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POTENTIAL FOR GROWING AND PROCESSING DURABLE EUCALYPTS IN NEW ZEALAND

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FOREST GROWERS RESEARCH

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EXECUTIVE SUMMARY

In NZ there is considerable commercial interest in finding alternative forest species to radiata pine which (1) are naturally durable and do not require chemical preservative treatment for either in ground or out of ground use and (2) provide higher stiffness wood/veneer. Eucalypt species are an obvious choice.

In this report a number of naturally durable eucalypt species were reviewed by authors on both sides of the Tasman, as to their suitability for growing and processing in NZ. Because there have been very little plantings of these species until recently in New Zealand, most of the processing evidence is from Australian experience. Information arising from past and on going research was examined. In NZ the available information was assembled by Barry Poole and in Australia by Gary Waugh and Jun Li Yang.

The research being undertaken by the New Zealand Drylands initiative is of particular relevance as this group recently established evaluation trials of the following naturally durable species for the purposes of producing vineyard poles.

E.bosistoana *E.argophloia*
E.quadrangulata *E.globoidea*
E.cladocalyx *E.macrorhyncha*
E.camaldulensis *E.tricarpa*

The trials are yielding very good information, including some innovative early work on growth stress and wood quality, but the oldest trials are only ~5 years old and no substantive growth or processing information is yet available.

The Australian authors considered a group of 12 eucalypt species (some non durable species, but already widely established in NZ) based on their potential to be grown successfully in NZ. These species and their natural durability data are shown below:

Standard common name and scientific/botanical name		Natural durability class of heartwood	
		In-ground contact	Outside above ground
Blackbutt	*Eucalyptus pilularis*	2	1
box, grey, coast	*Eucalyptus bosistoana*	1	1
box, white-topped	*Eucalyptus quadrangulata*	2	2
box, yellow	*Eucalyptus melliodora*	1	1
gum, blue, Sydney	*Eucalyptus saligna*	3	2
gum, red, river	*Eucalyptus camaldulensis*	2	1
gum, spotted	*Corymbia maculata*	2	1
gum, sugar	*Eucalyptus cladocalyx*	1	1
ironbark, red	*Eucalyptus tricarpa*	1	1
mahogany, southern	*Eucalyptus botryoides*	3	2
stringybark, yellow	*Eucalyptus muelleriana*	3	2
tallowwood	*Eucalyptus microcorys*	1	1

Note: 1 = highest ranking

Their findings are summarised in a series of tables covering aspects such as

- Tree description in its natural environment
- Site requirements
- Susceptibility to insect attack
- Natural forest wood description and uses
- Wood working characteristics
- Adaptability to plantations grown for solid wood products
- Internal log defects and growth stress
- Engineering properties of 12%MC wood
- Density and shrinkage of wood

Of the species considered, *Eucalyptus saligna, E.muelleriana, E. globoidea, E. macrorhyncha* and *E.botryoides* do not meet the criteria to be classified as 'durable' species as they are classified as Class 3 for in-ground applications. *E.camaldulensis* should be considered with care due to a high susceptibility to insect defoliation in Australia.

If in-ground durability is less important, then *E.muelleriana* should command more attention, as the species has shown good growth rates, resistance to pest and disease and good adaptability to a range of sites for a long period of time in the NZ landscape.

There are other species which have shown promise in Australia but could only be considered for the far north of NZ due to their inability to withstand cooler temperatures, e.g. *E.pilularis, E.laevopinea, C.maculata, E.microcorys.*

As the natural occurrence of *E.microcorys* is confined to warm humid coastal areas in Australia, north of Sydney, suitable site selection will be very limited in New Zealand. Where frosts and colder winter months are not going to be a problem, there should be sites suited for the establishment of *E.pilularis* and *Corymbia maculata*. Both are fast-growing and durable species with good self-pruning properties. Both species are popular in Australia for flooring and decking.

E. tricarpa, has been successfully established in limited plantations in Australia, but has never shown very good growth rates.

The three box eucalypts (*E.bosistoana, E.quadrangulata* and *E.melliodora*) all produce high density, light coloured, fine grain wood which has both high durability and is also suitable for high-value appearance use. Of these three, *E.melliodora* is more frost tolerant, but will not achieve the same growth rates or good form in plantations. However, in Australia, it produces high quality honey, which could be an important selection factor for agroforestry.

