.06	13.24		12.96		13.35		11.51		3.57
		Majorca		5.65	5.36	26.62	14.32		16.21		12.87		11.43		3.73
		Mt Burr		6.13	*	25.17	15.87		15.94		14.17		11.81		4.79
South Flinders		Wail		5.72	*	*	13.44		14.67		10.77		8.10		5.14
		Mt Remarkable		5.12	2.87	9.71	9.67		11.47		10.48		7.88		3.11
		S Wilmington PO		5.32	*	11.13	10.29		12.23		10.39		9.16		2.81
		Wilmington		4.59	2.78	20.16	9.49		10.31		9.35		*		2.46
	Wirrabara SF		5.62	4.45	18.70	12.74		13.50		11.91		10.45		3.56	

• <i>Std. error of difference</i>	• 1.04	• 0.67	• 5.52	• 1.348	• 1.59	• 1.34	• 2.12	• 0.43
• <i>Significance (provenance)</i>	• <0.001	• 0.003	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001
• <i>Family-within- provenance</i>	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001

† Volume estimates on these sites are based on height estimates modelled on a height-diameter relationship from the other sites

Figure A2.6. Region-of-provenance means - stem volume ($\times 10^{-3} \text{ m}^3$) (bars indicate average standard errors of difference). Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

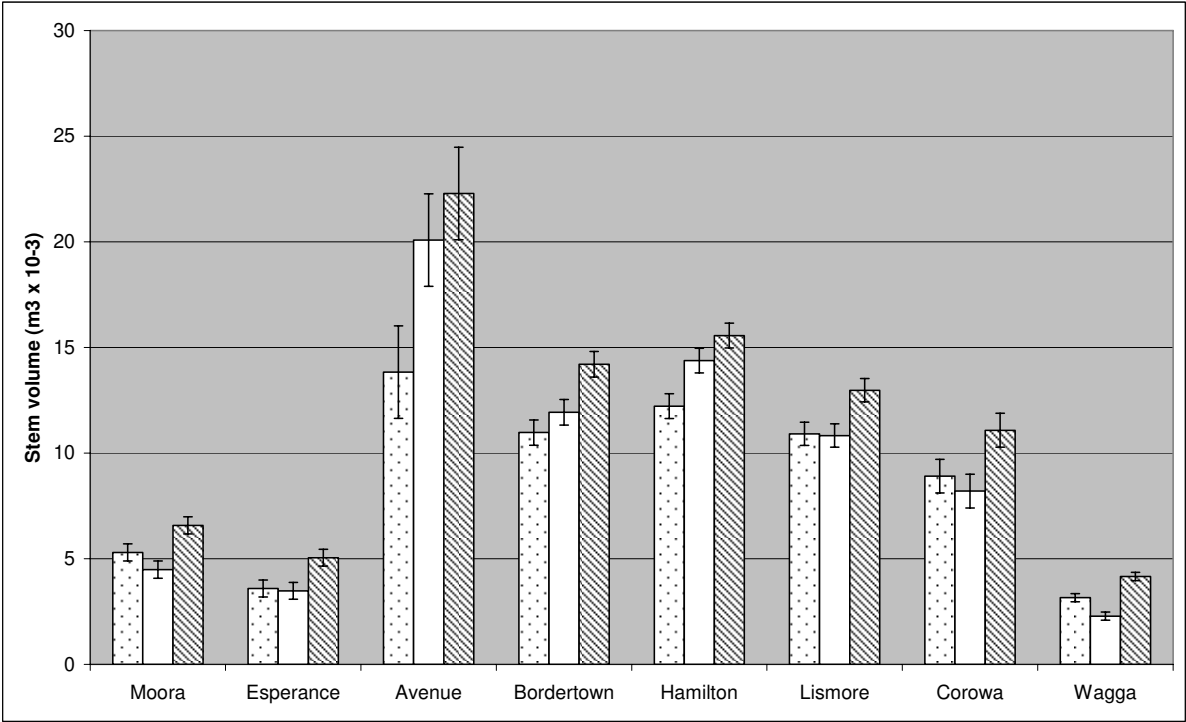


Table A2.7. Provenance means: dominance (3=subdominant; 4=codominant; 5=dominant)

	Provenance	Moora	Esperance	Avenue	Bordertown	Hamilton	Lismore	Corowa	Wagga
Kangaroo Island	American River	3.55	3.9	*	*	*	*	*	*
	Cygnet River	3.81	4.2	*	*	*	*	*	*
	Flinders Chase	3.92	*	*	*	*	*	*	*
	Flinders Chase NP	3.75	4.0	*	*	*	*	*	*
	Kersbrook SO	3.98	*	*	*	*	*	*	*
	Lismore	3.88	4.0	*	*	*	*	*	*
	Majorca	3.77	4.2	*	*	*	*	*	*
	Mt Burr	3.95	*	*	*	*	*	*	*
	Wail	3.79	*	*	*	*	*	*	*
	Mt Remarkable	3.72	3.7	*	*	*	*	*	*
South Flinders	S Wilmington PO	3.62	*	*	*	*	*	*	*
	Wilmington	3.72	3.7	*	*	*	*	*	*
	Wirrabara SF	3.79	4.1	*	*	*	*	*	*
	Std. error of	0.14	0.1	*	*	*	*	*	*

<i>difference</i>							
• Significance (provenance)	• <0.001	• <0.001	• *	• *	• *	• *	• *
• Family-within- provenance	• 0.005	• <0.001	• *	• *	• *	• *	• *

Figure A2.7. Region-of-provenance means - dominance (bars indicate average standard errors of difference). Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

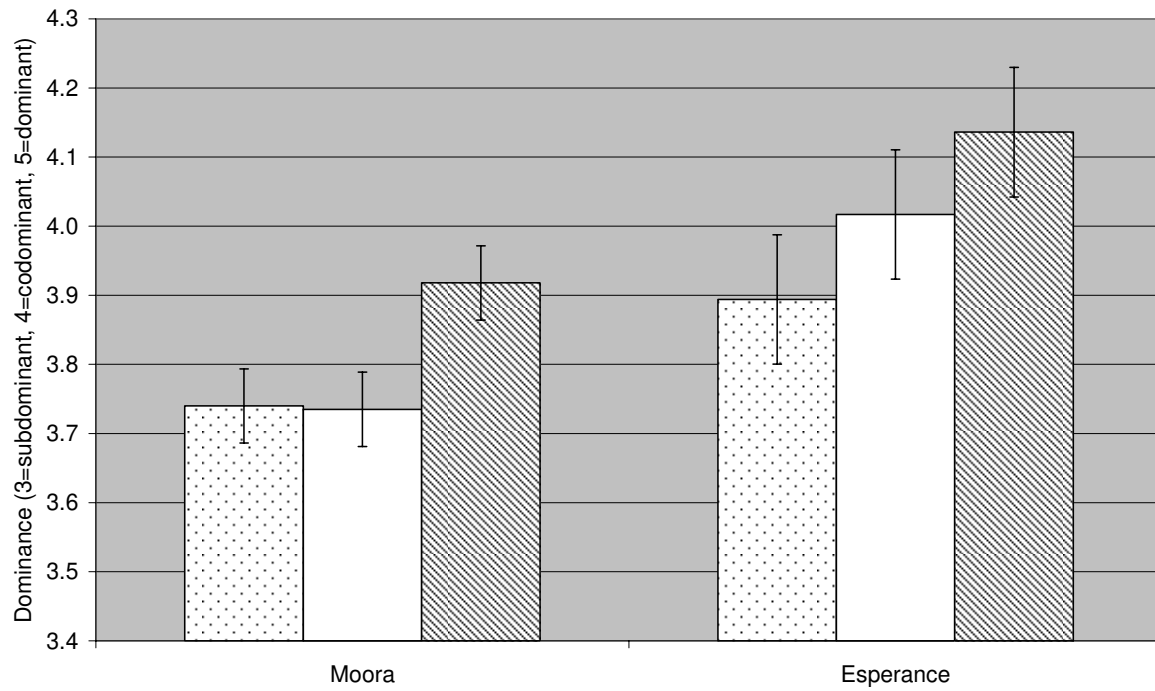


Table A2.8. Provenance means: number of stems

		Provenance						Bordertown		Hamilton								
			Mo ora		Espera nce		Aven ue					Lism ore		Cor owa		Wa gga		
Kangaroo Island		American River	•	*	•	*	•	1.00	•	1.226	•	*	•	1.076	•	*	•	*
		Cygnnet River	•	*	•	*	•	1.00	•	1.203	•	1.065	•	1.04	•	*	•	*
		Flinders Chase	•	*	•	*	•	0.99	•	1.112	•	1.183	•	1.063	•	*	•	*
		Flinders Chase NP	•	*	•	*	•	1.03	•	1.159	•	*	•	1.069	•	*	•	*
Planted stands	•	Kersbrook SO	•	*	•	*	•	1.00	•	1.024	•	1.016	•	1.05	•	*	•	*
		Lismore	•	*	•	*	•	0.99	•	1.00	•	1.105	•	1.016	•	*	•	*
		Majorca	•	*	•	*	•	1.00	•	1.002	•	1.04	•	1.04	•	*	•	*
		Mt Burr	•	*	•	*	•	1.00	•	1.015	•	1.027	•	1.041	•	*	•	*
•		Wail	•	*	•	*	•	*	•	1.016	•	1.037	•	1.016	•	*	•	*
South Flinders		Mt Remarkable	•	*	•	*	•	1.00	•	1.011	•	1.018	•	1.032	•	*	•	*
		S Wilmington PO	•	*	•	*	•	0.99	•	1.036	•	1.075	•	1.043	•	*	•	*
		Wilmington	•	*	•	*	•	1.00	•	1.003	•	1.024	•	1.022	•	*	•	*
		Wirrabara SF	•	*	•	*	•	1.00	•	1.019	•	1.021	•	1.023	•	*	•	*

•

• <i>Std. error of difference</i>	• *	• *	•	0.024	•	0.036	•	0.039	•	0.028	• *	• *
• <i>Significance (provenance)</i>	• *	• *	•	0.406	•	<0.001	•	<0.001	•	0.118	• *	• *
• <i>Family-within- provenance</i>	• *	• *	•	0.007	•	<0.001	•	<0.001	•	0.002	• *	• *

Figure A2.8. Region-of-provenance means – number of stems. Bars indicate average standard errors of difference. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal

