An Australian Government Initiative

Developing Genetically Adapted Tree Varieties for Marginal Areas of Northern Australia

A report for the RIRDC / Land & Water Australia / FWPRDC Joint Venture Agroforestry Program

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Foreword

There is a growing interest in commercial forestry on cleared marginal land in the 650-900 mm mean annual rainfall zone of northern Australia. Local timber industries are significant employment sources, and are under pressure from diminishing supply from native forests. Opportunities exist to establish private hardwood plantations for multiple benefits on cleared agricultural land.

This study responded to this interest and opportunity by identifying taxa suitable for commercial plantation development and by initiating the genetic improvement of eucalypt species and hybrids with potential as commercial hardwood tree crops in this zone.

A genetic resource of *E. camaldulensis* has been planted, providing genetic material for future hybrid breeding trials in tropical north Queensland. Taxa–site matching trials are now in place to evaluate the potential of a large suite of taxa, including eucalypt hybrids on marginal sites across northern Australia. Studies initiated on the vegetative propagation of eucalypt hybrids provide further critical information needed to advance commercial plantation development in this region.

This project was funded by the Natural Heritage Trust through the Joint Venture Agroforestry Program (JVAP). The JVAP is supported by three R&D Corporations — Rural Industries, Land & Water Australia and Forest and Wood Products, together with the Murray-Darling Basin Commission. The R&D Corporations are funded principally by the Australian Government. State and Australian Governments contribute funds to the MDBC.

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Abbreviations

ATSC	Australian Tree Seed Centre
CCC	*Corymbia citriodora* subsp. *citriodora*
CCV	*Corymbia citriodora* subsp. *variegata*
CSIR	Council for Scientific and Industrial Research (Republic of South Africa)
CSO	Clonal seed orchard
FS	Full sibling
FSC	Queensland Department of Primary Industries, Forestry Tree Seed Centre
FWPRDC	Forest and Wood Products Research and Development Corporation
HSHalf sibling	
IBA	Indole butyric acid - an hormone used to induce roots on cuttings
LWRRDC	Land and Water Resources Research and Development Corporation (now Land & Water Australia)
QFRI	Queensland Forestry Research Institute
RIRDC	Rural Industries Research and Development Corporation
RSA	Republic of South Africa
SAFCOL	South African Forestry Company Ltd. (Republic of South Africa)
SAPPI	South African Pulp and Paper Industries (Republic of South Africa)
SO	Seed orchard
MAR	Mean annual rainfall
MASL	metres above sea level

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Executive Summary

This project was developed with the aim of identifying and initiating the genetic improvement of eucalypt species and hybrids with potential as commercial hardwood tree crops in the 650–900 mm rainfall zone in northern Australia. The project builds on the Queensland Forestry Research Institute's species-site matching trials recently established on selected marginal areas (Lee *et al.,* 2001), using some eucalypt hybrids developed overseas. The study reported here developed controlled pollination and vegetative propagation skills, planted a genetic resource of *E. camaldulensis*, a potentially valuable parent of *Eucalyptus* hybrids, and commenced the testing of a selection of eucalypt species and hybrids on marginal areas in northern Australia.

This study achieved three major outcomes, which will facilitate the development of plantation forestry on marginal areas in northern Australia:

- An *E. camaldulensis* genetic base (a future seed orchard) was established on the Davies Creek State Forest near Mareeba, in north Queensland, and comprises 58 seedlots, originating from 500+ seed parents. The seedlots assembled are genetically diverse and should provide tropical northern Australia with a great asset for future hybrid breeding trials.

- Five taxa (species – provenance – hybrids) trials were established across three key regions in the marginal rainfall area of Queensland – far north Queensland, the Burnett Valley and the Darling Downs. These trials were designed to test as many appropriate and available taxa as possible, for initial growth and survival potential (0-3 years) for the region. These types of trial are called 'species elimination trials', and are used when superior species, provenances or hybrids have not been identified for an area. Early results suggest that some provenances of spotted gum (*Corymbia citriodora* subsp. *citriodora* and *Corymbia citriodora* subsp. *variegata*) and several eucalypt hybrids have good early potential in marginal sites in northern Australia, and indicate that further testing and development of the hybrids is justified. One particularly promising aspect of the study is the very encouraging early performance of the hybrids which were developed in Queensland. Through development of a larger range of these hybrids, and their testing in replicated field trials, followed by intensive selection and possibly clonal testing, it is envisaged that superior, locally-produced hybrids will be available for commercial forestry in marginal areas of northern Australia.

- Two trials evaluating the rooting success of a suite of eucalypt species and hybrids were undertaken. The ability to vegetatively propagate eucalypt hybrids is critical if they are to play a role in commercial plantations in northern Australia. The first trial (not reported here) was a pilot study to evaluate the rooting success of eucalypt species and hybrids. The second vegetative propagation trial tested potting medium and rooting hormone concentration and clearly showed that no single treatment is optimal for the rooting of all *Eucalyptus* and *Corymbia* species and hybrids tested; however, higher concentrations of rooting hormone generally resulted in higher rooting success. The best conditions to root each of 12 taxa were tested, although further refinement will be required for each taxon.

1. Background and introduction

In tropical and sub-tropical Australia, the primary source of hardwood timber is the native forests. However, supply from native forests is diminishing owing to declining private forest supplies caused by unsustainable logging practices and increasing environmental controls on harvesting of Crown forests. This decline mirrors worldwide trends. Locally, this decline in the timber industry is putting pressure on many rural communities where forestry and its associated support industries are one of the major sources of employment. At the same time, substantial increases in world demands for timber and timber products are predicted (DPI-Forestry, 1998). To meet this shortfall, a commitment to establish a hardwood plantation sector is needed. Further, possible trade in carbon credits/taxes is likely to provide incentives for expansion of the forest estate on cleared land and make establishment of plantations in areas previously considered marginal a commercially viable proposition. In northern Australia, the land available for this expansion is in the 650-900 MAR zone where, potentially, millions of hectares are available for hardwood plantings. Large viable plantation estates have been developed on similar marginal lands in Brazil, India, China, and South Africa through use of hardy, high yielding eucalypt hybrids (Eldridge *et al*. 1993).

Commercial agroforestry in rural areas is well developed in southern Australia, but the need is just as great in northern Australia. This study has helped underpin the development of a plantation grown hardwood timber industry in northern Australia. Development of this industry will produce a range of benefits to the rural sector and ultimately the nation. For example, farmers will benefit from:

- Greater financial flexibility through income diversification and enhanced prospects for utilisation of marginal lands.
- Development of wind and shelter belts which will reduce wind speed and run-off, thereby increasing soil retention, reducing crop damage and increasing livestock production.

Other benefits include:

- Increased supply of a valuable product to meet the increasing domestic and international demands for hardwood timber.
- Development of new industries based on tree crops could provide an ecologically sustainable industry and long term employment.
- More private companies will be encouraged to invest in commercial timber growing in northern Australia.
- Aesthetic and environmental benefits such as reductions in salinity levels by lowering water tables.

In late 1996, QFRI began implementation of a three year Research and Development program designed to underpin a commercial hardwood tree growing industry in the 900+ mm MAR zone of Queensland (Keenan *et al.*, 1998). Part of this program included a Genetic Resources Project to develop taxa-site matching, population improvement, testing of hybrids and studies on the amenability of target species to vegetative propagation. That project succeeded in making significant progress in all these areas (Lee *et al*., 1998, Catesby and Walker 1997a).

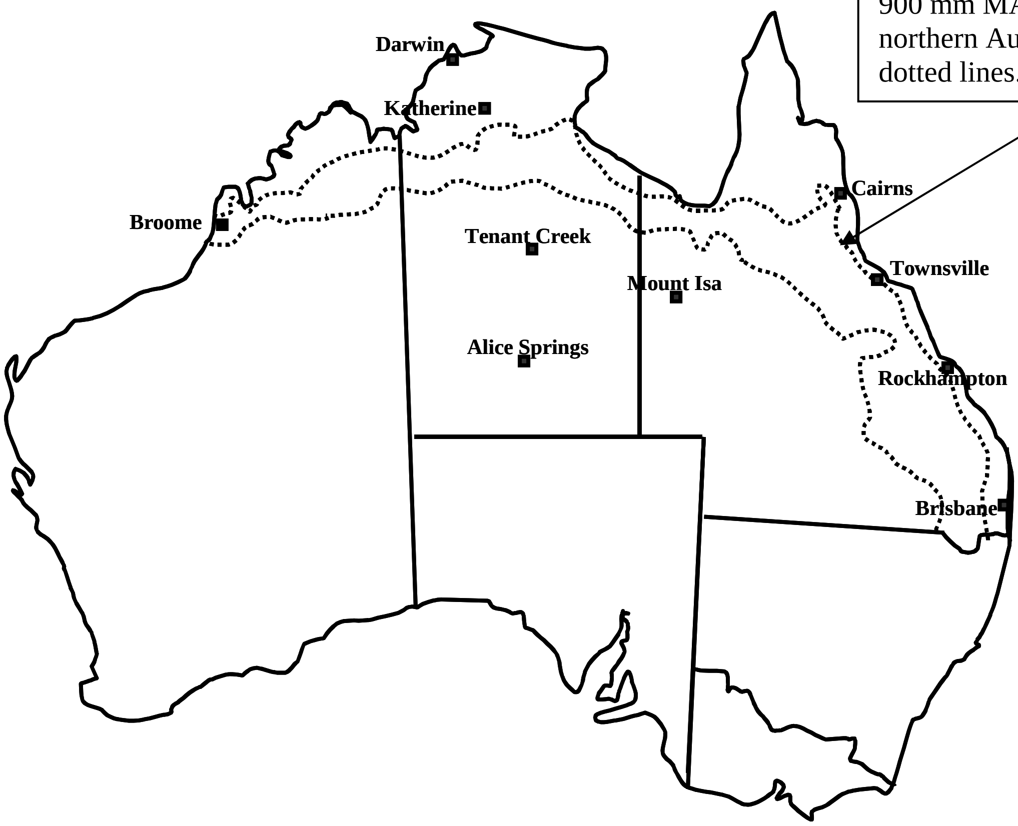
The JVAP study discussed here allowed the extension of this work to new environments in the 650-900 mm MAR zone. For commercial plantation development in this zone, the trees should be stress tolerant and fast-growing; based on earlier work, some of the tree varieties that matched these criteria were eucalypt hybrids. This project builds on QFRI's limited taxa-site matching trials established in 1998 and 1999 in marginal areas, initially using eucalypt breeding technology and hybrid varieties developed overseas (refer Lee *et al*. 2001). The ultimate aim of the research was to develop information and germplasm that would allow commercial tree growing and environmental amelioration over a much larger area than that targeted by existing schemes.

The two-year JVAP project "Developing genetically adapted tree varieties for marginal areas of northern Australia" began in September 1999, with funding by the RIRDC/LWRRDC/FWPRDC

Joint Venture Agroforestry Program and the National Heritage Trust (NHT). The project was developed and managed by the Queensland Forestry Research Institute (QFRI) with the overall aim of identifying and initiating the genetic improvement eucalypt species and hybrids with potential as commercial hardwood tree crops in the 650–900 mm MAR zone in northern Australia (Fig. 1).

This study developed skills in vegetative propagation and controlled pollination, initiated the genetic improvement of a potentially valuable parent of *Eucalyptus* hybrids (*E. camaldulensis*) and commenced the testing of a selection of eucalypt hybrids on marginal areas in northern Australia. This work is documented in the following four chapters.

Figure 1. Low rainfall (650 – 900 mm MAR) zone in northern Australia bounded by dotted lines.



Adapted from Bureau of Meteorology records

2. *Eucalyptus camaldulensis* genetic improvement program

2.1 Background

In northern Australia, genetic improvement programs have been established for many of the species suited to marginal lands, for example *E. argophloia*, *E. tereticornis* and *Corymbia citriodora* subsp. *variegata* (Nikles *et al*. 2000). One critical omission is *E. camaldulensis*, which has potential for marginal areas and potential as an important parent of hybrids suitable for this region. This study addresses this issue via the development of a base population of *E. camaldulensis* for northern Australia.

Eucalyptus camaldulensis (river red gum) is the most widely distributed of all the eucalypts, occurring in all mainland states. It ranges from 12°48'S in the Northern Territory to 38°15'S in Victoria. This species grows under many climatic conditions from warm to hot, dry to sub-humid and is exposed to winter rainfall in the south to summer (monsoonal) rainfall in the north. It is typically found along streams and riverine plains where soils are typically sandy alluvium.

Eucalyptus camaldulensis is probably the most widely used tree species for plantings in arid and semi-arid lands (Eldridge *et al*., 1993). Trials evaluating the plantation potential of many provenances of *E. camaldulensis* are discussed in detail in Eldridge *et al*. (1993) and will not be repeated here. In general, the southern form of *E. camaldulensis* from the Lake Albacutya region is more suitable for plantations in Mediterranean winter rainfall zones, whereas provenances from Petford and Kennedy River (north Queensland), Katherine (Northern Territory) and Gibbs River (West Australia) generally have superior growth and form in the tropical summer rainfall zone (Pinyopusarrerk *et al*., 1996).

The wood of *E. camaldulensis* from natural stands is hard and durable, termite-resistant and has a density of about 880 kg /m^3. It is used for heavy construction, railway sleepers, flooring, fencing, turnery and firewood. The pulp yield of *E. camaldulensis* is lower than many other species including *E. grandis*, *E. globulus* subsp. *globulus* and *C. maculata*, and has poor paper strength properties. Hence, it is not considered a viable wood chip species for Australia (Clark *et al*., 1999), although it is used for this purpose in California, United States of America (Arnold *et al*., 1999) and elsewhere.

Eucalyptus camaldulensis has high drought and frost tolerance, and is used extensively in interspecific hybrids. In summer rainfall zones, *Eucalyptus* interspecific hybrids have great importance in plantation forestry in several countries where rainfall is less than 1000 mm MAR such as China, Congo, Brazil and South Africa (Eldridge *et al.*, 1993, van Wyk *et al*., 1988, Denison and Kietzka, 1993). Therefore, it is likely that hybrids should contribute to higher plantation yields in northern Australia than those currently achievable. Supporting the development of hybrids is the complementary nature of some desirable traits of certain pairs of species. For example *E. grandis* has good form and growth rates on high quality sites, but its wood is not durable, whereas *E. camaldulensis* has generally poor form but good, durable wood and adaptability to a wider range of sites. In northern Australia, we are interested in developing hybrids involving *E. camaldulensis*, and had tests underway on several sites prior to the start of this project (Lee *et al*., 2001).

2.2 Reproductive biology of the species

Eucalyptus camaldulensis is amenable to propagation as rooted cuttings from coppice, with 49% rooting success at 6 weeks exhibited in trials conducted during this project (discussed in chapter 5). This is comparable to levels found overseas (Sachs *et al.*, 1988). As with results from other eucalypt species, e.g. *E. pellita* (Catesby and Walker, 1997a) and *E. cloeziana* (Catesby and Walker, 1997b), we would expect considerable variation in the rooting success of *E. camaldulensis* provenances and families. The operationally accepted limit for rooting success in eucalypt vegetative propagation programs in Aracruz (Brazil) and Smurfit Carton de Colombia (Colombia) is at least 70% (Zobel, 1993). As the rooting success of *E. camaldulensis* is relatively high, a breeding program for this species using clonal deployment could focus on selection for growth, form and resistance traits and possibly ignore selection for ease of rooting.

Eucalyptus camaldulensis appears to be insect pollinated and it avoids self-pollination at the single flower level, as the stigma does not become receptive until all pollen is shed from the anthers (Visuthitepkul and Moncur, 1993). As with most eucalypts, *E. camaldulensis* is expected to have a mixed mating system, whereby outcrossing is preferential but without precluding self-pollination from other flowers on the same tree and without precluding mating with neighbouring close genetic relatives in natural stands. Thus, open pollinated seed will be a mixture of outcrossed and inbred seed.

E. camaldulensis flowers at 4 to 7 years in southern Australia (Harwood *et al.*, 2001) and has high seed yields per tree (Boland *et al.*, 1980). Flowering generally occurs between December and February with capsules maturing in 3 to 4 months (Oddie and McComb, 1998).

A conventional breeding program using recurrent selection is envisaged for E. camaldulensis, since the species is amenable to propagation via rooting of cuttings and produces good seed yields. As pointed out by Nikles et al. (1998), a tree improvement program for a pure species effectively begins with selection of seed sources (natural stand provenances and improved seed from external tree improvement programs), followed by the establishment of diverse breeding populations from the best of these seed sources. The process may stop with either the culling of the base population followed by seed collection, or culling all but the very best trees. More often, however, a program of recurrent selection (phenotypic and/or genotypic) is undertaken. This process is well documented by White (1987).

2.3 Current and projected planting areas and environments

There are few target areas for planting of *E. camaldulensis* as a pure species on marginal sites in the 650–800 mm MAR zone in northern Australia. The main reason for this is that other species such as *C. citriodora* subsp. *variegata*, *E. argophloia*, *E. longirostrata* and *E. tetrodonta* appear more promising in terms of growth and form in young trials in north Queensland (QFRI unpublished reports). Nevertheless, *E. camaldulensis* is classed as a species suitable for saline sites that are subject to waterlogging (House *et al*., 1998) and hence will be suitable in areas in the Murray Darling Basin along saline watercourses. *E. camaldulensis* will mainly be deployed in northern Australia as a parent of interspecific hybrids with species in the *Eucalyptus* subgenus Symphyomyrtus. Already, introduced hybrids involving *E. camaldulensis* are showing early promising form and vigour (Lee *et al*., 2001).

2.4 Genetic resources available to the program

Studies overseas in environments similar to that of the Davies Creek State Forest in the Mareeba region, have indicated the suitability of the widely adaptable provenances of upland and lower-elevation, eastern-cape river systems of *E. camaldulensis* for a range of sites in northern Australia (e.g. Pinyopusarrerk *et al*., 1996). Therefore, seedlots from local natural stands and overseas

Table 2.1. Details of seedlots supplied by the DPI-Forestry Tree Seed Centre*, and / or from overseas programs for the *E. camaldulensis* population improvement program

Entry number	Batch No	Provenance	No seed parents	Lat. (°S)	Long. (°E)	Alt.	MAR	Original supplier
1	16021*	Emu / Gibbs Ck ex EB 29	32	20 08	28 42	1341	564	Zimbabwe
2	10530*	Walsh River, Dimbulah	55	17 15	145 18	560	1100	Dendros
3	10532*	Wrotham Park	47	16 48	144 10	240	831	Dendros
4	10534*	Kennedy River	68	15 26	144 11	60	900	Dendros
5	10540*	Morehead River	66	15 05	143 35	100	1144	Dendros
6	10531*	Laura River	61	15 39	144 33	100	903	Dendros
7	10533*	Petford	57	17 20	144 56	570	845	Dendros
8	10626*	Palmer River	28	16 05	144 45	400	1025	FTSC
9	10528*	Wrotham Pk ex EB 30	25	20 08	28 42	1341	564	Zimbabwe
10	16020*	Petford ex EB 27	47	18 56	27 48	1012	60	Zimbabwe
11	16027*	Laura ex EB 15	25	18 10	25 50	900	550	Zimbabwe
12	10547*	Salique selects	?	24 6	30 54	760+	760	RSA
13 to 20, 58	11300- 1* to 11300-9*	Laura ex BSO, Dongmen, China	9	22 15	107 40	150	1213	Dongmen
140 to147, 161, 162, 164 to 167	R9-F1, R6-F66, R12-107, R10-113, R10-118, R10-173, R1-F176, R1-F187 1R13-F1, R15-F1, R13-107, R5-F113, R12-118, R9-F173	Petford ex SSO, Ratchaburi	14	13 20[1]	99 29	160	1100	Thailand
148 to 156, 160, 168 to 171	R1-F193, R6-F203, R4-F209, R13-221, R6-F234, R10-236, R1-F244, R12-245, R13-247, R13-244, R3-F236, R15-236, R4-F244, R7-F244	Walsh/ Mitchell River	14	-	-	-	-	Thailand
157 to 159, 173	R15-309, R5-F312, R12-315, R15-315	Thailand race	4	-	-	-	-	Thailand
174 to 178	7-002, 7-003, 7-007, 7-009, 7-0145	Petford ex selects at Jabiru, NQ	5	-	-	-	-	NQ select
		Total seed parents	557+					

breeding programs were assembled. The seed orchard established at Davies Creek comprises samples from collections from 557+ seed parents from 58 seedlots (Table 2.1). Specifically:

1. Entries 2-8 were available natural stand sources representing a broadly based coverage of provenances likely to be well adapted for good growth and survival in foreseeable target planting regions in Queensland and elsewhere.

2. Entries 1, 9-20, 140-173 are imported seedlots from generally similar regions of provenance to those of "1", but had undergone selection for growth and form in environments fairly similar to our foreseeable target regions.

[1] 13 20°N

3. Some of the imported seedlots were from THE SAME provenances as “1”, permitting opportunity to quantify the effect of a generation (or more) of selection elsewhere.

4. A few families (Entries 174-178) comprising phenotypically selected trees of the Petford provenance from a planted stand near Mareeba. This provenance, which is represented in groups “1” and “2” (above), gives some opportunity to check the effect of local mild selection.

It should be noted that the seedlots assembled have provided a facility (germplasm base) with an expected large amount of genetic diversity and potential merit of performance. This is expected to provide tropical northern Australia with a valuable asset for the future.

2.5 Breeding objectives

2.5.1 Short term

Rapid production of *E. camaldulensis* germplasm (seed and cuttings) that is better that that currently available to north Australia.

2.5.2 Long term

The long-term population improvement of *E. camaldulensis* using recurrent selection to improve the species specifically for hybrid production in northern Australian plantations.

2.6 Establishment details

The 3.9-hectare seed orchard was established in February 2000 at Davies Creek, northwest of Cairns in North Queensland (Fig 2.1), using a row-column design. It has five replicates of five tree line plots. Hence, each seedlot is nominally represented by 25 seedlings. The initial stocking in the trial was 1000 stems / hectare. The trial was fertilised following planting with an NPK fertiliser which delivered 50kg of phosphorus / hectare. Weed free conditions were maintained during the first 18 months of the trial to ensure good survival and growth. In June 2002, survival in the orchard was 98%.

2.7 Schedule of tree improvement activities

The tree improvement program for *E. camaldulensis* is summarised below.