E.cladocalyx has been widely established in windbreaks in the south-west region of Victoria, exposed to the cold winds of the Southern Ocean during the winter months. The wood is light and fine-grained and meets category 1 for both above and in-ground durability and below average shrinkage for the group included in this review. Plantation-grown wood is used for decking in Australia and is gaining in popularity.

Conclusions

The overall potential suitability of the various species for NZ has been roughly 'ranked' for the benefit of the reader (see Table below). The ranking criteria were as follows:

1. Durability above ground and in ground
   High durability was essential for the study objectives but some class 3 species were included. The rankings shown are the actual durability ratings published for the various species.
2. Growth rate
   Based principally on the data for natural forests gathered by Gary Waugh three rankings were given per hectare per annum:
   1 = more than 20 cubic metres
   2 = 5 to 20 cubic metres
   3 = less than 5 cubic metres
3. Processing suitability
   This was a general classification based on the best available information.
   1 indicates very good suitability for processing and 2 less suitable etc. On information available this ranking is an amalgam of factors contributing to the ease of processing and reduced degrade.

As much of the available growth information is from natural forests (rather than plantation forests), the climatic conditions and pest species in NZ will be different, there are large gaps in some of the information for some species and the potential for genetic improvement of various species cannot be predicted, the rankings must be considered with caution.

The Table is intended to provide clarity for the reader rather than to rigidly rank options.

No.	Name	Durability above ground	Durability in ground	Growth rate	Processing suitability	Comment
1	*E.bosistoana*	1	1	2	1	Consistent reports on processing
2	*E.argophloia*	1	1	3	1	Slow growth in early trials
3	*E.tricarpa*	1	1	3	1	Slow growth in early trials
4	*E.microcorys*	1	1	2	2	Frost sensitive –limits sites in NZ
5	*E.cladocalyx*	1	1	2	2	Withstands coastal winds
6	*E.camaldulensis*	1	2	1	2	Wide gene pool to select from in Australia
7	*E.quadrangulata*	2	2	2	3	Growing well in early trials
8	*C.maculata*	1	2	2	2	Suitable only in North?
9	*E.melliodora*	1	1	3	1	Slow growing but frost tolerant
10	*E.laevopinea*	2	3	2	2	Provenance important for frost
11	*E.muelleriana*	2	3	2	1	Not ground durable –good growth
12	*E.pilularis*	1	2	2	1	Provenance important for frost
13	*E.globoidea*	1	2	1	1	Not ground durable but good growth
14	*E.macrorhyncha*	2	2	2	2	Not ground durable but good timber

Of the twelve species reviewed, around nine would appear to have opportunities to be grown in New Zealand to produce naturally durable wood. Some may be restricted due to intolerance to frost and others, while producing high-quality wood, may have growth rates unacceptable for commercial forestry, but could gain acceptance for broader agroforestry applications.

Though the eucalypt resource in New Zealand is quite small in comparison to our major species, *P.radiata*, eucalypts have made a considerable contribution to our pulping industry and have the potential to contribute much more to our solid wood and veneer based industries. There is good evidence already, and more to come from trials in the ground, that eucalypt species which confer strength and natural durability have a part to play in our future plantation development.

There are some caveats around some of the naturally durable species being considered, either regarding growth rate or potential for pest/disease debilitation. At a later point in the evaluation phase, some of the species should be discarded so that gene improvement is concentrated on the best performing 2-3 species.

Considerable capital is required to develop broad scale plantations of these relatively new species in NZ . This will need to be justified as much on desirable wood characteristics and environmental considerations as economic argument is driven predominantly on growth rates. In tandem with the broad scale plantation development, genetic improvement of these species needs to proceed to reduce variation and facilitate better utilisation and processing.

1. Introduction

The Eucalypt genus comprises more than 500 species and apart from a couple of species existing in Indonesia and the Southern Philippines is entirely Australian continent in origins. Thus the range of climates covered by eucalypt species is even broader than the Australian continent and the introduction of eucalypts to exotic locations has revolved around testing species for suitability and adaptability to the new climate.

In New Zealand the first plantings of eucalypts were attributed to goldminers coming from Australia in the 1860's and so examples of the genus have been in the New Zealand landscape for approximately 150 years. Despite this period of time, the total resource of eucalypts in New Zealand is still very small in relation to our major plantation species, *Pinus radiata.* The latest National Exotic Forest Description (April 2012) indicates a resource of 23,000 hectares of eucalypts in New Zealand from a total plantation resource of 1.72 million hectares.

