Half a century of *Pinus radiata* tree improvement in New South Wales

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The Forests NSW *P. radiata* estate

New South Wales has the largest softwood plantation estate in Australia and currently supplies around 23% of Australia's total softwood log output (National Forest Inventory, 2007; Forests NSW internal report, 2007). The current radiata pine estate in NSW of 207,972ha (Forests NSW internal report, 2007) is centred on, or around, the Great Dividing Range, the main north-south mountain range in Australia. The estate comprises several disjunct forest areas (northern, central west, southern inland and south east - see Figure 1) which are spread over approximately 900 kilometres and cover most of the latitudinal range of the state (29 - 37°S). Within this range both climate and soil types vary (Turner *et al*., 2001). Average rainfall across the *P. radiata* plantation estate is generally in the 700 to 1200 mm with only relatively small areas receiving over 1300 mm per annum. Seasonality of the rainfall also differs with the northern end of the range being in a sub-tropical climate and the southern end in a Mediterranean climate.

The northern end of the estate is situated on the New England Tablelands of the Great Dividing Range (altitudes of 1000-1300 m) in a summer rainfall zone and largely on basaltic soils. In contrast, the southern inland section (South West Slopes region of NSW) of the estate is to the west of the mountains, in a winter rainfall zone, covers a wide range in altitude (300 to 1000 m) with higher elevation areas receiving snow in the winter months. The underlying geology includes granodiorite and dolerite in the higher altitude areas, siltstone, shale, quartzite in the lower areas plus small areas of basalt. On the other side of the Great Dividing Range, the south eastern section is generally at altitudes of 800 - 1000m and has a more even rainfall distribution. Parts of the southern section of this area are very cold in winter and can receive considerable amounts of snow. The northern section of this area has a milder climate and is dominated by relatively poor soils derived from sandstone.

The central west region is the most complex in terms of geology and rainfall. This region covers a number of disjunct forest areas to the west of the mountain range around the same latitude as Sydney. The range in altitude is large, 750 to 1200m. The geology ranges from sandstone in the east, through a range of shales, siltstones, mudstones, greywacke with the odd granite intrusions and, towards the western edge of the range, a range of acid lavas, dacite, trachyte and basalt areas. Rainfall is also variable, generally decreasing with decreasing altitude and towards the west of the distribution. However, the distribution of rainfall is relatively even throughout the year, when compared with the northern and southern inland areas.

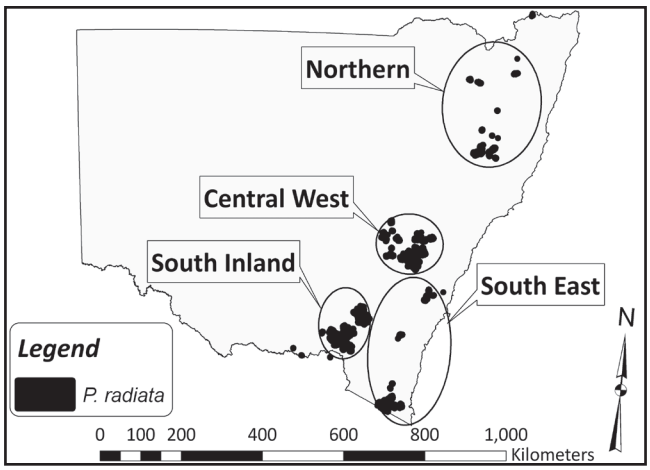

Figure 1 Distribution of radiata pine plantations in NSW.

A short history of how radiata pine came to be in NSW and the development of the current estate is presented below.

Introduction of *Pinus radiata* to Australia

Pinus radiata is native to California in the United States of America and was introduced to England in 1833 and proved to be the fastest growing of the Pinus species but was hardy only in the most favoured regions (Grant, 1989). *P. radiata* was brought to Australia around 1857 and is recorded as being in cultivation in Hobart in that year. The same year it is also recorded as being received by the Sydney Botanical Gardens in a shipment that arrived on the vessel Duncan Dunbar (Grant, 1989). In 1858 the government botanist in Victoria, Baron Ferdinand Von Mueller, mentioned the species in his report to Parliament as growing in the Melbourne Botanic Gardens. Von Mueller seems to have played a major role in disseminating the species by distributing thousands of seedlings throughout Victoria in 1859 and later introducing the species to South Australia where it was recorded as growing in 1866.