Measures:

Subsequent to this project funding and analysis, all plants were measured for height at ages 12, 36 months, and will be measured 60 months. DBH and stem form will be measured/assessed based on the 36 and 60 month measures. Other traits of economic significance such as resistance to disease, axis persistence, branching, etc will be scored if there is significant variation evident. These traits will be assessed to allow age – age correlations to be estimated.

Thinning:

No thinning is intended prior to the measure at 36 months. After this period, an assessment will determine the necessary thinning prescription. The initial thinning will remove the poorest tree per five tree line plot.

Selection of outstanding phenotypes for grafting into a clone bank / clonal seed orchard will follow the measure at 60 months.

Hybridisation:

The best *E. camaldulensis* germplasm in the seed orchard will be used as pollen parents in a controlled crossing program, for the production of interspecific hybrids with other Symphyomyrtus species. Progeny from this crossing program will be tested in replicated trials in the 650-900 mm MAR of northern Australia.

Seed collection:

It is anticipated that seed may be available from this seed orchard from approximately 2006. However, seed will not be collected until after the trial is thinned to a single stem per five tree line plot and following the first widespread flowering in the orchard to maximise selection intensity and minimise the level of inbreeding. The quality of the seed from the orchard will be further improved following complete removal of trees from the poorer families and seedlot bulks to leave a final stocking of approximately 150 stems / hectare.

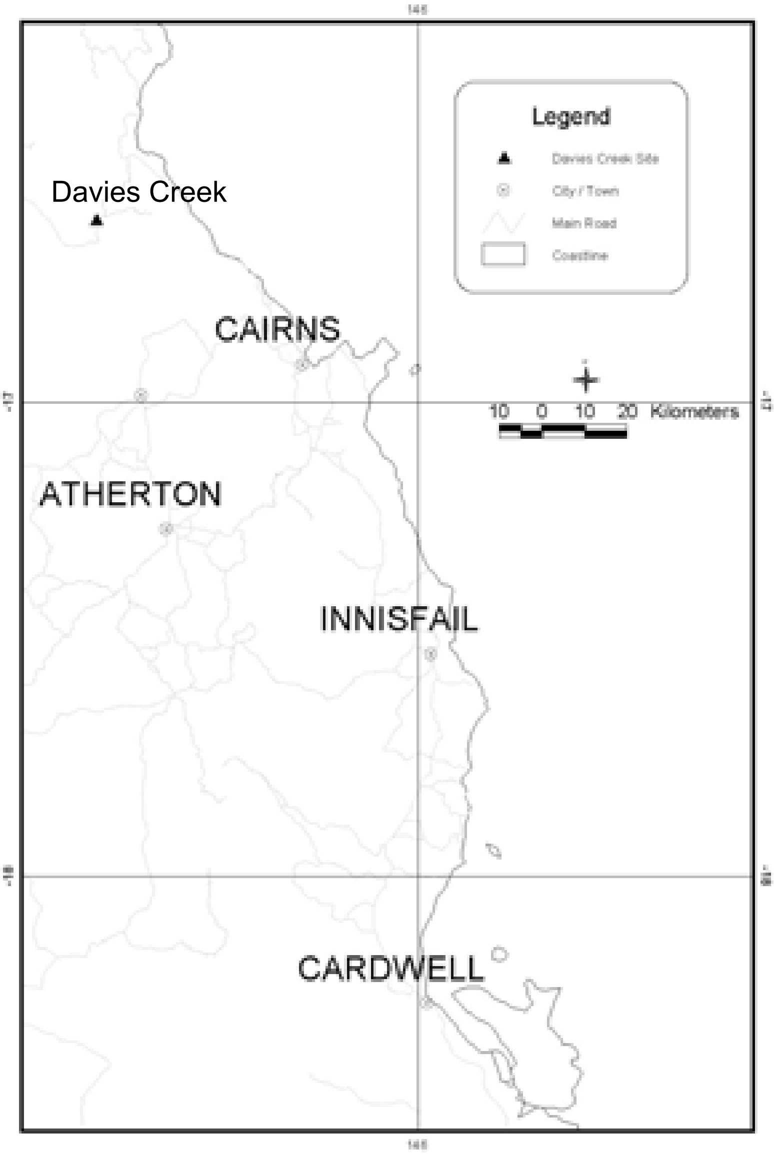


Figure 2.1
Location of *E. camaldulensis* seed orchard planted at Davies Creek, northwest of Cairns.

2.8 Predicted genetic gains

An essential component of a tree improvement program is the monitoring and realisation of genetic gain through replicated progeny tests. Such genetic gain trials test the “improved” germplasm produced by the program against valid routine controls (the best material currently available to the program). Seed for the first of these trials may be available from 2006 and will be made available to any party interested in developing such tests (e.g. Regional Plantation Committees in northern Australia).

2.9 Review of progress

A review of the progress and achievements against milestones is an essential component of all tree improvement programs. The first of these reviews is planned following the measure at 36 months. A subsequent review will be undertaken following the measure at 60 months. These reviews will be undertaken using resources within the Queensland Forestry Research Institute. However, an external review by an appropriate worker associated with other similar programs, such as the Australian Low Rainfall Tree Improvement Group, will also be considered.

2.10 Recommendations

This *E. camaldulensis* trial, established in the dry tropics of north Queensland, is important for the development of a viable and sustainable hardwood plantation industry in northern Australia. If maintained and properly monitored, this trial will provide a source of improved *E. camaldulensis* seed for operational deployment and pollen for the production of interspecific hybrids with other Symphyomyrtus species.

It is recommended that these trials be maintained, measured and assessed according to the schedule of tree improvement activities detailed above. Furthermore, it is recommended that development of hybrids including *E. grandis* × *E. camaldulensis* be developed when pollen from select trees becomes available in the orchard.

3. Taxa site matching in north Queensland

3.1 Background and target region

There are very few trials evaluating the potential of taxa and matching taxa to specific sites in marginal rainfall areas of tropical northern Australia. Overseas, large viable plantation estates have been developed on similar marginal lands using hardy, high yielding eucalypt hybrids (Eldridge *et al*. 1993). This study aimed to compare the site suitability of a range of eucalypt species, provenances and hybrids in the 650-900 mm MAR zone of tropical north Australia.

The two trial sites in north Queensland are located in areas where community groups and commercial forestry companies are expressing interest in tree growing. Specifically, the trials were established on the western side of the Atherton Tablelands in low rainfall areas, which includes the region where tobacco was previously grown. One trial was established during the 2000-planting season at Walkamin. The other trial was established during the 2001-planting season on a marginal site on Sugarbag Station near Mount Garnet (Fig. 3.1).

3.2 Objectives

There were three main objectives to the taxa site-matching component of this work in north Queensland.

- In north Queensland, the objectives of the trials differed from those established in southern Queensland since no previous trials had identified species and hybrids that were expected to suit the selected sites in this region. Hence, the north Queensland trials aimed to compare a wide spectrum of taxa in irrigated and unirrigated conditions, to gain indications of those taxa (species, provenances and hybrids) with potential ('best bet' taxa).

- The second aim was to establish demonstration plantings that can be used to promote agroforestry in areas currently considered marginal for commercial tree growth.

- The final aim was to enhance technical skills in eucalypt hybrid production and to create and begin testing new, locally produced hybrids. These hybrids are potentially better adapted to marginal sites in northern Australia than the imported hybrids that have been bred and selected under conditions overseas.

3.3 Controlled pollinations and seed procurement

Based on overseas and local experience, seed of selected hybrids was obtained from overseas breeding programs, or produced locally for testing in marginal areas of northern Australia. In north Queensland, the single visit pollination technique (Williams *et al*., 2000) was adopted by QFRI staff to initiate the local production of hybrids that may have potential for northern Australia. Interspecific crosses successfully attempted in the program include:

- *Corymbia torelliana* × *C. citriodora* subsp. *variegata*. Viable seed has been produced and stock is currently being tested - see section on Sugarbag Station.
- *Eucalyptus urophylla* × *E. pellita*. Viable seed has been produced and stock is currently being tested - see section on Sugarbag Station.

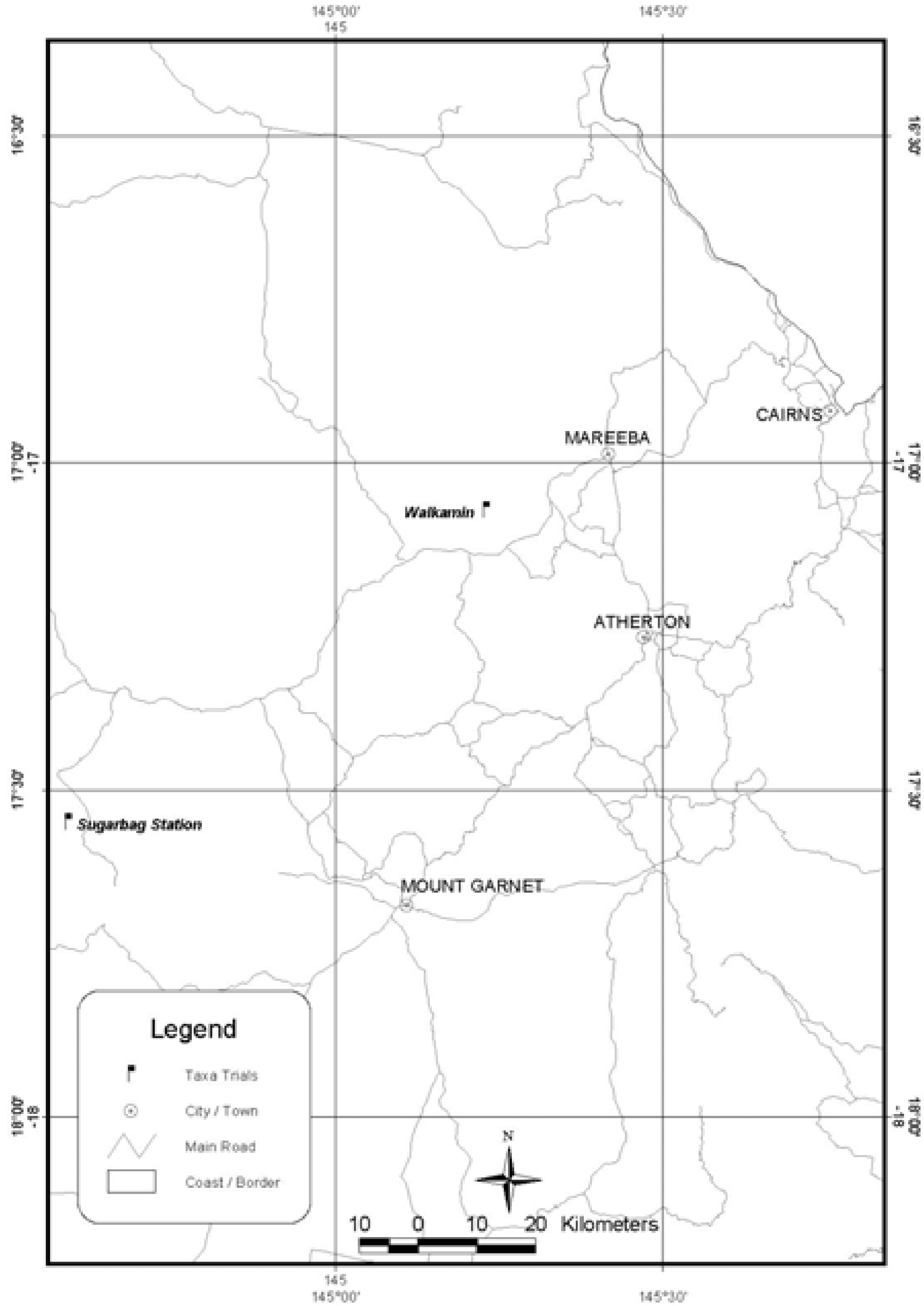


Figure 3.1 Location of the two taxa trials established in the 650–900 mm MAR zone of north Queensland.

3.4 Methods

3.4.1 Taxa under test

Seed of interspecific hybrids was obtained from the Council for Scientific and Industrial Research (CSIR), Republic of South Africa. The supplied seed was bulks composed of seed mixtures of several individual full-sib crosses. Seed of pure species bulks was provided by the Australian Tree Seed Centre (ATSC), Queensland's Forestry Tree Seed Centre (FSC) and Dendros Seed Supplies. Details of the seedlots and their origins are given in Appendix 1.

3.4.2 Nursery details

Seedlings were raised at DPI-Forestry Walkamin Nursery on the Atherton Tablelands. The seeds were sown into 200 ml plastic pots in December 2000 for the Walkamin trial and in November 2001 for the Sugarbag Station trial. The potting mix consisted of 1/3 pine bark-peat, 2/3 grade 3 vermiculite and 1.25 kg osmocote per m^3. Pots were watered as required and thinned to one seedling per pot four weeks after sowing. Plants were hardened off in full sun from age 1.5 months.

3.4.3 North Queensland study sites

The two north Queensland trials were planted in February 2000 (Walkamin) and February 2001 (Sugarbag Station) on sites representative of areas in north Queensland where land is likely to be available for hardwood plantations. Site descriptions are given in Table 3.1.

3.4.4 Experimental design

Previously, some testing of taxa on marginal areas had been conducted in southern Queensland, but had not been completed in northern parts of the state. Hence, it was considered that a more extensive range of taxa should be tested in the northern Queensland trials than at sites in southern Queensland. Limitation imposed by land availability and financial constraints led us to establish "species elimination" trials in northern Queensland, which provide good indications of taxa warranting further evaluation. However, competition for space between line plots from about 2.5–3 years after planting will confound any patterns present among provenance regions. Thus, these experiments should be viewed as short-term trials only. In each trial, one or more provenances of 'best bet' species (*Corymbia*, *Eucalyptus* and *Khaya)* and several *Eucalyptus* interspecific hybrids were compared.

Table 3.1. Site descriptions for the two taxa trials in north Queensland.

Location/description	**5 km west of Walkamin**	**Sugarbag Station, 40 km west of Mt Garnett**
Latitude (°S)	17° 07´ 679´´	17° 55´ 445´´
Longitude (°E)	145° 23´ 697´´	144° 59´ 631´´
Altitude m above sea level	620	400
Rainfall (MAR) mm	1014	793
Soil type [2] and depth	Sesquic Aeric Podosol, >60cm	Yellow Kandosol, >60cm
Original vegetation	Dry sclerophyll forest (mainly *E. tessellaris*)	Dry sclerophyll forest (mainly *E. moluccana and E. camaldulensis*)
Vegetation prior to trial commencement	Improved pasture	Unimproved pasture
Initial stocking (stem / ha)	1000	1000
No. replicates	4	4
Area planted	1.15 ha	1.40 ha

The trial at Walkamin has a randomised complete block design with four replicates. To assess the effect of irrigation on early growth and survival, two of the four replicates were irrigated three times during the establishment phase of the trial and the remaining two replicates were not irrigated. Each replicate consists of nine taxa treatments, each planted as a whole plot (four rows × eight trees). The whole plots are further split into four line plots, to which four provenance regions (referred to as entries) were randomly allocated, one entry per line plot (Table 3.2). There are two exceptions to the allocation of entries to line plots. First, two entries of *E. tetradonta / E. raveretiana* were allocated to the same line plot due to a shortage of stock at planting (entries 34 and 35). Second, there was only one entry of *Khaya senagalensis* so it was allocated to all four line plots within the whole plot.

The trial at Sugarbag also has a randomised complete block design with four replicates. Each replicate consists of ten taxa treatments, each planted as a whole plots (four rows × ten trees, see Table 3.3). The whole plots are further split into four line plots, to which four provenance regions (also referred to as entries) were randomly allocated, one entry per line plot (Table 3.3). There are two exceptions to the allocation of entries to line plots in this trial. First, only small numbers of seedlings of the hybrid *C. torelliana* × *C. citriodora* subsp. *variegata* were available so the line plots were planted as a mixture of *C. torelliana* × *C. citriodora* subsp. *variegata* and *C. torelliana* seedlings with full identity of all seedlings retained. Second, there were only two sources of *Khaya* available (entries 50 and 51), which were allocated as random line plots in the *Khaya* whole plots. No irrigation treatment was available at this site.

3.4.5 Trial establishment

The seedlings were planted at 2 metre spacing within the planting row and fertilised with a NPK fertiliser (DAP) at 50 kg P /ha as an individual tree application within one month of establishment. Weed free conditions were maintained in the planting row for the first 12 months of the trial.

[2] Using the Australian Soil Classification system

Table 3.2 Allocated treatments for the Walkamin trial established in February 2000. Full information on entries is presented in Appendix 1.

Taxa Treatment	**Type**	**Entries / seedlot planted in line plots**	**Entry number[3]**
1	*E. camaldulensis* SO	• Petford (Zimbabwe) • Wrotham Park (Zimbabwe) • NE Petford (Zimbabwe) • Thailand seed orchard	• 20 • 24 • 21 • 19
2	*E. camaldulensis* wild	• Walsh River, Dimbulah • Kennedy River • Palmer River • Petford	• 23 • 13 • 16 • 18
3	*E. camaldulensis* mix	• Morehead River • Laura River south of Laura • Petford • Salique provenance selects (RSA)	• 15 • 14 • 17 • 22
4	*E. cloeziana*	• Mt Mulligan • Mt Pinnacle • Helen vale • Herberton– Irvinebank	• 28 • 29 • 30 • 27
5	*E. tereticornis*	• Helen vale • Palmer River (Zimbabwe) • Mt Garnet (Zimbabwe) • Holmes Ck (Zimbabwe)	• 36 • 39 • 38 • 37
6	*Corymbia citriodora* subsp. *citriodora* (CCC) and *variegata* (CCV)	• CCC Herberton • CCC Hughenden • CCV Brooyar • CCV Wondai	• 4 • 5 • 2 • 3
7	*E. tetrodonta* / *E. raveretiana*	• *E. tetrodonta* Mutchilba • *E. tetrodonta* Archer River • *E. tetrodonta* Laura • *E. tetrodonta* Adelaide River • *E. raveretiana* Rockhampton • *E. raveretiana* Yeppoon	• 46 • 44 • 45 • 43 • 34 • 35
8	*Khaya senagalensis*	• Ex Darwin NT	• 52
9	*Eucalyptus* hybrids	• *E. urophylla* × *E. tereticornis* (FS) • *E. urophylla* × *E. camaldulensis* (FS) • *E. grandis* × *E. camaldulensis* (HS) • *E. grandis* × *E. urophylla* (HS)	• 60 • 57 • 47 • 49

[3] Some entries were planted in the trial at Walkamin and the trial at Sugarbag Station. This is indicated in Appendix 1

Table 3.3 Allocated taxa treatments for the Sugarbag Station trial established in February 2001. Full information on entries is presented in Appendix 1.

Taxa Treatment	**Type**	**Entries / seedlot planted in line plots**	**Entry number**[4]
1	*E. camaldulensis*	• Kennedy River • Morehead River • Laura via Dongmen, China • NE Petford (Zimbabwe)	• 13 • 15 • 25 • 21
2	*E. tereticornis*	• Holmes Ck (Zimbabwe) • Mt Molloy • Laura, via Dongmen, China • Palmer River (Zimbabwe)	• 37 • 41 • 40 • 39
3	*E. tetrodonta / urophylla × pellita*	• *E. tetrodonta* Starke River • *E. tetrodonta* Mutchilba • *E. tetrodonta* Coen • UxP	• 42 • 46 • 44 • 59-1, 59-2
4	*E. cloeziana*	• Koorboora • My Mulligan • Helen vale • Gympie	• 32 • 28 • 30 • 31
5	*C. citriodora* subsp. *citriodora*	• Herberton • Glendon • Mt Garnet • Cheviot Hills	• 4 • 7 • 8 • 6
6	*Corymbia (Other)* *C, citriodora* subsp. *variegata* (CCV), *C. torelliana* (Tor) and their hybrids (Tor × CCV)	• CCV Coominglah • CCV Brooyar • CCV Wondai • Tor Flaggy Creek • Tor × CCV	• 1 • 2 • 3 • 11 • 53 to 56
7	Mixed eucalypts	• *E. argophloia* Burncluith S.F • *E. cambageana* Charters Towers • *E. moluccana* Gunnawarra • *C. nesophila* Helen vale	• 12 • 26 • 33 • 10
8	*Grandis × camaldulensis* clones	• Dendros Seed Supplies ex Brazil	• 48-9 • 48-12 • 48-13 • 48-20
9	*Urophylla × grandis* clones	• Dendros Seed Supplies ex Brazil	• 58-58 • 58-59 • 58-60 • 58-61
10	*Khaya species (K. senagalensis; Sen) (K. anthothecia; Ant)*	• Ant ex Darwin NT • Sen ex Burkina Faso, Africa	• 50 • 51

3.4.6 Assessment and analysis

Height and survival were assessed to 18 months for the Walkamin trial and 12 months for the younger trial at Sugarbag Station. At Walkamin, height and survival differences among taxon groups

[4] Some entries were planted in the trial at Walkamin and the trial at Sugarbag Station. This is indicated in Appendix 1

were analysed as a randomised complete block design, using irrigation and taxa treatment as factors. The design of the two Far North Queensland trials precluded the analysis of height or survival among provenance regions for all taxa combined. Therefore, differences in height and survival among provenance regions were analysed for each taxa treatment individually with the exception of *Khaya senagalensis* (treatment 8) at Walkamin. This treatment was analysed for differences between irrigation treatments only, due to the lack of partitioning into different entries.

Differences in height and survival between irrigation treatments and/or among entries were analysed as a randomised complete block analysis, using irrigation and /or entry as factors. However, in the trial at Sugarbag Station, *E. tereticornis* (taxa treatment 2) and *E. tetrodonta* (taxa treatment 3) were analysed using ANOVA for unbalanced designs as some line plots had additional entries due to shortages of the target entry. Furthermore, survival differences between *E. camaldulensis* mix provenances (Treatment 3, at Walkamin) were analysed with the block effect omitted since there was no variance attributed to differences among blocks.

Taxa treatment 7 at Walkamin (*E. tetrodonta* / *E. raveretiana*) and taxa treatment 3 and 6 at Sugarbag Station (*C. citriodora* subsp. *variegata, C. torelliana* and their hybrids) included plots that contained multiple seedlots within an 8-tree or 10-tree line plot. When analysing differences among provenance regions within these taxa, all represented entries / seedlots were included in the analysis.