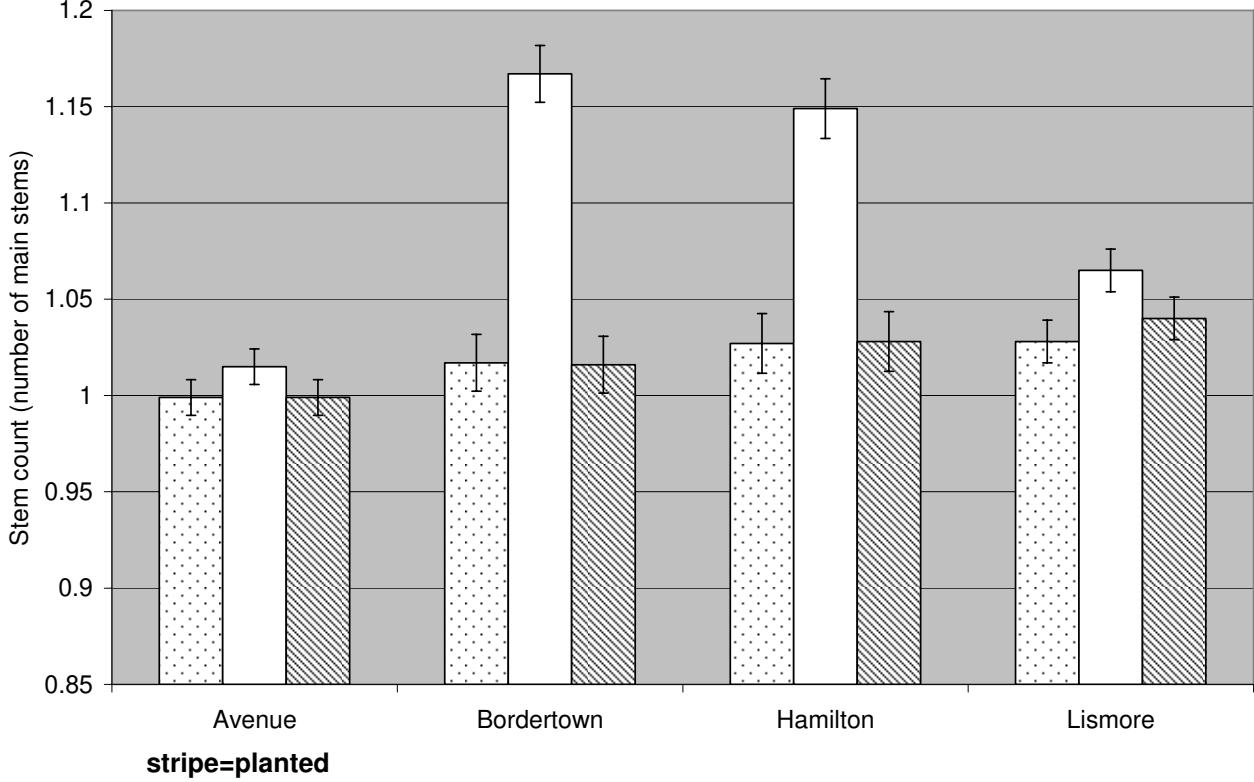
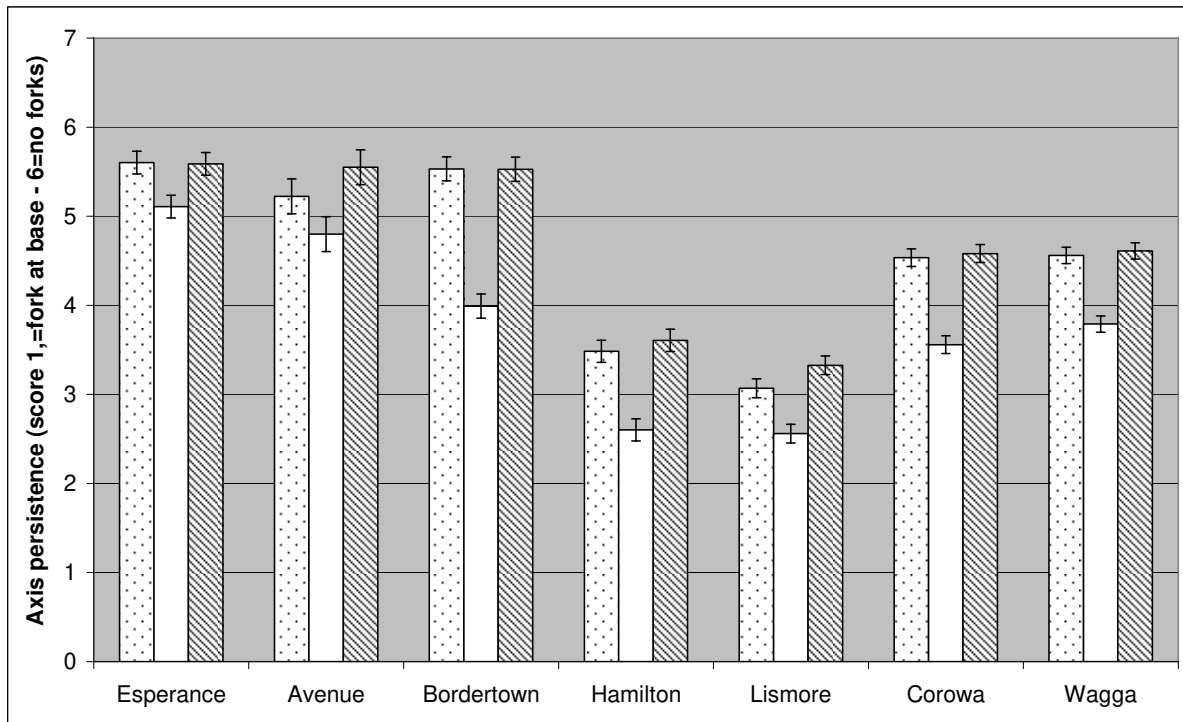


Table A2.9. Provenance means: axis persistence scored from 1 (fork at base) to 6 (no forks)

	Provenance	Mo ora	Espera nce	Avenu e	Bordertown	Hamilton	Lismor e	Corow a	Wagga
Kangaroo Island	American River	*	3.86	5.24	3.86	3.10	2.77	3.56	3.61
	Cygnnet River	*	4.50	5.107	4.28	2.82	2.70	3.81	3.88
	Flinders Chase	*	*	4.517	4.22	2.65	2.55	3.44	3.95
	Flinders Chase NP	*	4.15	4.58	3.87	2.43	2.47	3.55	3.81
Planted stands	Kersbrook SO	*	*	5.38	5.47	3.77	3.34	4.62	4.64
	Lismore	*	4.62	5.82	5.68	3.12	3.13	4.13	4.42
	Majorca	*	4.49	5.97	5.70	3.55	3.34	4.50	4.53
	Mt Burr	*	*	5.47	5.32	3.28	3.34	4.66	4.71
	Wail	*	*	4.92	5.52	3.57	2.99	4.40	4.50
South Flinders	Mt Remarkable	*	4.57	5.62	5.51	3.19	2.82	4.71	4.40
	S Wilmington PO	*	*	*	5.65	3.70	3.40	4.56	4.59
	Wilmington	*	4.44	5.71	5.66	3.30	3.11	*	4.54
	Wirrabara SF	*	4.69	5.44	5.50	3.54	3.19	4.70	4.65

• <i>Std. error of difference</i>	• *	• 0.24	• 0.51	• 0.33	• 0.33	• 0.26	• 0.28	• 0.24
• <i>Significance (provenance)</i>	• *	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001
• <i>Family-within-provenance</i>	• *	• 0.033	• 0.057	• <0.001	• <0.001	• <0.001	• <0.001	• <0.001

Figure A2.9. Region-of-provenance means - axis persistence scored from 1 (fork at base) to 6 (no forks)



(bars indicate average standard errors of difference). Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

Table A2.10. Provenance means: stem straightness

	Provenance	Moora	Esperance	Avenue	Bordertown	Hamilton	Lismore	Corowa	Wagga
Kangaroo Island	American River	4.00	2.92	*	1.18	2.10	2.37	*	*
	Cygnets River	4.52	4.10	*	1.28	1.72	2.66	*	*
	Flinders Chase	4.23	*	*	1.21	1.77	2.36	*	*
	Flinders Chase NP	4.17	2.95	*	1.41	1.88	2.53	*	*
	Kersbrook SO	4.84	*	*	0.89	2.69	2.47	*	*
	Lismore	4.52	2.99	*	1.00	1.62	2.36	*	*
	Majorca	4.64	3.31	*	1.08	2.29	2.42	*	*
	Mt Burr	4.84	*	*	0.58	2.07	2.46	*	*
	Wail	4.33	*	*	1.25	2.41	2.55	*	*
	Mt Remarkable	4.36	3.07	*	1.32	2.47	2.36	*	*
	S Wilmington PO	4.64	*	*	0.91	1.95	2.56	*	*
	Wilmington	4.20	3.02	*	1.35	2.51	2.44	*	*
	Wirrabara SF	4.61	3.11	*	1.05	2.20	2.48	*	*

• <i>Significance (provenance)</i>	•	<i><0.001</i>	•	<i>0.65</i>	•	<i>*</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i>0.05</i>	•	<i>*</i>	•	<i>*</i>
• <i>Family-within- provenance</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i>*</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i><0.001</i>	•	<i>*</i>	•	<i>*</i>
• <i>Std. error of difference</i>	•	<i>0.25</i>	•	<i>0.23</i>	•	<i>*</i>	•	<i>0.19</i>	•	<i>0.36</i>	•	<i>0.13</i>	•	<i>*</i>	•	<i>*</i>

Figure A2.10. Region-of-provenance means – stem straightness. Scored worst-best 1-4 in Victoria and 1-6 in WA and deviation score (lower is better) at Bordertown. Bars indicate average standard errors of difference. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

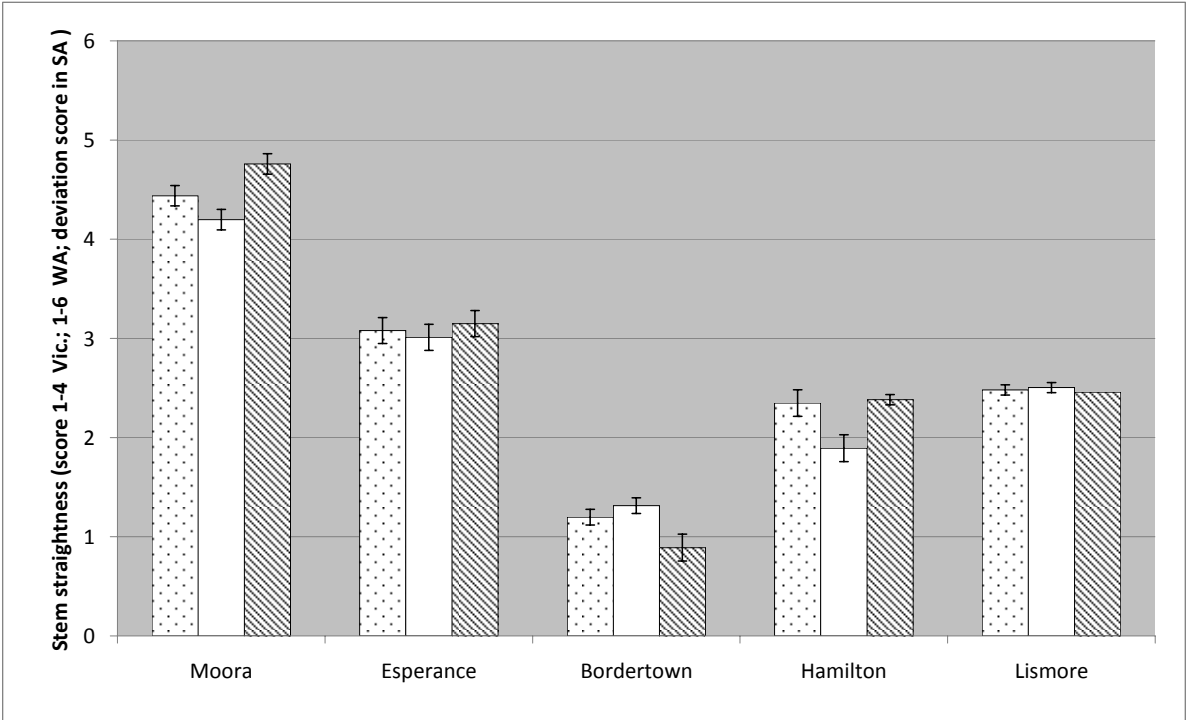


Table A2.11. Provenance means – Branch weight

	Provenance	Moorabool	Esperance	Avenue	Bordertown	Hamilton	Lismore	Corowa	Wagga
Kangaroo Island Planted stands	American River	• *	• *	• *	• 1.31	• 7.34	• 2.43	• *	• *
	Cygnnet River	• *	• *	• *	• 1.76	• 7.74	• 2.58	• *	• *
	Flinders Chase	• *	• *	• *	• 1.49	• 9.33	• 2.41	• *	• *
	Flinders Chase NP	• *	• *	• *	• 1.78	• 8.41	• 2.52	• *	• *
	Kersbrook SO	• *	• *	• *	• 0.92	• 6.09	• 2.36	• *	• *
	Lismore	• *	• *	• *	• 0.67	• 5.49	• 2.70	• *	• *
	Majorca	• *	• *	• *	• 0.65	• 7.26	• 2.26	• *	• *
	Mt Burr	• *	• *	• *	• 0.57	• 6.48	• 2.30	• *	• *
	Wail	• *	• *	• *	• 0.62	• 6.80	• 2.60	• *	• *
	Mt Remarkable	• *	• *	• *	• 0.83	• 6.12	• 2.44	• *	• *
	S Wilmington PO	• *	• *	• *	• 1.01	• 5.70	• 2.31	• *	• *
	Wilmington	• *	• *	• *	• 0.91	• 6.15	• 2.49	• *	• *
	Wirrabara SF	• *	• *	• *	• 0.81	• 6.36	• 2.47	• *	• *