In NSW the earlier record of *P. radiata* being planted by the Forestry Branch was in 1885 when 83 trees, originating from the Sydney Botanical gardens, were planted in the railway reserve at Cootamundra (Grant, 1989). It appears that radiata pine was also planted in

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other parts of NSW around this time: in 1910 a photograph appeared in the Department of Forestry Annual Report of a 25 year old tree at Gosford, north of Sydney.

Other early plantings in NSW were at Ettamogah which is near Albury and Emmaville, northwest of Glen Innes on the Great Dividing Range in northern NSW. Two acres of radiata pine were planted at Ettamogah in 1878 and by 1908 many of these trees had been felled, sawn and used for building purposes (Grant, 1989). The trees at Emmaville had been planted in the hospital grounds in 1885 or 1886 and were reported in 1908 by the District Forester from Armidale as being both large in size and healthy (Grant, 1989).

Early establishment of plantations

Grant (1989) reports an experimental plantation, established in about 1894, at Gosford, just north of Sydney, was followed by the first attempt at a commercial plantation of radiata pine in 1912 at Tuncurry. A Royal Commission of Inquiry on Forestry in 1908 had recommended planting of "exotic softwood trees of commercial value on suitable lands throughout the state" and noted that the world's supply of conifer timber was diminishing. At this time 75% of the softwood timber used was imported.

In 1919, the NSW Minister for Lands and Forests announced a policy to plant poorly timbered unproductive lands with softwoods with the aim of making the state self sufficient in softwood timber. At this time the Minister reported that five new plantation schemes had been initiated in the cooler regions of the state, preliminary surveys were being done in the central and southern tablelands and the government aimed to set aside 500,000 acres (202,343 hectares) for progressive planting of softwoods (Grant, 1989). Following the release of this policy, the foundations were laid for the current large plantation estates in the Bathurst and Tumut areas with the first plantings occurring near Bathurst in 1919 and the first plantations near Tumut established in 1921-2 (Table 1). At the same time,

Table 1 Major pine plantations established in NSW (information extracted from Grant, 1989).

Region	Initiated	Location
Northern	1910's	Armidale
	1920's	Nundle, Mt Topper & Mt Mitchell
	1970's	Nowendoc & Riamukka
Central West	1910's	Lidsdale
	1920's	Jenolan, Mullion Range, Newnes, Sunny Corner & Vulcan
	1930's	Gurnang
	1940's	Canobolas
	1950's	Glenwood
	1960's	Dog Rocks, Hampton & Mt Macquarie
	1970's	Blenheim, Lowes Mount & Norway
	1980's	Kinross, Pennsylvania & Vittoria
South east	1910's	Belanglo & Penrose
	1920's	Bondi, Wingello & Nalbaugh
	1960's	Tallaganda
	1970's	Coolangubra, Glenbog & Meryla
South inland	1920's	Bago, Billapaloola, Buccleuch, Carabost, Green Hills, Mannus, Murraguldrie & Tumut
	1930's	Wee Jasper
	1960's	Bondo & Mundaroo
	1980's	Maragle

plantations were also established on the southern Tablelands around the Moss Vale area.

In 1934, the NSW forest estate was reviewed by the Conservator of Forests from Western Australia. The following year the Forestry Act was amended to restrict establishment of exotic species until the soil, site and climate were judged by the Minister to be suitable and the planting of trees to be in the public interest (Grant, 1989). The Forestry Commission then surveyed all of its 30 existing plantations and classified them for retaining, discontinuing and salvage logging or for future extension. Planting of additional areas of exotic conifers essentially ceased after 1935 (with the exception of the Prison Afforestation Camps) and was not resumed until after the 1939/45 war. In 1946/47, Government loan funds were made available for establishment of plantations.

Given the break in the time line of planting around World War 2 the plantation estate in NSW is generally grouped in pre-war and post-war plantings. Table 1 lists the major plantation areas established in each time period for each part of the state (taken from Grant, 1989).