Broad scale plantings have taken place in the last 40 years, largely by virtue of pulp and paper companies intent on establishing a short fibre resource. These plantings have concentrated on a few species which grow quickly, have good fibre characteristics for pulping and are reasonably cold resistant to cope with New Zealand winter conditions and altitude.
In recent years investigation of the naturally durable eucalyptus species for production of vineyard poles was initiated under the NZ Drylands Forest Initiative(NZDFI) and this has widened to consideration of durable eucalypt timber for cross arms on transmission poles ; outdoor furniture and decking ; use in LVL beams to add strength and stiffness. (See Section 5)

2. Objectives of the study

The objectives for this study were to

- Provide an overview of research on eucalypts; particularly on aspects of processing of the genus in New Zealand.
- Based on Australian experience, review the potential of growing and processing naturally durable eucalypts in NZ.

In Australia, Gary Waugh and Jun Li Yang reviewed Australian activities, past and present and Barry Poole reviewed work conducted in New Zealand. Because of his long involvement in the growing of eucalypts in New Zealand, Barry Poole was also asked to comment on aspects of growing plantation eucalypts in NZ.

3. Solid wood research on Eucalypts (New Zealand)

Much of the early work in New Zealand was conducted on older eucalypts and focussed on sawing and seasoning characteristics of the timber. Early work by AN Haslett, JM Harris and GD Young focussed on the species nominated below.

In 1981 the NZ Forest Service, as the largest forest estate owner in NZ, issued a list of special purpose eucalypts that were considered suitable for furniture, veneer, engineering end uses and turnery.

The species nominated were;

E.delegatensis
E.regnans
E.fastigata
E.saligna
E.botryoides

Much of the work centred on how to handle these fast growing species and their different wood characters when grown as exotics in New Zealand, compared to the natural forest in Australia. (Note that none of these species are classed as being naturally durable.)

Harris and Young reported on wood properties, effect of genotype and environment on NZ grown eucalypts whilst Haslett reported on how best to handle the growth stresses, end splitting and sawing distortions that are associated with these species.

It was established through sawing and seasoning studies that generally the NZ eucalypt wood tended to be slightly lower in density and strength when compared to Australian grown wood, presumably as a function of faster growth rate. (Wood age similar - fast growth, thinner cell walls, lower density.)

Guidelines were established for sawing and seasoning methods, as well as how to handle the fresh logs and remove bark , dimensions of the logs sought (to mitigate growth stress and end split) and also aspects of storage, veneer procedures, and gluing preparation. Logs of DBH 70cm+ were recommended to mitigate end split and other growth stress effects, such as distortion of the timber, post sawing. This indicated a rotation period of 30 - 40 years to gain logs of this diameter.

By 1988/1990 Haslett had moved on to species more suited to timber end use and reported on studies involving a wider range of species including some of the stringybarks. He noted in a paper published as an FRI bulletin that the NZ Forest Service estate has resources of;

E.botryoides	162 ha.
E.saligna	1350 ha.
E.globoidea	6 ha.
E.muelleriana	9 ha.
E.pilularis	15 ha.

Species within Kaingaroa and Kinleith forests were not accounted for as by that time there was 6-7000 hectares of *E.regnans* within Kinleith forest, designated for pulp. Kaingaroa forest also had approximately 1500 ha of *E.regnans* and *E.fastigata* plantations. (Small areas of *E.delegatensis* also.)

Conference papers were presented by the above gentlemen at the Australian Bicentenary forestry conference in Albury in 1988 on most aspects covering the differences between NZ grown eucalypts and Australian grown species.

Aspects of strength – Modulus of Elasticity (MOE), durability, sawing method, air drying, kiln drying and then steam reconditioning as conducted in Australian mills were all discussed.
Thus a picture emerged from these studies that some of the problems of trying to saw and season the fast growing ash type eucalypts, could be negated by utilising members of the stringybark group – *E.globoidea, E.muelleriana and E.pilularis* etc.
Some of the photos in Haslett's reports indicating the degree of log end split in species such as *E.saligna* do not need any further explanation!