• <i>Std. error of difference</i>	• *	• *	• *	• 0.20	• 0.68	• 0.13	• *	• *
• <i>Significance (provenance)</i>	• *	• *	• *	• <0.001	• <0.001	• <0.001	• *	• *
• <i>Family-within-provenance</i>	• *	• *	• *	• <0.001	• <0.001	• <0.001	• *	• *

Figure A2.11. Region-of-provenance means – branch weight. Scored worst-best 1-4 at Lismore and combined heavy and very heavy branch score (lower is better) at Bordertown and Hamilton. Bars indicate average standard errors of difference. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

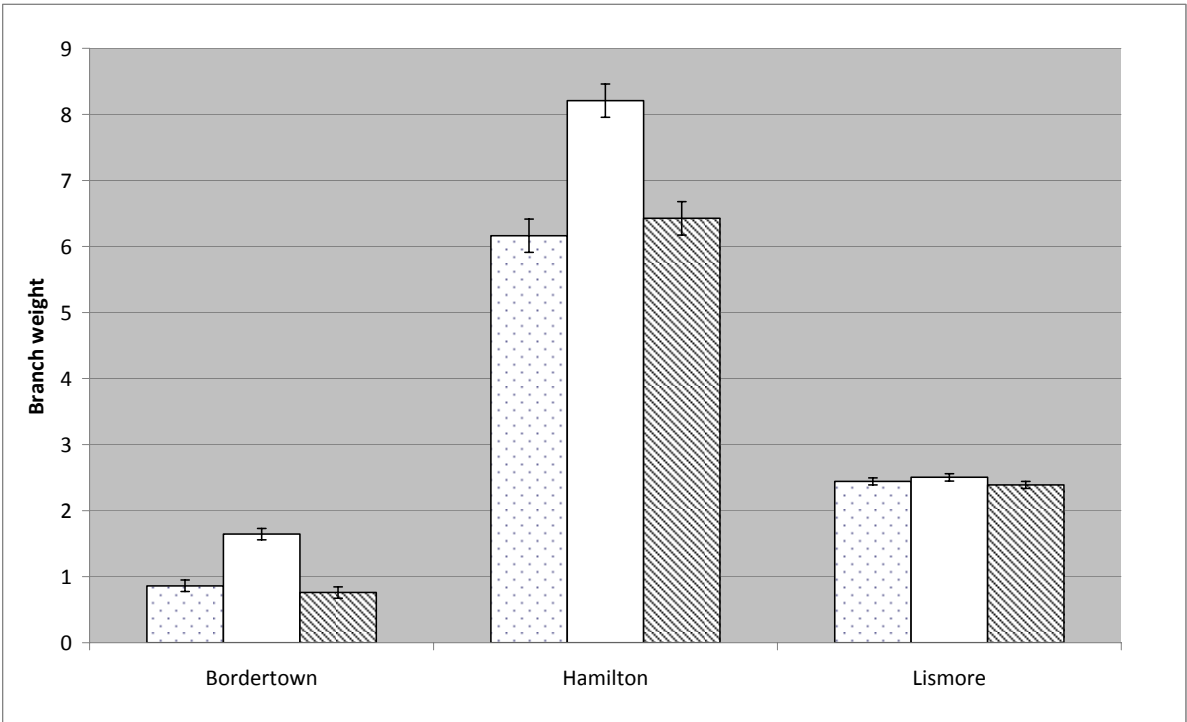


Table A2.12. Provenance means: stem erectness at Hamilton, Victoria

		Provenance	Mo ora	Espera nce	Ave nue	Bordertown	Hamilton	Lismo re	Cor owa	Wa gga
601	Kangaroo Island	American River	• *	• *	• *	• *	• 2.86	• *	• *	• *
		Cygnnet River	• *	• *	• *	• *	• 2.74	• *	• *	• *
		Flinders Chase	• *	• *	• *	• *	• 2.61	• *	• *	• *
		Flinders Chase NP	• *	• *	• *	• *	• 2.62	• *	• *	• *
	Planted stands	Kersbrook SO	• *	• *	• *	• *	• 2.96	• *	• *	• *
		Lismore	• *	• *	• *	• *	• 2.86	• *	• *	• *
		Majorca	• *	• *	• *	• *	• 2.93	• *	• *	• *
		Mt Burr	• *	• *	• *	• *	• 2.87	• *	• *	• *
		Wail	• *	• *	• *	• *	• 2.80	• *	• *	• *
	South Flinders	Mt Remarkable	• *	• *	• *	• *	• 2.90	• *	• *	• *
		S Wilmington PO	• *	• *	• *	• *	• 2.96	• *	• *	• *
		Wilmington	• *	• *	• *	• *	• 2.91	• *	• *	• *
		Wirrabara SF	• *	• *	• *	• *	• 2.87	• *	• *	• *

•	Std. error of difference	•	*	•	*	•	*	•	*	•	0.12	•	*	•	*	•	*
•	Significance (provenance)	•	*	•	*	•	*	•	*	•	<0.001	•	*	•	*	•	*
•	Family-within- provenance	•	*	•	*	•	*	•	*	•	<0.001	•	*	•	*	•	*

Figure A2.12. Provenance means – stem erectness at Hamilton, Vic. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

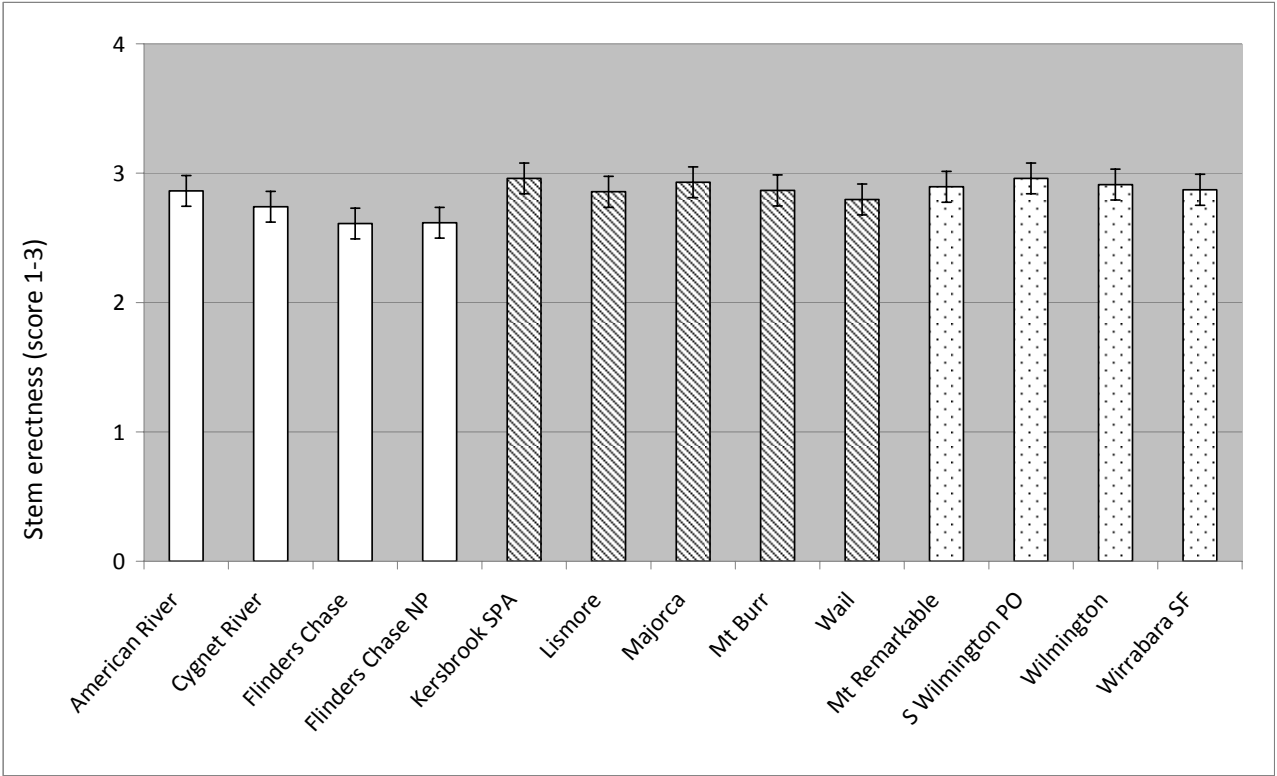


Table A2.13. Provenance means: form

	Provenance	Moora	Esperance	Avenue	Bordertown	Hamilton	Lismore	Corowa	Wagga
Kangaroo Island Planted stands	American River	4.4	3.9	*	*	*	*	*	3.2
	Cygnets River	4.6	4.5	*	*	*	*	*	3.5
	Flinders Chase	5.1	*	*	*	*	*	*	3.1
	Flinders Chase NP	4.7	4.1	*	*	*	*	*	2.9
	Kersbrook SO	5.5	*	*	*	*	*	*	4.0
	Lismore	5.4	4.6	*	*	*	*	*	3.5
	Majorca	5.6	4.6	*	*	*	*	*	3.6
	Mt Burr	5.6	*	*	*	*	*	*	3.8
	Wail	5.7	*	*	*	*	*	*	3.5
	Mt Remarkable	5.4	4.7	*	*	*	*	*	3.4
	S Wilmington PO	5.6	*	*	*	*	*	*	3.5
	Wilmington	5.3	4.6	*	*	*	*	*	3.4
	Wirrabara SF	5.5	4.5	*	*	*	*	*	3.7
Std. error of		0.12	0.32	*	*	*	*	*	0.2

Figure A2.13. Region-of-provenance means: form. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

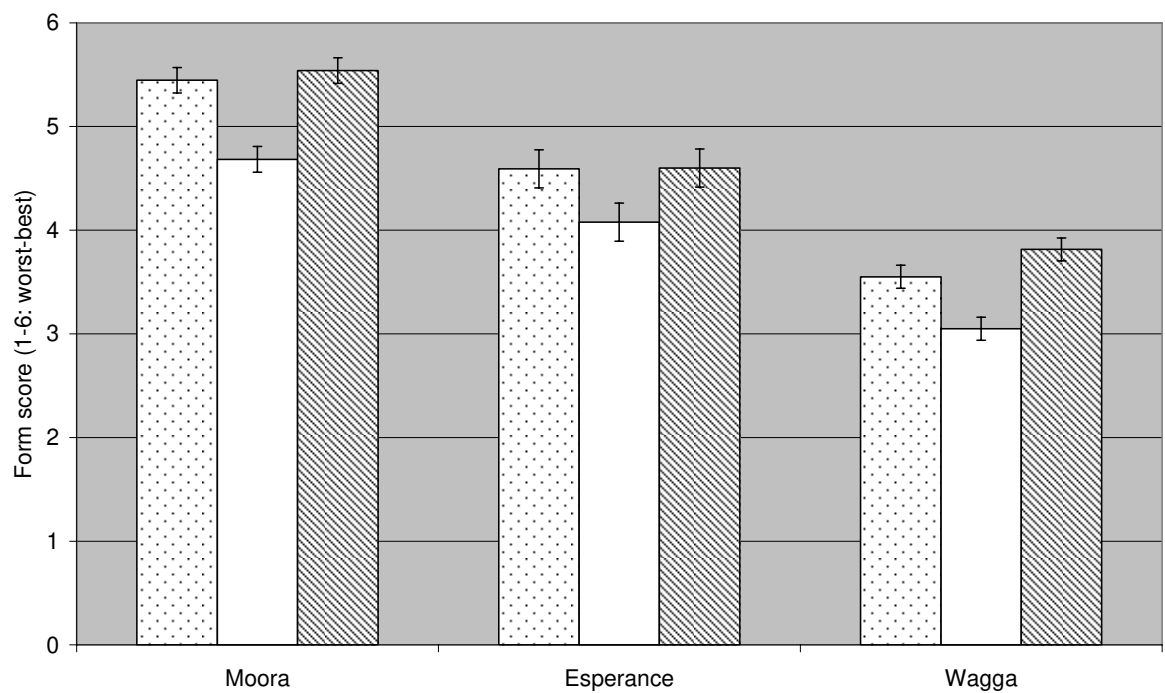


Table A2.14. Provenance means: crown score at two sites in Western Australia. The scale is 1-6 with higher scores having better crown form