Post World War 2 plantations

From 1966 onwards, establishment of *Pinus radiata* plantations received a major boost from Commonwealth government funding in a series of softwood forestry agreements. The Commonwealth government provided loans to meet the cost of all new plantings in excess of what would normally have been established. During the 11 years covered by a series of these agreement a total of 76,005 ha of softwood plantations were established (Grant, 1989). Whilst the bulk of these plantations were *P. radiata*, several other *Pinus* species were also planted including *elliotti*, *caribaea*, *taeda*, *ponderosa*, *laricio*, *pinaster*, *muricata*, *patula* and *contorta*. Smaller plantings were made of *Pinus canariensis*, *halepensis*, *jefferyi*, *lambertiana* and *monticola*. Between 1924 and 1972 1,267 ha of Douglas fir (*Pseudotsuga menziesii*) were also established on the southern Tablelands.

Commencement of the NSW *P. radiata* breeding program

The NSW breeding program for *Pinus radiata* was initiated in 1958 with plus trees selected in pre-war plantations dating from the 1920's and 1930's. Similar breeding programs were also initiated in other states and by the precursor to CSIRO around this time, with all programs following the same general approach. Selection of plus tree was restricted to plantations which were at least 20 years old (Johnson, 1987). The ideal phenotype at that time was considered to be a healthy tree which was outstandingly vigorous when compared to surrounding trees and having a straight cylindrical stem with few stem cones, minimal taper, no forks or other gross stem defects and small diameter branches emerging at right angles from the stem (Ades and Johnson, 1984).

In NSW, about 4,000 ha of plantations were surveyed in the Tumut, Batlow, Tumbarumba and Bombala areas and 77 plus trees selected. Tree identities were later allocated by Research Working Group 1, with serial numbers commencing with 20- as, for example, 20001. Subsequently, the pre war stands in the Bathurst area were searched and an additional 26 plus trees selected. Most of these plus trees were assessed for spiral grain and wood basic density using either cores or blocks (Johnson, 1985).

The plus trees which most closely resembled the ideal phenotype were propagated as grafts into clonal seed orchards in Green Hills and Vulcan State Forests (see below). Open-pollinated progeny tests of these clones were established to allow for rouging in the future.

First round of plus tree testing

The history of the first 28 years of tree breeding (1958-1986) in NSW was documented by Ian Johnson (1987). The NSW tree breeding program has gone through several cycles of intense activity, followed by periods of relative inactivity (Johnson, 1987). Between 1958 and 1967 the foundations of the breeding program were established including:

- 1959-72: establishment of clone banks at Bondo, Green Hills and Ardrossan, all near Tumut. These clone banks contained NSW plus trees and select material from other Australian states and New Zealand
- 1962-1967: establishment of open-pollinated progeny tests of NSW and ACT plus trees in 3 regions of NSW - southern inland at Tumut, south east coast at Eden and northern NSW at Glen Innes
- 1967-1969: control pollination used to produce full-sib families
- Late 1960's: first generation clones from other Australian states and other countries established into clone banks

Following this, there was a three year period (1971-4) of new trial establishment:

- 1971: first control-pollinated progeny test established
- 1973: International Gene Pool Trails (Johnson, 1989a, 1992; Burdon *et al.*, 1997b) were established on 3 sites in Tumut, Bathurst and Glen Innes areas. These trials contained select material from a range of different countries and from different states within Australia and greatly expanded the base population of unrelated genetic material available for future selections.
- 1974: Progeny trials containing both open and control pollinated seedlots from NSW, other Australian states and from New Zealand established near Tumut and Bathurst

Early seed orchards

Three first-generation seed orchards were established in NSW between 1957 and 1972 (Johnson, 1987):

- 1957-63: Tallaganda seed orchard which was established by the precursor to CSIRO. This 4.4 ha orchard contained 28 ACT clones, plus one clone from each of New Zealand (the now infamous NZ tree 55) and Victoria. Most of this orchard was clear felled in 1981, leaving only 4 complete blocks of the original 30. The orchard was then re-established in 1984, with material from a northern NSW progeny trial (see below).
- 1961-1969: Green Hills clonal seed orchard, near Tumut. This 17 ha orchard contained clones from the best 35 NSW plus trees based on growth and form. The orchard was heavily thinned and rogued in 1978.
- 1966-1972: Vulcan clonal seed orchard, near Bathurst, a 67 ha orchard established with clones from 36 NSW plus trees. The northern section was heavily thinned and rogued in 1982 -3 with the southern section thinned several years later.