Significant differences among treatments were tested by calculating Least Significant Difference (LSD) at the 5% significance level. If the difference between two treatment means was equal to or greater than the LSD, the difference was declared significant at the 5% level. In the trial at Walkamin, 5% LSDs were applied to detect significant differences between entries within an irrigation treatment.

The analysis of percentage survival is based on arcsine square root transformed data to meet the standard assumptions of normality and variance equality across groups, where survival was defined as the survival of useful stems, which excluded runts, useless and dead stems.

As the height and survival measures occurred at 1.5 years and 1 year after planting for Walkamin and Sugarbag trials respectively, cross-site analysis was not undertaken.

3.5 Results

Walkamin - taxa treatments differences

Height

Irrigated treatments out performed those that were not irrigated for all taxa combined ($P = 0.01$), although the degree to which irrigation affected height growth tended to differ among taxa ($P = 0.08$). The best height growth at 1.5 years was exhibited by irrigated taxa treatment 6 (*Corymbia* species CCC. and CCV; Fig. 3.2). In contrast, three non-irrigated taxa treatments (7, 8, 9; *E. tetrodonta / E. raveretiana*, *K. senagalensis* and *Eucalyptus* hybrids respectively) exhibited the poorest height growth observed. Results at the entry level are presented in Appendices 2 and 3. Height at age 1.5 years was significantly affected by taxa treatment after combining irrigation treatments ($P < 0.001$).

Survival

Percentage survival of live and useful stems was significantly influenced by taxon after combining irrigation treatments at age 18 months ($P < 0.001$), with *E. cloeziana*, *E. tetrodonta / E. raveretiana* and the *Eucalyptus* hybrids (taxa treatment 4, 7 and 9) exhibiting significantly poorer survival than other taxa (Fig. 3.3). The effect of irrigation at age 1.5 years tended to be significant for all taxa treatments after pooling taxa ($P = 0.06$, Fig. 3.4). However, its effect on survival was not significant among taxa treatments ($P = 0.87$). Results at the entry level are presented in Appendices 2 and 3.

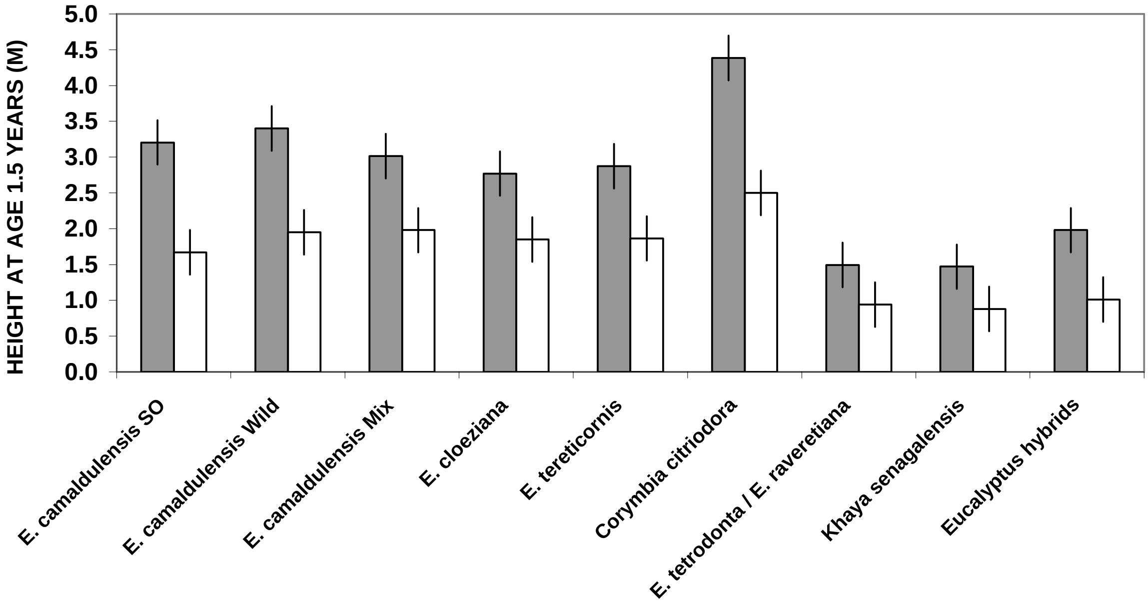


Figure 3.2. Mean height (m) for taxa treatments in irrigated (dark) and non-irrigated (clear) treatments at age 1.5 years at Walkamin. Lines represent the Least Significant Difference for comparisons within the same irrigation treatment (5% LSD = 0.6); the height of one taxon is significantly different from another within the same level of irrigation if the lines do not overlap. Details of taxa treatments are given in Table 3.2.

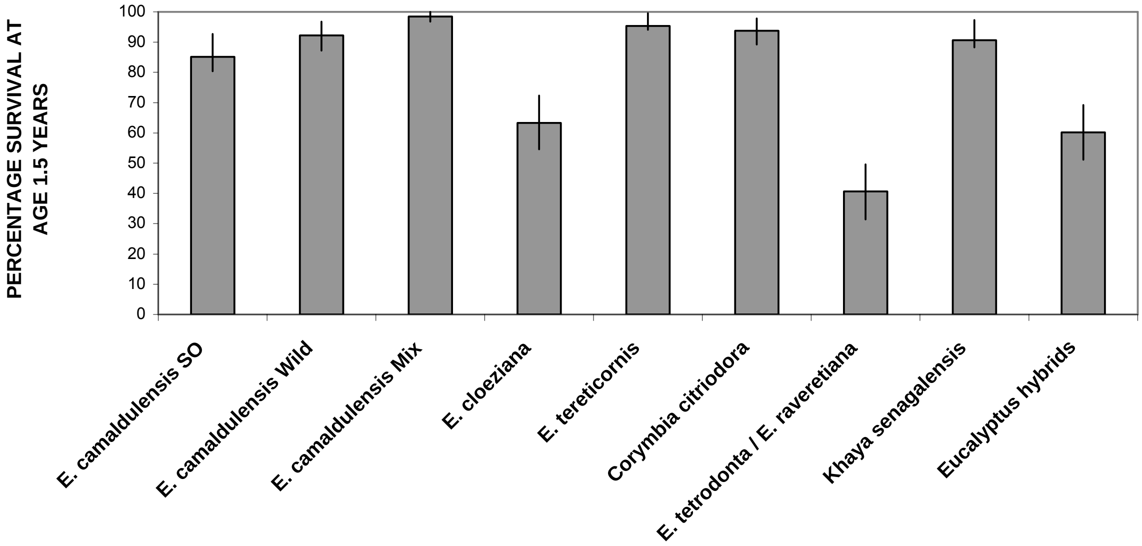


Figure 3.3. Mean percentage survival of useful stems from each taxon at age 1.5 years at Walkamin, with irrigated and non-irrigated treatments combined. Lines represent the Least Significant Difference (5% LSD = 0.2); the survival of one taxa treatment is significantly different from another if the lines do not overlap. Details of taxa treatments are given in Table 3.2.

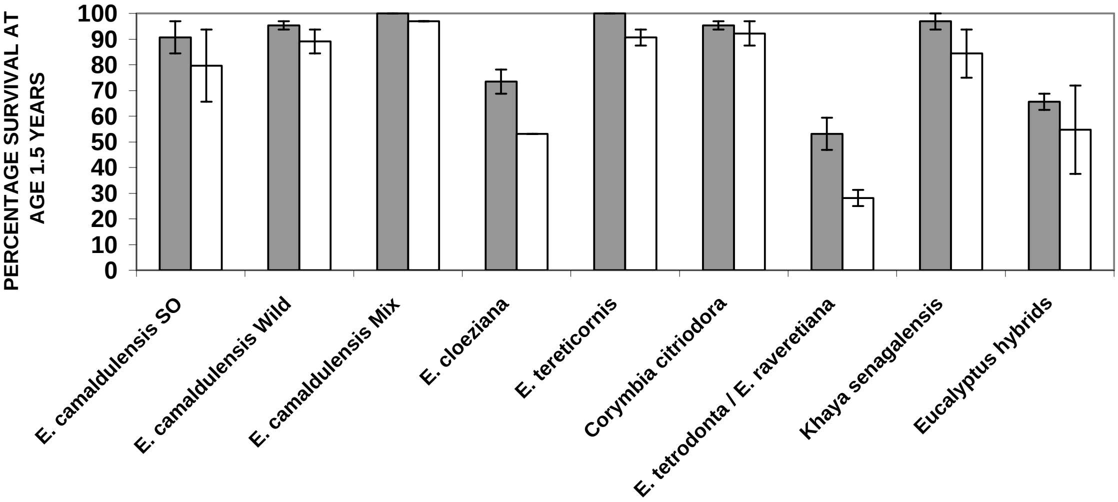


Figure 3.4. Percentage survival (mean ± SE) of useful stems in irrigated (dark) and non-irrigated (clear) treatments at age 1.5 years at Walkamin. Details of taxa treatments are given in Table 3.2.

Sugarbag Station - taxa treatment differences

Height

Height varied significantly among taxa treatments at one year ($P < 0.001$). The *E. grandis* × *E. camaldulensis* hybrid clones (taxa treatment 8) were significantly taller than all other taxa at this age (5% LSD = 0.5; Fig. 3.5). The poorest height growth was exhibited by *E. cloeziana*, mixed eucalypts and *Khaya* spp. (taxa treatments 4, 7 and 10), which were significantly lower than all other taxa treatments. Results at the entry level are presented in Appendices 4 and 5.

Survival

There were significant differences in the survival of useful stems among taxa at one year ($P < 0.001$). The highest survival was exhibited by *E. camaldulensis* (taxa treatment 1) and *E. grandis* × *E. camaldulensis* hybrids (taxa treatment 8), while *E. tetrodonta* / *E. urophylla* × *E. pellita* (taxa treatment 3) and *E. cloeziana* (taxa treatment 4) showed significantly poorer survival than all other taxa (5% LSD = 0.2; Fig. 3.6). Results at the entry level are presented in Appendix 2.

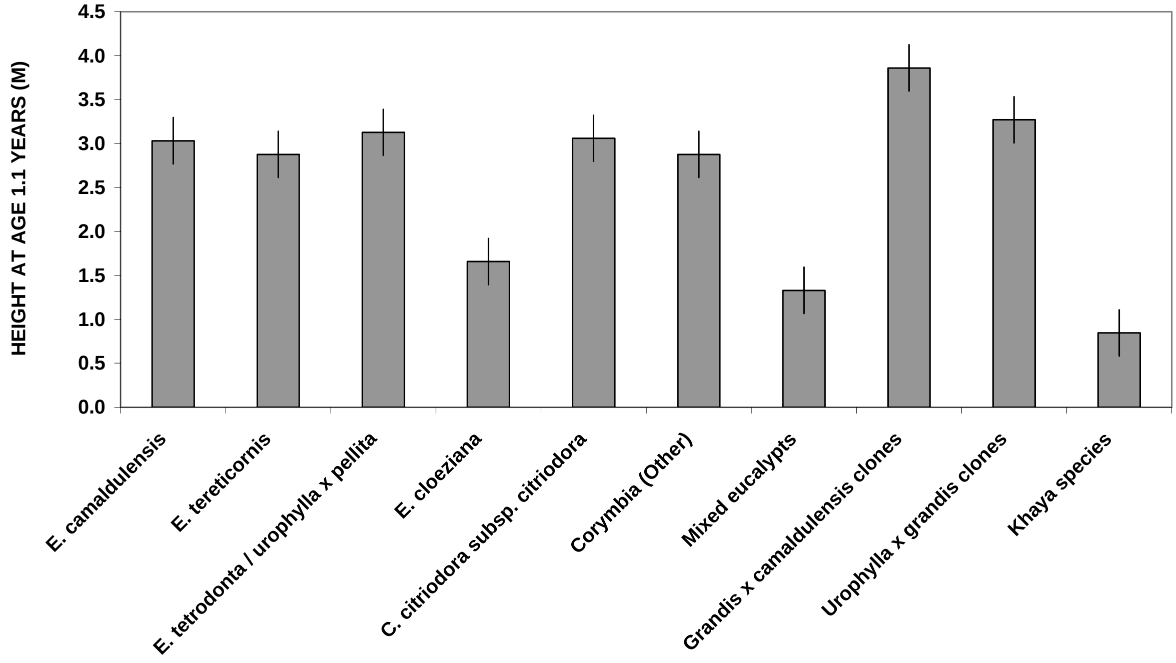


Figure 3.5. Mean height (m) for taxon treatments at one year in at Sugarbag Station. Lines represent the LSD for comparisons among taxa (LSD = 0.5); the height of one taxon is significantly different from another if the lines do not overlap. Details of taxa treatments are given in Table 3.3.

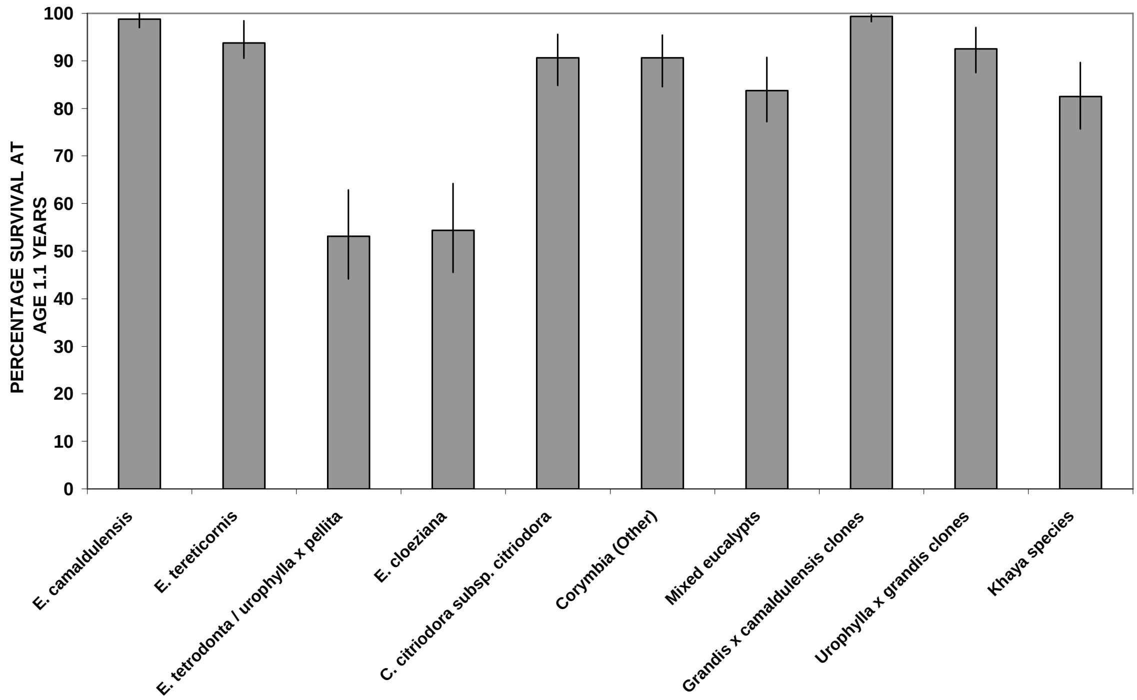


Figure 3.6. Mean observed survival of useful stems for taxon treatments at age one year at Sugarbag Station. Lines represent the LSD for comparisons among taxa (LSD = 0.2); the survival of one taxon is significantly different from another if the lines do not overlap. Details of taxa treatments are given in Table 3.3.

3.6 Discussion of north Queensland taxa trials

Comparisons at "taxa treatment" level

Across the Walkamin and Sugarbag Station trials, (aged 1.5 years and one year at the time of measure respectively), there were marked differences in growth and survival that are probably due to the combination of climate and edaphic effects. The soil at Walkamin is typical of many degraded areas west of Mareeba, on the Atherton Tablelands. The Sesquic Aeric Podsol (Table 3.1) is a sandy soil with a low nutrient status and is susceptible to leaching. Hence, even though high nutrient fertiliser was applied following planting, the nutrient status of this type of soil is likely to be limiting to growth. This is a possible reason for the modest growth and survival at this site with the fastest growing taxa treatment only reaching 4.4 m under irrigation and 2.5 m without irrigation at 1.5 years (*Corymbia* species, taxa treatment 6). The similar taxa treatments at Sugarbag (Fig. 3.5) grew approximately 3.0 m without irrigation in one year (Taxa treatment 5, CCC. was 3.1 m; Taxa treatment 6, CCV. was 2.9 m). The Yellow Kandosol soil at Sugarbag Station is typical of many drier areas of northern Australia and it is likely to have a better nutrient status and water holding capacity than the soil found at Walkamin.

At Walkamin and Sugarbag Station, 85% and 88% of the average rainfall respectively falls during the five months from November to March, meaning that both locations experience seven months of extreme dry in most years. The long dry period and higher evapo-transpiration is the main reason that growth rates in marginal regions in North Queensland are lower than similar rainfall zones (e.g. 710 mm) in southern Australia. Indeed, the height of the best taxon (*E. globulus* subsp. *globulus*), in a trial near Mount Gambier, South Australia reached 5.8 m at 1.5 years on a sandy soil (Cotterill *et al*., 1985).

In the Sugar Bag Station trial, the outstanding taxa treatments were number 8 (*E. grandis* × *E. camaldulensis* clones) and number 9 (*E. urophylla* × *E. grandis* clones), which reached heights of 3.9 m and 3.3 m in one year, respectively (Fig. 3.5). These taxa treatments contain eucalyptus hybrid clones selected in Brazil for fast growth and good survival under tropical conditions, so it will be interesting to see if they maintain their fast early growth. A large group of taxa treatments had intermediate growth: Taxa treatments 1 (*E. camaldulensis*), 2 (*E. tereticornis*), 3 (*E. tetrodonta*) 5 (*Corymbia citriodora* subsp. *citriodora*), and 6 (*Corymbia citriodora* subsp. *variegata*) with height growth ranging from 2.9 to 3.1m in one year. Taxa treatments performing poorly at this site at one year were numbers 4 (*E. cloeziana*), 7 (mixed eucalypts) and 10 (*Khaya* spp.). The poor growth of these later taxa treatments may indicate they are not adapted to this site. However, it is too early to make any firm conclusions.

Interestingly, height growth of the three *E. camaldulensis* taxa treatments at Walkamin showed little variation within irrigation treatments; ranging from 1.7 to 2.0 m in non-irrigated treatments and from 3.0 to 3.4 m in irrigated treatments. (Fig. 3.2). As these differences are not statistically significant, it indicates that importing seed from overseas breeding programs may not have any major benefit for early growth of this species when it is grown on a marginal site in north Queensland. The other "red gum" species *E. tereticornis* exhibited similar growth to *E. camaldulensis* in this trial.

Irrigation during the trial establishment phase at Walkamin has significantly improved the establishment and height growth of all treatments (Fig. 3.2) and enhanced the survival within taxa treatments. However, each taxa treatment responded differently to the irrigation treatment. *Eucalyptus camaldulensis* (Taxa treatments 1 to 3) and the spotted gums (CCC and CCV; Taxa treatment 6) exhibited good survival under both irrigation treatments (Fig. 3.4). Others such as *E. cloeziana* (Taxa treatment 4) and the *E. tetrodonta* and *E. raveretiana* (Taxa treatment 7) had much higher survival under the irrigated treatment. This trial demonstrates there are benefits to be gained by the use of irrigation as a means to reduce risks during plantation establishment in northern Australia on marginal sites. Most of these benefits, however, appear to be in increased growth rather than enhanced survival across taxa. The effect of irrigation needs to be evaluated in further trials in areas where irrigation is feasible for plantation development.

Comparisons at "entry" level

At Walkamin, the best growth with and without irrigation was by the spotted gums (Entries 2 to 5, Appendix 3). In this trial, the outstanding height growth under irrigation was by CCV from Brooyar (5.2 m) and Wondai (4.9 m), which were both sourced from south Queensland. Without irrigation, the CCC Herberton and CCV Brooyar were the outstanding entries, exhibiting height growth of 2.9 m and 3.2 m respectively. Entries of *E. camaldulensis*, *E. cloeziana*, *E. tereticornis*, *E. tetrodonta*, *E. raveretiana* and the four eucalypt hybrids from CSIR (South Africa) did not show outstanding height growth at Walkamin. Heights ranged from 0.4 m for non-irrigated *E. tetrodonta* from Laura (entry 45) to 3.7 m for irrigated *E. camaldulensis* from NE Petford ex Zimbabwe (entry 21).

At Sugarbag Station, the best taxa treatments were *E. grandis* × *E. camaldulensis* (taxa treatment 8) and *E. urophylla* × *E. grandis* clones (taxa treatment 9) from Brazil as discussed above. However, when the entries within taxa treatment are considered, the fastest growing entry was a *C. torelliana* × *C. citriodora* subsp. *variegata* seedlot (entry 54) from controlled pollinations undertaken as a component part of this project (4.6 m, Appendix 5). Another of these hybrids (entry 56) ranked third (4.0 m) at twelve months. The *E. grandis* × *E. camaldulensis* clone (entry 48-12) was the best of the clones from Brazil at 4.4 m, ranking second at 12 months. Overall, *E. grandis* × *E. camaldulensis* clones (entry 48) and *E. urophylla* × *E. grandis* clones (entry 58) were uniform in their height growth exhibiting height ranges of 3.7 to 4.2 m and 3.0 to 3.6 m, respectively. Good early performance was also exhibited by *E. urophylla* × *E. pellita* hybrids (entries 59-1 and 59-2), which were both derived from controlled pollinations undertaken as part of this project (3.5 and 3.6 m), CCC Herberton (entry 17, 3.6 m), CCC Mt Garnet (entry 19, 3.5 m) and another of the *C. torelliana* × *C. citriodora* subsp. *variegata* seedlot (entry 41 at 3.5 m). At Sugarbag Station, 10 of the 12 entries that showed growth of at least 3.5 m at 12 months (Appendix 3) are eucalypt hybrids. Five of these hybrids are selected clones from Brazil and the other five are from controlled pollinations undertaken by QFRI staff using native materials as a component of this project. Similar early results in northern Australia are reported by Lee *et al*. (2001), although they found that many of the hybrids were subsequently attacked by insect pests and diseases. Even so, there was enough variation to allow selection of apparently tolerant hybrid genotypes that could be assessed further in clonal tests. The same is expected at this site.

