

# Achievements in forest tree genetic improvement in Australia and New Zealand

## 1: *Eucalyptus pilularis* Smith tree improvement in Australia

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### Summary

*Eucalyptus pilularis* Smith (blackbutt) is an important commercial plantation species on the north coast of NSW, with the first plantations being established in 1939. In 1997 Forests NSW established its first breeding population of *E. pilularis* and in the subsequent 9 y the organisation has undertaken an aggressive improvement program for the species. Forests NSW has established 4.9 ha of clonal seed orchards of *E. pilularis*, and in parallel, is developing clones for commercial deployment through selection and testing. The Forests NSW tree improvement program for *E. pilularis* places heavy emphasis on improving the wood properties of young plantation-grown material so it can successfully replace wood from the native forest resource that is the feedstock for the established processing industry in the region.

**Keywords:** breeding programs; clones, seed orchards; wood density; *Eucalyptus pilularis*; New South Wales

### Introduction

*Eucalyptus pilularis* Smith (blackbutt) is a member of the subgenus *Eucalyptus* (the Monocalypts) section *Pseudophloius* as defined by Brooker and Kleinig (1999). It occurs naturally in coastal regions of New South Wales (NSW) and south-eastern Queensland from south of Bega, NSW, (37°30'S) to Maryborough, Queensland, (25°30'S), including Fraser Island, and at altitudes from near sea level to 600 m (Boland *et al.* 1984). It generally grows on gentle hill slopes between the sea and the coastal escarpment of the Great Dividing Range. It is a key species for high-quality log production from native forests in these regions, and also a major plantation species within its natural range. The species is well known for site specificity — well drained soils of moderate to high fertility, and sites that are frost free with a reliable rainfall >900 mm y<sup>-1</sup> (Queensland Department of Primary Industries and Fisheries 2006).

*Eucalyptus pilularis* is the principal species of hardwood timber sawn in northern coastal NSW. It is a high-quality timber, with a number of uses including poles, sleepers, decking, flooring, furniture and building framework (Timber Development Association (NSW) Ltd 2003; Bootle 2005). In 2005/2006, about 217 000 m<sup>3</sup> of *E. pilularis* logs were harvested from state forests in the northern coastal areas of NSW, of which over 60% was for

high-quality solid-wood products (Forests NSW MIS data). The volume of high-quality product was almost 20% of the total product harvest for hardwoods from native forests and plantations in the north coast area for 2005/2006. Regional Forest Agreements (RFAs) between the NSW and Commonwealth governments have led to the transfer of some north coast state forests to the national park estate. The reduction in area of harvestable native forest has provided the impetus for plantations to supply a greater proportion of the log quota needed to support the industry in the future.

The first planting of *E. pilularis* established by Forests NSW (formerly State Forests of NSW) was in 1939 in Whian Whian State Forest near Mullumbimby, and this was managed as a commercial plantation using silvicultural regimes to optimise growth, including being thinned in 1955 (Grant 1989). About 15 000 ha of *E. pilularis* plantations have been established by Forests NSW, mainly in northern NSW. In recent years the program has aimed to supplement the supply of high-quality logs from native forests for the sawlog market. *Eucalyptus pilularis* has become an increasingly important species within this program due to its expected high wood quality. Since 1994, 4820 ha of *E. pilularis* have been established in new commercial plantations by Forests NSW (Forests NSW MIS data). In addition, sites originally planted by Australian Paper Manufacturers Ltd to *Eucalyptus grandis* W.Hill ex Maiden, for pulp, are being converted in the second rotation to plantations that specifically focus on log production for solid wood and veneer. *Eucalyptus pilularis* is the species of choice for these plantations, and other species are advised for planting only when factors site-limiting for *E. pilularis* exist<sup>1</sup>.