	Provenance	Moora	Esperance	Avenue	Bordertown	Hamilton	Lismore	Corowa	Wagga
115	Kangaroo Island	American River	2.63	2.87	*	*	*	*	*
		Cygnnet River	2.85	3.44	*	*	*	*	*
		Flinders Chase	3.03	*	*	*	*	*	*
		Flinders Chase NP	2.71	2.61	*	*	*	*	*
		Kersbrook SO	3.57	*	*	*	*	*	*
	Planted stands	Lismore	3.33	3.48	*	*	*	*	*
		Majorca	3.10	3.70	*	*	*	*	*
		Mt Burr	3.88	*	*	*	*	*	*
		Wail	3.48	*	*	*	*	*	*
		Mt Remarkable	3.27	3.80	*	*	*	*	*
	South Flinders	S Wilmington PO	3.15	*	*	*	*	*	*
		Wilmington	3.19	3.69	*	*	*	*	*
		Wirrabara SF	3.30	3.66	*	*	*	*	*

• <i>Std. error of difference</i>	• 0.22	• 0.22	• *	• *	• *	• *	• *	• *	• *
• <i>Significance (provenance)</i>	• <0.001	• <0.001	• *	• *	• *	• *	• *	• *	• *
• <i>Family-within-provenance</i>	• <0.001	• <0.001	• *	• *	• *	• *	• *	• *	• *

Figure A2.14. Provenance means – crown score. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

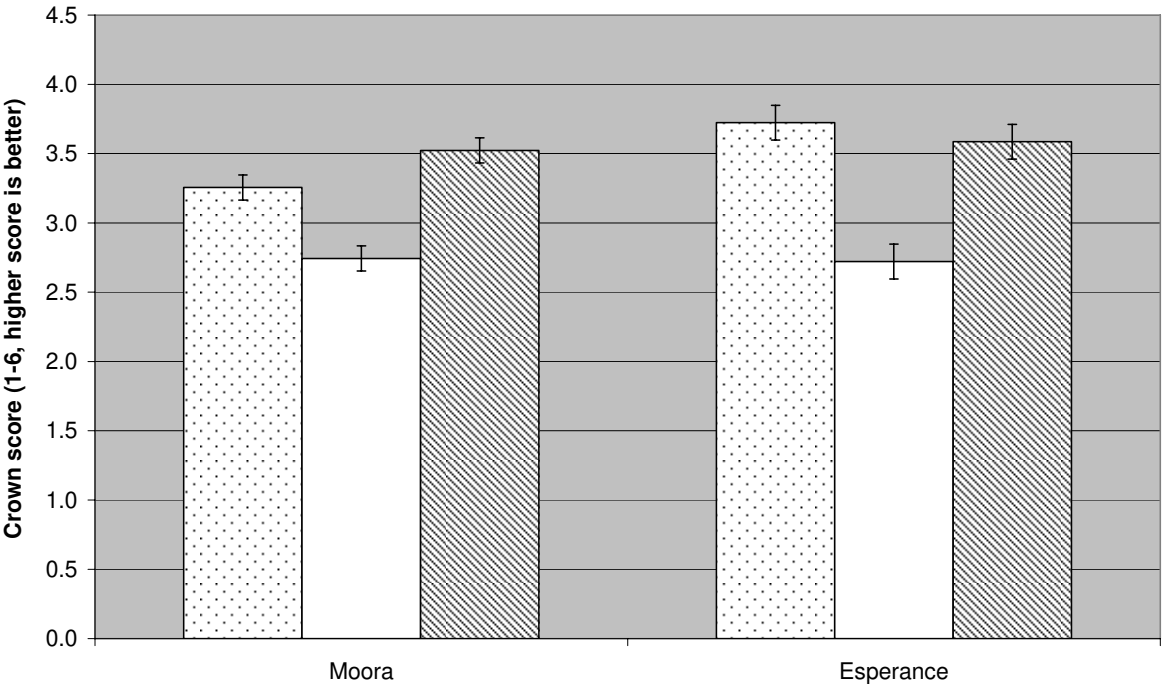


Table A2.15. Provenance means – Leaf-shed at Lismore, Victoria (scored from 1=few leaves shed to 4=high proportion of leaves shed)

	Provenance	Mo ora	Espera nce	Ave nue	Bordertown	Hamilton	Lismor e	Cor owa	Wa gga
Kangaroo Island	American River	• *	• *	• *	• *	• *	• 2.18	• *	• *
	Cygnnet River	• *	• *	• *	• *	• *	• 2.17	• *	• *
	Flinders Chase	• *	• *	• *	• *	• *	• 2.26	• *	• *
	Flinders Chase NP	• *	• *	• *	• *	• *	• 2.27	• *	• *
Planted stands	Kersbrook SO	• *	• *	• *	• *	• *	• 1.89	• *	• *
	Lismore	• *	• *	• *	• *	• *	• 2.45	• *	• *
	Majorca	• *	• *	• *	• *	• *	• 1.93	• *	• *
	Mt Burr	• *	• *	• *	• *	• *	• 1.70	• *	• *
	Wail	• *	• *	• *	• *	• *	• 2.17	• *	• *
South Flinders	Mt Remarkable	• *	• *	• *	• *	• *	• 2.03	• *	• *
	S Wilmington PO	• *	• *	• *	• *	• *	• 2.17	• *	• *
	Wilmington	• *	• *	• *	• *	• *	• 2.09	• *	• *
	Wirrabara SF	• *	• *	• *	• *	• *	• 2.17	• *	• *

Figure A2.15a. Provenance means – leaf shed at Lismore. Bars indicate average standard error of difference. Stipple=S. Flinders; solid=Kangaroo Is.; diagonal stripe=planted

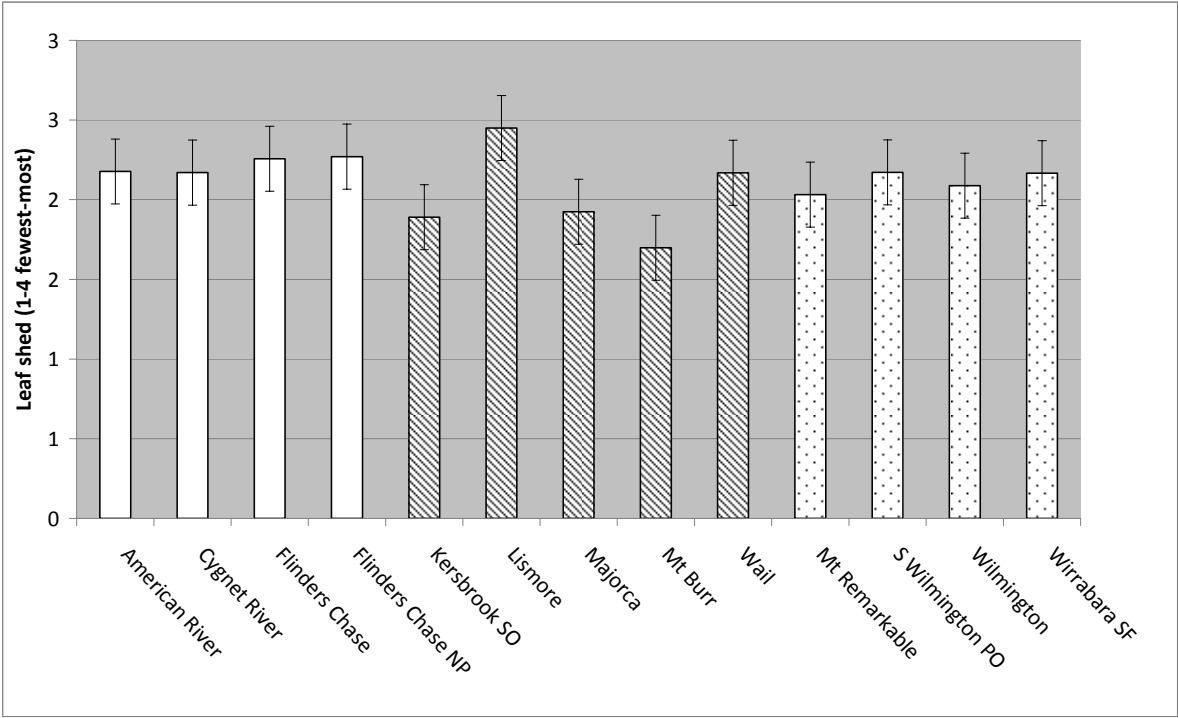


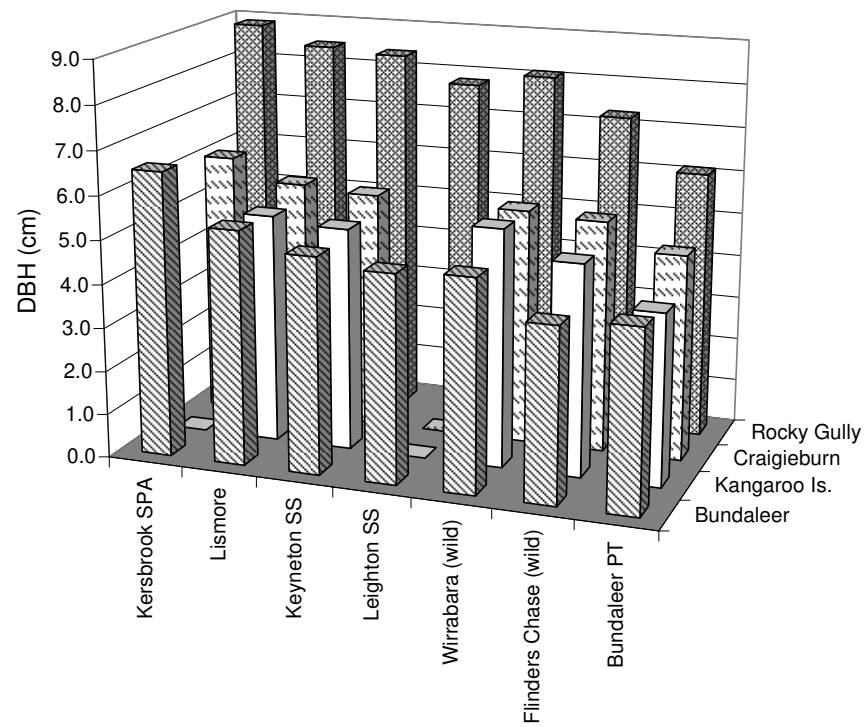
Table A2.16. Summary of seed source trial results

Trait	Rocky Gully	Bundaleer	Kangaroo Is.	Craigieburn	Lismore
A2.16a. Survival (proportion)					
Bundaleer PT	0.98	0.88	0.65	0.88	0.87
Flinders Chase (wild)	0.99	0.87	0.64	0.87	0.74
Kersbrook SPA	0.99	0.96	*	0.90	0.73
Keyneton SS	0.98	0.89	0.69	0.81	0.78
Leighton SS	0.95	0.83	*	*	0.76
Lismore	0.98	0.92	0.66	0.88	0.74
Wirrabara (wild)	0.98	0.87	0.73	0.84	0.86
s.e.d.	0.02	0.06	0.06	0.05	0.08
significance	n.s.	n.s.	n.s.	n.s.	n.s.
A2.16b. DBH^s					
Bundaleer PT	6.1	4.2	3.9	4.7	*
Flinders Chase (wild)	7.3	4.0	4.8	5.3	*
Kersbrook SPA	8.9	6.5	*	6.1	*
Keyneton SS	8.4	4.9	5.1	5.5	*
Leighton SS	7.8	4.8	*	*	*
Lismore	8.5	5.4	5.3	5.6	*
Wirrabara (wild)	8.1	4.8	5.4	5.4	*
s.e.d.	0.2	0.5	0.34	0.1	*
significance	<0.001	<0.001	<0.001	<0.001	*
A2.16c. Height					
Bundaleer PT	4.3	3.7	3.6	3.5	3.0
Flinders Chase (wild)	5.2	4.0	4.3	4.0	3.4
Kersbrook SPA	5.6	5.5	*	4.2	3.3
Keyneton SS	5.3	4.5	4.6	3.9	3.4
Leighton SS	5.2	4.1	*	*	3.1
Lismore	5.6	4.8	4.5	4.1	3.2
Wirrabara (wild)	5.2	4.3	4.6	3.8	3.3
s.e.d.	0.1	0.4	0.2	0.1	0.1
significance	<0.001	<0.001	<0.001	<0.001	<0.001

