Achievements in forest tree genetic improvement in Australia and New Zealand 3: Tree improvement of *Eucalyptus dunnii* Maiden

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Summary

Eucalyptus dunnii Maiden has been widely planted in subtropical Australia, with a total of almost 39 000 ha established in commercial plantations in northern NSW and southern Queensland. Internationally, it has become recognised as a premium pulpwood species and its sawing properties have been considered superior to those of *Eucalyptus grandis*. Forests NSW established a pedigreed tree improvement program for *E. dunnii* in 1995, and this is the most advanced program for this species in Australia. The main breeding population has been characterised for both pulpwood and sawlog traits, and improving the timber's dimensional stability during drying has been identified as a priority of the program. As clonal propagation of *E. dunnii* by cuttings is not an economic means to deploy improved germplasm into commercial plantations, Forests NSW has established three clonal seed orchards for solid wood and pulp end uses, and plans to establish a fourth in 2007. A range of *E. dunnii* hybrids with high-value timber species has been produced with the aim of improving the wood properties of the species.

Keywords: breeding programs; hybrids; wood properties; shrinkage; dimensional stability; pulpwood; propagation; *Eucalyptus dunnii*

Introduction

Eucalyptus dunnii Maiden (Dunn's white gum) is a member of the subgenus *Symphyomyrtus* section *Maidenaria* (Pryor and Johnson 1971). It is a species of limited natural distribution, having two disjunct populations in north-eastern New South Wales (NSW) and extending into south-eastern Queensland (Boland *et al.* 1984; Brooker and Kleinig 1999). The species occurs on moist, highly fertile soils of basaltic or alluvial origin, with a summer rainfall regime and a mean annual rainfall of 1100–1500 mm, and predominantly at altitudes of 400–650 m (Benson and Hager 1993).

Within NSW, Regional Forest Agreements (RFAs) between the State and Commonwealth governments have led to a reduction in the area of native forest that is available for harvest. Forests NSW (formerly State Forests of NSW) reintroduced a hardwood plantation program in 1994 with the aim of eventually supplementing the wood supply from native forests.

Prior to 1994, Forests NSW had established only 93 ha of *E. dunnii* plantations. Since that time the species has become important to the organisation, with over 8500 ha established — 32% of the total hardwood planted in the period (Forests NSW MIS data) — although the significance of the species in the annual planting program is now declining. Private forestry companies in subtropical Australia have almost 30 000 ha established for diverse uses, and a recent planting rate of > 5000 ha y^{-1}.

Eucalyptus dunnii has been viewed as an alternative species to *E. grandis* W.Hill ex Maiden (flooded gum), versatile enough to be planted on a wide range of sites, although this perception has led to the species being planted 'off site' in a number of cases. In trial plantings in northern NSW, *E. dunnii* has equalled or outperformed *E. grandis* in growth on some sites (Johnson and Stanton 1993), with the additional benefit of being better adapted to drier or frost-prone sites (Johnson and Arnold 2000).

Eucalyptus dunnii is commonly subjected to leaf defoliation by Christmas beetles but, when compared to *E. grandis*, generally shows little susceptibility to wood borers such as cossid moth, wood moth and longicorn beetles (Carnegie 2002) that cause significant damage to trees and their timber (Phillips 1996). With the expansion of *E. dunnii* plantations, the psyllid, *Creiis lituratis*, has become a significant insect defoliator of young plantations in north-eastern NSW and south-eastern Queensland and a serious problem, particularly where trees are stressed (Carnegie and Angel 2005). Recently it has been found that *E. dunnii* trees that are stressed, for instance by psyllid attack, are also susceptible to cossid moth (A. Carnegie, NSW Department of Primary Industries, West Pennant Hills, *pers. comm.*, 2006).