*Eucalyptus pilularis* tends to suffer less leaf damage from insects and fungal diseases than species in the subgenus *Symphyomyrtus* (Simpson *et al.* 1997). This, along with its inherent wood qualities, makes it an ideal species for growing in plantations in its natural range, where pest and disease pressures can be great. The large range of insects that commonly attack *Symphyomyrtus*

<sup>1</sup>Kearney, D. (2005) Forests NSW North Coast hardwood plantation strategy Part 1 — native forest operations estate. Forests NSW confidential report, Coffs Harbour, NSW.

species (e.g. *E. grandis* and *E. dunnii*), often limit the commercial viability of these species in plantations (Carnegie 2002).

Deployment of *E. pilularis* into commercial plantations has been problematic. Seed production may be unreliable, with great variation in the extent of flowering between sites, and large bud crops dropping buds before flowering (Florence 1964). Development of seed for this species is lengthy, with the average time from bud initiation to flowering being 15 months or longer (Law *et al.* 2000), and the interval between flowering and mature seed being about 12 months (Florence 1964; Gunn 2001). Seed viability is often low, with average estimates at around 500–700 viable seeds per 10 g (Florence 1964; Gunn 2001).

*Eucalyptus pilularis* seedlings often have poor root quality, being affected by j-root and root coiling (Heagney *et al.* 2006). When seedlings are established in plantations, this phenomenon, in conjunction with the shallow-rooting habit of the species, often leads to instability, resulting in socketing, buttsweep and wind-throw. While post-planting mortality is generally low, it may be up to 10% after heavy rainfall or in years of high winds (Carnegie 1999). Plants derived from vegetative propagules, particularly minicuttings, have a root architecture that is different to that of seedlings and do not have j-root deformation (Thomas and Henson 2005).

Forests NSW commenced a limited tree improvement program for *E. pilularis* in 1964 when 11 provenance trials were established on the coast and northern escarpment of NSW (Johnson and Stanton 1993). With the greater importance of *E. pilularis* as a plantation species in the post-1994 plantation program, a pedigreed program was initiated in the mid-1990s to produce superior genotypes for solid wood production<sup>2</sup> (Johnson and Nikles 1997; Smith *et al.* 2004). Deployment issues have also been addressed in recent years (Henson and Smith 2004; Smith *et al.* 2004).

## Breeding objectives and strategy

### Breeding objectives

A breeding plan was written by Johnson and Nikles (1997) for developing and deploying genetically improved material of *E. pilularis* in NSW. The breeding objective was identified as ‘the efficient, cyclical establishment and management of a number of breeding and propagation populations, for the accumulation of favourable genes, and the realisation of large genetic gains in yield and quality of plantation sawlogs, poles and veneer logs on per-hectare, per-year and per-cost bases’.

The Forests NSW Tree Improvement Strategic Plan<sup>3</sup> identifies three general breeding objectives for all species under genetic improvement. These are:

- i) Growth — to optimise the productivity in terms of volume of the plantation crop
- ii) Quality — to ensure that every plant established has the potential to produce an economic stem (i.e. one that is ‘fit for purpose’)
- iii) 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 a comprehensive breeding objectives study for eucalypt plantations and associated processing industries on the north coast of NSW in the next few years. One of the expected outputs of this study is economic weights for key traits for important commercial species, including *E. pilularis*.

The principal objective for improvement of *E. pilularis* will always be increasing productivity of the forest estate by improving growth and form traits, while maintaining desirable solid-wood properties. The weighting placed on quality and adaptability trait objectives will vary depending on the species’ inherent wood properties and the exposure to risk in target environments. Given its high wood quality and the preference for the species by local sawmillers, maintaining or improving solid-wood properties must have a high priority within the breeding program. Forests NSW, in collaboration with Southern Cross University, is undertaking an extensive study of the wood properties of the *E. pilularis* breeding population, and the results will define the solid-wood traits of importance for plantation-grown trees.