Assessment of growth performance of bulked orchard seed against routine control seedlots (collected from clearfelled stands) in gain trials planted across multiple sites indicated an average increase, at age 6 years, of 12% in DBH for Tallaganda, 14% for Green Hills and 8% for Vulcan (Johnson, 1991). Johnson also noted that orchard seed performed much better on the lower quality sites. These orchards provided much of the seed used for plantation establishment across NSW for many years, up until 1990.

Further progeny testing and new clone banks

The original first generation progeny trials were assessed in 1977-8 for growth and form traits and data from these assessments were used to cull the Green Hills seed orchard in 1978. Also in 1978 new clone banks at Helms and Lochinvar, both in Green Hills Forest, were initiated and establishment of clones continued for a number of years. Otherwise, little activity occurred in the main NSW breeding population between 1975 and 1980.

From 1980 onwards another round of first-generation progeny trial establishment occurred, with 6 trials established in 1980-81 across the Tumut and Bathurst areas containing open-pollinated progeny of earlier NSW selections plus progeny from selected trees within the clone banks.

Second round of plus tree selection and testing

A second round of plus tree selection occurred between 1980 and 1986, with an additional 347 first-generation plus trees identified in the post war plantations mostly in the Bathurst region and on sedimentary rock sites in the Tumut area. Thirty seven trees were also selected near Nundle in northern NSW. The criteria for selecting plus trees were superior vigour and stem form, relative to the surrounding stand. Average branching characteristics or a slight degree of malformation (such as a fork or ramicorn) was accepted provided the tree was clearly superior in growth and form. Large progeny trials of these trees were established over several sites in the Tumut and Bathurst regions during 1985- 7.

Native California population collections and testing

In 1978, a collection of seed from the native populations in the USA was jointly funded by Australian and New Zealand Governments (Burdon *et al.*, 1997a; Johnson *et al.*, 1997; Moran and Bell, 1987). The aim of this collection was to expand the genetic base of *Pinus radiata* available for future breeding. In 1979-82 both bulk plantings and provenance trials of seedlings from this native collection were established as gene conservation resources and for future selections:

- 1979: eight provenance trials, containing 13 sub-populations plus Tallaganda seed orchard control, were established across the state
- 1980: large bulk plantings of the 13 mainland sub-populations were established in Buccleuch, near Tumut
- 1980: a single large open-pollinated progeny/provenance trial was planted in Green Hills forest, near Tumut in collaboration with CSIRO. Progeny of 506 parents were planted including families originating from Guadalupe and Cedros islands.
- 1982: open-pollinated progeny trial of 34 families from Cedros island and 44 from Guadalupe island was planted in Billapaloola forest, near Tumut in collaboration with CSIRO

Plus trees from progeny trials

A third round of plus tree selection was commenced in 1981 using existing progeny trials aged 7 years or older. These second generation plus trees were selected from families with high vigour, good stem straightness and branch quality. However, the greatest emphasis was on stem diameter. By the end of 1986, 240 new plus trees had been selected from open or control pollinated families and allocated RWG plus tree register numbers. Generally, only one tree was selected from each family; however, many of the selections were related as half-sibs and a few as full-sibs. All selections were grafted and planted into either of the new clone banks at Helms or Lochinvar.

In 1985 the three international gene pool trials were assessed for growth and form traits (Johnson, 1989a, 1992) and selections from these trials formed the basis of new progeny tests established at multiple sites across the state in 1992 and 1993. Two additional trials were established using a selection of these families established as seedlings and cuttings to investigate propagation effects. Selections from the northern gene pool trial at Nundle were used

between 1984 and 1987 to re-establish the Tallaganda seed orchard (which had been clear felled in 1981). These new clones were selected based on family average Dothistroma resistance, vigour and stem form.

A new 40 ha irrigated seed orchard was established in 1985-6 at Windamere, near Mudgee in western NSW, using 1.5 and second generation selections. Clones were selected from families which displayed superior growth and form across a wide range of test sites. Another seed orchard was established in 1987-9 at Walcha in northern NSW and contained 108 second generation clones selected in the local area which was prone to *Dothistroma* infection

Breeding plan

By the late 1980's NSW had a large (>1,000 selections) and diverse base breeding population of radiata pine available but needed to ascertain a direction for the advanced generation breeding program. Johnson (1987) recognised this need and recommended that a long-term breeding plan for radiata pine be written and published to ensure the continuity of the program. The 1989 breeding operational plan document (Johnson, 1989b) outlines several key principles including the need for continuity of operations, and maintenance of a hierarchy of populations to preserve genetic diversity.