Economically viable protocols for the vegetative propagation of *E. dunnii* have yet to be developed, so current plantation establishment is by seedlings. Catesby and Walker (1997) considered the species to be recalcitrant in vegetative propagation, with cuttings harvested from 40 seedling-based hedges having a mean rooting success of 3.2% at nine weeks, and 97.5% of clones having less than 30% rooting of cuttings. Results of initial Forests NSW studies were similar[1]; subsequent studies using potted mother

[1]Smith, H.J. and Bacon, K.A. (2003) Vegetative propagation of plantation eucalypts. A practical manual for the propagation of eucalypts for the North Coast region of NSW. State Forests of NSW Confidential Internal Report, West Pennant Hills, NSW. 75 pp.

plants, flood irrigated with defined nutrient solutions to optimise production of minicuttings, have been unable to identify a method to economically propagate this species by cuttings (C. Moran, Forests NSW Grafton, *pers. comm*., 2004).

Eucalyptus dunnii timber from native forests has a basic density of 610 kg m^{-3} and is used for light construction such as building framework and joinery (Bootle 2005). The heartwood is of low durability and therefore not suitable for external use (Boland *et al.* 1984; Bootle 2005). *Eucalyptus dunnii* is becoming an internationally-favoured species for pulp, and extensive areas are being planted in southern China, and Central and South America, as well as on the eastern seaboard of Australia. Plantation-grown *E. dunnii* has pulping properties similar to those of plantation-grown *E. grandis* (Swain and Gardner 2003), but a higher pulp yield and superior paper-making properties (Backman and De León 1998). In studies on the Forests NSW breeding population, mean pulp yield was found to be 53.3% for the high-quality Boambee site and 50.1% for the lower-quality Megan site (Henson and Vanclay 2004).

The suitability of *E. dunnii* for solid wood products has been addressed in a number of studies (Calori and Kikuti 1997; Dickson *et al*. 2003; Henson *et al.* 2004; Joe *et al.* 2004). Problems include dimensional stability during drying, probably resulting from high growth stresses and high differential shrinkage. The species has a reputation for end-splitting, but South African trials showed that there are family differences for this trait; trees can be selected for little splitting and therefore used for both mining and sawn timber production (Swain and Gardner 2003). Similarly Dickson *et al*. (2003) found that 9- and 25-y-old plantation-grown trees produced timber that was of acceptable hardness and strength for a range of solid-wood end uses, although wood quality varied significantly within and among trees. Studies by Forests NSW and Southern Cross University (Henson *et al.* 2004; Murphy *et al*. 2005; Thinley *et al*. 2005) have found that most wood property traits are under moderate or high genetic control, suggesting there is the potential to improve such traits through tree improvement programs.

Breeding objectives

The Forests NSW Tree Improvement Strategic Plan[2] identifies three general breeding objectives for all species under genetic improvement. These are:

1. Growth — to optimise productivity in terms of volume of the plantation crop
2. Quality — to ensure that every plant established has the potential to produce an economic stem (i.e. one that is 'fit for purpose')
3. Adaptability — to reduce risk of economic losses through plantation failure, by breeding trees that are resistant or tolerant to pests and/or diseases and are adapted to their target planting environment (e.g., frost and drought tolerant).

Forests NSW plans to complete, in the next few years, a comprehensive study of breeding objectives for eucalypt plantations and associated processing industries on the north coast of NSW. It is expected that one of the outputs of this study will be economic weights for key traits to be improved in important commercial species.

Improving productivity

A high priority for Forests NSW will always be improving forest productivity. The weighting placed on quality and adaptability traits will vary depending on the species' inherent wood properties and risks in target plantation environments. The financial importance of the increased productivity that can be achieved using improved genetic material is indicated in a study by Henson and Vanclay (2004): a plantation established on a high-quality site using improved genetic planting stock had an internal rate of return (IRR) of 13.0–13.6%, compared to an IRR of 11.4–11.6% for a plantation established using wild planting stock on the same site. On the poorer site only improved material resulted in the plantation returning a profit.