Recently, extending the planting range of *E. pilularis* has become an issue of importance as optimal sites for *E. pilularis* become rarer and less economic to plant, due to competition by other land uses and the high land costs. Increasing the potential range of sites for economically planting *E. pilularis* has become a key objective for the breeding program. Interspecific hybridisation of selected *E. pilularis* clones with other members of the subgenus *Eucalyptus* — able to tolerate heavier and less well structured clay soils and frosts — is being investigated to enhance its adaptation to sites with these characteristics, while maintaining the high-quality solid-wood product of *E. pilularis*.

### Breeding strategy

The breeding strategy was initially one of genetic improvement within species, using a single population established from selected plus trees in native forests and older plantations. Forests NSW has a single breeding population consisting of open-pollinated families from 38 provenances, established in progeny trials on three sites in northern NSW.

It is the target in the next 10 years that all Forests NSW commercial plantations of *E. pilularis* will be established using clones. To this end, two elite populations were selected and established at the Grafton Forest Technology Centre in 2005. Each population consists of ten clones from ten different provenances, and will be used for controlled crosses, both within and between the elite populations, with the seed being used to establish clonal selection blocks.

<sup>2</sup>Johnson, I.G. (2002) Blackbutt (*E. pilularis*) breeding seedling orchards — growth and form at age 3 years, and selection for clonal seed orchards. State Forests of NSW, confidential unpublished report, West Pennant Hills, NSW. 70 pp.

<sup>3</sup>Forests NSW Tree Improvement Program (2006) Strategic Plan 2006–2007. Forests NSW confidential internal report, Coffs Harbour, NSW. 6 pp.

The second generation of the breeding population will be established in 2009, with selected material from the three NSW open-pollinated progeny trials, the two elite populations, control-pollinated and open-pollinated clonal seed orchard seedlings, and with infusion of material from selected provenances.

Hybrids of *Eucalyptus agglomerata* Maiden and *E. pilularis* have been found in the Forests NSW nursery, originating from seed collected from a thinned *E. agglomerata* progeny trial established with an *E. pilularis* control seedlot (Johnson and Kaldor 1998). Exploitation of 'natural' hybrids as well the production of hybrids of selected *E. pilularis* clones with other stringybarks, through controlled pollination, is being investigated. Crossing of *E. pilularis* with *E. agglomerata* and *Eucalyptus laevopinea* R. Baker may produce germplasm tolerant of frost-prone sites, while hybridising with *Eucalyptus pyrocarpa* L. Johnson and Blaxell, *Eucalyptus planchoniana* F. Muell. and the white stringybarks, including *Eucalyptus nigra* R. Baker and *Eucalyptus tindaliae* Blakely, may produce better growth on heavier clay soils. Field trials of hybrids between *E. pilularis* and *E. planchoniana* were established by Forests NSW as early as 1964.