Apart from mitigating sawing and seasoning problems by a change in species, improvements in strength, stiffness, hardness and durability were gained at the expense of volume growth.
If one can fashion an argument to the accountant that time cost of money, volume production and ROI matter less than timber characters and durability, then a change in species is warranted. Unfortunately the accountants have prevailed so far and NZ foresters have persisted primarily with the fast growing non-durable species for end uses such as pulp, paper, some timber and more recently engineered wood such as laminated veneer lumber. (LVL)

By laying up veneer sheets and creating an LVL glued beam, uniform strength and stability can be gained for house and commercial structural purposes.
NZ *P.radiata* displays a density gradient which is highest from Northland forests and lowest in Southland forests. When an LVL beam of pine is manufactured it is difficult to reach the MOE specifications as decreed in the engineering codes. However inclusion of some eucalypt veneer sheets can improve the Modulus of Elasticity considerably.

A number of LVL manufacturers have experimented with this method of improving MOE, but have had difficulty in gaining regular veneer supply. Some have experienced gluing problems due to the mixing of veneer materials, and some have had problems associated with the lower density ash group eucalypts – viz. end split, surface checking etc. Whilst it is not necessary to have natural durability in an LVL beam, some manufacturers are keen to incorporate along with improved strength and stiffness.
However all industry personnel spoken to were agreed; ***If the eucalypt resource was available, they would work out ways of utilising it.***

Recent solid wood eucalypt studies

Recently solid wood studies have focussed on sawing and seasoning of younger wood as well as studies in engineered wood such as LVL.
It is interesting to note that in countries where eucalypt resources have been created for primarily pulp end use,(Brazil, Chile, Australia and Argentina), there are continuing studies on how to manipulate young eucalypt plantations silviculturally for solid wood as well as studies on how to use the wood for solid or reconstituted end uses.
e.g. The work in Brazil by Aracruz and latterly Urufor in Uruguay on sawing young eucalypts has added to the evidence that young eucalypt wood is capable of producing quality products.

Some of this work is motivated by desires to expand markets into higher value products, and return more to the investors, but the time cost of money is also driving processors towards utilising the timber at younger ages.

Some examples of these studies on younger wood include sawing studies on 25 year old trees from Rotoehu forest.
Species involved include; *E.fastigata*
E.globoidea
E.muelleriana
E.pilularis
The sawing /wood characteristics results show a strong site influence on growth and density when compared to some other sites evaluated. As expected *E.fastigata* was most productive but displayed more end split than the other species and *E.pilularis* struggled with the cool conditions prevailing on this site - slowest growth - low volume outturn.

E.fastigata also competed well with the better regarded timber species in board grade recovery, percentage of clears, acoustic velocity (measure of microfibil angle), kiln density and modulus of elasticity but was lower in hardness measure than *E.globoidea*, *E.meulleriana* and *E.pilularis*.
The study also noted that whilst some good quality timber was produced by age 25 years, grade out turn could be improved by pruning during the growing phase.
(Reported to FFR members of the Eucalypt group.)

Sawing and Veneer studies by McKenzie et.al on pruned 15 year old *E.nitens* indicated further that fast grown eucalypts whilst giving impressive volumes also give a lot of grief and degrade when sawn or veneered. Pruning reduced the degrade in both sawn timber and veneer but end split, surface checking and some internal collapse reduced the conversion factor considerably.
There was also a lot of variation in stiffness (as measured acoustically) and sheet thickness though the latter could be attributed to incorrect knife and pressure bar settings.

In short, variability, either inherent in the sample logs or created by the processing methods, made it difficult to envisage uniform production runs with this type of raw material.

Part 2 of this study dwelt on ways of predicting product quality from a sampling of wood properties by increment cores, disc analysis and acoustic sampling of the timber samples.
Whilst good indicators of resulting timber quality are possible, the inherent variability within tree as well as between tree variation, meant large sample numbers are required to get good prediction of wood quality.
Improvement of the future generations via genetics and possibly cloning were seen as positives for future plantations.

Further studies were made of the same 15 year old *E.nitens* material after manufacture of the veneer sheets into Laminated Veneer Lumber (LVL) by Gaunt et al.

The veneer sheets were ultrasound tested (Pundit device) and graded into stiffness classes as is frequently done with *P.radiata* veneer sheets destined for LVL manufacture. Whilst knots degraded the veneer sheets (need for pruning) the LVL produced was of better strength and stiffness properties than most *P.radiata*.
It was suggested that the inclusion of much stiffer eucalypt veneer sheets in LVL made predominantly from *P.radiata* veneer would raise the MOE of the LVL beam to meet strength standards.