Across site variation

Only 11 of the 60 entries were duplicated across both trials in north Queensland (Appendix 1) due to limited availability of seed and seedlings during the two years of planting. Of the entries duplicated in both north Queensland trials, 9 out of 11 were taller at 12 months at Sugarbag Station than the non-irrigated growth at Walkamin at 18 months. This was not tested statistically as the measures were carried out at different ages. The two entries that were shorter at 12 months at Sugarbag Station were only marginally shorter than their Walkamin counterparts at 1.5 years (Appendix 3 and 5), and thus are thought to be growing at a comparable rate across both sites. For those entries common to both sites, the enhanced growth at Sugarbag indicates that the soils at the former site are better suited to hardwood plantation development than those at Walkamin, despite the higher rainfall at Walkamin (Table 3.4).

3.7 Summary

At one to 1.5 years, it is too early to nominate superior growth and survival taxa from the "species elimination" trials in north Queensland. All taxa treatments and entries in the Walkamin trial exhibited better height growth with irrigation than without irrigation at age 1.5 years. However, the effect of irrigation was not always significant at the entry within taxa treatment level. A range of species and hybrids including *C. torelliana* × *C. citriodora* subsp. *variegata* hybrids, *E. urophylla* × *E. pellita* hybrids, selected *E. grandis* × *E. camaldulensis* and *E. urophylla* × *E. grandis* clones, and the spotted gum species (CCC and CCV) are the most promising at this early stage across the two sites.

Table 3.4 Yearly rainfall totals for the north Queensland study sites

Location	**Long term average**	**Rainfall (mm) 2000**	**Rainfall (mm) 2001**
Walkamin	1014	1578 [5]	**877**
Mt Surprise (70 km SW of Sugarbag Station)	794	1106	828
Sugarbag Station	711[6]	-	718

3.8 Recommendations

The two trials established in the dry tropics of north Queensland, are critical for the identification of taxa that could be suitable for the development of a viable and sustainable hardwood plantation industry in northern Australia. If maintained and properly monitored the trials will provide a good indication of the potential of a large suite of species, provenances and hybrids in a region that previously lacked any tests of hardwood species.

Subsequent to this project funding, these trials were monitored and remeasured at age three years. Following analysis of the trials, new replicated large multi-row block trials should be established with the taxa showing the greatest potential for long-term growth and survival in this region. Furthermore, it is recommended that development of hybrids including *E. grandis* × *E. camaldulensis, C. torelliana* × *C. citriodora* subsp. *variegata* and *E. urophylla* × *E. pellita* continue via development of controlled pollination programs for this region of north Australia.

[5] 894 mm of this rain fell in February 2000 leaving only 684 mm over the rest of the year.
[6] Estimated by property owner.

4. Taxa site matching in southern Queensland

4.1 Background and target region

In subtropical northern Australia, there are many trials evaluating the potential of taxa and matching taxa to specific sites in areas over 900 mm MAR. However, fewer trials have been established in the low rainfall zone. This study aimed to compare the site suitability of a range of eucalypt species, provenances and hybrids in the 650-900 mm MAR zone of sub tropical north Australia.

The three trial sites are located in areas where community groups and commercial forestry companies are expressing considerable interest in tree growing. Specifically the target regions included:

- The Burnett Valley, where large areas of red soils are becoming available for forestry owing to dwindling returns from the traditional peanut, sorghum and sunflower industries. The region is also characterised by increasing salinity levels. Growing trees in recharge areas may reduce this problem.
- The Darling Downs, where large areas of currently under-utilised land previously used for dairy and cropping is potentially available for tree establishment.

During the 2000 planting season, one trial was established on the Darling Downs (near Warwick) and two were planted in the Burnett Valley (near Kingaroy and Wooroolin).

4.2 Objectives

There were three main objectives to the taxa site-matching component of this work in southern Queensland.

- The primary aim of establishing the trials in the low rainfall zone of sub-tropical Queensland was to provide an experimental base from which high quality long-term growth and survival could be measured for 'best bet' taxa relative to previously unavailable or newly developed taxa (particularly hybrids) for Queensland.
- A secondary aim was to provide a future timber resource that could be used for wood quality testing, mensuration studies and selection for taxa domestication.
- The third aim was to establish demonstration plantings that can be used to promote agroforestry in areas currently considered marginal for commercial tree growth.

4.3 Methods

4.3.1 Taxa under test

Seed of interspecific hybrids comprising bulks that were made up from mixtures of seed of several individual full-sib crosses (number varying among seed lots) was obtained from the Council for Scientific and Industrial Research (CSIR), Republic of South Africa. Seed of the pure species bulks was provided by the Australian Tree Seed Centre (ATSC) and the Queensland's Forestry Tree Seed Centre (FSC). Details of the seedlots (entries) and their origins are given in Table 4.1.

4.3.2 Nursery details

Seedlings were raised at DPI-Forestry's Toolara Nursery (east of Gympie, Queensland). The seeds were directly sown into 90 ml plastic pots in November 2000. The potting mix consisted of 1/3 pine bark-peat, 2/3 grade 3 vermiculite and 1.25 kg osmocote per m^3. Pots were watered as required and thinned to one seedling per pot, four weeks after sowing. Plants were hardened off in full sun from age 1.5 months.

4.3.3 Study sites in southern Queensland

Three sites were planted between February and April 2000, on sites representative of areas where land is likely to be available for hardwood plantations (Fig. 4.1, Table 4.2). In two areas, Wooroolin and Kingaroy in the Southern Burnett, two organisations have already commenced development of hardwood plantations. Currently, the main species used in this area are CCV and *E. dunnii*, although the long-term growth and potential of these species as plantation crops are unknown. The third site is on the Darling Downs where large tracts of land that were previously used for cropping and dairying are now potentially available for plantation development.

Table 4.1. Details of seedlots supplied by the Australian Tree Seed Centre and the Forestry Tree Seed Centre, Queensland Department of Primary Industries – Forestry, for trials in southern Queensland.

Entry no.	**Taxa**	**Provenance (All Queensland except as indicated)**	**Seedlot**	**No. of seed parents**	**Lat. (°S)**	**Long. (°E)**	**Altitude (m)**	**MAR (mm)**
43	*E. grandis* × *E. urophylla*	CSIR bulk, RSA	FSC10504	10	-	-	-	-
50	*E. globulus* subsp. *maidenii*	Bolaro Mt, NSW	ATSC18728	78	35 40	150 02	380	-
63	*Araucaria cunninghamii*	Yarraman CSOs	NA	9	-	-	-	-
64	*C. citriodora* subsp. *citriodora*	Gladstone	ATSC20016	8	23 50	151 09	20	1200
66	*C. citriodora* subsp. *variegata*	Woondum	FSC5567	12	26 17	152 47	120	1148
67	*C. citriodora* subsp. *variegata*	Brooyar	FSC10248	12	26 10	152 30	90	1143
69	*E. argophloia*	SF302 Ballon	FSC5520	18	26 20	150 40	300	685
70	*E. cloeziana*	Wolvi	FSC4363	11	26 07	152 47	120	1148
71	*E. cloeziana*	Mungy	FSC10823	20	25 17	151 21	400	730
72	*E. drepanophylla*	Mt Mee SF	ATSC17388	4	27 01	152 42	350	-
73	*E. dunnii*	Urbenville NSW	FSC5562	95	28 28	152 29	340	-
74	*E. dunnii*	SAPPI, RSA	FSC10513/10853	Bulk	-	-	-	-
76	*E. globulus* subsp. *maidenii*	Bondi SF, NSW	ATSC 19454	24	37 11	149 28	480	-
77	*E. longirostrata*	Coominglah	ATSC19312	6	24 48	150 57	480	730
79	*E. tereticornis*	SF60 Rundle	FSC10456	7	23 38	151 00	30	970
80	*E. tereticornis*	Laura ex Zimbabwe	FSC16027	Bulk	18 10	25 50	900	550
81	*E. grandis* × *E. camaldulensis*	CSIR bulk, RSA	FSC10500	11	-	-	-	-
82	*E. grandis* × *E. resinifera*	CSIR bulk, RSA	FSC5991	10	-	-	-	-
83	*E. grandis* × *E. tereticornis*	CSIR bulk, RSA	FSC10502	7	-	-	-	-
97	*E. urophylla* × *E. grandis*	CSIR bulk, RSA	FSC11302	3	-	-	-	-
98	*E. resinifera* × *E. grandis*	CSIR bulk, RSA	FSC11303	2	-	-	-	-
99	*E. tereticornis* × *E. grandis*	CSIR bulk, RSA	FSC11305	1	-	-	-	-
100	*E. grandis* × *E. camaldulensis*	CSIR bulk, RSA	FSC11307	1	-	-	-	-

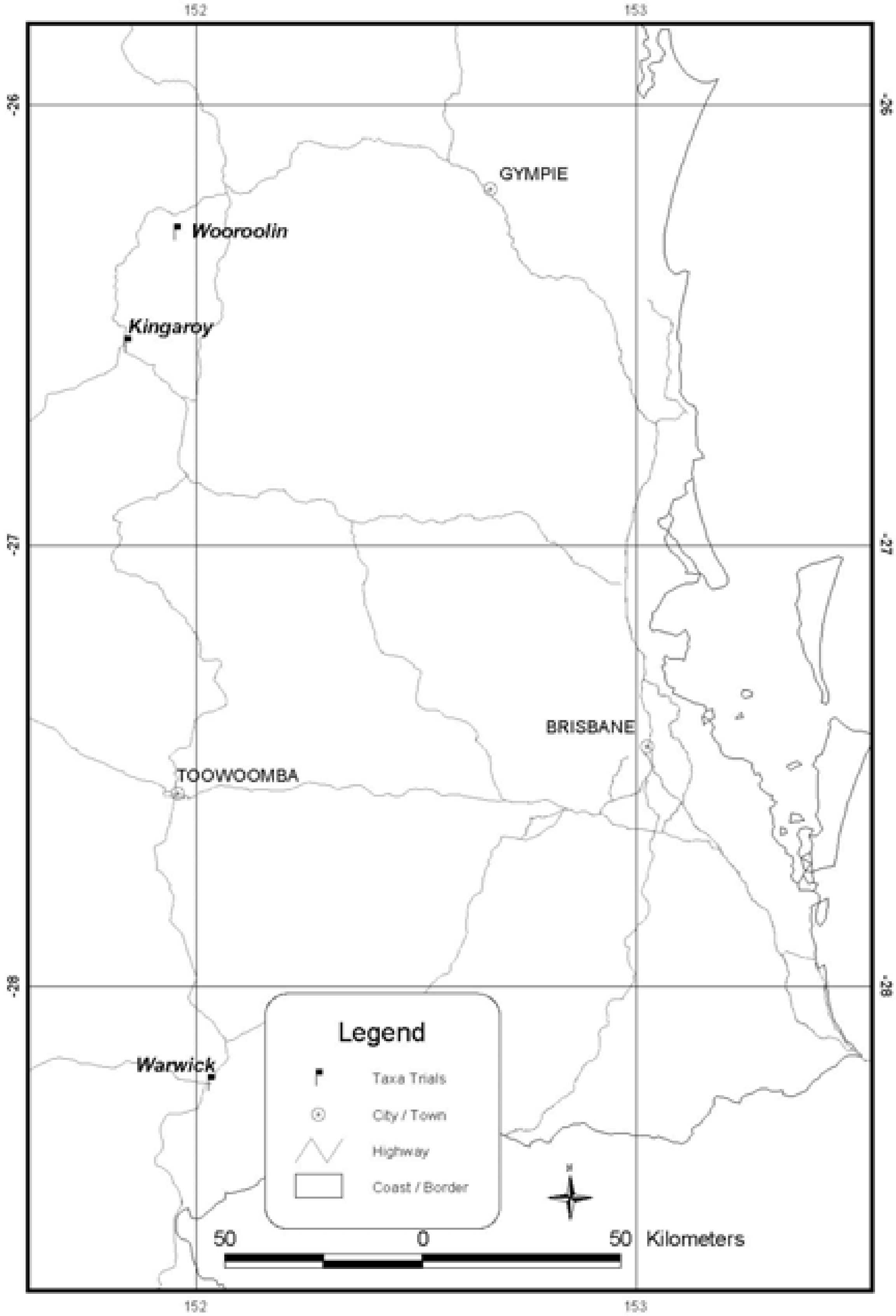


Figure 4.1 Location of the three taxa trials established in the 650–900 mm MAR zone in southern Queensland.

4.3.4 Experimental design

Each trial employed a randomised complete block design with three or four replicates / blocks according to site limitations (Table 4.2). Twelve or 13 taxa treatments were randomly allocated to one plot per treatment within each replicate, with plot size varying according to seedling and land availability. At Wooroolin and Kingaroy, gross plots contained 72-trees (6 rows × 12 trees), whereas gross plots contained approximately 60 trees at Warwick (6 rows × 10 trees). In each trial, one or more provenances of 'best bet' species (*Corymbia, Eucalyptus* and *Araucaria cunninghamii)* and several *Eucalyptus* interspecific hybrids were tested. Based on earlier trials, a group of taxa (CCV, *E. cloeziana, E. dunnii,* and *E. globulus* subsp. *maidenii*) that previously showed potential in the 650–900 mm MAR zone (Lee *et al.*, 2001) were tested against hybrids new to the program in Queensland. As these trials have replicated, large plots of each entry, they will provide data on the long-term growth, form and wood properties of the taxa under test.

4.3.5 Trial establishment

The seedlings were planted at 2 metre spacing within the planting row and fertilised with a NPK fertiliser (Starterfos) at 60 kg phosphorus /ha as an individual tree application within one month of establishment. Weed free conditions were maintained in the planting row for the first 12 months of the trial. The trial at Wooroolin was watered three times (each of approximately five litres) to assist with survival and growth during the first four months as no follow-up rain fell.

4.3.6 Assessment and measurements

Height and survival were assessed and differences among taxon groups at the latest measure were analysed as a randomised complete block design, using taxa / entry as the treatment factor and replicate / block as the blocking factor for each site. Where necessary, height and survival were transformed to meet standard assumptions of normality and variance equality prior to analysis. Survival was defined as the survival of useful stems, which excluded runts, useless and dead stems. Latest measures of height and survival were recorded at age 10 months at Wooroolin, 15 months at Kingaroy and 24 months at Warwick. The ages of the assessments vary at this early stage as the trials were also being used for field day demonstration purposes (a component of this project). Part of the extension material used on these field days was summaries of their growth at the time of the field day. Hence, comparisons across sites were not analysed. Subsequent to this project funding, three-year measures were undertaken in 2004. Across-site analysis are underway.

Table 4.2. Site descriptions for the three taxa trials in southern Queensland.

Location/description	Wooroolin	Kingaroy	Warwick
Latitude (°S)	25° 26´ 01´´	25° 42´ 20´´	28° 15´ 02´´
Longitude (°E)	151° 51´ 29´´	151° 27´ 05´´	153° 08´ 09´´
Altitude MASL	500	540	480
Rainfall (MAR) mm	794	780	665
Soil type [7] and depth	Ferrosol (Krasnozem), >60cm	Reps 1-3 Ferrosol , >60cm, Rep 4 Grey Dermosol >60cm	Grey clay (Brown Vertosol), >60cm
Original vegetation	Dry rainforest	Dry rainforest	Open sclerophyll forest (mainly *E. populnea*)
Vegetation prior to commencement of the trials	Improved pasture	Intensive cropping (sorghum, maize, sunflowers)	Intensive cropping / pasture
Initial stocking (stem/ha)	1000	1000	1000
No. replicates	3	4	3
Area planted	2.75 ha	5.23 ha	2.16 ha

4.4 Results

4.4.1 The trial at Wooroolin

Height varied significantly among taxa at Wooroolin at age 10 months ($P < 0.001$; Appendix 6). *E. tereticornis* × *E. grandis* (entry 99) exhibited the greatest height growth at 1.7 m, which was significantly taller than all other taxa with the exception of *E. urophylla* × *E. grandis* and *E. resinifera* × *E. grandis* (5% LSD = 0.3; entries 97 and 98). The height of *Araucaria cunninghamii* (entry 63) was significantly poorer than all other taxa at age 10 months (Fig. 4.2). In contrast to height trends, there was no significant difference in survival of useful stems among taxa at age 10 months ($P = 0.103$; Appendix 6, Fig. 4.3).

[7] Using the Australian Soil Classification system

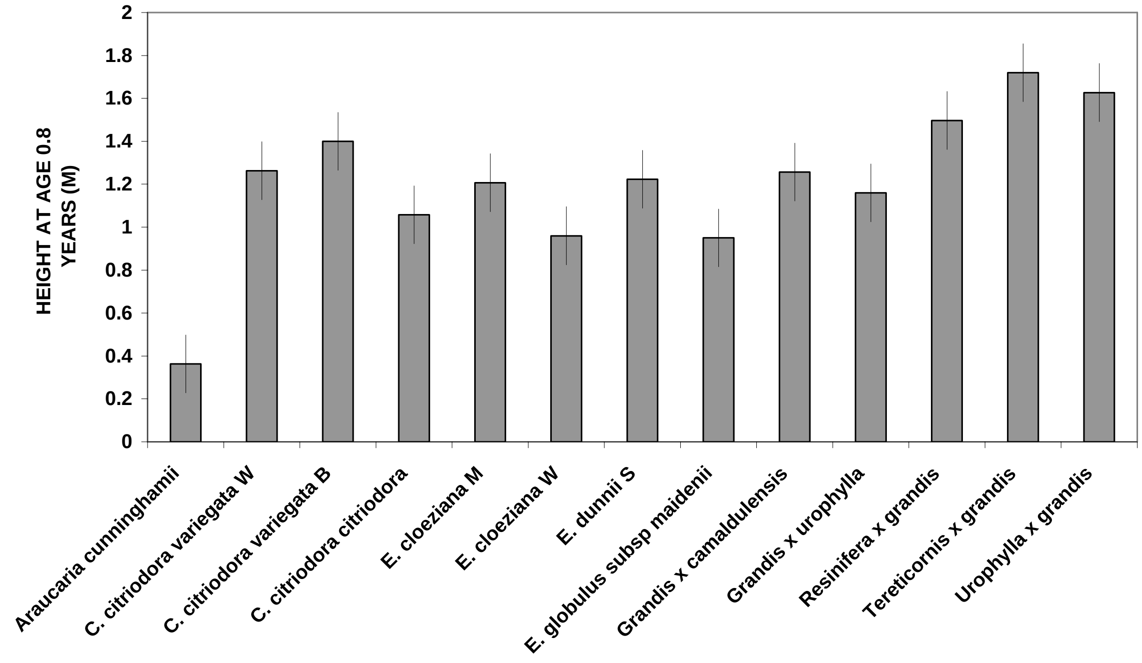


Figure 4.2. Mean height of taxa treatments planted at Wooroolin at age 10 months. Lines represent the Least Significant Difference for comparisons among taxa (5% LSD = 0.3); the height of one taxon is significantly different from another if the lines do not overlap. Entry details are given in Table 4.1.

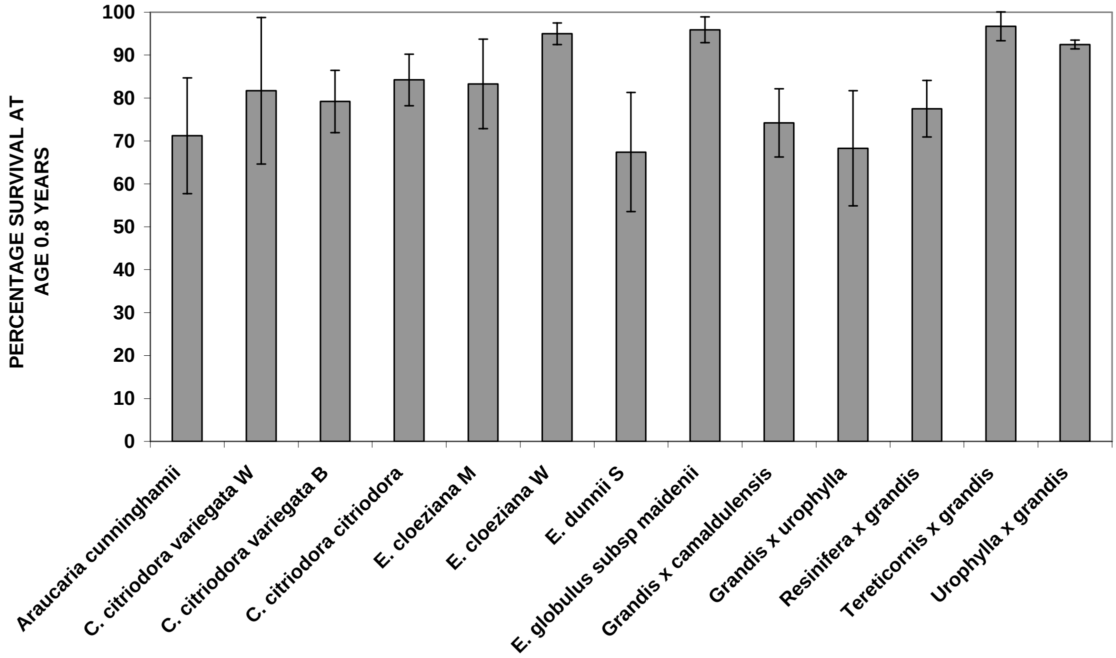


Figure 4.3 Percentage survival (mean ± SE) of Entries planted at Wooroolin at age 10 months. Entry details are given in Table 4.1.

4.4.2 The trial at Kingaroy

There were significant height differences among entries at age 15 months (P < 0.001; Appendix 6). *E. dunnii* SAPPI, RSA (entry 74) and *E. grandis* × *E. resinifera* (entry 82) were the tallest at 15 months, being significantly taller than all other entries with the exception of *E. globulus* subsp. *maidenii* Bolaro Mt, NSW (entry 50), *E. dunnii* Urbenville, NSW (entry 73) and *E. grandis* × *E. tereticornis* hybrids (entry 83; 5% LSD = 0.1; Fig. 4.4). Survival also varied significantly among entries (P = 0.039). The *E. tereticornis* Laura ex Zimbabwe (entry 80) had the highest survival (5% LSD = 0.1), although survival for all taxa at 15 months was above 90 % for all entries (Appendix 6, Figure 4.5).