Improving wood properties

As timber from plantation-grown *E. dunnii* has high differential shrinkage, reducing that shrinkage is currently a major objective of the improvement program. Bandara (2006) found that mean annual increment (under bark, standing), Pilodyn penetration (a measure of wood density) and tangential shrinkage are the best selection criteria for the objective of maximising profit for a vertically-integrated, grower–processor flooring production system for *E. dunnii*.

Improving pest tolerance

Creiis lituratus has caused substantial economic loses in *E. dunnii* plantations on the north coast of NSW, with up to 500 ha classified as 'failed' or deemed 'unsalvageable' in both Forests NSW and private plantations in the past 6 y (A. Carnegie, NSW Department of Primary Industries West Pennant Hills, *pers. comm*., 2006). While the pest outbreak may be an indirect result of prolonged and severe drought and severe damage to trees associated with 'off site' planting, individual trees exhibiting tolerance to *C. lituratus* attack have been identified (Carnegie and Angel 2005) and propagated for inclusion in the breeding program. Intra-specific hybridisation is being considered as an option to overcome the *C. lituratus* problem.

Improving pulpwood properties

Forests NSW has made clonal selections from the breeding population for pulpwood production and has developed a Near Infrared Analysis model for pulpwood prediction in collaboration with the Brisbane Forestry Research Centre (Muneri *et al*. 2005, 2007). Maximising pulp production and quality is not a key objective for the improvement of *E. dunnii* in Forests NSW estate. However, the organisation maintains a pulpwood deployment population to provide seed to both domestic and international pulpwood companies.

[2]Forests NSW Tree Improvement Program (2006) Strategic Plan 2006–2007. Forests NSW Confidential Internal Report, Coffs Harbour, NSW. 6 pp.

Breeding strategy

Currently Forests NSW has one main *E. dunnii* breeding population consisting of 219 open-pollinated families from natural provenance collections. These are being tested on two sites in northern NSW in progeny trials established in 1995. It is planned to establish a second population as progeny trials across four sites in northern NSW in autumn 2007. This will consist of 190 new families composed of new native provenance collections (139 families), 31 families selected from provenance and progeny trials in NSW, and 20 families from trees selected in plantations. In addition, 77 families from the 1995 trials will be included on three of the sites, to link the two series of trials.

The long-term strategy will be to maintain a single multipurpose main population. Over the next few years, selections will be made in the 1995 progeny trials for the establishment of the second-generation main population, and selections from the 2007 trials will be infused into the second generation over time. Two solid-wood elite populations will be selected along with a single pulpwood elite population. Each elite population will consist of 15 clones, and will be the focus of the pure species and hybrid breeding programs, with the aim of providing selected clonal material to be included in the deployment populations.

The production and testing of interspecific hybrids, with *E. dunnii* as one of the parents, is being investigated as a strategy to improve wood quality and to produce genotypes better suited to poorer sites, which in turn may overcome the *Creiis* problem. Forests NSW has successfully crossed *E. dunnii* with *E. pellita* F.Muell., *E. resinifera* Smith and *E. longirostrata* (Blakely) L.A.S.Johnson & K.D.Hill with the aim of improving the sawlog value of the species. Hybrids of *E. urophylla* × *E. dunnii* created by Shell Forestry and tested in Queensland and South America have shown great growth potential, and Forests NSW has recently imported more of this material from South America. Natural hybrids of *E. dunnii* × *E. tereticornis* have been identified in the nursery and it is hoped to test this material along with *E. dunnii* × *E. longirostrata* and *E. dunnii* × *E. urophylla* on drier sites.

Hybrid production may also help overcome the problems with vegetative propagation of *E. dunnii*. Forests NSW established about 4 ha of potential open-pollinated *E. dunnii* × *E. grandis* hybrids in 2004. In 2005, 11 superior trees were selected and felled, and eight of the 11 trees were propagated from coppice. The rooting of minicuttings from these coppice-based mother plants is being investigated, and early results suggest that propagation may be more successful than for *E. dunnii* (C. Moran, Forests NSW Grafton, *pers. comm.*, 2006).