Of the species targeted for this review, there is virtually no information on growth or processing outside anecdotal information on individual trees.

4. NZFFA / SCION stringybark evaluation

Most of the above eucalypt research and plantings dwelt on species which grew rapidly, and could fulfil a short fibre pulp/paper need. Some of these species are used extensively in Australia for high end timber use but there are problems in sawing and seasoning due to high internal growth stresses.

Both members of the NZ Farm Forestry Association and some scientists at SCION,
felt that a number of the stringybark group of eucalypts represented a better opportunity for solid wood processing and in a number of cases, the natural durability of the eucalypts under consideration was greater than the ash/ gum species receiving most attention.
Thus in 2003/2004 a number of plantings of these species were made on sites throughout the country. The project, highly ambitious in its initial undertaking, was to establish species trials across 55 sites on farms throughout NZ. The logistics of this are impressive and a credit to all farm foresters participating.
SCION staff that assisted, Ruth McConnochie and Ian Nicholas, distilled results down to 9 northern sites and reported on growth and survival in 2007.

Species included; *E. agglomerata,; E.eugenoides, E.globoidea, E.laevopinea,*
E. muelleriana, E.maidenii, E.microcorys, E.obliqua and E. pilularis. Group 1.
E.baxteri, E.blaxlandii, E.caliginosa, E.cameroni, E.cladocalyx, C.maculata, E.macroryncha, E. youmani. Group 2 smaller number of trees /plot than Group 1.

E.nitens and *E.fastigata* were added at some sites since their performance was quite well documented. Group 3.
A number of good timber species with moderate durability indicated good growth and survival across a range of sites.
A recent update of the trials is underway and will be published shortly.
Species performing well are; *E.globoidea, E.laevopinea, E.macroryhncha,*
E.meulleriana, E.pilularis, E.youmanii and the control species *E.fastigata*.

The trials are still too young to consider wood properties.

5. Dryland Eucalypt initiative

About 5 years ago, Blenheim forester, Paul Millen noted that many *P.radiata* posts employed in Marlborough vineyards were not performing well and he conceived the concept of replacement with naturally durable eucalypt posts.

Apart from exiting the use of preservatives with heavy metals (Cu, Cr, As) that could partially leach into soils, the strength of the eucalypt posts was better placed to withstand glancing blows from tractor tyres.
With help from people such as Shaf van Ballekom (Proseed) and Dr John Walker at Canterbury University's School of Forestry, Paul formed the NZ Dryland Forest Initiative (NZDFI).

The major objective was to test a number of durable eucalypts for their suitability and adaptability to the drier climates along the eastern parts of New Zealand.

Whilst vineyard posts were the initial target market, they quickly realised that end uses such as power pole cross arms, garden furniture, decking etc. could also be considered as future markets and substitute some of the timbers being imported into New Zealand for these purposes.
A series of trials (9 sites in North Island and 4 sites in South Island) have been implemented at a number of locations.
Species include; *E.bosistoana, E.quadrangulata, E.cladocalyx, E.camaldulensis, E.argophloia, E.globoidea, E.macrorhyncha, E.tricarpa* .

Apart from *E.globoidea*, most of these species are relative new comers or plantings have been so small that very little is known of the species in New Zealand.

The Drylands Intiative is now gathering growth data and laying the platform to refine some of the species genetically.
Early results are encouraging, with species such as *E.camaldulensis*, *E.quadrangulata, E.cladocalyx* and *E.globoidea*, are showing good growth and good adaptability across all sites.

There is some innovative allied work proceeding at the University of Canterbury on some of these species to test for growth stress and onset of durability - heartwood development.

The field trials are too young to be making species selection or refining the genetics yet, but interim evaluations of growth are indicating some good potential in these species.

6. Considerations for broadscale plantations of eucalypts

New Zealand has a very small hardwood plantation resource, in contrast to its pine resource (95% of the plantation resource is softwood) and when compared to the softwood /hardwood mix in other countries reliant on plantation wood resources - e.g. Brazil, Argentina, Chile, South Africa and Australia.

There are other reasons why eucalypts have not gained a greater share of our plantation landscape for other than economic and market perceptions.

Establishment

Eucalypts are much more sensitive to both weeds and chemicals than *P.radiata* and this affects both nursery costs and initial establishment field costs. This leads to intensive management of the establishment process, often on an extensive scale.