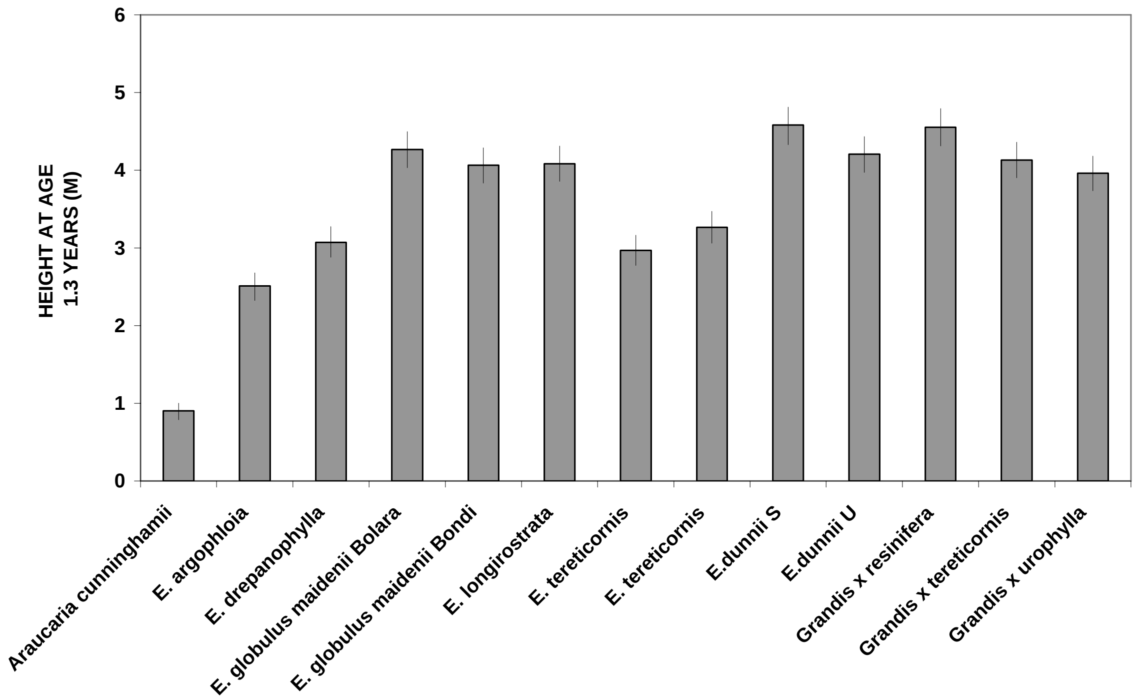


Figure 4.4. Mean height of entries at 15 months at Kingaroy. Lines represent the Least Significant Difference for comparisons among entries (5% LSD = 0.1); the height of one entry is significantly different from another if the lines do not overlap. Entry details are given in Table 4.1.

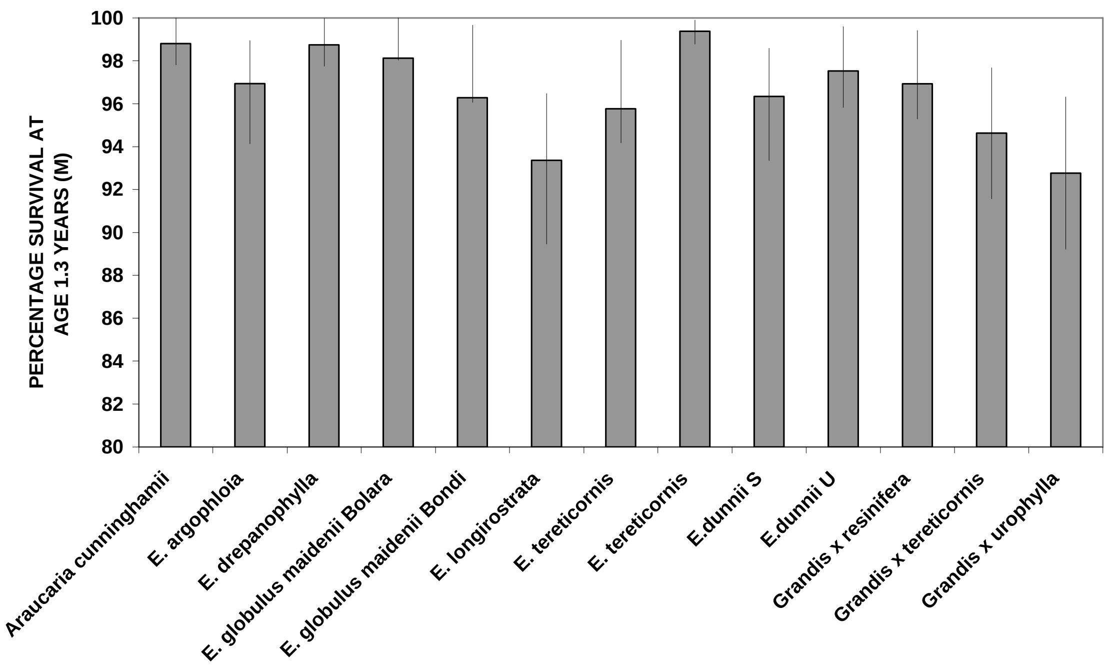


Figure 4.5. Mean percentage survival of entries at 15 months at Kingaroy. Lines represent the Least Significant Difference for comparisons among entries (5% LSD = 0.1); the survival of one entry is significantly different from another if the lines do not overlap. Entry details are given in Table 4.1.

4.4.3 The trial at Warwick

Height and survival varied significantly among taxa treatments at 24 months (height: $P < 0.001$; survival: $P < 0.001$; Appendix 6). *E. argophloia* (entry 69) exhibited the greatest height at age 2 years (3.5 m) and it also exhibited the equal best survival over the period (96.9 %) with *E. longirostrata* (entry 77). The three spotted gum entries (64, 66 and 67) exhibited significantly lower height growth at 24 months than all other taxa (5% LSD = 0.5; Fig. 4.6). Furthermore, all three-spotted gum entries had poor survival in comparison with other Entries; the poorest survival was by the CCV provenance from Brooyar (entry 67); its survival was significantly poorer than all non-*Corymbia* taxa at 24 months (LSD = 0.3; Fig. 4.7). For most trees belonging to *Corymbia* treatments heights recorded at the second measure (August 2000) were lower than those recorded during the first measure (March 2000), indicating that damage occurred during Autumn/Winter 2000. Survival sharply decreased between the second measure (August 2000) and third measure (February 2002), which may reflect the subsequent death of the trees. All plots of *Corymbia* treatments were similarly affected, and plots containing other entries were either not affected, or the effect was considerably reduced. Thus, the spotted gums are susceptible to either the soil or the climate at Warwick.

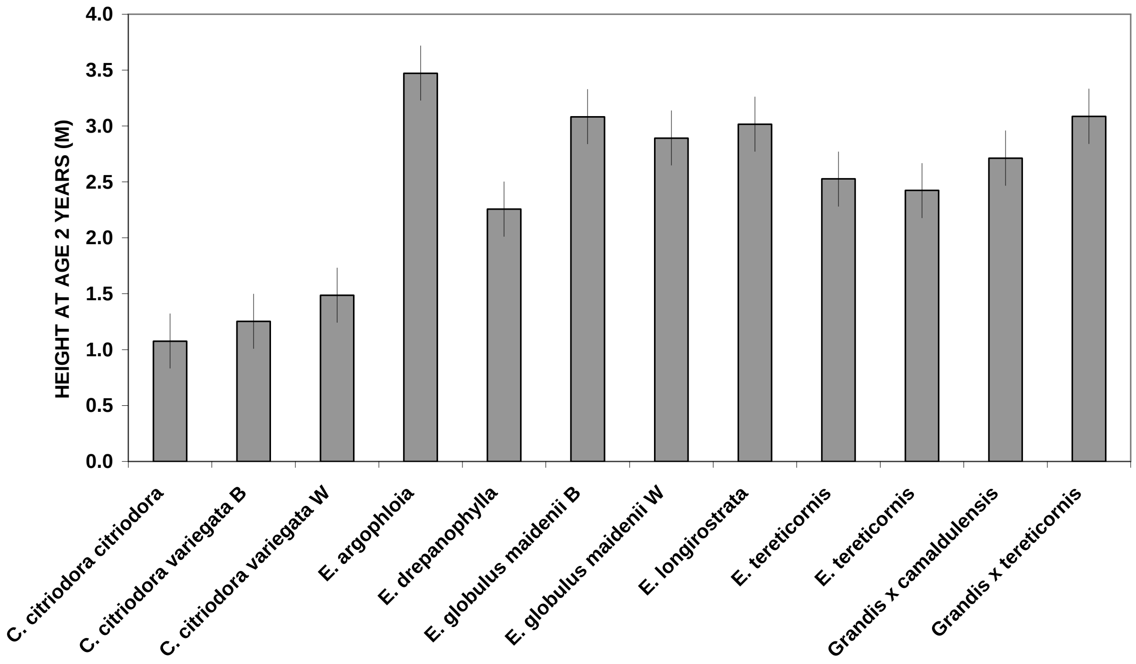


Figure 4.6. Mean height of taxa treatments at age 2 years planted at Warwick. Lines represent the Least Significant Difference for comparisons among entries (5% LSD = 0.5); the height of one entry is significantly different from another if the lines do not overlap. Entry details are given in Table 4.1.

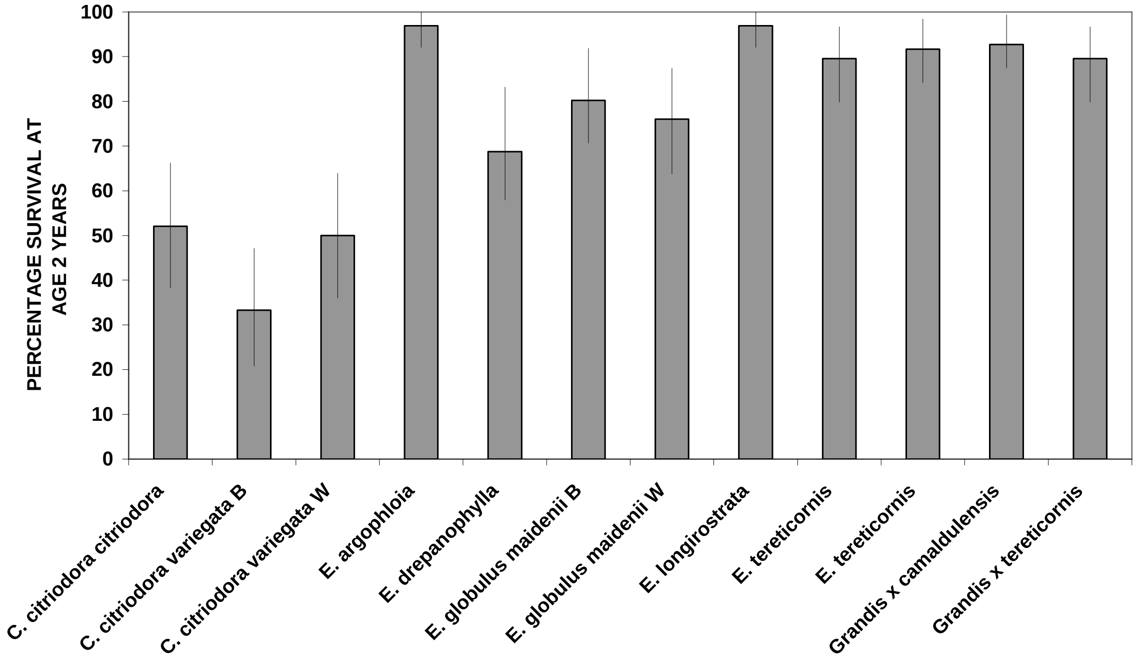


Figure 4.7. Mean percentage survival of taxa treatments at age 2 years planted at Warwick. Lines represent the Least Significant Difference for comparisons among taxa (5% LSD = 0.3); the survival of one taxon is significantly different from another if the lines do not overlap. Entry details are given in Table 4.1.

4.5 Discussion of the southern Queensland taxa trials

There were marked differences in growth and survival across the three trials in southern Queensland, probably due to the combination of climate and edaphic effects. The Ferrosol soils at Wooroolin and Kingaroy (Table 4.2) are similar with both having limited availability of phosphorus to the trees. All other nutrients, however, should be non-limiting as differences in soil fertility between the sites were probably overcome by high fertiliser inputs. As Ferrosol soils are free draining, water-limiting events are likely in times of drought. The Kingaroy trial has the highest survival and at the latest measure, it was the most productive site for height growth (Appendix 6). The best growth at Kingaroy at 15 months was 4.6 m by both SAPPI *E. dunnii* (entry 74) and the *E. grandis* × *E. resinifera* hybrids (entry 82). The apparently large difference in height growth and survival between the two trials in the Burnett Valley (even taking into account the different measure dates) may be explained by the rainfall at the two sites. The Wooroolin site had no rainfall recorded during the 2000 calendar year (average rainfall is 794 mm; Table 4.2). It is therefore remarkable that survival is as high as that observed at Wooroolin. This site is only 20 km away from the Kingaroy site, which had 647 mm rainfall in the same twelve-month period. This demonstrates the large variation in rainfall that can occur in the 650–900 mm MAR in northern Australia.

Even after accounting for the three initial waterings applied during trial establishment, four entries (CCV Brooyar entry 67, *E. cloeziana* Mungy entry 71, *E. resinifera* × *E. grandis* entry 98, and *E. tereticornis* × *E. grandis* entry 99) had survival over 90% at 10 months. This suggests that these entries have a higher adaptability to this site that those entries with lower survival (Appendix 6).

The contrasting Brown Vertosol soil at Warwick should have a better water holding capacity than the Ferrosol soils in the Burnett Valley due to its greater clay content. However, as this soil is moderately alkaline (pH range top to bottom of profile 7.5-9) there may be limited availability of some nutrients for to the trees (particularly phosphorus, manganese and boron; Taiz and Zeiger 1991). A shortage of nutrients may not be the only growth-limiting factor at this site. The availability of soil moisture and occurrences of severe frosts are other possible limiting factors on plant growth; the site at Warwick received only 466 mm during the 2000 calendar year (Table 4.3) and experienced one week three months after establishment where the daily minimum temperature was –5°C. The frost was followed by another 53 frosts during 2000 and 49 frosts during 2001. This is the main cause of the low survival at the site, particularly for the spotted gum entries (64, 66, 67).

Table 4.3 Yearly rainfall totals for the southern Queensland study sites

Location	**Long term average**	**Rainfall (mm) 2000**	**Rainfall (mm) 2001**
Kingaroy	**780**	647	712
Wooroolin	794	0[8]	675
Warwick	665	466	660

Overall, the early height growth in these three trials suggest that eucalypt hybrids have good early potential in marginal sites in southern Queensland and indicate that further testing and development of these types of hybrids is justified. However, while these trials are interesting in terms of early growth and survival, they are not mature enough to provide reliable predictions on productivity at rotation age.

4.6 Summary

Despite the fact that at age 10 to 24 months it is too early to nominate taxa with superior growth potential, the three trials in southern Queensland have identified outstanding early growth taxa. In the Burnett, *E. dunnii, E. globulus* subsp. *maidenii*, *E. longirostrata,* CCV and a range of *Eucalyptus* hybrids (*E. grandis* × *E. resinifera*, *E. resinifera* × *E. grandis*, *E. tereticornis* × *E. grandis* and

[8] This is not a mistake the site had no rain during the 2000 calendar year.

E. urophylla × *E. grandis*) have exhibited the best growth. On the Darling Downs (the Warwick trial), the promising taxa are: *E. argophloia*, *E. globulus* subsp. *maidenii* and a eucalypt hybrid *E. grandis* × *E. tereticornis*. The early performance of the *Eucalyptus* interspecific hybrid seedlots from CSIR in South Africa confirms the decision to test such material prior to commercial plantations being developed.

4.7 Recommendations

This series of three trials is critical for the identification of taxa that could be suitable for the development of a viable and sustainable hardwood plantation industry in northern Australia. If maintained and properly monitored, the trials will provide a good indication of the potential of a large suite of species, provenances and hybrids in a region that until now lacked any tests of hardwood species. The trials in southern Queensland were established as replicated large block plantings. Provided these are maintained and monitored, these trials will provide long term information on taxa growth, survival, form, wood properties and can also be used to give information that will allow development of volume equations and other mensuration data essential for the development of a commercial hardwood plantation sector in marginal lands in northern Australia. It will also be possible to begin the domestication of the taxa by mild selection in the large plots of those taxa used in these trials.

Since the analyses reported here, the trials have been monitored and remeasured at age three years. It is recommended that these trials be monitored and remeasured at age five and ten years. Following each of these measures, summary reports should be written and made available to the developing hardwood industry in marginal areas of northern Australia. Furthermore, it is recommended that development of hybrids including *E. grandis* × *E. camaldulensis, E. grandis* × *E. resinifera*, *E. grandis* × *E. tereticornis* and *C. torelliana* × *C. citriodora* subsp. *variegata* continue via development of controlled pollination programs in northern Australia.

5. Vegetative propagation

5.1 Introduction

Viable plantation programs using hardy, high yielding eucalypt hybrid clones have been established in marginal areas of Brazil, India, China, and South Africa (Eldridge *et al*., 1993). These hybrids are subjected to intensive selection and clonal evaluation before they are released as proven commercial clones. The genetic gains achieved through hybrid breeding can be maximised and rapidly realised through vegetative propagation of outstanding families and individuals (Haines and Walker, 1996). Clonal testing may be undertaken using seedlings of superior families managed as hedges to retain juvenility; or by using coppice from the stumps or basal girdles of selection-age trees, with each procedure having some advantages (England *et al.,* 2000).

In northern Australia, the potential of vegetative propagation of many of the eucalypt taxa of interest, still needs to be established. One reason for this is that eucalypt taxa with potential for this region are not planted elsewhere. The Queensland Forestry Research Institute has focussed on the vegetative propagation of some of these species for the high rainfall zone, but very little work has been undertaken for the taxa suitable for marginal lands in the 650-900 mm MAR region. This trial tested the vegetative propagation of a range of eucalypt species and hybrids that have potential as plantation taxa in this region of northern Australia.

A pilot study undertaken during August 1999 developed protocols for the vegetative propagation of promising eucalypt taxa for plantation development on marginal land in northern Australia. The current trial tested the rooting ability of a suite of eucalypt species and hybrids under a range of soil mediums and rooting hormone treatments. It is expected that particular protocols may be required for optimal rooting of different species and hybrids.

5.2 Objectives

To evaluate the amenability of target eucalypt species and hybrids (with potential for development as commercial plantation varieties in marginal areas of northern Australia) to propagation as rooted cuttings.

5.3 Materials and methods

5.3.1 Experimental design

The trial employed a randomised complete block design consisting of four replicates of two potting media × two-hormone treatments. Each replicate contained 12 taxa that is, three species and nine interspecific hybrids each represented by 28 cuttings. Details of the parental hedges (seedlots) and their origins are given in Table 5.1. As the rooting ability of families and individuals in a taxa can be highly variable and highly heritable (Tibbits *et al.*, 1997), equal numbers of cuttings were taken from each hedge to ensure that an equally diverse range of cuttings were collected for each taxa.

Table 5.1. Taxa evaluated for their amenability to propagation as rooted cuttings. Seedlots are from the Forestry Tree Seed Centre unless otherwise indicated.

Taxa	**Seedlots / provenance details**
E. camaldulensis × *E. pellita*	10523 / (Shell – QFRI) hybrids (pollen from PNG *E. pellita*)
E. grandis × *E. camaldulensis*	5990-1, 5990-2, 5990-4, 5990-6 / CSIR bulks unspecified
E. grandis × *E. pellita*	10521 and 10522 / (Shell – QFRI) hybrids (pollen from PNG and Irian Jaya *E. pellita*)
E. grandis × *E. resinifera*	5991-1 / CSIR bulks unspecified
E. grandis × *E. tereticornis*	5992 / CSIR bulk unspecified
E. grandis × *E. urophylla*	5993 / CSIR bulk unspecified
E. tereticornis × *E. urophylla*	10506 / CSIR bulk unspecified
E. camaldulensis	ATSC 14518, ATSC 18304 / Tenant Creek, Petford
E. tereticornis × *E. pellita*	NA / *E. tereticornis* FNQ select × *E. pellita* 9 tree poly mix (PNG origin)
E. pellita	NA / 10 *E. pellita* selects PNG origin
E. torelliana	3551, 3120 / Flaggy Creek, Kirrima
E. urophylla × *E. pellita*	10552-10557 / (SAPPI – QFRI) hybrids (pollen from PNG and Irian Jaya *E. pellita*)

5.3.2 Treatments

Potting media

Two potting media were used in this study. These were:

- A moderately drained potting mix of 100% PBS[9] (50% of pine bark fines, 25% "Aussie" peat and 25% coarse river sand).
- A poorly drained potting mix of 50% PBS (50% of pine bark fines, 25% "Aussie" peat and 25% coarse river sand) and 50% peat.

Both potting media treatments had the same fertiliser application of three kg/m^3 of six month Osmocote.

Rooting Hormone

Two commercial rooting gels were used, Clonex gel (green) for softwood cuttings with 1.5g/1 IBA content and Clonex gel (red) for hardwood cuttings with 8.0g/1 IBA content.

The combination of potting treatments and rooting hormone treatments gave the following four treatments evaluated in this study:

- Treatment 1 = moderately drained potting mix + 1.5g/1 IBA
- Treatment 2 = moderately drained potting mix + 8.0g/1 IBA
- Treatment 3 = poorly drained potting mix + 1.5g/1 IBA
- Treatment 4 = poorly drained potting mix + 8.0g/1 IBA

Cutting collection

Cuttings were collected from the QFRI hedge bank at the DPI Forestry nursery at Beerburrum. The shoots selected for cuttings were a maximum of 30cm long. These cuttings were placed in moistened plastic bags, immersed for a short period in an ice slurry to rapidly cool the cutting prior to being placed in an icebox for transportation to Gympie.

The cuttings were set in the QFRI shade house at ambient air temperature in February 2000. Two-node cuttings from semi-lignified wood for all taxa were set in 90 ml pots in blocks. The misting system was activated for five seconds every 20 minutes.

5.3.3 Assessment and analysis

At six weeks, each cutting was removed from the potting medium and the rooting was assessed. For each taxa, the number of dead cuttings, cuttings with callous growth and no primary roots and cuttings with primary roots were recorded.

Differences in rooting percentage among taxa were analysed as a randomised complete block analysis, using treatment (rooting hormone × potting medium) and taxa as factors. Duncan's multiple range test (Duncan, 1955) on the raw data and arcsine square root transformed data were used to evaluate differences between taxa and treatments. No difference was found between the analysis of raw data and the arcsine-transformed data, so only the analysis of the raw data is reported here.