Trait	Rocky Gully	Bundaleer	Kangaroo Is.	Craigieburn	Lismore
A2.16d. Stem count[§]					
Bundaleer PT	*	1.07	1.00	*	*
Flinders Chase (wild)	*	1.10	1.00	*	*
Kersbrook SPA	*	1.03	*	*	*
Keyneton SS	*	1.04	1.05	*	*
Leighton SS	*	1.01	*	*	*
Lismore	*	1.03	1.01	*	*
Wirrabara (wild)	*	1.03	1.05	*	*
s.e.d.	*	0.024	0.02	*	*
significance	*	0.003	0.013	*	*
A2.16e. Axis persistence					
Bundaleer PT	4.7	*	*	4.6	*
Flinders Chase (wild)	4.4	*	*	4.6	*
Kersbrook SPA	5.2	*	*	5.6	*
Keyneton SS	5.3	*	*	5.7	*
Leighton SS	5.2	*	*	*	*
Lismore	5.3	*	*	5.8	*
Wirrabara (wild)	4.7	*	*	5.6	*
s.e.d.	0.2	*	*	0.2	*
significance	<0.001	*	*	<0.001	*
A2.16f. Form					
Bundaleer PT	2.9	*	*	*	*
Flinders Chase (wild)	3.2	*	*	*	*
Kersbrook SPA	3.9	*	*	*	*
Keyneton SS	3.4	*	*	*	*
Leighton SS	3.4	*	*	*	*
Lismore	3.5	*	*	*	*
Wirrabara (wild)	3.5	*	*	*	*
s.e.d.	0.1	*	*	*	*
significance	<0.001	*	*	*	*

§ DBH is equivalent DBH (i.e. geometric mean of individual stems) at Bundaleer and Kangaroo Island

Figure A15b. DBH at four seed source trial sites: Rocky Gully, WA; Craigieburn, Vic.; Kangaroo Is. SA; Bundaleer, SA



3 Metadata Part 3: *Corymbia maculata* provenance-progeny and seed source trials

T. Jackson, D. Bush, J. Driscoll

3.1. Background

Corymbia maculata (spotted gum) has a widespread natural distribution along the coastal plains and hills of New South Wales, where it makes an important contribution to commercial wood production. It also occurs naturally in one small stand in far eastern Victoria. Uses of its hard, strong, versatile wood include heavy construction, housing, flooring and tool handles, and sawn timber recovery is excellent.

C. maculata has performed well in southern Australian farm plantations. In areas of winter-dominant rainfall, it usually grows faster than the closely related northern spotted gum, *C. citriodora* ssp. *variegata*. It has superior stem form to most low rainfall species and its growth rates are good on appropriate sites receiving greater than 500-600 mm annual rainfall. However, it is not suited to sites which are frost-prone, waterlogged, saline or very dry.

3.2. Genetic improvement

Spotted gum was selected for genetic improvement in the ALRTIG program because of its demonstrated growth and form in farm plantations in southern Australia, its good timber properties and the availability of data from provenance trials.

Breeding strategy

The improvement objective is to maximise the value of logs produced by plantations in the target

planting zones on a rotation of 15-30 years. The main products are expected to be small sawlogs, poles, and posts. The initial selection criteria were improved volume production, straight stem, absence of forking and tolerance to drought, pests and diseases. Selection and breeding for improved wood properties has commenced with a study on the genetic variation of traits relating to natural durability for in-ground use including some basic wood properties of young-aged material such as basic density and heartwood-sapwood ratios (RIRDC project CSF66A).

Provenance information and interim seed sources

Superior natural provenances were initially identified from the results of provenance trials in Western Australia, southern NSW and Victoria. Some improved material from SSOs near Deniliquin is available through CSIRO's ATSC and some clonal material from FPC WA.

Breeding population

ALRTIG established a main breeding population of 6 provenance-progeny trials at select sites in Victoria and WA. These trials incorporate 116 families from (i) mother trees sampled to be representative of wild populations and (ii) superior trees in planted stands. The trials will serve the dual purposes of supplying data on variation and estimates of genetic parameters of target traits, and supplying genetically improved seed (Mazanec and Harwood 2001).

Some of the sites are being converted by selective thinning to seedling seed orchards (SSOs), which will supply genetically improved seed for plantations and for the next generation of the main breeding population. Three Victorian sites have been thinned, with the removal of 3 trees per 5-tree plot. These trials are termed progeny trial – seedling seed orchards (PT-SSOs) and are starting to produce small amounts of seed. The WA trial may also be used to produce scions for clonal seed orchard development. Trials will be used to supply genetically improved material for the next generation.

Vegetative propagation of spotted gums by stem cuttings is difficult, with low levels of success reported by research groups worldwide. Micropropagation from spotted gum seedlings is much more successful (Brammall and Harwood 2001), but difficult to apply on a production scale. In the absence of major technical improvements, mass vegetative propagation for clonal forestry is unlikely to contribute to ALRTIG's improvement strategy.

Seed source trials

These seed source trials test the performance of genetically improved material against unimproved controls. Four *C. maculata* seed source trials were established across the target planting zone in 2003 (Table 2). The trials at Rocky Gully (WA) and Craigieburn (Vic.) were established, managed and measured by Integrated Tree Cropping Ltd and Woollybutt Pty Ltd respectively. Each trial was established using local best practice management and silviculture. ALRTIG 'best-bet' seedlots (on the basis of partners' previous trial data) were compared with wild provenance material.

3.3. Genetic resources

Details of seedlots (open pollinated families) in the progeny trials are summarised in Table 3.1a. They include 116 families from 11 seed sources. The seed sources were of two main sorts: wild provenance collections, with families randomly sampled so as to be representative of the population, and collections from planted stands, with families phenotypically selected as candidate plus trees. Not all families were included at all sites; however there is sufficient overlap for joint analysis.

Table 3.1a. Details of seedlots and number of families of each seedlot in each progeny trial

Seedlot source	Seedlot code	Latitude (° ' S)	Longitude (° ' E)	Altitude (m)	Hensley Park*	Buckley Swamp	Balmoral	Cavendish	Brynerion	Total
Barclays SSO [#]		35 29	145 15	100	17 (1)	17	16	19	8	19
Bodalla SF	ATSC 19102, 19422	36 11	150 06	124, 60	11 (3)	10	11	11	6	11
Curryall SF	ATSC 19663, 20150, 20397	32 04	149 50	650	32 (5)	29	25	13	8	32
Kioloa SF	ATSC 19308	35 35	150 20	70	10 (2)	9	10	10	8	10
Mottle Range	ATSC 19382, NN157	37 37	148 13	280	6 (1)	6	6	4	5	6
Mumbula SF	ATSC 19421	36 38	149 56	120	5 (0)	5	5	4	4	5
Nelligen	ATSC 19481	35 37	150 04	200	11 (2)	10	11	10	6	11
Pokolbin SF	ATSC 19752	32 47	151 13	500	8 (2)	7	7	7	2	8
Wando Heights [#]	CEH501	37 25	141 35		1 (0)	1				1
Wingello SF	ATSC 19263, 20324	34 44	150 11	580, 530	12 (1)	12	12	12	5	12
Yarrat SF	ATSC 19751	31 50	152 25	60	3 (1)	2	1	1	1	3
Total seed sources					11 (9)	11	10	10	10	11
					116 (18)	108	105	89	53	118

* At Hensley Park all families were assessed for DBH; brackets indicate the number of families assessed for height and form traits

[#] Planted stands (other sources are wild provenances)

Seedlots for the seed source trials, including both *C. maculata* and *C. citriodora* ssp. *variegata* are listed in Table 3.1b. Available “improved” seedlots of each species were tested against best-bet wild seedlots (Bodalla and Paddys Land) selected on the basis of good growth performance (Bird *et al.* 2000) and cold tolerance (Larmour *et al.* 2000) in earlier studies.

Table 3.1b. Seedlots in the seed source trials

Seedlot	Seedlot information	Description
<i>C. maculata</i>		
Hamilton PT	Seed supplied by DPI, Victoria	Bulk seed from 7 trees in provenance trial in Victoria
Deniliquin SSO	ATSC 20658	Bulk seed from 18 trees in selectively thinned progeny trial in NSW
Bodalla	ATSC 20598	Bulk seed from 10 wild trees at Bodalla, NSW
<i>C. citriodora</i> ssp. <i>variegata</i>		
Hamilton PT	Seed supplied by DPI, Victoria	Bulk seed from 9 trees in provenance trial in Victoria
Paddys Land	ATSC 20396	Bulk seed from 10 wild trees at Paddys Land, NSW

3.4. Sites, trial designs and establishment

Sites for provenance-progeny trials and seed source trials were representative of the target planting zone in Australia's southern wheat-sheep zone. This area is characterised by low annual rainfall and high evaporation relative to traditional plantation-forestry areas. Sites were generally selected with adequate drainage and freedom from heavy frost, though the Brynterion site was relatively harsh. Summarised details are given in Table 3.2.

Table 3.2. Summary of site locations, soils and climate for the progeny and seed source trials

Site name	State	Latitude (° S)	Longitude (° E)	Altitude (m)	MAR	Evap.	Soil, Geology
<i>Progeny trials</i>							
Hensley Park	Vic	-37.68	142.06	230	670	1300 +	Clay loam over medium clay. Basalt plains.
Buckley Swamp	Vic	-37.83	142.08	205	690	1300	Clay loam over medium clay. Basalt plains.
Cavendish	Vic	-37.57	142.05	220	650	1300 +	Loam over light clay. Laterised sedimentary.
Brynterion	Vic	-36.74	142.63	140	430		Grey clay, poor drainage. Alluvial.
<i>Seed source trials</i>							
Melville Forest	Vic	-37.50	141.92	250	650	1300 +	Loam over medium clay. Laterised sedimentary.
Craigieburn	Vic	-37.58	144.93	230	600		Duplex, Basalt plains
Bordertown	SA	-36.25	140.57	30	450		Loamy sand over ironstone clay.
Rocky Gully	WA	-34.05	117.93	220	835		Shallow. Granitic.

The provenance-progeny trials were established in spring of 2001 (see Table 3). Each family (Table 3.1a) was represented by 20 progeny arranged in 4 randomized complete block replicates of 5-tree line-plots. The progeny trials were of resolvable incomplete block design, with incomplete blocks in a two-dimensional row-column arrangement where possible (not at Buckley Swamp or Cavendish, due to limited space). Initial trial stocking was 1250 stems per hectare (4 m x 2 m spacing) except at Cavendish where it was 1000 stems/ha (4 m x 2.5 m).

The seed source trials were established in 5-8 replicates of 40-64 tree plots in winter or spring 2003. The common design was randomized complete blocks (RCB) with incomplete block structures superimposed in some cases (resolvable ICB). The seed source trials were established at 1000 stems/ha (4 m x 2.5 m spacing).

All trials were prepared using best local management practice at each site. This involved cultivation (shallow or deep ripping with or without mounding) and weed control, either using chemicals in the eastern States or by scalping in WA. Second year weed control was applied at most sites as necessary.