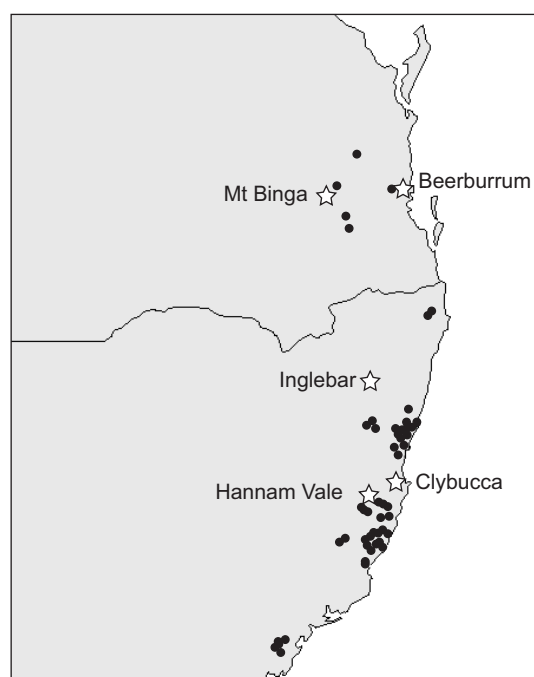
## Selecting and testing superior trees

### Selection of trees in base population

From late 1993 to 1995, intensive phenotypic selection of superior trees was undertaken in high-quality natural stands and older commercial plantations within central and northern coastal NSW. The NSW south coast sites and sandy coastal sites such as Myall Lakes were not included in the selections due to their poor performance in previous provenance trials (Johnson and Stanton 1993). In all, 600 trees were selected, but resource restraints, logistical difficulties and natural factors reduced seed collection to about 310 open-pollinated families from 34 provenances.

## Progeny trials

The progeny trials referred to in the breeding strategy section were established during 1997 and 1998, on three Forests NSW sites on the north coast of NSW (Fig. 1). These range from a high-quality fertile site with reliable rainfall near Hannam Vale (150 m asl), to a less fertile site near Clybucca (150 m asl), to a more marginal site at Inglebar (295 m asl), an 'inland' site where drought is more likely to occur. Full site details are in Table 1.



**Figure 1.** Provenances of *Eucalyptus pilularis* with families included in progeny trials (dots) and location of the five progeny trials (stars)

**Table 1.** Details of *Eucalyptus pilularis* progeny trial sites in New South Wales and Queensland

Attribute	Hannam Vale	Clybucca	Inglebar	Beerburrum	Mt Binga
State	NSW	NSW	NSW	Queensland	Queensland
Property	Buttsworth LP	Rolleston LP	Inglebar Station	Tripconys LA SF 611	Mt Binga SF 258
Latitude/Longitude	31°40'S, 152°33'E	30°54'S, 152°55'E	29°31'S, 152°36'E	26°56'S, 153°01'E	27°00'S, 151°59'E
Annual rainfall (mm)	1500	1260	1200	1505	941
Altitude (m)	150–170	150–170	285–305	15	600
Soils	Deep yellow earths to yellow podzolics	Deep red earths and red podzolics, shallower yellow podzolics	Deep red and yellow podzolics		Red lateritic kraznozom
Planting date	March 1997	March 1998	February 1998	March 1998	March 1998
Replicates	6	4	4	5	5
Design	Row–column: 18R × 17C	Row–column: 18R × 18C	ICB, 22 blocks × 14 plots	ICB, 95 blocks × 12 plots	ICB, 95 blocks × 12 plots
Plot size	4-tree row	4-tree row	4-tree row	4-tree row	4-tree row
No. families	308	324	308	228	228
No. provenances	37	38	38	37	39
Total no. trees	7344	5184	4928	4560	4560
No. trees in control seedlots	120	48	48	60	0
No. trees in treatment seedlots	7224	5136	4880	4500	4560

**Table 2.** Family matrix for *Eucalyptus pilularis* progeny trials (number of families common between trials)

Site	Site				
	Hannam Vale	Clybucca	Inglebar	Beerburrum	Mt Binga
Hannam Vale	308	265	258	135	151
Clybucca		324	308	166	171
Inglebar			308	160	162
Beerburrum				228	100
Mt Binga					228

The progeny trials incorporate seedling progeny from open-pollinated family seedlots, from 307 of the NSW selected plus trees and 52 plus tree selections from natural stands in Queensland. Five unimproved bulk seedlots were used as controls. Thirty-eight provenances are represented within the breeding population with a maximum of 324 families at any one site. Each family is represented by either four or six replicates of four-tree plots. The trials are designed as incomplete blocks with a row–column layout.

Queensland Department of Primary Industries and Fisheries, Horticulture and Forestry Science (then Queensland Forest Research Institute) also established two progeny trials at Beerburrum and Mt Binga (Fig. 1, Table 1) in 1998, containing many of the families included in the NSW trials (Table 2). A total of 356 families drawn from the species range was planted, including 248 families from NSW State Forests and 108 families from the south-eastern and south-western regions of Queensland (Collins 1998). One hundred families are common to both trials. At both sites, the progeny trial is planted in five replicates of four-tree line plots using a randomised incomplete block design (Collins 1998).