This has led to eucalypts being regarded as more site sensitive compared to *P.radiata*, despite evolving in generally low nutrient soils in Australia.
As small plants, eucalypts are more sensitive to transplant handling abuse, frost, chemicals, weed competition and in some cases browsing animals, than pine.

A number of eucalypts are more sensitive to soil differences than *P.radiata* and this can manifest across a plantation as variable growth. Nutrition and soil depth as well as temperature range and fluctuation can all influence growth, hence variability in the plantation.

Regardless of whether the crop is destined to be short term for pulp, or long term for timber, conservation or carbon, it makes economic sense to capture the site quickly with a tree crop. If you want to do this with eucalypts you have to pay much more care and attention to the young crop and costs can be considerably higher than establishing a crop of pines.

Silviculture

If maximum productivity is required then initial plantings need to be established at 1000 stems per hectare at least. (Hardwood Management trials.) This can be important in consideration of carbon sequestration where many pruned and thinned stands have lost potential revenue. The higher stocking also allows for more selection within, if thinning /pruning are contemplated.

Eucalypts have some ability to self prune (some species better than others) and trials by Hardwood Management and NZ Forest Products indicated if stands are left unthinned, natural mortality reduces the stand to the dominants or final crop trees over time. This may be species specific –i.e. ash type eucalypts perform differently to gum type eucalypts in monocultural stands.

There does not seem to be the disease potential often associated with overstocked pine stands and the dominants stems carry on growing somewhat regardless of the stocking per hectare. This needs to be qualified by ensuring that species /site matching has been considered prior to planting.

In early teenage stands in Kinleith Forest of approx. 1000-1200sph. Some 70% of the basal area addition was contributed by the top 300 stems in the stand. (Woollons /Poole – unpublished NZFP reports.)

If solid wood is designated as the end use then some pruning and thinning may prove economic to gain good clears at an earlier felling date. Work by McKenzie et

al. indicated higher conversion factors were possible if on-time pruning had been conducted in young *E.nitens* solid wood conversion.
There has been some work done on these aspects in both Australian and South. American eucalypt plantations.

Pests and Disease

New Zealand's relative proximity to Australia, the home of most eucalypts, has prevailing winds which blow toward NZ, and increasing air travel between the countries. These factors raise the potential for both insects and fungi to be inadvertently imported and affect eucalypt crops.

Over the last 35 years, a number of eucalypt fungal leaf pathogens have established in New Zealand and whilst none of them are fatal at the outset, the loss of photosynthetic leaf area gradually debilitates the tree, causing loss of growth and predisposing the crop toward other pathogens.

7. Growth and wood properties of durable Eucalypts with potential for establishment and processing in NZ – Gary Waugh and Jun Li Yang Australian review.

Introduction

This review has been prepared at the request of SWI to conduct a review of: "Growth & Wood Properties of Durable Eucalypts with Potential for Establishment & Processing In New Zealand." The guidelines, suggested eight species, to which the authors have added a further four species as summarised in Table 1a. These additional species were selected based on both durability and the potential to grow in the cooler temperate regions in New Zealand.

Table 1a: Species selection and natural durability (AS5604 2005)

Standard common name and scientific/botanical name		Natural durability class of heartwood	
		In-ground contact	Outside above ground
Blackbutt	*Eucalyptus pilularis*	2	1
box, grey, coast	*Eucalyptus bosistoana*	1	1
box, white-topped	*Eucalyptus quadrangulata*	2	2
box, yellow *	*Eucalyptus melliodora*	1	1
gum, blue, Sydney	*Eucalyptus saligna*	3	2
gum. red, river	*Eucalyptus camaldulensis*	2	1
gum, spotted *	*Corymbia maculata*	2	1
gum, sugar	*Eucalyptus cladocalyx*	1	1
ironbark, red *	*Eucalyptus tricarpa*	1	1
mahogany, southern	*Eucalyptus botryoides*	3	2
stringybark, yellow	*Eucalyptus muelleriana*	3	2
Tallowwood *	*Eucalyptus microcorys*	1	1

* Included at suggestion of the authors

Table 1b: Natural Durability – Probable Life Expectancy (AS5604 2005)

Durability class	Probable in-ground life expectancy (in yrs)	Probable above-ground life expectancy (in yrs)
1	Greater than 25	Greater than 40
2	15 - 25	15 - 40
3	5 - 15	7 - 15
4	0 - 5	0 - 7