Key breeding objectives identified were primary traits of volume, stem straightness and branch quality along with secondary considerations of stand health (especially *Dothistroma* resistance) whilst maintaining the level of juvenile wood density above 337 kg/m^3. The aim was to include at least 300 unrelated second generation selections in the total breeding population. It was recommended that this breeding population be divided into about 13 sublines of 30 selections with the aim of controlling inbreeding.

Genotype by environment interaction

The potential importance of genotype by environment interaction as a factor which may reduce genetic gains was recognised in the early 1980's (Ades and Johnson, 1984). So, a policy was implemented of planting progeny trials on a range of sites, covering the major growing regions. Interestingly, the written breeding strategy (Johnson, 1989b) recommended splitting the breeding population into 2 separate groups based on the soil parent material of potential planting sites. This recommendation stemmed from observed genotype x environment interactions for growth (Johnson, 1989b).

The breeding strategy was written around the time that a technical soil classification system was being developed and applied to the NSW forestry land base (Turvey, 1987; Turner *et al.*, 1990, 1996). This soil classification system was based on parameters which could be observed in the field and which were relevant for plantation management and grouped soil types according to the similarity of their parent materials or geological origins (Turner *et al.*, 1996).

Johnson (1989b) breeding strategy recognised three main geology types as being important for the breeding program: granite, sedimentary and basalt (basic). It was recommended that a granite/sedimentary breeding population be developed based on selections from progeny tests on these sites types. This population was then to be used for deployment onto granite, granodiorite and/or medium to high fertility sedimentary sites. A separate breeding population would be developed for sites either prone to *Dothistroma* and/or located on basic rock material including basalt, dolerite or gabbro.

To further investigate the potential for site by genotype interactions caused by geology, a series of 8 clonal trials were established in 1991 across different geology types in the southern inland and central west sections of the estate.

Seed imports

By the late 1980's, the annual establishment program included second rotation plantings on the high elevation sites plus new plantations on lower altitude ex-farm sites. In 1989, Johnson noted that the current seed requirement for the NSW Forestry Commission was 1300 kg per annum. However, little seed had been available from the NSW seed orchards over the past few years. So part of the 1988 shortfall was made up by purchasing seed with GF rankings (Growth and Form ranking, New Zealand FRI, 1987) of 14 and 16 from New Zealand. This appears to be the first major importation of New Zealand seed into Australia and seems to have ultimately led to Forests NSW joining the New Zealand breeding co-operative.

Joining the New Zealand Radiata Pine Breeding Co-operative

In 1990 a decision was taken to join the New Zealand based Radiata Pine Breeding Co-operative (RPBC). By this time the seed supply issue had become critical due to poor flowering and losses from bird foraging in the existing NSW orchards. An external review of Forests NSW and STBA breeding programs had included an analysis of available Australian progeny test data which had indicated that approximately half of the selections being used in Forests NSW seed orchards did not rank highly. This result, combined with poor flowering and other management issues, led to the abandoning or closure of the existing seed orchards. There was thus an urgent need to find an alternate seed supply for NSW and the New Zealand program provide a solution.

At this time two breeding co-operatives existed - the Southern Tree Breeding Association (STBA), based in Mt Gambier, South Australia and the RPBC. In terms of climate and soil types, the majority of the Forests NSW pine

estate is quite different and much more variable that the South Australian estate which is planted mainly on sandy soils in areas with less than 1000mm rainfall and a winter rainfall climate (Turner *et al*., 2001). Similarly, the NSW estate differs to that in New Zealand, where the majority of plantations are in areas receiving over 1000mm of rainfall evenly distributed throughout the year and on deep rhyolitic pumice or gravely laterite soils (Turner *et al*., 2001).

After considering the technical merits of the two organisations at that time, a decision was taken to join the RPBC rather than the STBA. This decision was largely based on the ability of the RPBC to provide large quantities of genetically improved seed immediately to address the seed supply issues. The original plan was to infuse superior clones from the Forests NSW program in to the RPBC main breeding program. However, after several attempts that failed due to issues associated with the international transport of germplasm the plan was shelved. After joining the RPBC there was less focus on the "in-house" tree improvement program, and in 1994 it was effectively abandoned.