### Other resources

In addition to the breeding populations, the two main NSW sites at Hannam Vale and Clybucca were planted with:

- Family selection blocks (FSB) of the expected best 115 NSW and 10 Queensland families, to provide superior trees for clone development and testing
- Extensive seedling seed orchards (ESSO) from bulked OP seedlots from 100 phenotypically superior NSW selections, planted for early production of improved seed
- Provenance resource stands (PRS) from bulked seedlots or provenances not represented in the breeding populations, to provide genetic diversity and an infusion population for the second generation of the breeding populations (Johnson and Nikles 1997).

The ESSOs have not been used to date, although the FSBs at both Hannam Vale and Clybucca have been a source of superior trees propagated for clone development.

### Assessment of trials

All three progeny trials in NSW and the two in Queensland were assessed at 3 y for growth and form traits including height, diameter over bark at breast height (dbhob), stem form and branch

diameter. Joint analysis of assessment data from all five sites<sup>4</sup> has provided a maximum amount of information on the performance of the families for both organisations.

Growth and form traits in the Hannam Vale trial were reassessed in October 2005 at age 8 years 8 months. Subsequently a range of wood properties was assessed by non-destructive methods on selected trees, including Pilodyn penetration (all trees), acoustic velocity, peripheral growth strain, circularity of the stem at breast height and crown diameter. A total of 1068 selected trees were cored for assessment of radial and tangential shrinkage. In August 2006 the Hannam Vale trial was thinned to the best tree per plot. Of the trees felled, 1116 were selected for detailed analysis of wood properties, including spiral grain, acoustic stiffness and heartwood:sapwood ratio. Five hundred and sixteen trees were sent to Forest Enterprises Australia's Hew Saw in Tasmania for commercial milling studies. The other 600 trees were destructively assessed for wood properties including shrinkage, collapse, basic density, hardness, modulus of elasticity, modulus of rupture, colour, cell wall thickness and wood chemistry (cellulose, lignin and hemi-cellulose). Leaf samples from all 1116 destructively sampled trees were collected for use in a molecular genetic association study seeking links between genes and wood properties.

It is planned to assess the Clybucca progeny trial in 2007 for growth and form, and to destructively assess the wood properties of a limited number of families. It is hoped that this will provide data on the effect of site on wood quality as well as on the importance of genotype × environment interaction for growth and wood property traits.

### Genetic parameters and selection criteria

Heritabilities for dbhob (3 y) on the three NSW sites ranged from 0.18 to 0.24, with cross-site genetic correlations ranging from 0.73 to 0.90 between the three sites. Straightness at 3 y was slightly more heritable, ranging from 0.20 to 0.34 for the NSW sites, with cross-site genetic correlations from 0.83 to 0.98.

At 38 months the progeny trial at Clybucca was assessed for severity of *Mycosphaerella* leaf disease, caused by *Mycosphaerella cryptica* (Cooke) Hansf. and *Mycosphaerella marksii* Carnegie

<sup>4</sup>Jarvis, S. (2003) Analysis of *Eucalyptus pilularis* trials. Commercial-in-confidence report for Queensland Forestry Research Institute and State Forests of NSW. Balmoral, Victoria. 25 pp.