[9] This is a commercial mix used by Queensland DPI Forestry

5.4 Results

Rooting percentage was significantly affected by taxa ($P < 0.001$), treatment ($P < 0.001$) and the interaction between taxa and treatment ($P < 0.001$). Rooting across the taxa and treatments ranged from 1.8 % for *E. pellita* under treatment 1 (moderately drained potting mix + 1.5g/1 IBA) to 67% for the *E. grandis* × *E. tereticornis* taxa under treatment 2 (moderately drained potting mix + 8.0g/1 IBA; Table 5.3).

The optimal treatment for potting media and rooting hormone varied among taxa. For example, the hybrid *E. grandis* × *E. tereticornis* had significantly better rooting under treatment 2, whereas *E. camaldulensis* had significantly better rooting under Treatment 4 (Table 5.2). Some taxa were constant in their response to treatments, such as *E. grandis* × *E. camaldulensis* for which rooting percentage ranged from 33.9% to 44.6% across the four treatments. In contrast, other taxa were highly variable in their response to treatment (e.g. rooting percentage of *E. camaldulensis* × *E. pellita* ranged from 7.1% to 62.5% across the four treatments).

Best treatment conditions for each taxon are detailed below (Table 5.2):

Table 5.2. Best treatment for rooting of cuttings in propagation experiment at six weeks

Taxon	Best treatment[#] in this experiment	Rooting percentage of cuttings
E. camaldulensis	Treatment 4,	49.1%
E. camaldulensis × *E. pellita*	Treatment 4	62.5%
E. grandis × *E. camaldulensis*	Treatment 1	44.6%
E. grandis × *E. pellita*	Treatment 2	14.3%
E. grandis × *E. resinifera*	Treatment 2	17.0%
E. grandis × *E. tereticornis*	Treatment 2	67.0%
E. grandis × *E. urophylla*	Treatment 2	42.9%
E. pellita	Treatment 4	18.8%
E. torelliana	Treatment 2	23.2%
E. tereticornis × *E. pellita*	Treatment 1	25.9%
E. tereticornis × *E. urophylla*	Treatment 2	26.8%
E. urophylla × *E. pellita*	Treatment 2	25.0%

Treatment 1 = moderately drained potting mix + 1.5g/1 IBA
Treatment 2 = moderately drained potting mix + 8.0g/1 IBA
Treatment 3 = poorly drained potting mix + 1.5g/1 IBA
Treatment 4 = poorly drained potting mix + 8.0g/1 IBA

Table 5.3. Mean rooting success of *Eucalyptus* and *Corymbia* species and hybrids at six weeks

	Treatment 1			Treatment 2			Treatment 3			Treatment 4		
Taxa	Strike rate	Rank	Significance DMRT ϕ	Strike rate	Rank	Significance DMRT ϕ	Strike rate	Rank	Significance DMRT ϕ	Strike rate	Rank	Significance DMRTϕ
E. camaldulensis	26.8%	4	d	39.3%	3	bc	42.9%	1	a	49.1%	3	b
E. camaldulensis × *E. pellita*	7.1%	8	ef	12.5%	12	f	10.7%	7	c	62.5%	1	a
E. grandis × *E. camaldulensis*	44.6%	2	b	40.2%	2	b	42.0%	2	a	33.9%	5	c
E. grandis × *E. pellita*	5.4%	9	ef	14.3%	10	ef	6.3%	9	cd	14.3%	8	d
E. grandis × *E. resinifera*	11.6%	7	ef	17.0%	8	ef	1.8%	12	d	12.5%	10	de
E. grandis × *E. tereticornis*	50.0%	1	a	67.0%	1	a	38.4%	3	a	51.8%	2	b
E. grandis × *E. urophylla*	38.4%	3	c	31.3%	4	cd	20.5%	5	b	42.9%	4	b
E. pellita	1.8%	12	fg	12.5%	11	ef	2.7%	11	d	18.8%	6	d
E. torelliana	4.5%	10	ef	23.2%	7	de	2.7%	10	d	3.6%	12	f
E. tereticornis × *E. pellita*	25.9%	5	d	16.1%	9	ef	21.4%	4	b	16.1%	7	d
E. tereticornis × *E. urophylla*	3.6%	11	efg	26.8%	5	d	11.6%	6	c	6.3%	11	ef
E. urophylla × *E. pellita*	13.4%	6	e	25.0%	6	d	8.9%	8	cd	13.4%	9	de

ϕ Means with the same letter are not significantly different at $\alpha = 0.05$. Significant differences were determined using Duncan's Multiple Range Test (DMRT). The Least Significant Difference (5% LSD) is 4.1% for comparison among treatments, within each taxon. The rooting percentage of one treatment is significantly different from another if they are equal to or greater than the LSD.

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5.5 Discussion on vegetative propagation

Strike rate was highly variable between species, with mean rooting success ranging from 1.8 % for *E. pellita* under Treatment 1 to 67% for the *E. grandis* × *E. tereticornis* taxa under Treatment 2 (Table 5.3). Sachs *et al*. (1988) referred to *E. camaldulensis* as one of the most easily rooted *Eucalyptus* species as its rooting often exceeded 60% in trials, although only 49% rooting success was achieved for this species in the present study. Using the rooting success of *E. camaldulensis* as a comparison, the rooting of *E. grandis* × *E. tereticornis* and *E. camaldulensis* × *E. pellita* (67.0% and 62.5% respectively) is impressive. Other taxa with good rooting success were *E. grandis* × *E. camaldulensis* (44.6% under Treatment 1) and *E. grandis* × *E. urophylla* (42.9% under treatment 4).

All the other taxa showed moderate rooting success similar to those described by Catesby and Walker (1997a), exhibiting a range of rooting success from 14.3% to 26.8% (Table 5.3). *E. pellita* was included in this study as it is a parent of many of the hybrids and has previously shown good rooting in northern Australia (83% at 15 weeks; Catesby and Walker, 1997a). Nevertheless, the highest level of rooting observed in this study for *E. pellita* was only 18.8% under Treatment 4. The cause of this large discrepancy in rooting success is unknown. Recent reports from South Africa (Arlene Bayley pers. comm. 2000, Leakey *et al*., 1992) indicate that hedge management and nutrition are critical for the maintenance of rooting success. The *E. pellita* hedges used in this study were the same as those used by Catesby and Walker (1997a). Perhaps the hedge age, nutritional status, management or some as yet to be identified factor caused the poor rooting of this species. This needs to be further investigated.

It is interesting to note the modest rooting success of *C. torelliana* in this study (23.2%, Table 5.3) which is higher than that observed in other Australian studies. In all other studies in Australia, rooting of *Corymbia* species has been low; Catesby and Walker (1997a) achieved 0.4 to 1.8% and McComb and Wroth (1986) recorded a rooting success of 1-2% for spotted gum species. Recent reports, however, indicate that through careful management of the hedge plants in hydroponics, higher rooting may be obtained for *Corymbia maculata* (25%+, Harwood pers. comm. 2001). Even so, tissue culture is generally considered necessary for the vegetative propagation of *Corymbia* species (Gupta *et al*., 1981, McComb and Wroth, 1986, Helen Smith SFNSW pers. comm 2001). In Brazil, the better rooting hybrids of *C. torelliana* × CCC are being propagated on a commercial scale (Teotonio de Assis pers comm. 2000). With the growing interest in this hybrid in northern Australia (Chapters 3 and 4), reports of the potential for successfully rooting of *C. torelliana* and its hybrids are encouraging further investment in the development of this hybrid for marginal lands.

Of the taxa evaluated in this study, five are currently being planted as commercial plantation varieties. These are:

- *Eucalyptus camaldulensis* (in India and Thailand on marginal site, Eldridge *et al.* 1993),
- *E. pellita* (authors observations in Indonesia),
- *E. grandis* × *E. camaldulensis* hybrids in the Republic of South Africa (Gardner 2000) and Australia (authors observations),
- *E. urophylla* × *E grandis* hybrids in the Congo (Vigneron 1992, Bouvet and Vigneron 1996b) and Brazil (Wright, 1997) ,
- *E. urophylla* × *E. pellita* in commercial plantations in the Congo (Vigneron, 1992, Bouvet and Vigneron 1996a).

With the exception of *E. pellita*, all of these taxa have potential for marginal lands in northern Australia. Most of these taxa are being deployed as vegetatively propagated cuttings as this has a range of advantages for the commercial grower. As previously discussed, these include overcoming shortages of improved seed, capture of increased genetic gain (as both the additive and non-additive genetic variation is captured under vegetative propagation), enhanced uniformity of the trees and end product, and matching of genotypes to sites. These advantages are discussed in more detail in Eldridge *et al.* (1993).

The other taxa were included in this study as they have potential for marginal lands in northern Australia or they have potential as parents of hybrids that may be suited to marginal areas in northern Australia. Thus, knowledge about their rooting success is desirable.

Out of 12 taxa tested in this study, 10 taxa had higher rooting success under high levels of rooting hormone than when exposed to lower hormone levels (Table 5.3). The exceptions to this were the hybrids *E. grandis* × *E. tereticornis* and *E. tereticornis* × *E. pellita*. Generally, it is considered that higher levels of auxin promote root formation (Salisbury and Ross, 1991) although this is not always the case as seen in this study. Drainage of the potting mix also affected the rooting of different taxa, with seven taxa having better rooting on the moderately drained potting mix (Treatments 1 and 2) and four having better rooting success on the poorly drained potting mix (Treatment 4). The *E. grandis* × *E. pellita* hybrid had equal rooting success in both potting media when exposed to the higher concentration of rooting hormone (Treatments 2 and 4).

Clearly, the variation in rooting success depends on the concentration of rooting hormone and the optimal selection of potting mix. Thus, each new taxon under test will need to be screened against a range on hormone and potting mixes to find the optimal combination for that taxon. The current study has achieved this for 12 taxa but each clone within a taxon is likely to have different optimal conditions under which it will have the greatest rooting success, which will require further refinements.

When the taxa being evaluated in the taxa site matching trials (Chapter 3) reach the stage where further clonal testing is appropriate, follow up vegetative propagation studies will be required to optimise the coppicing and rooting success for each taxon and possibly for clones within a taxon. This study has evaluated the amenability of many of the taxa now established in the site matching trials in marginal areas of northern Australia to vegetatively propagation. This information will shorten the lead time required to develop sufficient clones for clonal testing and the eventual release of proven commercial clones for commercial hardwood plantations in northern Australia.

5.6 Implications and recommendations

This trial has clearly shown that no single treatment is optimal for the rooting of *Eucalyptus* and *Corymbia* species and hybrids; however, higher concentration of rooting hormone generally resulted in higher rooting success for a given potting mix. The optimal rooting treatments detailed in this report for the 12 taxa tested are a good indication of the best condition to successfully root each taxon. However, further refinement is required for each taxon and may be required for clones within a taxon. Furthermore, the poor rooting of the *E. pellita* hedges observed in this study clearly indicates that further work is required on hedge management. The effect of season on coppice and rooting success of the species appropriate for marginal areas of northern Australia also needs further study. McComb and Wroth (1986) found that root development was seasonally influenced for coppice of *E. resinifera* and *E. maculata* (now called *Corymbia maculata*). Studies need to be undertaken to determine whether a seasonal influence applies to both cutting from hedges and coppice in northern Australia.

Several other areas of research need support. These include:

- Evaluation and optimisation of coppicing and collection of cuttings from field selects.
- Assessment of untested species and hybrids for amenability to propagation as rooted cuttings. This work will need to be undertaken when appropriate tree species and hybrids (E.g. *C. torelliana* × *C. citriodora* subsp. *variegata* hybrids) are identified in the taxa trials now established in marginal areas of northern Australia.

Appendix 1

Details of seedlots supplied by the Forestry Tree Seed Centre (FSC), Queensland Department of Primary Industries – Forestry for trials in north Queensland.

Entry	Species	Provenance (all Queensland except as indicated)	Seedlot (all FSC except as indicated)	No. of seed parents	Lat. (°S)	Long. (°E)	Altitude (m)	MAR (mm)	Trial in NQ[10]
1	*C. citriodora* subsp. *variegata*	Coominglah	5589	9	24 55	151 00	400	730	2
2	*C. citriodora* subsp. *variegata*	Brooyar	10248	12	26 10	152 30	90	1143	1,2
3	*C. citriodora* subsp. *variegata*	Wondai	10253	12	26 22	151 55	350	800	1,2
4	*C. citriodora* subsp. *citriodora*	Herberton	10657	300	17 29	145 22	900	1100	1,2
5	*C. citriodora* subsp. *citriodora*	Hughenden	11148	192	20 52	144 12	325	486	1
6	*C. citriodora* subsp. *citriodora*	Cheviot Hills	3506	20	19 38	144 12	920	673	2
7	*C. citriodora* subsp. *citriodora*	Glenden,	10895	Bulk	21 10	147 53	300	740	2
8	*C. citriodora* subsp. *citriodora*	Mt Garnet	10101	12	18 00	145 11	700	832	2
9	*C. intermedia*	Wondecla	Dendros 1009	59	17 28	145 23	920	-	2
10	*C. nesophila*	Helen vale	Dendros 1011	29	15 45	145 12	400	-	2
11	*C. torelliana*	Flaggy Creek	3551	24	16 45	145 34	440	2321	2
12	*E. argophloia*	Burncluith S.F	11167	10	26 35	150 45	320	690	2
13	*E. camaldulensis*	Kennedy River	10534	68	15 26	144 11	60	900	1,2
14	*E. camaldulensis*	Laura River south of Laura	10531	61	15 39	144 33	100	903	1
15	*E. camaldulensis*	Morehead River	10540	66	15 05	143 35	100		1,2
16	*E. camaldulensis*	Palmer River	10626	28	16 05	144 45	400	1025	1
17	*E. camaldulensis*	Petford	10533	57	17 20	144 56	570	845	1
18	*E. camaldulensis*	Petford	10535	22	17 20	144 56	570	845	1
19	*E. camaldulensis*	Thailand Seed Orchard[11]	Bulk*	15					1
20	*E. camaldulensis*	Petford (Zimbabwe)	16020	47	18 56	27 48	1012	60	1
21	*E. camaldulensis*	NE Petford (Zimbabwe)	16022	42	20 23	28 30	1347	572	1,2
22	*E. camaldulensis*	Salique ex provenance selects (RSA)	10547	Bulk	25 41	28 12			1
23	*E. camaldulensis*	Walsh River, Dimbulah	10530	55	17 15	145 18	560	1100	1
24	*E. camaldulensis*	Wrotham Park (Zimbabwe)	16024	Bulk	17 48	31 03	1500	820	1
25	*E. camaldulensis*	Laura via Dongmen, China	11300	9					2
26	*E. cambageana*	Charters Towers	11124	25+	20 04	146 16	306	645	2
27	*E. cloeziana*	Herberton – Irvinebank	137	10+	17 22	145 18	800	2000	1
28	*E. cloeziana*	Mt Mulligan	10104	10	16 54	144 51	700	771	1,2
29	*E. cloeziana*	Mt Pinnacle	10105	11	17 15	145 04	600	1400	1
30	*E. cloeziana*	Helen vale	134	7	15 45	145 14	180	1300	1,2
31	*E. cloeziana*	Gympie	4363	8	26 03	152 42	220	1148	2
32	*E. cloeziana*	Koorboora	10682	10	17 32	144 56	-	-	2
33	*E. moluccana*	Gunnawarra	10684	43	17 58	145 09	640	832	2
34	*E. raveretiana*	Rockhampton	10280	4					1
35	*E. raveretiana*	Yeppoon	11025	5	23 10	150 40	50	1100	1
36	*E. tereticornis*	Helen vale	10539	35	15 45	145 14	180	1300	1
37	*E. tereticornis*	Holmes Ck (Zimbabwe)	16032	Bulk?					1,2
38	*E. tereticornis*	Mt Garnet (Zimbabwe)	10873						1

[10] Trial 1 is at Walkamin and trial 2 is at Sugarbag Station.
[11] This is a mix of seedlots from seed orchards in Thailand. Original provenances are from Petford, Thailand land race, Walsh River and Mitchell River.

Entry	Species	Provenance (all Queensland except as indicated)	Seedlot (all FSC except as indicated)	No. of seed parents	Lat. (°S)	Long. (°E)	Altitude (m)	MAR (mm)	Trial in NQ[10]
39	*E. tereticornis*	Palmer River (Zimbabwe)	10874						1,2
40	*E. tereticornis*	Laura, via Dongmen, China	5994	2					2
41	*E. tereticornis*	Mt Molloy	10538	3	16 41	145 23	365	1150	2
42	*E. tetrodonta*	Starke River	Dendros 1003	105	17 17	144 58	200	-	2
43	*E. tetrodonta*	Adelaide River, NT	ATSC 11461	2	13 21	131 07	120	-	1
44	*E. tetrodonta*	Archer River Coen	5602	2	13 27	142 57	150	1050	1
45	*E. tetrodonta*	Laura	ATSC 13673	5	15 30	144 16	152	-	1
46	*E. tetrodonta*	Mutchilba	3539	5	17 13	145 11	600	682	1,2
47	*E. grandis* × *E. camaldulensis*	CSIR, RSA	11308	10	-	-	-	-	1
48	*E. grandis* × *E. camaldulensis clones 9, 12, 13, 20*	Yuruga ex Brazil	NA	NA					2
49	*E. grandis* × *E. urophylla*	CSIR	11301	3	-	-	-	-	1
50	*K. anthothecia*	Ex Darwin, NT	NA	?					2
51	*K. senagalensis*	Burkina Faso, Africa	NA	?					2
52	*K. senagalensis*	Darwin NT	NA	?					1
53-56	*C. torelliana* × *C. citriodora* subsp. *variegata hybrids*	QFRI crosses	NA	4	-	-	-	-	2
57	*E. urophylla* × *E. camaldulensis*	CSIR, RSA	10508	8	-	-	-	-	1
58	*E. urophylla* × *E. grandis clones 58, 59, 60, 61*	Yuruga ex Brazil	NA	NA	-	-	-	-	2
59-1, 59-2	*E. urophylla* × *E. pellita hybrids*	QFRI cross	NA	2	-	-	-	-	2
60	*E. urophylla* × *E. tereticornis*	CSIR, RSA	10506	10	-	-	-	-	1

Appendix 2

Walkamin differences among entries within taxa treatment

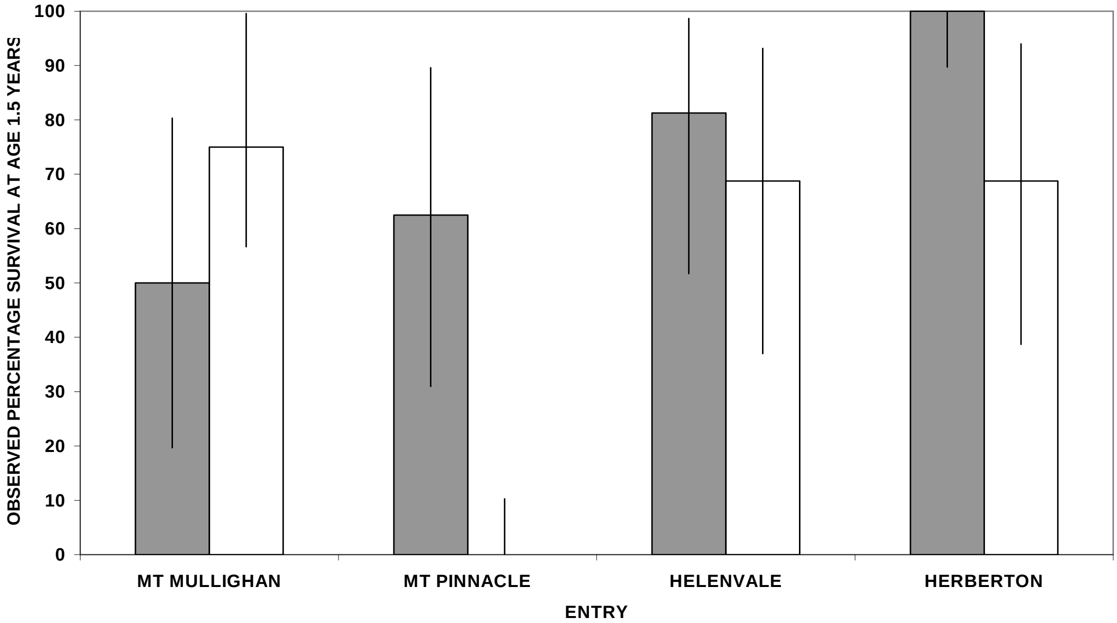
Taxa treatment 1, *E. camaldulensis* ex seed orchards
Height at age 1.5 years differed significantly among entries within this taxa treatment (P = 0.02). Both entries of *E. camaldulensis* from around Petford – Zimbabwe (entries 20 and 21) were significantly taller than *E. camaldulensis* Wrotham Park – Zimbabwe (entry 24) and *E. camaldulensis* Thailand seed orchard (entry 19) after 1.5 years (5% LSD = 0.5). Irrigated entries were significantly taller (P = 0.03) than those without irrigation, but the effect of irrigation was not significantly different among entries (P = 0.23). There was no effect of irrigation on percentage survival of useful stems at age 1.5 years (P = 0.50). Survival at 1.5 years also did not vary significantly among entries (P = 0.80) and there was no significant interaction between irrigation and entry (P = 0.40)

Taxa treatment 2, *E. camaldulensis* natural stand
For all entries, the irrigated treatment was significantly taller than the unirrigated treatment at age 1.5 years (P = 0.03). However, the effect of irrigation was not significant among entries (P = 0.85). Furthermore, there were no significant height differences among entries (P = 0.38). Survival of useful stems at age 1.5 years did not vary between irrigation treatments (P = 0.29) or among entries (P = 0.31) and no interactions were observed between survival and irrigation (P = 0.63).

Taxa treatment 3, *E. camaldulensis* mix
There was no significant impact of irrigation on entry tree height at age 1.5 years (P = 0.13), however, after combining irrigation treatments there were significant differences in height among entries (P = 0.03). Salique RSA and Petford provenance regions were significantly taller than provenances from Morehead and Laura rivers (5% LSD = 0.4, Appendix 3). There was no significant interaction between entry and irrigation (P = 0.22). Survival of useful stems at age 1.5 years did not vary between irrigation treatments or among Entries, and there was no significant interaction between irrigation and provenance (Appendix 3).