Pruning and thinning

The Hensley Park and Cavendish progeny trials were pruned and thinned prior to assessment. Two trees in each plot were selected for retention, based on growth and form for sawlog production, and then pruned; the other three trees were culled. Hence only 2 trees per plot were assessed at those sites, and it is highly likely that the selection and removal of culls will have positively biased both growth and form data with respect to the other sites, and possibly masked genetic differences within sites.

3.5. Measurements

The provenance-progeny trials were measured at around five years, and the seed source trials at three years (Table 3.3). Various traits were measured at each site, as summarised in Table 3.3. At Hensley Park, all trees were assessed for DBH but only some genetic material was assessed for other traits.

Table 3.3. Traits measured at each trial site

Site	Date planted	Date measured	Height	DBH	Axis persistence	Branch weight	Stem straightness	Other
<i>Progeny trials</i>								
Buckley Swamp	25/9/2001	Apr 2005	Yes	Yes†	Yes	Yes	Yes	Erectness
Cavendish	1/11/2001	Jul 2005		Yes	*	*	*	
Brynterion	4/10/2001	May 2007	Yes	Yes†	*	*	*	
Hensley Park	1/10/2001	Oct 2006	Yes [#]	Yes	Yes [#]	Yes [#]		
<i>Seed source trials</i>								
Melville Forest	30/10/2003	Jan 2007	Yes	Yes	Yes	*	*	
Craigieburn	1/9/2003	Sept. 2006	Yes	Yes	*	*	*	
Bordertown	17/7/2003	Nov. 2006	Yes	Yes	Yes	*	*	Pruning ease
Rocky Gully	23/7/2003	Nov. 2006	Yes	*	*	*	*	

[#] Not all material at Hensley Park was assessed for height and form traits (see Table 3)

† Stem count (number of stem diameters recorded) of each tree was used as an extra trait at Buckley Swamp and Brynterion

Notes on each of the traits follow:

Survival

Survival was calculated and analysed on the basis of plot mean survival.

Growth traits

Height

Height was measured from ground level to the highest point of the crown.

Diameter at breast height

For trees which had multiple stems, the DBH of all stems with DBH greater than half of that of the largest stem were measured. Equivalent diameter was calculated as the geometric mean of the individual measurements:

$$\text{Equivalent DBH} = \sqrt{\text{Stem}_1^2 + \text{Stem}_2^2 \dots \text{Stem}_n^2}$$

Stem volume

For sites where both DBH and height were measured, individual stem volumes were estimated by:

$$Volume = 1/3 \times \pi \times (EquivalentDBH/2)^2 \times height$$

Mean annual stem-volume increment was also estimated. Where no height measurements were available for the calculation, heights were first estimated using a regression between height and diameter, developed for sites where both were measured.

Form traits

Axis persistence

Axis persistence is a measure of forking, where a fork is defined as being greater than half the thickness of the stem at the point of union, and apical dominance, scored as follows:

0 = lowest fork at base

1 = lowest fork occurs in lowest quarter of tree

2 = lowest fork in first half of tree

3 = lowest fork in third quarter of tree

4 = lowest fork in highest quarter of tree

5 = no forks

Branch weight

At Buckley Swamp, branch weight was scored as the number of branches with $D > 1/4$ of stem diameter at that height (including non-basal forks), from ground level to 4 m or to $D = 2$ cm, whichever came first. Therefore, at this site, a high score indicates poor branch habit.

At Hensley Park, branching was scored from 1 (heavy branching, difficult pruning) to 3 (uniform branching, easy pruning).

Stem straightness

Stem straightness was analysed on a scale of 1-4 (worst-best).

Erectness

Stem erectness – score of 1 (not vertical, lean > 15 degrees), 2 (almost vertical, lean ~ 5 -10 degrees) or 3 (vertical, no lean).

3.6. Data analysis

Trial data from each progeny trial site was screened for errors and outliers and analysed separately. The trials were analysed for each trait using an individual tree model with genetic groups corresponding to the provenances detailed in Table 1a implemented with ASREML software (Gilmour *et al.* 2006). This procedure gives Best Linear Unbiased Estimators (BLUEs - an adjusted mean value) for the provenances and Best Linear Unbiased Predictors (BLUPs – an adjusted mean often used for genetic ranking) for each mother and each individual tree. This report considers the more generally useful provenance estimates, while the BLUPs are being used to guide selection and thinning and for

calculation of more complex genetic parameters. Preliminary assessment of the data showed that the region-of-provenance groupings of provenances provides a useful way of examining the data, and this genetic grouping was also analysed in separate model runs as a fixed effect. Site, provenance and region-of-provenance means have been reported, with standard errors of difference and chi-squared probabilities on Wald tests that the treatments are equal for provenances and families-within-provenances. Probabilities $0.05 < p < 0.001$ are considered to be ‘weakly’ significant, whereas $p < 0.001$ are considered to be ‘highly’ significant. This is because the chi-square distribution used with Wald tests is an asymptotic approximation (i.e. for large samples) and underestimates the probabilities in other cases (Payne *et al.* 2007).

A preliminary analysis of GxE was carried out at the provenance level for those traits having data from multiple sites sharing a broad range of genetic material. The objective was simply to provide an indication of whether there is likely to be significant GxE, not to characterise the GxE in detail. There are a number of ways that this can be done (see for example White *et al.* 2007). We have chosen a mixed modelling approach with sites treated as fixed effects and provenances and the interaction of provenances and sites treated as random effects (see also White *et al.* 2007 for an explanation of the difference between fixed and random effects). This gives variance components for the provenance and provenance-by-site interaction. Shelbourne (1972) suggests that, as a rule of thumb, when the provenance-by-site interaction variance is more than 50% of the provenance variance, the level of GxE is likely to be of concern in making selections. The GxE analyses were carried out using the ASREML software described above. More sophisticated GxE analyses could include fitting of a more comprehensive model to account for heterogeneous residual (error) variances at each site, and such analyses are recommended if more detailed information on GxE is required. It should be noted that some of the provenances were represented by different numbers of families at the different sites (Table 3.1a); this introduces a certain degree of error into the assessment of GxE.

The seed source trials with incomplete block structures were analysed using a mixed-model reml procedure, with replicate and seedlot effects treated as fixed, and incomplete blocks as random. Trials without incomplete blocks were analysed using fixed-effects ANOVA. These analyses were implemented with Genstat software (Payne *et al.* 2007).

3.7. Results

Results are presented in the following sections:

Section A - progeny trials

Section B – seed source trials

A. Progeny trials

Table 3.4 gives the results of the provenance-by-site interaction analysis described in Section 3.6. Interaction components were identified and in the case of survival and DBH, interaction components were a significant proportion (>50%) of the genotype component, which Shelbourne (1972) suggests is the approximate point where GxE is of practical significance.

Table 3.4. Variance components and ratios for provenance and site-by-provenance for each trait. Variance component ratios over 50% (shown in bold typeface) indicate GxE that is likely to be of practical significance for selection.

Variance components

Trait	Provenance	Site-by-provenance (SxP)	Ratio of SxP to P
Survival	~0	0.00041*	High
Equivalent DBH	0.168	0.104	62%
Height	0.053	0.029	55%
Axis persistence	0.028	0.011	38%

* This component had a high standard error

Survival

Survival was good (94%) at Buckley Swamp and poor (51%) at the drier, frostier Brynterion site (Table 3.5, Figure 3.1). The Brynterion site is clearly marginal for this species, whereas Buckley Swamp is quite suitable. The Hensley Park and Cavendish sites were thinned prior to measurement, but survival at six months was very good (99% and 97% respectively). Significant differences in survival were found among families-within-provenances and among provenances at Buckley Swamp (Table 3.5), but only Wando Heights trees had substantial mortality. A high site-by-provenance interaction component was found (Table 3.4), though this term had a high standard error and the practical significance of the comparison across only two sites which clearly performed very differently is limited.

Figure 3.1. Mean survival for provenances in the provenance-progeny trials

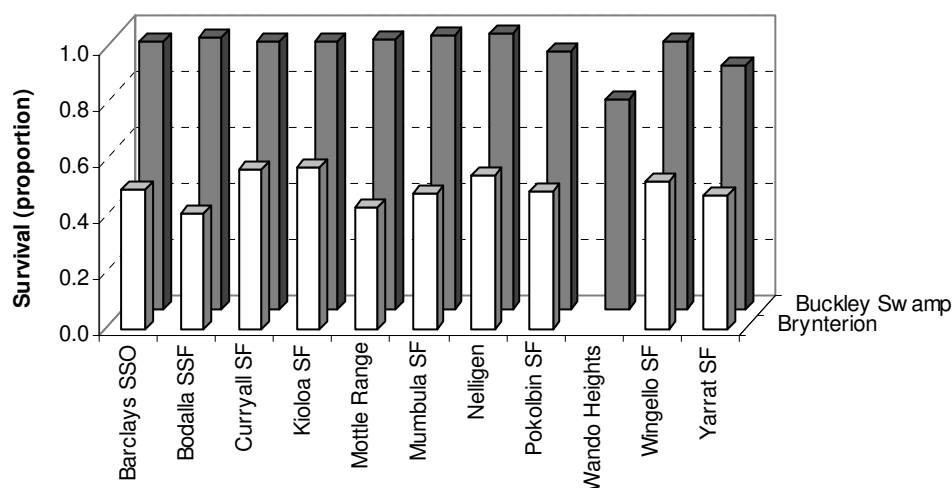


Table 3.5. Mean survival, growth and form data for each provenance in the provenance-progeny trials

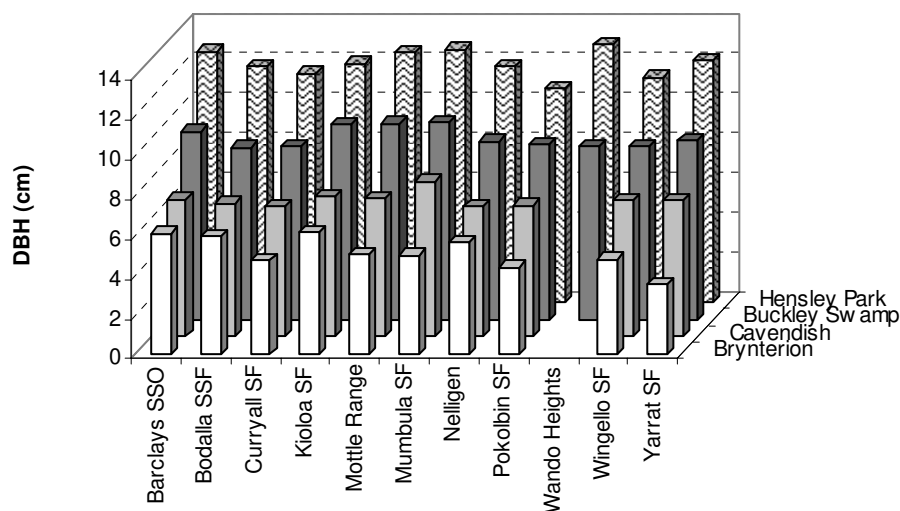
Provenance	Survival (proportion)		DBH (mm)				Height (m)			Stem volume (x10 ⁻³ m ³)			Axis persistence		Stem straight-ness	Erect-ness	Branching*		Stem count	
	Buckley Swamp	Brynterion	Buckley Swamp	Cavendish	Brynterion	Hensley Park	Buckley Swamp	Brynterion	Hensley Park	Buckley Swamp	Brynterion	Hensley Park	Buckley Swamp	Hensley Park	Buckley Swamp	Buckley Swamp	Buckley Swamp	Hensley Park	Buckley Swamp	Brynterion
Barclays SSO	0.96	0.50	9.5	6.9	6.1	12.7	6.8	5.1	9.3	18	6.6	43	2.9	3.6	2.5	2.9	2.9	2.6	1.3	1.4
Bodalla SF	0.98	0.41	8.7	6.7	5.9	11.9	6.4	5.0	8.6	15	6.2	33	2.7	2.9	2.3	2.9	3.3	2.0	1.4	1.4
Curryall SF	0.96	0.57	8.7	6.6	4.7	11.6	6.2	4.1	8.2	14	4.0	30	2.6	3.4	2.6	2.9	2.7	2.2	1.3	1.5
Kioloa SF	0.96	0.58	9.8	7.1	6.1	12.1	6.7	4.9	8.3	18	6.9	33	2.4	3.9	2.2	2.8	3.3	1.8	1.5	1.5
Mottle Range	0.97	0.44	9.9	7.0	5.0	12.6	6.9	4.5	9.2	19	4.2	45	2.9	4.2	2.2	2.8	2.6	2.8	1.3	1.2
Mumbula SF	0.98	0.49	10.0	7.8	5.0	12.8	7.1	4.8		21	4.8	*	2.3	*	2.3	2.8	3.4	*	1.4	1.2
Nelligen	0.98	0.55	9.0	6.5	5.6	11.9	6.4	4.8	8.1	15	4.6	32	2.2	3.5	2.5	2.8	3.2	2.0	1.5	1.4
Pokolbin SF	0.92	0.49	8.9	6.6	4.4	10.8	6.4	3.9	8.0	15	2.5	23	2.8	3.8	2.7	2.9	2.5	2.6	1.3	1.4
Wando Heights	0.75		8.7	*	*	13.0	6.1	*	*	15	*	*	2.2	*	1.7	2.8	2.7	*	1.3	*
Wingello SF	0.96	0.53	8.8	6.9	4.8	11.4	6.7	4.5	8.3	15	4.4	27	2.8	4.4	2.3	2.9	2.8	2.1	1.4	1.3
Yarrat SF	0.88	0.48	9.0	6.9	3.5	12.2	6.5	3.9	8.1	15	2.2	28	2.7	3.8	2.3	2.9	2.8	1.9	1.2	1.0
s.e.d.	0.029	0.090	0.34	0.30	0.63	0.39	0.19	0.40	0.35	1.3	1.4	4.3	0.28	0.55	0.16	0.05	0.29	0.28	0.10	0.14
Site mean	0.93	0.50	9.2	6.9	5.0	12.0	6.6	4.5	8.4	16	4.0	32	2.6	3.6	2.3	2.8	2.9	2.2	1.3	1.3
<i>P</i> (prov)	<0.001	0.304	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.042	<0.001	<0.001	<0.001	0.004	0.010	0.006
<i>P</i> (prov.family)	0.005	0.468	<0.001	<0.001	<0.001	<0.001	<0.001	0.028	0.012	<0.001	0.012	0.028	<0.001	0.091	<0.001	<0.001	<0.001	<0.001	0.034	<0.001