The tree breeding trials which had been planted by Forests NSW remained standing but received no further assessments or management. However, since 2003 there has been a resurgence of interest in these trials and a program of assessment for growth, form and wood properties has commenced. These assessments are being financially supported by the RPBC. The assessments aim to quantify genotype by environment interactions for a range of growth, form and wood quality traits and identify superior material for infusion into the RPBC breeding program. So, the issues raised by Johnson back in 1989 in relation to influences of site geology on genotype performance will now be properly addressed using the trials which were part of the original Forests NSW breeding program.

In the first decade after joining the RPBC only a few trials of New Zealand pedigreed material were established including:

- two Female Tester trials - the first was planted in 1993 in the Central West region and the second planted in 1997 in Northern region
- A Native Population trial planted in 1995 at Kangaroo Vale in the Southern Inland region
- Elite populations trials planted in 2003 at one site each in the Central West and Southern Inland regions

In 2003 the need to test material across a range of sites was identified and a series of large progeny trials containing forward selects from the RPBC were established in the winter of 2005 across 4 sites although subsequently one site has been burnt. Two additional trials containing Guadalupe populations, including pure Guadalupe and inter-provenance hybrids were also established in 2005, targeted on drier sites.

A dedicated controlled pollinated seed orchard was established in Boyd Town near Eden on the south coast of NSW. The orchard contained a selection of the best clones from Forests NSW "in-house" breeding program as well as clones from the RPBC. Yields from the orchard were low owing to significant loses from the feeding habits of Black Cockatoos that took up residence in the orchard. The orchard was abandoned in 2004 and crosses between Forests NSW and New Zealand pedigrees are planned to be established in a series of progeny trials in 2008.

Current situation

One current issue for Forests NSW is the question of potential genotype by environment interactions between the two countries. Given the differences in soils types and climate there is a need for research into how seedlots selected in New Zealand perform in Australia. Several recently published reports have indicated potentially large genotype by environment interactions between the two countries. The recent paper of Kumar (2004) found the genetic correlation for diameter between Kaingaroa on the north island of New Zealand and Warrengong, a relatively dry site near Bathurst in NSW, to effectively be zero. Heritabilities for the assessed wood properties (density, acoustic stiffness and internal checking) differed dramatically between the sites and significant rank changes were also noted. Kumar noted that the number of families included in this study was small and suggested further investigation.

Similar but less dramatic interactions between New Zealand and NSW sites have also been found in earlier studies. Using data from the International Gene Pool trials planted in the 1970's Burdon *et al*. (1997b) noted that the genetic correlations between the three NSW sites and the New Zealand site for diameter growth were around 0.4 to 0.5 (excluding seedlots from the native populations which had performed poorly at many sites). The Australasian Breeds Trial (Low *et al*., 2003) analysed growth and form data from one Forests NSW site plus additional Australian sites and compared the results with multiple sites in New Zealand. Results from this analysis indicated that the correlation for diameter between Kaingaroa in New Zealand and Green Hills in NSW was around 0.6. Overall, Low *et al*. (2003) concluded that "The New Zealand seedlots were ranked better than Australian seedlots on New Zealand sites, but were often bettered by Australian seedlots on Australian sites." However, other yield trials in NSW would suggest there is no difference for growth between Australian and NZ improved material.

The potential for genotype by environment interactions within New Zealand is also an issue. Following a workshop of RPBC members in August 2005 a strategy was developed that included greater levels of regional evaluation of germplasm to attempt to understand the level, importance and drivers of any genotype by environment interaction.

In conclusion, future work planned for the NSW radiata pine breeding program will include:

- Continuing evaluation of "in-house" progeny trials and breeding population
- Wider testing of RPBC material across sites
- Better understanding of genotype by environment interactions, including site typing combined with resource mapping to develop climate-soil domains within which similar performance is expected for growth and wood properties
- Where possible, cross-match these domains with New Zealand sites
- Identification of genotypes with superior performance in each domain
- Using combinations of RPBC and Forests NSW material for deployment orchards
- In the long term the program aims to move from using good "all round" open pollinated seed to site specific deployment of high value genetic material.