Taxa treatment 4, *E. cloeziana*
Irrigated provenances tended to grow taller than those without irrigation at age 1.5 years for all entries combined (P = 0.06) and, after pooling irrigation treatments, there was a tendency for height to vary among entries (P = 0.06). However, the effect of irrigation on tree height did not vary among entries (P = 0.96). Provenances from Herberton and Mount Mulligan were significantly taller than the provenance from Mount Pinnacle at age 1.5 years (5% LSD = 0.9, Appendix 3).

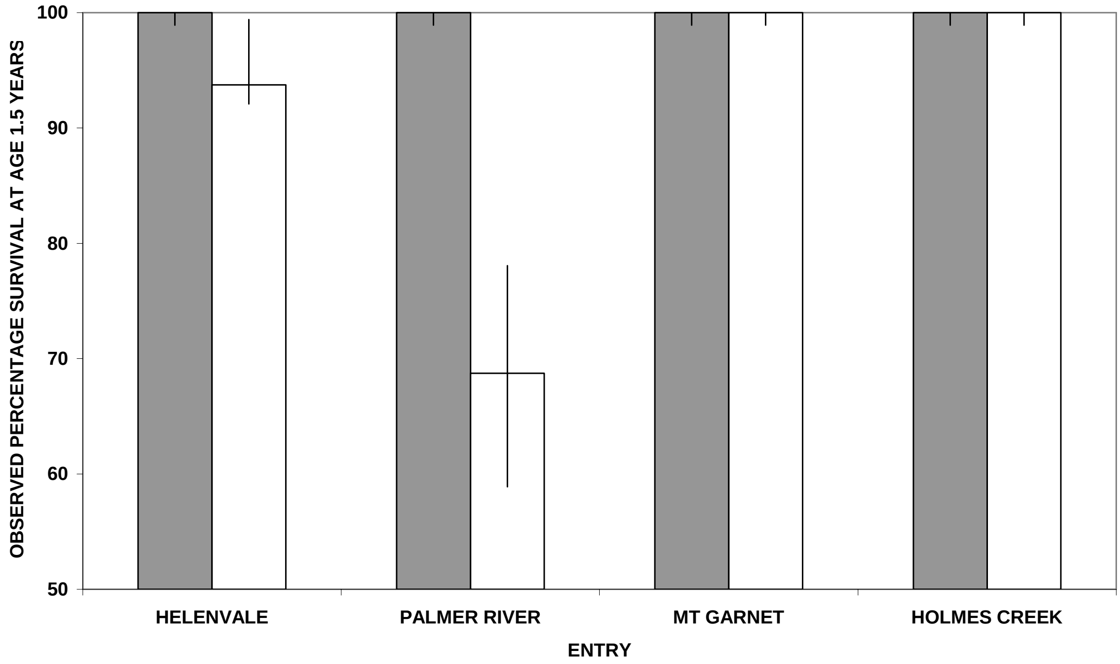
At age 1.5 years, survival of useful stems was significantly greater in irrigated blocks than in blocks without irrigation (P = 0.03). Survival varied significantly among Entries (P = 0.02) and the effect of irrigation on survival tended to vary among entries (Irrigation × entry, P = 0.06; Figure 2.4, Appendix 3). Trees from Mount Pinnacle growing on unirrigated blocks had significantly lower survival than all other unirrigated provenances (5% LSD = 0.7, Appendix 2, Fig. 1).



Appendix 2, Figure 1. Mean observed percentage survival of useful stems from each *E. cloeziana* entry for irrigated (dark) and unirrigated treatments (clear) at age 1.5 years. Lines represent the 5% LSD for the comparison of groups within the same level of irrigation treatment.

Taxa treatment 5, *E. tereticornis*
Irrigated entries tended to be taller than provenances that were unirrigated at age 1.5 years (P = 0.07), but there were no significant height differences among provenance regions after combining irrigation treatments (P = 0.27). Furthermore, the effect of irrigation did not significantly vary among provenances (P = 0.34; Appendix 3).

Irrigated taxa treatments tended to yield greater survival than unirrigated blocks (P = 0.090), and there were significant differences in survival among entries after combining irrigation treatments (P = 0.008). The effects of irrigation varied significantly among entries (Irrigation × entry: P = 0.008; Appendix 2, Fig. 2 and Appendix 3). A pair-wise comparison showed that the Palmer River provenance had significantly poorer survival in unirrigated blocks when compared to other unirrigated provenances (transformed 5% LSD = 0.2).

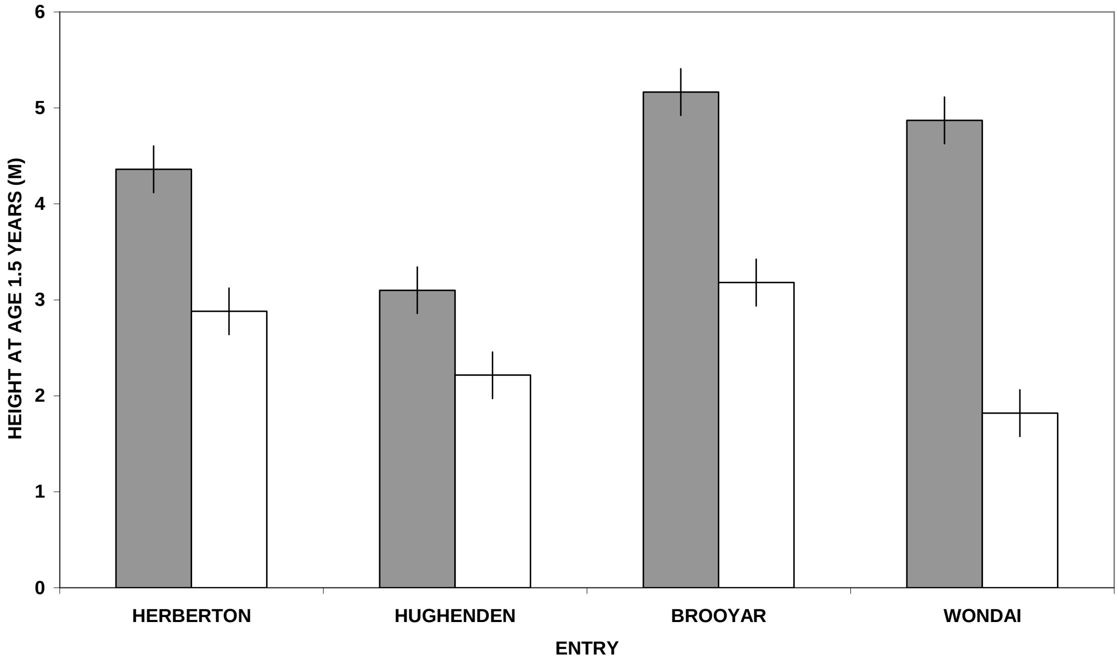


Appendix 2, Figure 2. Mean observed percentage survival of useful stems from each provenance region of *E. tereticornis* for irrigated (dark) and unirrigated (clear) treatments at age 1.5 years. Lines represent the LSD for the comparison of groups within the same level of irrigation (LSD = 0.2); the survival of one entry is significantly different from another within the same irrigation treatment if the lines do not overlap.

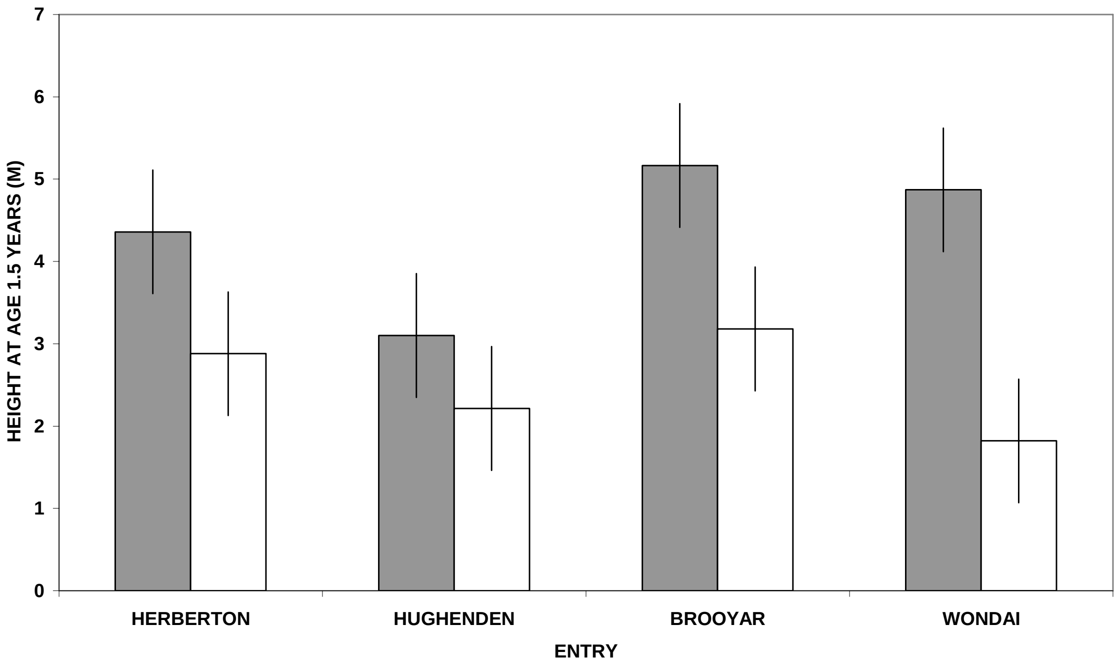
Taxa treatment 6, *Corymbia* species

The height of Corymbia species treatment was significantly greater in irrigated blocks than in unirrigated blocks at age 1.5 years ($P = 0.05$). There was also a very significant effect of entry on height growth ($P < 0.001$), which varied significantly between irrigation treatments ($P = 0.001$; Appendix 3). Trees originating from Brooyar and Wondai in irrigated blocks grew significantly taller than irrigated Herberton and Hughenden entries (5% LSD = 0.5; Appendix 2, Fig. 3). The Brooyar and Wondai entries were significantly taller in the irrigated blocks when compared to their growth under no irrigation. The height growth of the Entries from Herberton and Hughenden however, were not significantly different under the two irrigation treatments (5% LSD = 1.5, Appendix 2, Fig. 4).

There were no differences in the survival of useful stems at age 1.5 years between irrigation treatments or among entries. Furthermore, there was no significant interaction between irrigation and provenance (Appendix 3).



Appendix 2, Figure 3. Mean height (m) of useful stems from each entry of *Corymbia* spp. for irrigated (dark) and unirrigated (clear) treatments at age 1.5 years. Lines represent the LSD for the comparison of groups within the same level of irrigation (5% LSD = 0.5); the survival of one entry is significantly different from another within the same irrigation treatment if the lines do not overlap.



Appendix 2, Figure 4. Mean height (m) of useful stems from each Corymbia entry for irrigated (dark) and unirrigated (clear) treatments at age 1.5 years. Lines represent the LSD for the comparison of groups between irrigation treatments (5% LSD = 1.5); the survival of one provenance is significantly different from another of the opposite irrigation treatment if the lines do not overlap.

Taxa treatment 7, <u>*E. tetrodonta /E. raveretiana*</u>

There were significant height differences among entries at age 1.5 years (P = 0.039) but no significant difference between irrigation treatments after combining all entries. Both entries of *E. raveretiana* grew significantly taller than *E. tetrodonta* from Adelaide River. Further, the *E. raveretiana* from Rockhampton was significantly taller than *E. tetrodonta* from Mutchilba, Archer River and Laura at age 1.5 years (5% LSD = 1.1). Irrigation did not significantly influence the pattern of height growth among Entries (P = 0.45; Appendix 3).

Irrigation treatment did not significantly affect survival of useful stems (P = 0.29). Furthermore, survival did not vary significantly among provenance regions, nor was there a significant interaction between irrigation and entry survival.

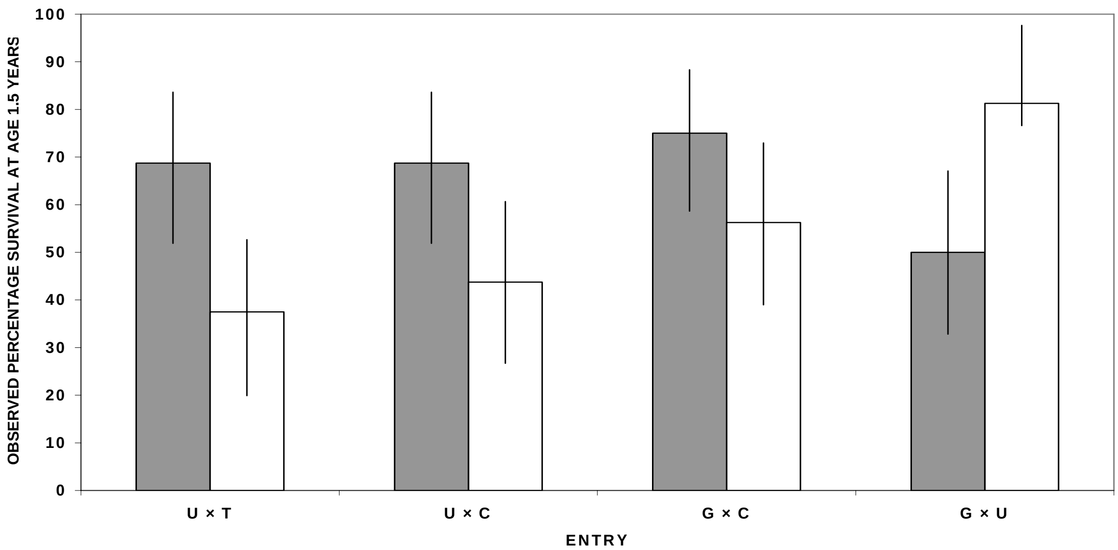
Taxa treatment 8. <u>*K. senagalensis*</u>

K. senagalensis grown in irrigated treatments were significantly taller than those in unirrigated treatments at age 1.5 years (P = 0.04). However, irrigation did not significantly influence the survival of useful stems at this age (P = 0.29; Appendix 3).

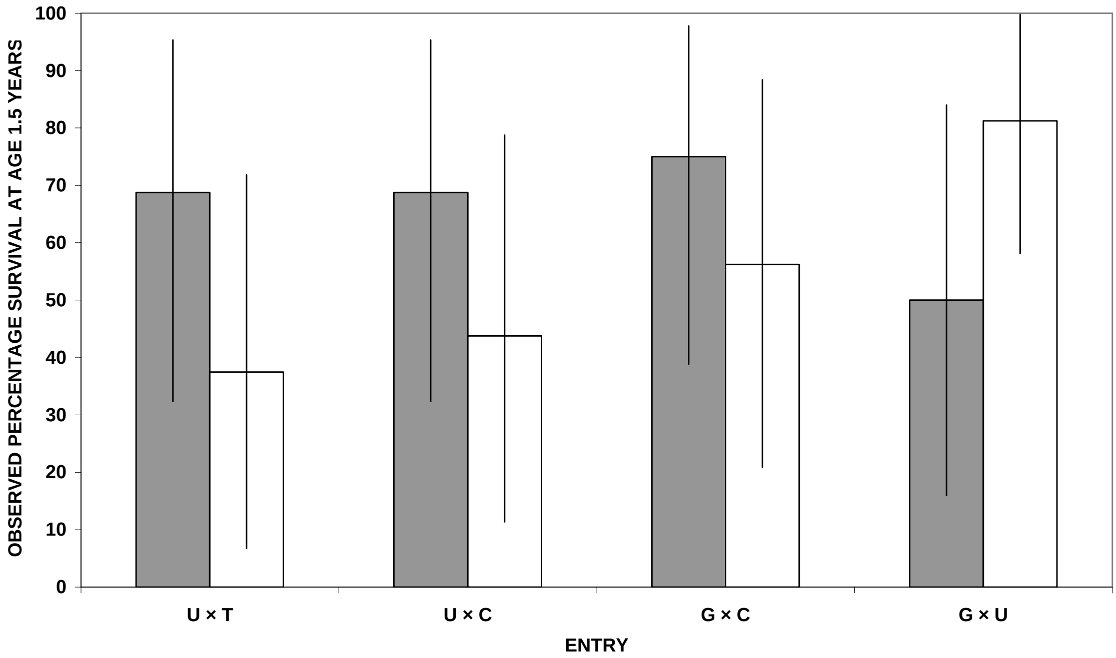
Taxa treatment 9. *Eucalyptus* hybrids

The height of hybrids was significantly greater in irrigated treatments than in treatments without irrigation (P < 0.001). There was also a tendency for height differences to occur among *Eucalyptus* hybrids when irrigation treatment was ignored (P = 0.06; Appendix 3). *E. urophylla* × *E. camaldulensis* hybrids grew significantly taller than hybrids of *E. grandis* × *E. camaldulensis* for irrigation treatments combined (5% LSD = 0.3), but differences between other hybrid pairs were not significant.

In contrast to height, there were no differences in survival of useful stems between irrigation treatments or among entries at age 1.5 years. However, there was a significant interaction between irrigation and entry (P = 0.02), with *E. grandis* × *E. urophylla* exhibiting significantly higher survival than the other three entries in the unirrigated treatment (5% LSD = 0.4; Appendix 2, Fig. 5 and Appendix 3). Pair-wise comparisons indicated that no significant differences between irrigation treatments existed for any entry (5% LSD = 0.7; Appendix 2, Fig. 6).



Appendix 2, Figure 5. Mean observed percentage survival of useful stems from each hybrid for irrigated (dark) and unirrigated (clear) treatments at age 1.5 years. Lines represent the LSD for the comparison of hybrids ***within*** the same irrigation treatment (transformed 5% LSD = 0.4); the survival of one hybrid is significantly different from another within the same irrigation treatment if the lines do not overlap.



Appendix 2, Figure 6. Mean observed percentage survival of useful stems from each hybrid for irrigated (dark) and unirrigated (clear) treatments at age 1.5 years. Lines represent the Least Significant Difference for the comparison of hybrids ***between*** irrigation levels (transformed 5% LSD = 0.7); the survival of one hybrid is significantly different from another of the opposite irrigation treatment if the lines do not overlap.

Appendix 3

Mean observed height (m) and survival of useful stems (%) for all combinations of irrigation and provenance region treatments at age 1.5 years at Walkamin.

Taxa Treatment	Provenance / seedlot (entry no.)	Irrigatio n	Height (m) (mean ± se)	Survival stems (%) (mean ± se)
1 (*E. camaldulensis* ex seed orchards)	Petford – ex Zimbabwe (20)	+	3.2 ± 0.1	93.8 ± 6.3
		-	2.2 ± 0.1	81.3 ± 6.3
	Wrotham Park – ex Zimbabwe (24)	+	2.9 ± 0.3	87.5 ± 12.5
		-	1.2 ± 0.0	62.5 ± 37.5
	NE Petford – ex Zimbabwe (21)	+	3.7 ± 0.5	100.0 ± 0.0
		-	1.8 ± 0.2	75.0 ± 12.5
	Thailand seed orchard (19)	+	3.0 ± 0.4	81.3 ± 18.8
		-	1.4 ± 0.1	100.0 ± 0.0
2 (*E. camaldulensis* natural stand)	Walsh River (23)	+	3.6 ± 0.2	93.8 ± 6.3
		-	1.8 ± 0.1	93.8 ± 6.3
	Kennedy River (13)	+	3.5 ± 0.1	93.8 ± 6.3
		-	2.2 ± 0.2	93.8 ± 6.3
	Palmer River (16)	+	2.9 ± 0.9	93.8 ± 6.3
		-	1.6 ± 0.4	68.8 ± 18.8
	Petford (18)	+	3.6 ± 0.2	100.0 ± 0.0
		-	2.1 ± 0.0	100.0 ± 0.0
3 (*E. camaldulensis* mix)	Morehead River (15)	+	2.7 ± 0.3	100.0 ± 0.0
		-	2.0 ± 0.4	100.0 ± 0.0
	Laura River south of Laura (4)	+	2.7 ± 0.3	100.0 ± 0.0
		-	1.7 ± 0.2	93.8 ± 6.3
	Petford (17)	+	3.4 ± 0.1	100.0 ± 0.0
		-	2.0 ± 0.2	93.8 ± 6.3
	Salique provenance selects RSA (22)	+	3.2 ± 0.2	100.0 ± 0.0
		-	2.3 ± 0.6	100.0 ± 0.0
4 (*E. cloeziana*)	Mt Mulligan (28)	+	3.1 ± 0.5	50.0 ± 0.0
		-	2.0 ± 0.3	75.0 ± 25.0
	Mt Pinnacle (29)	+	2.0 ± 0.4	62.5 ± 12.5
		-	—	0.0 ± 0.0
	Helen vale (30)	+	2.5 ± 0.2	81.3 ± 6.3
		-	1.5 ± 0.2	68.8 ± 6.3
	Herberton (27)	+	3.2 ± 0.5	100.0 ± 0.0
		-	2.0 ± 0.3	68.8 ± 18.8
5 (*E. tereticornis*)	Helen vale (36)	+	2.8 ± 0.4	100.0 ± 0.0
		-	1.9 ± 0.3	93.8 ± 6.3
	Palmer River (39)	+	3.0 ± 0.3	100.0 ± 0.0
		-	2.5 ± 0.3	68.8 ± 6.3
	Mt Garnet – ex Zimbabwe (38)	+	3.2 ± 0.3	100.0 ± 0.0
		-	1.6 ± 0.1	100.0 ± 0.0
	Holmes Creek – ex Zimbabwe (37)	+	2.6 ± 0.0	100.0 ± 0.0
		-	1.7 ± 0.4	100.0 ± 0.0
6 (*Corymbia* spp.)	*CCC* Herberton (4)	+	4.4 ± 0.1	93.8 ± 6.3
		-	2.9 ± 0.3	93.8 ± 6.3
	CCC Hughenden (5)	+	3.1 ± 0.2	93.8 ± 6.3
		-	2.2 ± 0.5	100.0 ± 0.0
	CCV Brooyar (2)	+	5.2 ± 0.1	93.8 ± 6.3
		-	3.2 ± 0.6	81.3 ± 18.8