* No. branches >50% of stem diameter at Buckley Swamp, Score 1-3 at Hensley Park

Equivalent DBH

There were highly significant ($p < 0.001$) differences in DBH among provenances and among families-within-provenances at all sites (Table 3.5, Figure 3.2). Mumbula State Forest, Mottle Range, Kioloa State Forest and Barclays SSO provenances generally ranked well, but less so at the drier frostier Brynterion site, which had more variable growth and survival and greater experimental error than the other sites. The Wando Heights provenance ranked highest at Hensley Park, but that estimate represented only one family. The Hensley Park and Cavendish data were based on only two trees per plot remaining after thinning. The Yarrat, Curryall and Wingello provenances were among the poorest at all trial sites. Despite the general trends there was a relatively high site-by-provenance interaction component (Table 3.4). The differing provenance performance at the dry frosty Brynterion site, which is beyond the usual planting range for *C. maculata*, contributed to this. Provenances which performed relatively poorly at Brynterion compared to other sites also had relatively low stem counts (see **Stem count**) at Brynterion, and this may have disadvantaged them in terms of early equivalent-diameter growth. More detailed analysis is required to better explore the nature of the GxE.

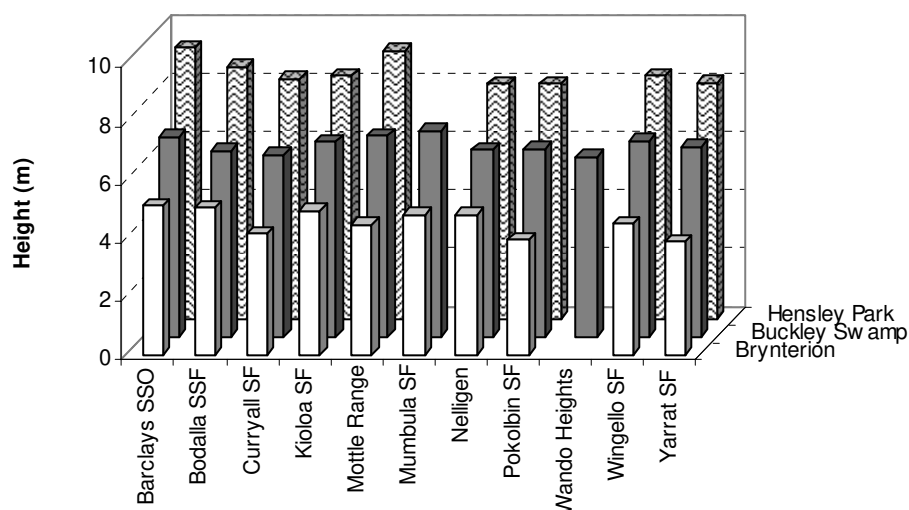
Figure 3.2. Mean DBH for provenances in the provenance-progeny trials



Height

Differences in height were highly significant ($p < 0.001$) among provenances at all sites and weakly ($p < 0.05$) to highly significant among families-within-provenances (Table 3.5, Figure 3.3). As was found for DBH, Mumbula, Mottle Range and Barclays SSO provenances ranked well, as did Kioloa, while Yarrat, Curryall and Wingello SF provenances ranked poorly. Note that only a small proportion of families at the Hensley Park site were assessed for height and form traits (Table 3.5), but height rankings were fairly similar to those at the thoroughly assessed Buckley Swamp site. There was a small site-by-provenance interaction component (Table 3.4).

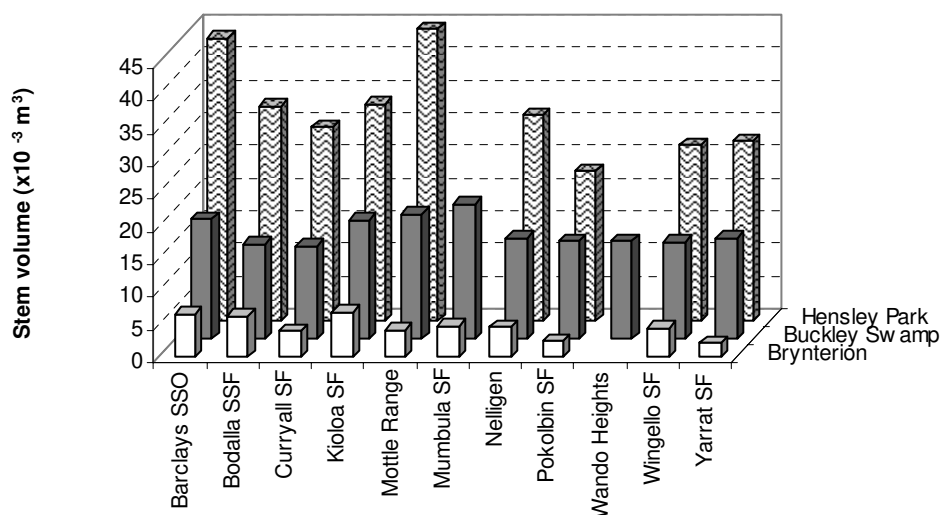
Figure 3.3. Mean height for provenances in the provenance-progeny trials



Stem volume

There were highly significant ($p < 0.001$) differences among provenances and weakly ($p < 0.05$) to highly significant differences among families-within-provenances for this trait (Table 3.5, Figure 3.4). Mumbula, Mottle Range, Kioloa and Barclays SSO were again among the top provenances. Only a small proportion of families at the Hensley Park site were assessed.

Figure 3.4. Mean stem volume for provenances in the provenance-progeny trials



Height and diameter relationship

The regression between height and diameter at three sites, where both were measured, accounted for 79.1% of phenotypic height variance, and is described by the equation:

$$\text{Height (m)} = 2.09 \text{ m} + 0.49 \times \text{DBH}$$

This relationship was deemed suitable for estimating heights for the purpose of volume calculation for comparison of productivity.

Productivity

Growth productivity was low-moderate across the sites (Table 3.6). Brynterion had low stocking due to mortality, and the site is unfavourable: a low growth rate is to be expected. Hensley Park and Buckley Swamp showed similar productivity, allowing for thinning immediately prior to assessment. Cavendish had also been thinned (3/5 stems removed), but even taking this into consideration the volume production is markedly lower than at Hensley Park and Buckley Swamp.

Table 3.6. Productivity as indicated by mean annual stem-volume increment (MAI) (m³/ha/year)

Site	MAI (m ³ /ha/year)	Age (years)
Buckley Swamp	5.45	3.5
Cavendish	0.79†♣	3.7
Brynterion	0.58	5.6
Hensley Park	3.05♣	5.0

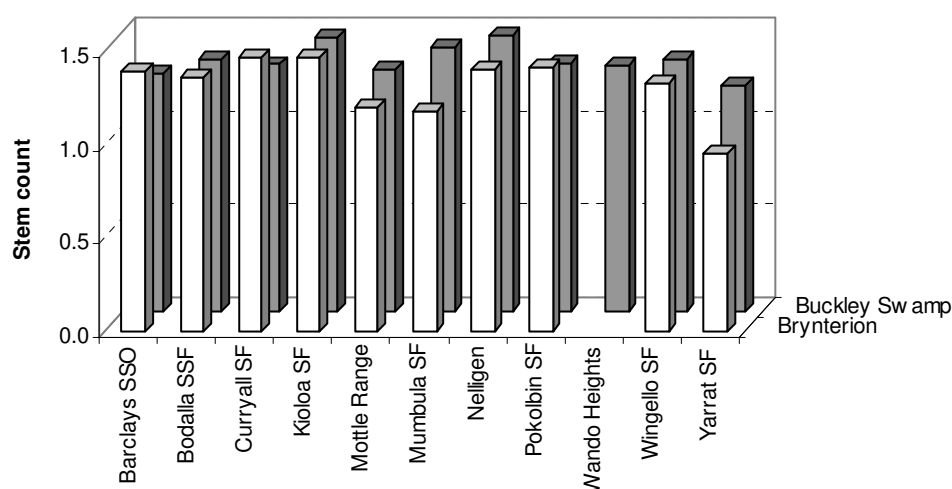
† Calculated using heights estimated using height-diameter relationship from other sites

♣ Thinned just prior to assessment

Stem count

Stem count was analysed for the Buckley Swamp and Brynterion sites. At Brynterion there were significant ($p < 0.05$) differences among provenances and highly significant ($p < 0.001$) differences among families-within-provenances (Table 3.5, Figure 3.5). Differences were less pronounced but weakly significant ($p < 0.05$ at both levels) at Buckley Swamp. Yarrat State Forest, Mumbula State Forest and Mottle Range provenances had notably low stem counts at Brynterion, where their equivalent-diameter was relatively poor compared to at other sites. At Buckley Swamp, Barclays SSO also had a low stem count.