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References

Ades, P.K. and Johnson, I.G. (1984) Assessment of *Pinus radiata* progeny trials Q14/1.14 and Q14/4.8 seven years after planting. Forestry Commission of NSW, Wood Technology and Forest Research Division, Report No: 940, Series SIL. 24pp.

Burdon, R.D., Firth, A., Low, C.B. and Miller, M.A. (1997a) Native provenances of *Pinus radiata* in New Zealand: performance and potential. *New Zealand Forestry* 41(4):32-36.

Burdon, R.D., Hong, S.O., Shelbourne, C.J.A., Johnson, I.G., Butcher, T.B., Boomsma, D.B., Verryn, S.D., Cameron, J.N. and Appleton, R. (1997b) International gene pool experiments in *Pinus radiata*: patterns of genotype-site interaction. *New Zealand Journal of Forestry Science* 27:101-125.

Forests NSW (2007). 'Seeing Report: Social, Environmental and Economic Report 2006-07', Indicator 22.

Grant, T.C. (1989) *History of Forestry in New South Wales*, 1788 to 1988. Publisher: T. C. Grant, Sydney 1989. 320pp.

Johnson, I.G. (1985) Selection and early progeny testing of "pre-war" series *Pinus radiata* plus trees in New South Wales, 1959-1978. Forestry Commission of New South Wales, Unpublished Report No. 1103. Sydney.

Johnson, I.G. (1987) The management strategy for radiata pine tree improvement in New South Wales. Part 1. History of improvement work 1958-1988 and a review of genetic gains. Technical Paper No. 40, Forestry Commission of New South Wales, Sydney. 142pp.

Johnson, I.G. (1989a) Performance of radiata pine families in the Shelbourne Gene Pool trials in New South Wales. Research Paper No. 7, Forestry Commission of New South Wales, Sydney. 55pp.

Johnson, I.G. (1989b) The breeding strategy for radiata pine in New South Wales. Part II. Proposed operations. Technical Paper No. 47, Forestry Commission of New South Wales, Sydney. 58pp.

Johnson, I.G. (1991) Realised gains for growth traits by radiata pine seed orchard seedlots in New South Wales. *Australian Forestry* 54:197-208.

Johnson, I.G. (1992) Family-site interactions in radiata pine families in New South Wales, Australia. *Silvae Genetics* 41:55-62.

Johnson, I.G., Ades, P.K. and Eldridge, K.G. (1997) Growth of natural Californian provenances of *Pinus radiata* in New South Wales, Australia. *New Zealand Journal of Forestry Science* 27:23-38.

Kumar, S. (2004) Genetic parameter estimates for wood stiffness, strength, internal checking, and resin bleeding for radiata pine. *Canadian Journal of Forest Research* 34:2601-2610.

Low, C., Dungey, H., Powell. M. and Miller, M. (2003) Performance and gains in the 1988 Australasian breeds trial - an Australasian analysis. RPBC Report No. 140. Confidential Report to Participants of the Radiata Pine Breeding Company. 42 pp.

Moran, G.F. and Bell, J.C. (1987) The origin and genetic diversity of *Pinus radiata* in Australia. *Theoretical and Applied Genetics* 43:616-622.

National Plantation Inventory (2007). 'Australia's Plantation Log Supply 2005-2049'

New Zealand FRI (1987) Which radiata pine seed should you use? What's New in Forest Research, No. 157. New Zealand Forest Research Institute, 1987.

Turvey, N.D. (Ed.) (1987) A technical classification for soils of Pinus plantations: field manual. Bulletin No. 6, School of Forestry, University of Melbourne.

Turner, J., Turvey, N.D., Booth, T.H. and Ryan, P.J. (1990) A soil technical classification system for *Pinus radiata* (D. Don) plantations. I. Development. *Australian Journal of Soil Research* 28:813-824.

Turner, J., Knott, J.H. and Lambert, M. (1996) Fertilisation of *Pinus radiata* plantations after thinning. I. Productivity gains. *Australian Forestry* 59:7-21.

Turner, J., Lambert, M., Hopmans, P. and McGrath, J. (2001) Site variation in *Pinus radiata* plantations and implications for site specific management. *New Forests* 21:249-282.