**Table 3.** Estimated genetic gains for traits in Forests NSW *Eucalyptus pilularis* clonal seed orchards

Site	No. clones	Backward selects	Forward selects	Genetic gains (%)		
				Height	Diameter	Straightness
Urunga Stage 1	55	28	27	7.6	5.4	6.0
Urunga Stage 2	43	5	38	8.6	5.6	22.4
Urunga D block	9	0	9	8.8	6.6	26.4
Grafton	46	7	39	8.6	5.8	21.8
Elite 1	10	7	3	10.8	7.2	30.4
Elite 2	10	10	0	11.6	8.2	28.4

and Keane, and target spot, caused by *Aulographina eucalypti* (Cooke and Mass.) von Ark and Muller, at the same time as growth and form were assessed. These are the most damaging leaf fungi in the NSW *E. pilularis* plantations (Stone *et al.* 1998). Carnegie *et al.* (2004) found significant variation in disease and defoliation among the provenances and families tested. The individual heritability estimates were moderate for *Mycosphaerella* damage ( $h^2 = 0.38$ ), and low for defoliation (0.22) and *Aulographina* damage (0.13).

Jarvis<sup>4</sup> developed a selection index based on volume, branch thickness and stem diameter. Trees and parents from the five trials were ranked using this index, and selections were made for clonal seed orchards discussed later in this paper.

## Deployment strategy

The long-term deployment strategy for *E. pilularis* in Forests NSW plantations is based on clonal forestry. In the interim, genetically improved seed is being produced in clonal seed orchards for deployment as seedlings or as a source of seedling-based mother plants for propagation of plants by cuttings. Improved material from the breeding program for *E. pilularis* has been deployed by several methods, and the strategy is evolving as more improved germplasm and technologies are developed.

## Deployment of plus tree seed

Forests NSW commercial plantations were traditionally established using bulked collections of preferred native forest provenances. Identification of superior families in the breeding population<sup>2</sup> allowed a strategy of 'backward selection' of parent trees to act as a source of open-pollinated plus-tree seedlots, when seed was available. The genetic gain of commercial planting stock produced from this source, over the bulked native collections, has been estimated to be 4.3% (Johnson and Nikles 1997).

## Clonal seed orchards

Clonal seed orchards (CSOs) can produce seed with substantial gains over native seed. Although a CSO is expensive to establish, the time to seed production is greatly reduced compared to a seedling seed orchard (SSO). Grafts of scions from mature parts of the tree tend to flower within one or two seasons (Eldridge *et al.* 1993); a SSO may take up to 8 y to flower (Johnson and Nikles 1997).

*Eucalyptus pilularis* CSOs have been established by Forests NSW on two sites: a coastal site near Urunga, south of Coffs Harbour, and a more inland site at Forests NSW Grafton Forest Technology Centre. Selection of superior individuals for the Stage 1 planting of the first orchard (Urunga) in November 2002 was based on the 3-y growth data of the progeny trials at Hannam Vale and Clybucca, and the form data for Hannam Vale. In all, 55 clones were planted in the CSO, including both original plus trees and progeny trees from the breeding population. These trees were unrelated with only either parent or one progeny selected from the better-performing trees<sup>2</sup>.

Further selections were made after joint analysis of data from all five progeny trials in NSW and Queensland<sup>4</sup>. Stage 2 of the orchard was planted in two distinct blocks in March 2004; the first block contains 38 forward selections and five backward selects and the second block (D) contains nine clones that are the best forward selections from eight different provenances.

CSOs are being established at multiple planting sites to reduce the risk of loss of seed production and genetic material due to unforeseen circumstances or extreme weather conditions, such as fire or hail damage. A second CSO was planted at the Grafton Forest Technology Centre in April 2005. Ramets of another 46 clones were included in this orchard. In addition, two elite populations, each composed of ten clones from ten different provenances, were established for use in further breeding work, particularly in the controlled crossing program. Predicted genetic gains for the clonal seed orchards are presented in Table 3.

The total CSO area for *E. pilularis* is currently 4.9 ha. Flower bud development was obvious in some ramets in the 2002 Stage 1 planting at Urunga within 15 months of planting and, at 24 months, 64% of the ramets were in bud. Flowering commenced in 2005 and with it, intensive multi-season studies of the flowering phenology of the clones. Ramets in Stage 1 of the Urunga orchard again commenced flowering in June 2006. About 71% of ramets were in bud, but some ramets aborted their buds prior to flowering, a phenomenon described by Florence (1964). However, the first commercial crop of open-pollinated seed was harvested over summer 2006/2007. In addition, a small number of controlled pollinations were successful and this seed is being grown for further testing.