Species Description

Other than *E.cladocalyx*, all of the species listed in Table 1a grow naturally in coastal NSW and far eastern Victoria, Australia. Figure 1 shows the natural distribution of all species, although *E.tricarpa and E.melliodora* also extend into central and more inland Victoria and NSW. The species selected in their natural environment range from tall trees, such as E.*pilularis* and *E.microcorys*, growing in moist deep soils in high rainfall areas in NSW, through to species such as *E.cladocalyx, E.tricarpa* and

E.melliodora, growing as small to medium trees adapted to low rainfall conditions in southern Australia. A description of each species is summarised in Table 2.

Site Requirements

Climate

The ability to match the natural site occurrence of any particular species is a good indication regarding the potential to domesticate a species, established in a plantation. However, eucalypts, being a well-recognised site pioneering genus have been successfully established on a wide range of sites with climatic conditions far different to where they may naturally occur. For example, *Eucalyptus globulus* does grow exceptionally well in Africa, within a few degrees of the equator in Kenya and Ethiopia (at altitude).

The critical factor influencing the potential distribution of many eucalypt species is intolerance to cold. This is perhaps the factor which will most limit the distribution of potential plantations in New Zealand.

Some species such as *Corymbia maculata, E.pilularis* and *E.microcorys* are intolerant to frosts, particularly in the early years of establishment, until crown closure is achieved and the site microclimate is moderated. It could be that any species with natural habitat confined to north of Sydney will have a very limited range of potential plantation sites in New Zealand, which makes *E.microcorys* a problematic species. (*E.pilularis* frosted in species trials at Warkworth –BP)

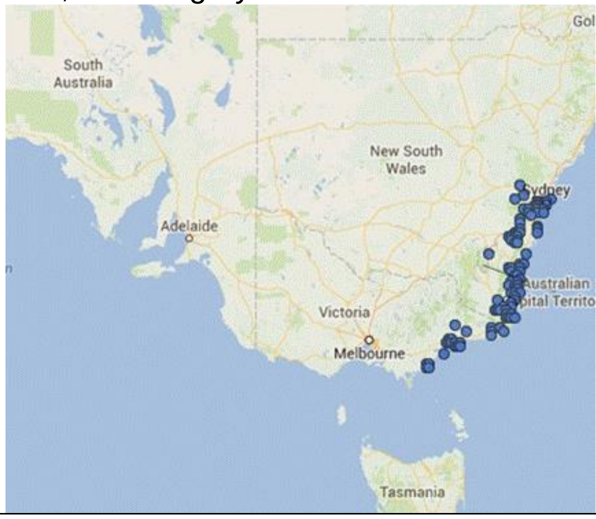
The species listed here which can best tolerate frost are *E.tricarpa* and *E.melliodora*. These species along with *E.cladocalyx* are also the most drought resistant and will grow with a moisture availability of 500-600 mm per year.

Software tools are available (BIOCLIM, ANUCLIM) (Booth et al 2013) which these days are primarily used to predict outcomes from climate change can readily be used to determine the potential climatic range of a particular species, based on inputting detailed monthly climatic data of the natural occurrence of a particular species. More information and how to gain access to this software is available on the following web site: http://fennerschool.anu.edu.au/research/products/anuclim-vrsn-61. Climatic conditions regarding the natural occurrence of the species listed in Table 1a are summarised in Table 3.

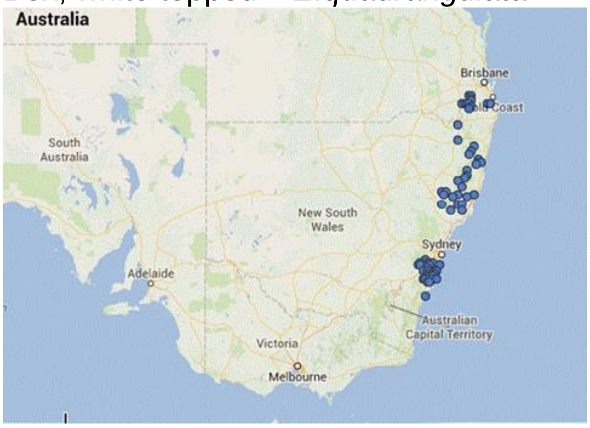
Figure 1: Natural distribution of selected durable eucalypts (http://avh.chah.org.au/)