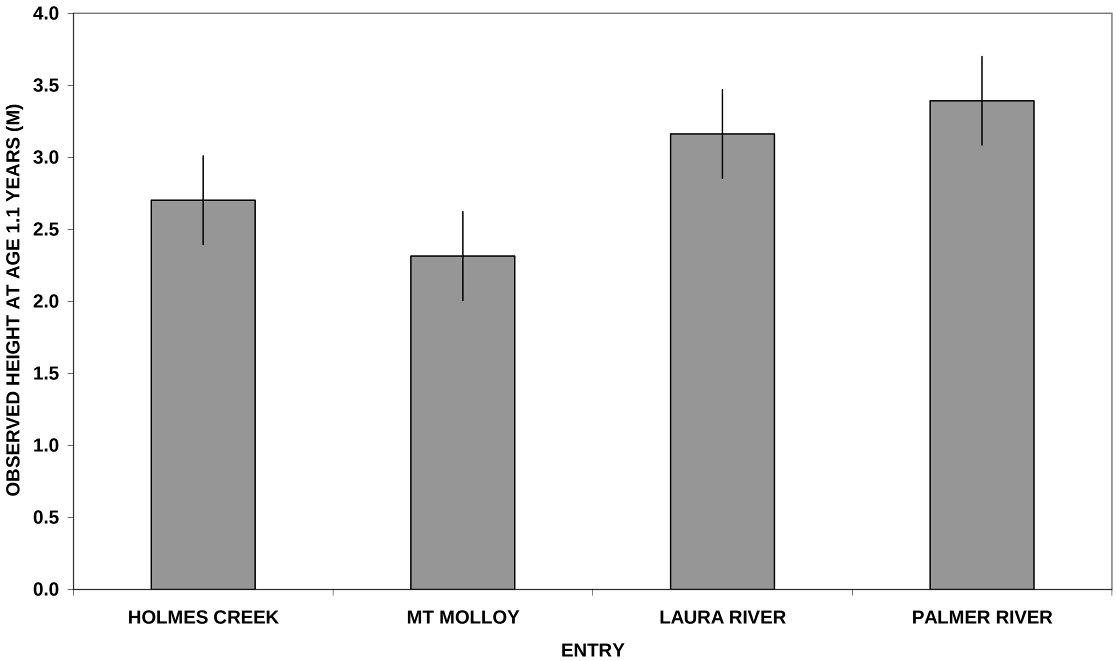
Taxa Treatment	Provenance / seedlot (entry no.)	Irrigation	Height (m) (mean ± se)	Survival stems (%) (mean ± se)
(Corymbia spp. cont.)	*CCV* Wondai (3)	+	4.9 ± 0.1	100.0 ± 0.0
		-	1.8 ± 0.2	93.8 ± 6.3
7 (*E. tetradonta / E. raveretiana*)	*E. tetrodonta* Mutchilba (46)	+	1.3 ± 0.1	43.8 ± 6.3
		-	0.6	18.8 ± 18.8
	E. tetrodonta Archer River (44)	+	0.7 ± 0.1	62.5 ± 12.5
		-	0.8 ± 0.0	25.0 ± 12.5
	E. tetrodonta Laura (45)	+	0.7 ± 0.1	40.0 ± 20.0
		-	0.4	10.0 ± 10.0
	E. tetrodonta Adelaide River (43)	+	0.9	16.7 ± 16.7
		-	—	0.0 ± 0.0
	E. raveretiana Rockhampton (34)	+	2.8 ± 0.7	75.0 ± 25.0
		-	1.4	50.0 ± 50.0
	E. raveretiana Yeppoon (35)	+	2.3 ± 1.0	75.0 ± 0.0
		-	1.1 ± 0.2	75.0 ± 25.0
8 (*K. senagalensis*)	Ex Darwin NT (52)	+	1.5 ± 0.1	96.9 ± 3.1
		-	0.9 ± 0.1	84.4 ± 9.4
9 (*Eucalyptus* hybrids)	*E. urophylla* × *E. tereticornis* (60)	+	2.0 ± 0.0	68.8 ± 6.3
		-	0.9 ± 0.2	37.5 ± 25.0
	E. urophylla × *E. camaldulensis* (57)	+	2.3 ± 0.2	68.8 ± 6.3
		-	1.1 ± 0.0	43.8 ± 18.8
	E. grandis × *E. camaldulensis* (47)	+	1.6 ± 0.0	75.0 ± 0.0
		-	0.9 ± 0.1	56.3 ± 6.3
	E. grandis × *E. urophylla* (49)	+	2.0 ± 0.1	50.0 ± 12.5
		-	1.0 ± 0.1	81.3 ± 18.8

Appendix 4

Sugarbag differences among entries within taxa treatments

Taxa treatment 1. *E. camaldulensis*
The four provenance regions did not significantly vary in height (P = 0.64) or in survival of useful stems (P = 0.631; Appendix 5) at age one year.

Taxa treatment 2. *E. tereticornis*
There were significant height differences among provenance regions at 12 months (P = 0.02, Appendix 5). *E. tereticornis* from Palmer River was significantly taller than trees from Holmes Creek and Mount Molloy (5% LSD = 0.6; Appendix 4, Fig. 1). Laura River was also significantly taller than Mount Molloy. Survival of useful stems did not vary significantly among provenance regions at this measure (P = 0.77; Appendix 5).



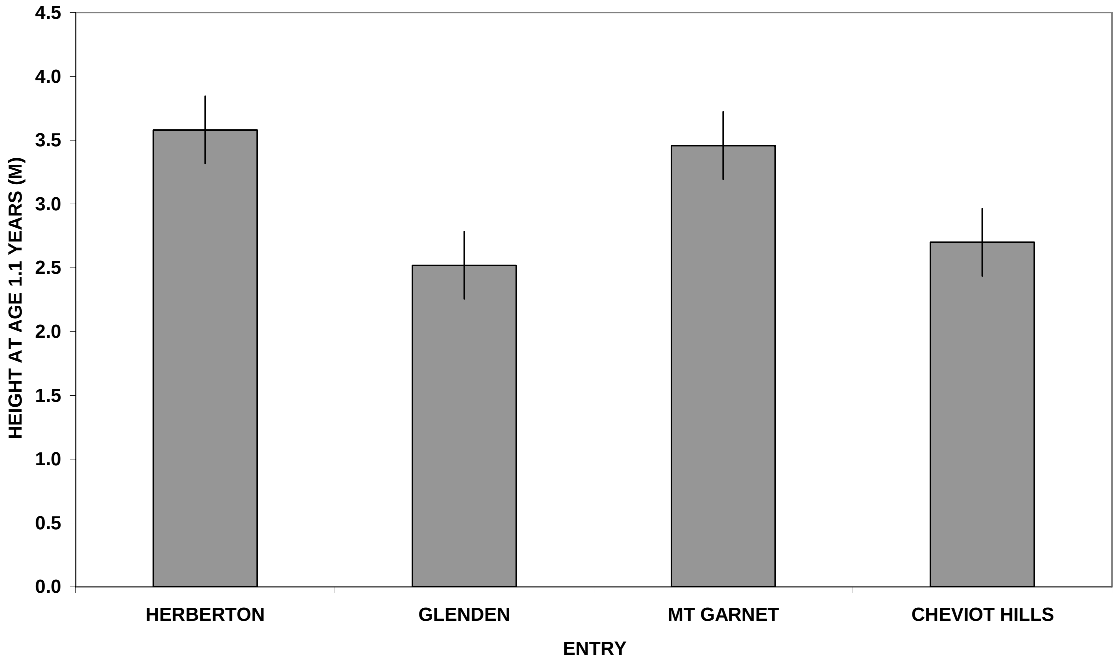
Appendix 4, Figure 1. Observed mean height (m) for *E. tereticornis* entries at 12 months at Sugarbag Station. Lines represent the 5% LSD of 0.6. If the lines did not overlap the difference in height was significantly different.

Taxa treatment 3. *E. tetrodonta / E. urophylla* × *E. pellita* hybrids
Height and survival varied significantly among entries at one year of age (height: P = 0.003; survival: P = 0.001; Appendix 5). The height of *E. urophylla* × *E. pellita* hybrids was significantly taller than *E. tetrodonta* from Starke River, Mutchilba and Coen. (5% LSD range 1.1 to 1.6). Furthermore, survival of useful stems was significantly greater for *E. urophylla* × *E. pellita* hybrids than for *E. tetrodonta* from Starke River and Mutchilba (5% LSD range 0.4 to 0.7). The survival of *E. tetrodonta* from Coen was not significantly different from the survival of *E. urophylla* × *E. pellita* (entry 59-1), although it was significantly lower than the survival of *E. urophylla* × *E. pellita* (entry 59-2; 5% LSD = 0.7).

Taxa treatment 4. *E. cloeziana*
There were no significant differences in height or survival among provenance regions at age one year (height: P = 0.97; survival: P = 0.66; Appendix 5).

Taxa treatment 5. *C. citriodora* subsp. *citriodora*

Height varied significantly among entries at age one year (P = 0.003; Appendix 5). The entries from Herberton and Mount Garnet were significantly taller than those from Glenden or Cheviot Hills (5% LSD = 0.5; Appendix 4, Fig. 2). Survival of useful stems did not vary significantly among entries (P = 0.76; Appendix 5).



Appendix 4, Figure 2. Mean height (m) for entries of *C. citriodora* subsp. *citriodora* at 12 months at Sugarbag Station. Lines represent the Least Significant Difference for comparisons among entries (5% LSD = 0.5); the height of one provenance region is significantly different from another if the lines do not overlap.

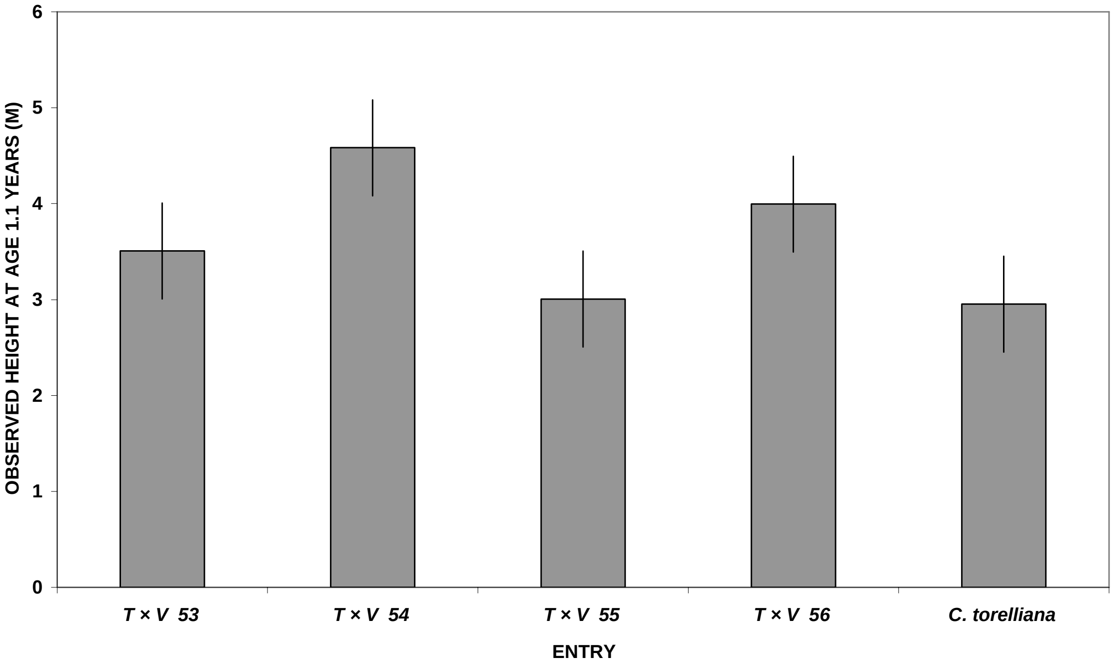
Taxa treatment 6. *C. citriodora* subsp. *variegata, C. torelliana and their hybrids*

a. *C. citriodora* subsp. *variegata*
There was no significant effect of entry on tree height or survival of useful stems at 12 months (height: P = 0.15; survival: P = 0.79; Appendix 5).

b. *C. torelliana* × *C. citriodora* subsp. *variegata* and *C. torelliana*
The *C. torelliana* and the *C. torelliana* hybrids were in the same line plot and were subsequently analysed separately from the *C. citriodora* subsp. *variegata*. The height varied significantly among entry numbers at age one year (P = 0.02). Entry 54 (*C. torelliana* × *C. citriodora* subsp. *variegata*) reached the greatest height, being significantly taller than entry 53 (*C. torelliana* × *C. citriodora* subsp. *variegata*) and entry 55 (5% LSD = 1.0, Appendix 4, Fig. 3.). Survival of useful stems did not significantly differ among entry numbers (P = 0.227, Appendix 5).

Taxa treatment 7. Mixed eucalypts (*E. argophloia* / *E. cambageana / E. moluccana / E. nesophila*)
There were no significant differences among these four eucalyptus species for height or survival at age one year (height: P = 0.19; survival: P = 0.54; Appendix 5).

Taxa treatment 8. *E. grandis* × *E. camaldulensis*
There were no differences in height or survival of useful stems among provenance regions at one year (height: P = 0.39; survival: P = 0.44; Appendix 5).



Appendix 4, Figure 3. Mean observed height (m) for hybrid crosses of *C. torelliana* × *C. citriodora subsp. variegata* and pure *C. torelliana* at one year at Sugarbag Station. Lines represent the Least Significant Difference for comparisons among entries (5% LSD = 1.0); the height of one entry is significantly different from another if the lines do not overlap.

Taxa treatment 9. *E. urophylla* × *E. grandis*
Height and survival of useful stems did not vary significantly among provenance regions at one year (height: P = 0.20; survival: P = 0.44; Appendix 5).

Taxa treatment 10. *Khaya* spp.
K. senagalensis was significantly taller and exhibited greater survival than *K. anthothecia* at one year of age (height: P = 0.04; survival: P = 0.03; Appendix 5)

Appendix 5

Mean observed height (m) and survival of useful stems (%) for all provenance region treatments at one year as Sugarbag Station.

Taxa treatment	Provenance (entry no.)	**Height (m) (mean ± se)**	**Survival of useful stems (%) (mean ± se)**
1 (*E. camaldulensis*)	Kennedy River (13)	3.0 ± 0.1	100.0 ± 0.0
	Morehead River (15)	2.9 ± 0.1	100.0 ± 0.0
	Laura via Dongmen, China (25)	3.0 ± 0.2	97.5 ± 2.5
	NE Petford ex Zimbabwe (21)	3.2 ± 0.2	97.5 ± 2.5
2 (*E. tereticornis*)	Holmes Creek – ex Zimbabwe (37)	2.8 ± 0.4	93.3 ± 3.3
	Mt Molloy (41)	2.3 ± 0.2	86.7 ± 6.7
	Laura via Dongmen, China (40)	3.1 ± 0.1	100.0 ± 0.0
	Palmer River (39)	3.4 ± 0.2	96.7 ± 3.3
3 (*E. tetrodonta* / *E. urophylla* × *E. pellita* hybrids)	Starke River (42)	1.1 ± 0.5	22.5 ± 13.1
	Mutchilba (46)	1.4 ± 0.1	15.8 ± 9.2
	Archer River Coen (44)	0.8	60
	urophylla × *pellita* (59-1)	3.5 ± 0.3	77.5 ± 2.5
	urophylla × *pellita* (59-2)	3.6 ± 0.2	92.5 ± 4.8
4 (*E. cloeziana*)	Koorboora (32)	1.6 ± 0.2	60.0 ± 9.1
	Mt Mulligan (28)	1.7 ± 0.2	45.0 ± 11.9
	Helen vale (30)	1.6 ± 0.1	57.5 ± 19.7
	Gympie (31)	1.6 ± 0.3	55.0 ± 17.1
5 (*C. citriodora* subsp. *citriodora*)	Herberton (4)	3.6 ± 0.4	90.0 ± 4.1
	Glenden (7)	2.5 ± 0.1	85.0 ± 8.7
	Mt Garnet (8)	3.5 ± 0.2	95.0 ± 2.9
	Cheviot Hills (6)	2.7 ± 0.3	92.5 ± 2.5
6 (*C. citriodora* subsp. *variegata*, *C. torelliana* and *C. torelliana* × *C. citriodora* subsp. *variegata* hybrids)	Coominglah (1)	2.6 ± 0.2	92.5 ± 4.8
	Brooyar (2)	3.0 ± 0.3	87.5 ± 4.8
	Wondai (3)	2.3 ± 0.2	92.5 ± 4.8
	torelliana × *variegata* (53)	3.5 ± 0.7	62.5 ± 23.9
	torelliana × *variegata* (54)	4.6 ± 0.3	100.0 ± 0.0
	torelliana × *variegata* (55)	3.0 ± 0.5	87.5 ± 12.5
	torelliana × *variegata* (56)	4.0 ± 0.2	100.0 ± 0.0
	C. torelliana ex Flaggy Creek (11)	3.0 ± 0.2	100.0 ± 0.0
7 (Mixed eucalypts)	*E. argophloia* Burncluith (12)	1.3 ± 0.1	90.0 ± 7.1
	E. cambageana Charters Towers (26)	1.2 ± 0.1	82.5 ± 7.5
	E. moluccana Gunnawarra (33)	1.6 ± 0.2	90.0 ± 4.1
	C. nesophila (10)	1.1 ± 0.2	72.5 ± 12.5
8 (*E. grandis* × *E. camaldulensis* clones (Yuruga ex Brazil))	GxC Clone (48-12)	4.2 ± 0.2	100.0 ± 0.0
	GxC Clone (48-13)	3.7 ± 0.2	100.0 ± 0.0
	GxC Clone (48-20)	3.7 ± 0.5	97.5 ± 2.5
	GxC Clone (48-9)	3.8 ± 0.4	100.0 ± 0.0
9 (*E. urophylla* × *E. grandis* clones (Yuruga ex Brazil))	UxC Clone (58-58)	3.0 ± 0.4	100.0 ± 0.0
	UxC Clone (58-59)	3.4 ± 0.4	92.5 ± 2.5
	UxC Clone (58-60)	3.6 ± 0.5	87.5 ± 9.5
	UxC Clone (58-61)	3.2 ± 0.5	90.0 ± 7.1
10 (*Khaya* spp).	Burkino Faso, Africa (51)	0.9 ± 0.0	91.7 ± 6.2
	K. anthothecia Ex Darwin, NT (50)	0.5 ± 0.1	55.0 ± 6.5

Appendix 6

Height, survival and rank of taxa planted for three southern Queensland trials, where rank is based on mean height relative to all other taxa within the same trial.

Entry Number	Species	Provenances[12]	Wooroolin (10 months)			Kingaroy (15 months)			Warwick (24 months)		
			Height (m)	**Survival (%)**	**Rank**	**Height (m)**	**Survival (%)**	**Rank**	**Height (m)**	**Survival (%)**	**Rank**
43	*E. grandis* × *E. urophylla*	CSIR bulk RSA	1.2 ± 0.1	71.2 ± 13.5	7	4.0 ± 0.2	92.8 ± 1.9	8			
50	*E. globulus* subsp. *maidenii*	Bolaro Mt, NSW	1.0 ± 0.1	81.7 ± 17.1	11	4.3 ± 0.1	98.1 ± 1.9	3	3.1 ± 0.2	80.2 ± 9.1	2
63	*Araucaria cunninghamii*	Yarraman CSOs	0.4 ± 0.0	79.2 ± 7.3	13	0.9 ± 0.1	98.8 ± 0.7	13			
64	*C. citriodora* subsp. *citriodora*	Gladstone	1.1 ± 0.1	84.2 ± 6.0	10				1.1 ± 0.2	52.1 ± 12.0	12
66	*C. citriodora* subsp. *variegata*	Woondum	1.3 ± 0.2	83.3 ± 10.4	5				1.5 ± 0.2	50.0 ± 7.9	10
67	*C. citriodora* subsp. *variegata*	Brooyar	1.4 ± 0.2	95.0 ± 2.5	4				1.3 ± 0.2	33.3 ± 2.8	11
69	*E. argophloia*	SF302 Ballon				2.5 ± 0.2	96.9 ± 0.6	12	3.5 ± 0.2	96.9 ± 1.8	1
70	*E. cloeziana*	Wolvi	1.0 ± 0.1	67.4 ± 13.9	11				2.3 ± 0.2	68.8 ± 15.4	9
71	*E. cloeziana*	Mungy	1.2 ± 0.1	95.9 ± 3.0	7						
72	*E. drepanophylla*	Mt Mee SF				3.1 ± 0.0	98.8 ± 0.7	10			
73	*E. dunnii*	Urbenville NSW				4.2 ± 0.2	97.5 ± 1.0	4			
74	*E. dunnii*	SAPPI, RSA	1.2 ± 0.1	74.2 ± 7.9	7	4.6 ± 0.3	96.3 ± 0.7	1			
76	*E. globulus* subsp. *maidenii*	Bondi SF, NSW				4.1 ± 0.2	96.3 ± 3.0	5	2.9 ± 0.1	76.0 ± 5.8	5
77	*E. longirostrata*	Coominglah				4.1 ± 0.1	93.4 ± 0.6	5	3.0 ± 0.2	96.9 ± 1.8	4
79	*E. tereticornis*	SF60 Rundle				3.0 ± 0.1	95.8 ± 2.1	11	2.5 ± 0.1	89.6 ± 2.1	7
80	*E. tereticornis*	Laura ex Zimbabwe				3.3 ± 0.1	99.4 ± 0.6	9	2.4 ± 0.1	91.7 ± 5.2	8
81	*E. grandis* × *E. camaldulensis*	CSIR bulk RSA	1.3 ± 0.2	68.3 ± 13.4	5						
82	*E. grandis* × *E. resinifera*	CSIR bulk RSA				4.6 ± 0.1	96.9 ± 1.5	1			
83	*E. grandis* × *E. tereticornis*	CSIR bulk RSA				4.1 ± 0.2	94.6 ± 1.8	5	3.1 ± 0.0	89.6 ± 2.1	2
97	*E. urophylla* × *E. grandis*	CSIR bulk RSA	1.6 ± 0.1	77.5 ± 6.6	2						
98	*E. resinifera* × *E. grandis*	CSIR bulk RSA	1.5 ± 0.1	96.7 ± 3.3	3						
99	*E. tereticornis* × *E. grandis*	CSIR bulk RSA	1.7 ± 0.2	92.5 ± 5.2	1						
100	*E. grandis* × *E. camaldulensis*	CSIR bulk RSA							2.7 ± 0.1	92.7 ± 4.5	6

[12] Provenances are from Queensland unless indicated.

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