Progeny trials

A breeding population, consisting of two progeny trials on contrasting Forests NSW sites in the Coffs Harbour–Dorrigo region (Fig. 1), was established in February 1995. Boambee is a low-altitude (60 m asl) mild coastal ex-hardwood plantation site, while the Megan site — formerly pasture — is at higher altitude (730 m asl) and colder (Johnson and Arnold 2000). Site and trial details are shown in Table 1. Both progeny trials were established with seedlings from 219 open-pollinated family seedlots collected from 14 provenances. Each family was represented by six replicates of four-tree plots. The trials were designed as incomplete blocks with a row–column layout.

Assessment of trials

The two progeny trials were first assessed in May 1998, at age 39 months. Survival at both sites (86% and 93%) was high. The growth of the trees at the Megan site is poorer than at Boambee, although the rankings of provenances at the two sites were generally similar. Frosts, repeated heavy insect infestations and the relatively shallow soils at the Megan site may all have had a

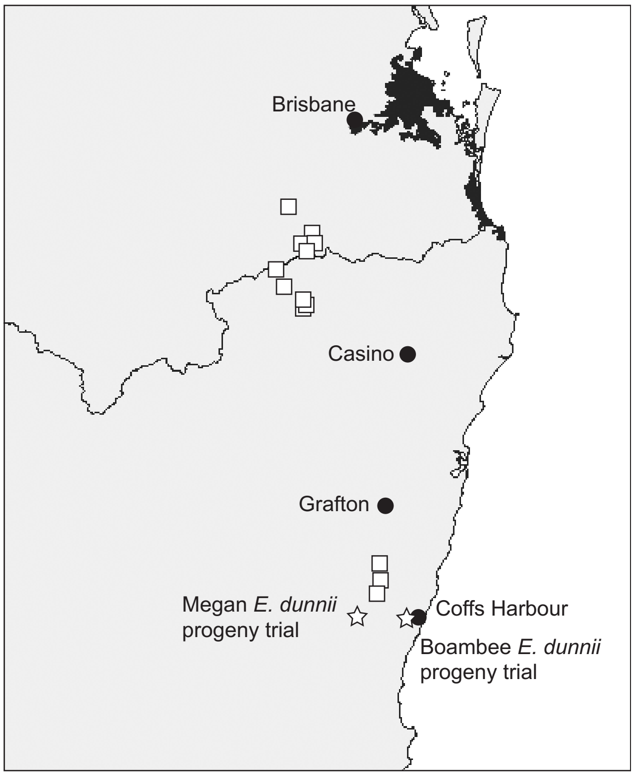

Figure 1. Location of provenances included in Forests NSW breeding population (white squares) and the two progeny trial locations (stars) in NSW

Table 1. *Eucalyptus dunnii* progeny trial site details

Site Name	Boambee	Megan
State	NSW	NSW
Property	Boambee SF	Wild Cattle Creek SF
Latitude/Longitude	30º18'S/153º03'E	30º17'S/152º47'E
Annual rainfall (mm)	1900	1600
Altitude (m)	60	730
Soils	Yellow podzolic	Yellow podzolic
Planting date	February 1995	March 1995
Replicates	6	6
Design	Row–column	Row–column
Plot size	4-tree row	4-tree row
No. families	219	219
Total no. of trees	5280[a]	5280[a]

[a] Includes one *E. grandis* bulk seedlot control

detrimental affect on growth at that site (Johnson and Arnold 2000).

Subsequent assessments were made at 75, 98, 102 and 108 months. Measurements included growth (height, diameter at breast height over bark (dbhob)), stem straightness and stem taper, but the primary focus has been on wood properties. At 75 months, bark-to-bark increment cores at a height of 0.9 m were taken from five trees from each of 50 families and assessed for basic density and collapse (Arnold *et al*. 2004). At 98 months, destructively-sampled trees from the better-performing families common to the Boambee and Megan trials were assessed for a number of pulpwood traits. Samples from the more productive site at Boambee had higher basic density and pulp yield, and longer fibres (Muneri *et al*. 2007).