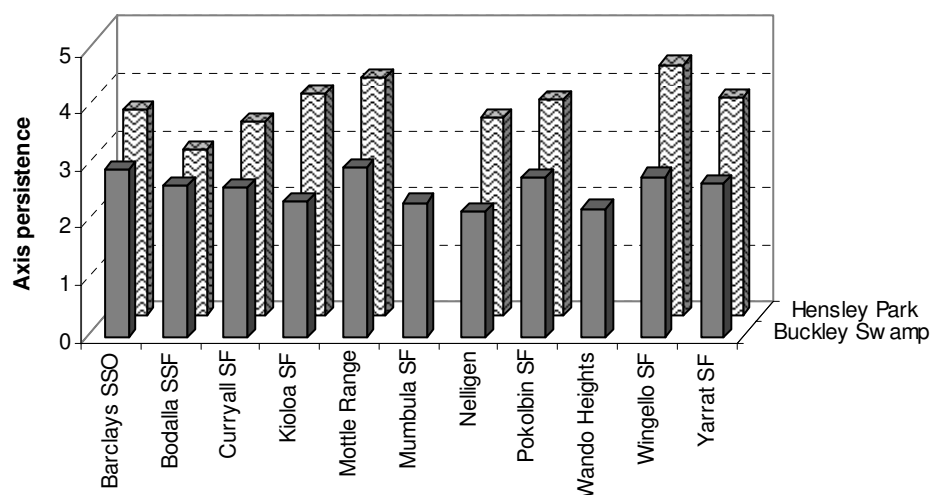
Figure 3.5. Mean stem count for provenances at Brynterion



Axis persistence

There were weakly ($p < 0.05$) to highly ($p < 0.001$) significant differences in axis persistence among provenances and among families-within-provenances at the two sites where the trait was measured (Table 3.5, Figure 3.6). Mottle Range and Barclays SSO sources again ranked well. Wingello ranked highest at Hensley Park, where only a small proportion of families including one from Wingello were assessed (Table 3.1a).

Figure 3.6. Mean axis persistence scores for provenances in the provenance-progeny trials

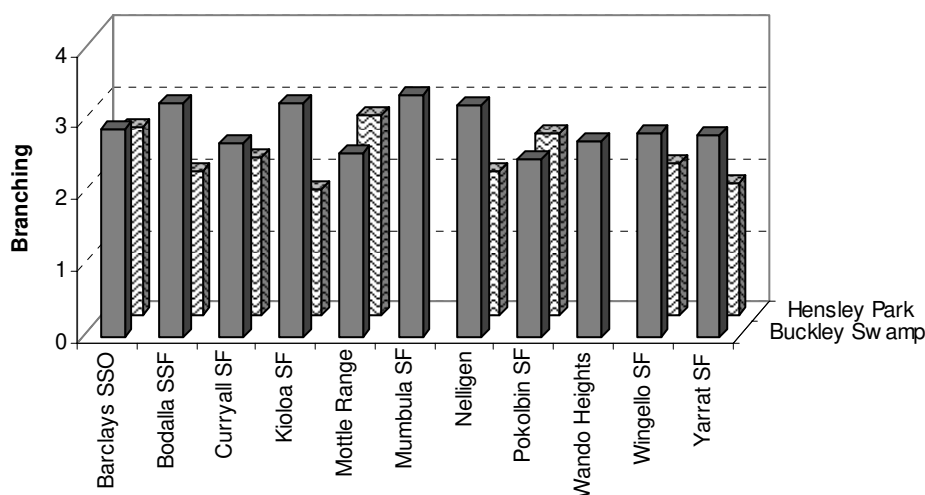


Branch weight

There were highly significant differences in branch weight among provenances and among families-within-provenances (Table 3.5, Figure 3.7). Top ranking families (lower scores at Buckley Swamp and

lower scores at Hensley Park) were Mottle Range and Pokolbin. Barclays SSO also ranked very well at Hensley Park, though only one family was assessed (Table 3.1a).

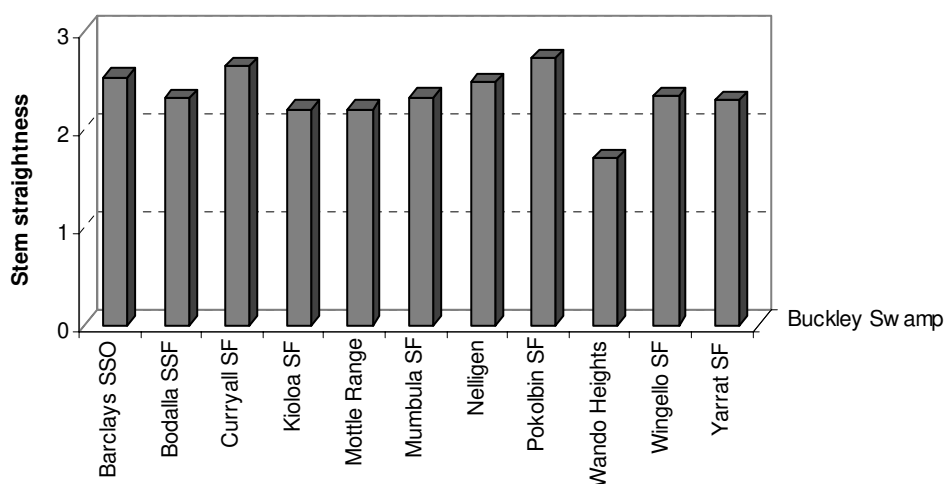
Figure 3.7. Mean branch heaviness scores for provenances in the provenance-progeny trials. A high score indicates heavy branching at Buckley Swamp, but light branching at Hensley Park.



Stem straightness

Stem straightness was assessed at the Buckley Swamp site, where there were highly significant ($p < 0.001$) differences among provenances and among families-within-provenances (Table 3.5, Figure 3.8). The planted stands Wando Heights (represented by only one family) and Barclays SSO, ranked well, as did Curryall, which performed poorly in respect to growth traits.

Figure 3.8. Mean stem straightness scores for provenances in the provenance-progeny trials



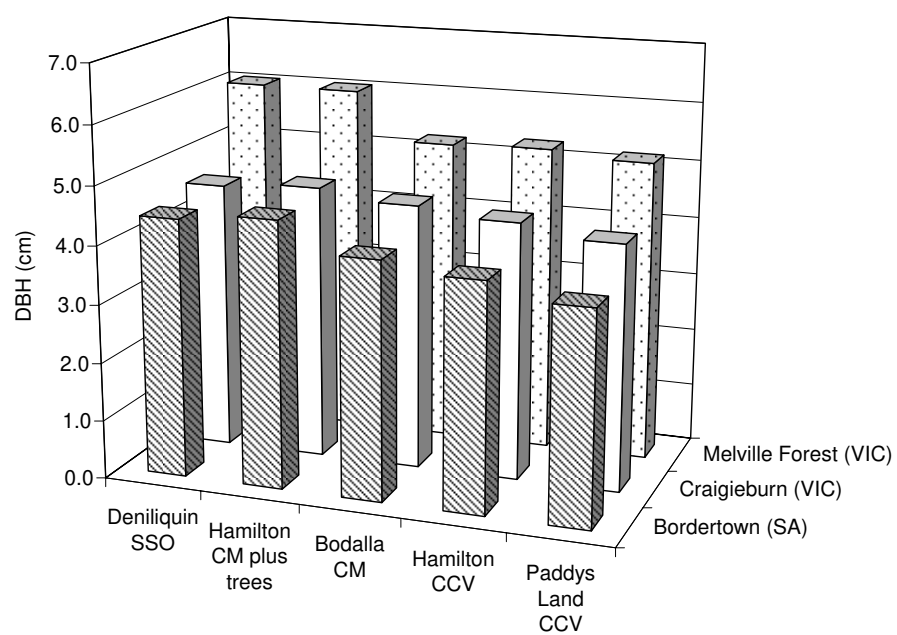
B. Seed-source trials

The seed source trial results are summarised in Table 3.6. There are significant differences for all traits (survival, DBH, height, pruning ease and axis persistence) at the South Australian site and for all traits except survival at the two Victorian sites. Survival was generally good, though the Rocky Gully trial has not grown well and is showing little promise. *C. maculata* has survived better than *C.c. variegata* at the Victorian and WA sites. Across sites, the seedlots derived from selected genetic material (Deniliquin SSO and the *C. maculata* plus trees) have performed better than the wild seedlots for both growth and form traits.

Table 3.6. Seed-source trial results for four sites

Site	Melville Forest (Vic)				Craigieburn (Vic)			Bordertown (SA)					Rocky Gully (WA)	
Seedlot	DBH (cm)	Ht (m)	Axis persist. (1-6)	Survival (%)	DBH (cm)	Ht (m)	Survival (%)	DBH (cm)	Ht (m)	Axis persist. (1-6)	Pruning ease (1-4)	Survival (%)	Ht (m)	Survival (%)
Hamilton CM plus trees	6.0	4.9	3.8	97	4.7	3.8	79	4.6	4.1	4.5	2.3	80	1.7	88
Deniliquin SSO	6.0	4.9	3.8	93	4.6	3.7	89	4.4	4.1	4.1	2.2	86	1.9	88
Bodalla CM	5.2	4.4	3.1	95	4.5	3.7	84	4.1	3.8	3.8	2.0	81	1.6	88
Hamilton CCV	5.3	4.7	4.2	80	4.4	3.9	83	3.9	3.8	4.7	2.3	51	1.9	72
Paddys Land CCV	5.2	4.5	4.3	78	4.2	3.4	76	3.6	3.2	4.6	2.2	54	1.9	83
s.e.d.	0.1	0.1	0.2	8	0.2	0.1	4	0.2	0.1	0.2	0.1	8	0.2	5
significance level ($p < x$)	<i>0.001</i>	<i>0.001</i>	<i>0.001</i>	<i>0.083</i>	<i>0.039</i>	<i>0.002</i>	<i>0.056</i>	<i>0.001</i>	<i>0.001</i>	<i>0.001</i>	<i>0.001</i>	<i>0.001</i>	<i>n.s.</i>	<i>0.025</i>

Figure 3.9. Mean DBH in the seed source trials



3.8. General discussion

The most valuable provenance data was that from the Buckley Swamp trial, where all trees were assessed for a good range of traits. There were similarities in provenance performance with most other sites, though each of those data sets was less robust due to poor survival, assessment of fewer traits and/or assessment of fewer trees. Relative provenance performance was somewhat different at the Brynterion site, which is beyond the normal *C. maculata* planting range due to low rainfall and potential frost damage.

The available improved material from Barclays SSO performed well across all traits measured, as did Mottle Range (also a recommended source), though its stem straightness ranked lower. In terms of growth, the previously untested Mumbula provenance ranked very highly, and highest at the important Buckley Swamp site. Northern material from Curryall, Pokolbin and Yarrat ranked relatively poorly for growth, as did the single Wando Heights planted stand which also scored poorly for form. Wando Heights was derived from Mottle Range material but inbreeding may have reduced the vigour of the bulk seedlot. The northern material did relatively better in terms of axis persistence and particularly stem straightness, as has been previously observed, but not well enough to warrant its recommendation as a wild seed source. However, it probably has a role in a breeding program where genetic diversity is valuable.

As expected in the seed source trials, selected seed sources outperformed wild ones. Overall, Deniliquin SSO material and *C. maculata* from Hamilton had the best height and diameter growth (Table 3.6, Figure 3.9). The Hamilton seed source is not generally available to growers, but will be integrated into ALRTIG's long term spotted gum program. The current best-bet is therefore SSO seed such as Deniliquin SSO, from which a clonal seed orchard has been established and is now producing seed. The trials confirm results from earlier provenance trials in Victoria that showed *C. citriodora* ssp. *variegata* displayed slower diameter growth than *C. maculata* (Bird *et al.* 2000). *C. maculata* may also be hardier than *C. citriodora* ssp. *variegata*, with the two *C. citriodora* ssp. *variegata* seedlots tending towards poorer survival across sites. Paddys Land is often chosen for its cold resilience (Larmour *et al.* 2000). It has not performed well in terms of growth or survival in these trials, and is therefore not recommended. The trial at Rocky Gully has grown very poorly from the time of establishment onward, with no significant difference between seedlot heights and a low overall mean.

3.9. References

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Australian Low Rainfall Tree Improvement Group

Metadata from measures of hardwood tree improvement trials in Southern Australia

RIRDC Publication No. 09/078

This report contains high level data summaries (metadata) taken from the measurement of 30 tree improvement trials established by partners of the Australian Low Rainfall Tree Improvement Group (ALRTIG). The report focuses on hardwood species that are suited to Australia's low rainfall sheep-wheat belt, an area that is of increasing interest to Australian society for a number of reasons including biodiversity, water security and potential for diversified agriculture including carbon sequestration and bioenergy production.

ALRTIG's goal, since its formation in 1999, has been to develop and genetically improve tree species that are both well-adapted to this region, and that will produce commercially valuable products in tandem with environmental outcomes.

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