The current assessment of the *E. pilularis* breeding population for wood properties will be the basis for making further selections

and roguing the CSOs to remove inferior clones. Grafting of ramets to establish a second CSO at Grafton, based on sawn-wood properties, will take place in 2007/2008.

### Family forestry

Family forestry is the mass vegetative propagation of seedlings of selected pedigreed families, without testing and identification of individual clones (Eldridge *et al.* 1993). The advantages of clonal forestry have been well documented (Eldridge *et al.* 1993) and include uniformity of both the plantations for management and the harvested wood product, the opportunity to match clones to sites and the ability to rapidly capture both additive and non-additive genetic variation. Family forestry provides greater genetic diversity in the planting stock than clonal forestry, a potential advantage for counteract the site specificity exhibited by *E. pilularis* clones when planted on NSW sites that may be sub-optimal for growth. Forests NSW has undertaken a program of deployment of genetically improved material by family forestry (Henson and Smith 2004; Smith *et al.* 2004). Propagation of *E. pilularis* by minicuttings produces plants with better root architecture than those propagated from seed (Thomas and Henson 2005), while also providing greater genetic gain in the planting stock.

Seed was collected, where possible, from the original ortets of the 30 families identified as the best-performing families over the five progeny trials. Potted seedling-based mother plants are raised in flood-and-ebb trays, and flood irrigated with defined nutrient solutions to promote shoot development and rooting of cuttings. Apical minicuttings are set to propagate planting stock, and a strike rate of over 90% is achieved. Since initiation of the family forestry program, over 80 000 plants of *E. pilularis* have been propagated for commercial planting by Forests NSW and private forestry companies.

Currently *E. pilularis* seed produced by control pollinations between selected parents is being grown for the family forestry program.

### Clone development and testing

The first clones of *E. pilularis* were developed by Forests NSW in 1994 from coppice on stumps of harvested trees in old plantations and native forests. Plants of nine clones propagated from two sites and seedling-based clones from six routine commercial seedlots were planted in the first clonal trial in Pine Creek State Forest in 1995. More of these clones were planted in 1997 on the same site as the progeny trial at Hannam Vale.

The identification of the better-performing families within the *E. pilularis* breeding population has allowed the development of improved clones for field testing. Seedling-based clones have been developed from 40 plus-tree families and field-select clones from 'family selection blocks' (FSBs). These clones have been supplemented by field-select clones developed from phenotypic selections in young plantations within the Forests NSW estate.

Forests NSW currently has 169 *E. pilularis* seedling-based and field-select clones being tested over three sites, one planted in 1999 and two in 2002. An additional 493 candidate clones have been developed from FSBs and the family forestry program (top

30 families identified from progeny trials), and field trials will be established on two sites in autumn 2007 and a third site in spring 2007.

The clone trial established in 1999 near Coffs Harbour, and composed of phenotypic selections from young plantations, was assessed for height, dbhob and form at age 32 months (Johnson and Smith 2003) and five clones selected for further testing and limited commercial deployment. At age 55 months, assessment of height, dbhob, straightness and solid wood properties, particularly density, stiffness and grain angle, resulted in selection of an additional five candidate clones for further testing and pilot-scale commercial deployment. Fifteen clones from the trial were destructively assessed for wood property traits at 65 months. These partially tested clones have been established as potted mother plants, along with the seedling-based mother plants for the family forestry program. The productivity (rooting success of harvested cuttings coupled with mother plant vigour) of these mother plants is far inferior when compared to that of the seedling-based clones (Henson and Smith 2004) and maturity issues affect their potential for plant production. To address these issues, a study of the nutritional aspects of mother plant management is planned.

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