At 102 months, the Boambee trial was reassessed for growth, tree form and density (using the Pilodyn). At 108 months, wood properties were assessed using increment coring (215 trees) and a range of non-destructive assessment tools including FAKOPP (a longitudinal stress wave acoustic device, Henson *et al*. 2004), and growth strain was assessed using resistance gauges (Murphy *et al*. 2005). One hundred and eighty one trees were destructively sampled and over 50 traits were assessed (Henson *et al*. 2004). In addition 40 trees from 27 families were sawn and kiln dried, then scored for potential value-limiting defects (Harwood *et al*. 2005). Results from this assessment have provided important information on the variation and genetic control of key wood properties, as well as the efficiency and effectiveness of a range of assessment techniques.

Genetic parameters

Heritabilities for some key traits are listed in Table 2, but for more detailed information see Arnold *et al*. (2004) and Henson *et al*. (2004). Cross-site genetic correlation between Megan and Boambee for dbhob at 6 y was 0.79 (se 0.14), suggesting that there is no significant genotype × site interaction for growth traits. Diameter (dbhob) and Pilodyn readings at 108 months were found to have a weak phenotypic correlation of 0.24 and a genetic correlation of 0.07 (se ±0.14), suggesting there is no genetic correlation between density and growth.

Deployment strategy

As clonal propagation of *E. dunnii* is variable and uneconomic for commercial production, delivery of genetically improved material to operational plantations is through production of improved seed and deployment as seedlings.

Seedling seed orchards

The Boambee progeny trial was selectively thinned in June 1999 at age 52 months using the results of the 39-month assessment, retaining the best two trees per four-tree plot. Flowering has not been widespread to date. Further thinning of the trial will take place in early 2007 to retain the best tree per four-tree plot. This site will then be managed as an open-pollinated seedling seed orchard (SSO). The Megan trial will be reassessed in 2007/2008 and is expected to be thinned on the basis of the assessment.

Clonal seed orchards

Forests NSW has established three joint-venture clonal seed orchards (CSOs) with private landholders, and ramets for a further CSO have been grafted for planting in 2007. The earliest of these CSOs was established in November 2002, in collaboration with CSIRO and a landholder, with 28 clones from eight provenances selected for volume, form and wood properties (density and collapse assessed on cores) from the Boambee and Megan progeny trials. Survival in this orchard has been poor, as grafted ramets of *E. dunnii* were found to suffer from later-age incompatibility at the graft union. Similar graft incompatibility has been reported in South Africa (Swain and Gardner 2003). Despite these setbacks, the CSO produced its first limited seed crop in summer 2005/2006. A small commercial seed crop has recently been harvested (December 2006). The estimated operational genetic gains from these clones, over the trial mean at age 75 months, is 22% for dbhob at 6 y, but nothing for density based on the 9-y Pilodyn assessment. Operational genetic gain is calculated to be half of the additive genetic gain.

The second CSO was established in 2005 after the destructive pulpwood evaluation (Muneri *et al.* 2005, 2007). A total of 50 elite clones from 11 provenances selected for pulpwood traits and volume from the Boambee progeny trial are included in the orchard, together with a further eight pulpwood selects from a progeny trial established by Dendrotech Pty Ltd in Eden. The estimated operational genetic gain for the Boambee clones in this orchard, over the trial mean at age 102 months, is 15% for dbhob and 7% for Pilodyn value (a positive gain in this value signifying an increase in density).

Table 2. Heritabilities for key traits of *Eucalyptus dunnii* from assessment of Boambee progeny trial[+]

Age (months)	Trait	*n*	Mean	CV (%)	h^2 (se)
102	Volume (m^3)	2031	0.37	54	0.302 (0.077)
102	Pilodyn 6J (mm)	2031	12.36	13	0.510 (0.085)
108	Tangential shrinkage (%)	179	11.7	18	0.695 (0.311)
108	Radial shrinkage (%)	180	3.1	19	0.562 (0.305)
108	Differential shrinkage	179	3.9		
108	MOR (MPa)	176	110.9	14	0.515 (0.320)
108	MOE (MPa)	176	16 466	13	0.263 (0.296)

[+] Data from Henson *et al*. (2004)

The third CSO planted in 2006 has been established with clones selected for solid-wood performance; it contains 11 clones selected for structural properties and 14 clones selected for dimensional stability. Predicted family additive genetic gains from the clones selected for structural properties are 4% for modulus of elasticity and 16% for hardness (expressing the gains as improvement over the average of 47 assessed families). The clones selected for stability have an estimated family additive genetic gain of 13% for reduced tangential shrinkage. The orchard as a whole has an operational genetic gain in dbhob of 16% over the trial mean at 102 months. The fourth CSO to be established in 2007 will contain the same clones.

Other organisations

Several organisations have established genetic trials for *E. dunnii* that have subsequently been managed as seedling seed orchards.

The Forest Products Commission (FPC) of Western Australia established a progeny trial containing 80 families, from eight provenances, on two sites in south-western WA in July 1996. These trials had some families in common with families in the Forests NSW progeny trials. Both sites were in the Manjimup region, one with high rainfall and fertile soils, the other a dryland site on sandy soils. Both trials were assessed in 2000. The more fertile site was thinned to three trees per family (originally established with ten replicates per family in single-tree plots), while the second site has been retained at the original stocking. The thinned trial has been managed as an open-pollinated SSO, and for the past two years has produced limited amounts of seed from many of the provenances (L. Barbour, Forest Products Commission WA, Wanneroo, *pers. comm.*, 2006).

CSIRO Forestry and Forest Products established three joint-venture progeny trials around Deniliquin, in southern NSW, in 1996. The trials consist of a subset of about 120 of the families represented in the 1995 series of the Forests NSW trials. With Deniliquin's mediterranean climate the flood-irrigated sites do not represent a typical commercial plantation environment for *E. dunnii*. However, the sites have been found to promote flowering and the normally shy-flowering *E. dunnii* has produced flowers at a relatively early age. Two of the three trials have been thinned to the best tree per plot (the trial was originally established with four-tree line plots), and are used as SSOs, but unfortunately the best trial was damaged by fire in 2005. CSIRO (now Ensis Genetics) established two second-generation progeny trials in the same region in 2005.

In 2000, Queensland Department of Primary Industries–Forestry established *E. dunnii* provenance/progeny trials on two sites in southern Queensland at Mount Binga and Pechey. The trials contain 21 improved pedigreed seedlots imported from South Africa, with an additional 80 families being represented in bulk seedlots (Queensland Government Department of Primary Industries 2003). One of the trials has been thinned to final stocking and is now producing small quantities of seed, while the other has been retained at high stocking for making selections and carrying out wood properties studies (D. Lee, Queensland Department of Primary Industries and Fisheries, Gympie, *pers. comm.*, 2006).

Hancock Victoria Plantations have two *E. dunnii* progeny trials established in 1989 at Stockdale and Jeeralang in Gippsland, Victoria. Both trials contain 57 families from four provenances, and one site has been assessed (dbh, density) and converted to an SSO (S. Elms, Hancock Victoria Plantations, Churchill, *pers. comm.*, 2007).

Conclusion

With the expanding establishment of *E. dunnii* plantations within north-eastern NSW and south-eastern Queensland, for both solid wood and pulp end uses, there is a continued need for the development of genetically-improved planting stock for specific end uses. The Forests NSW tree improvement program for *E. dunnii* will soon move into the second generation, and continue to develop and refine selections for the deployment populations to service both the local solid-wood industry as well as the domestic and international pulp industry.

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