Blackbutt- *E.pilularis*

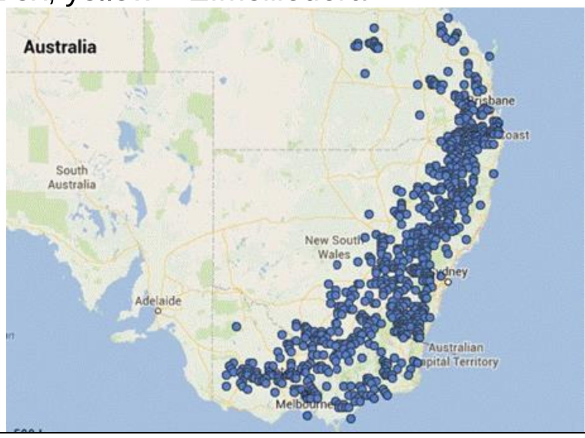
Box, coastal grey – *E.bosistoana*



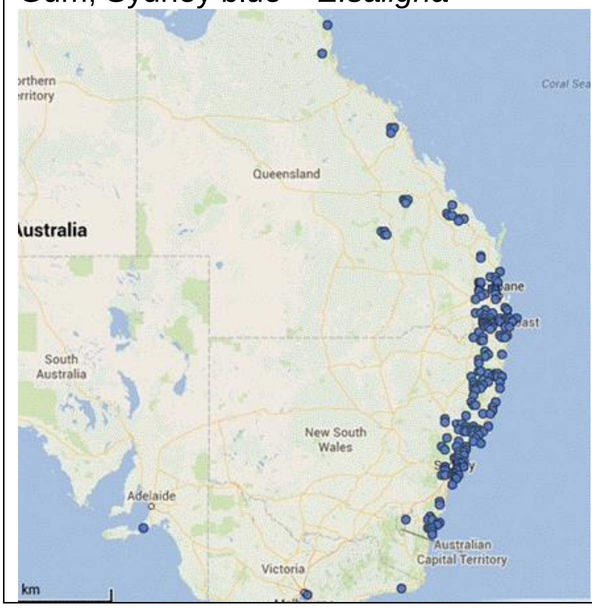
Box, white topped – *E.quadrangulata*



Box, yellow – *E.melliodora*



Gum, Sydney blue – *E.saligna*



Gum, river red – *E.camaldulensis*

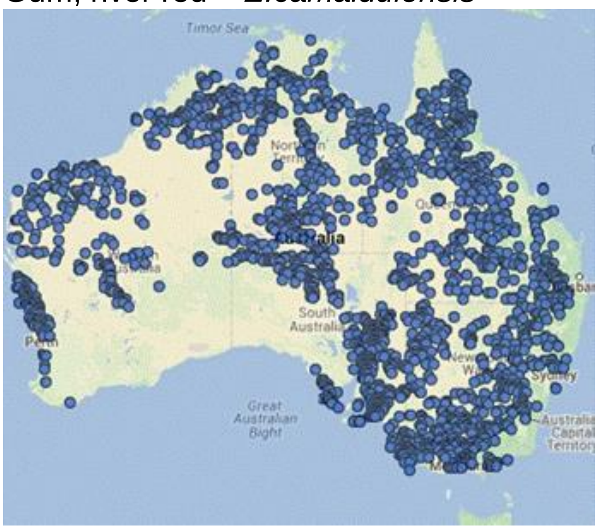
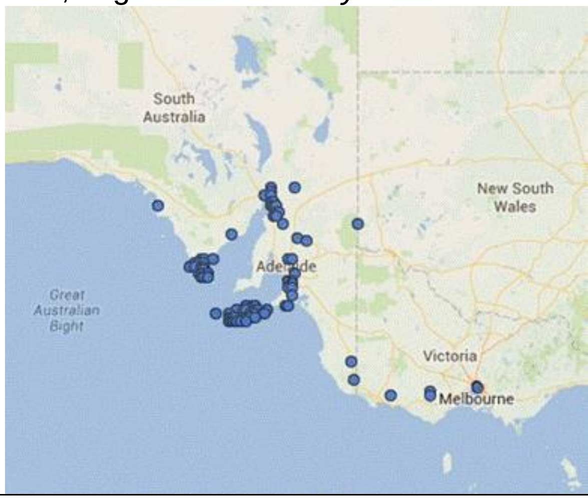


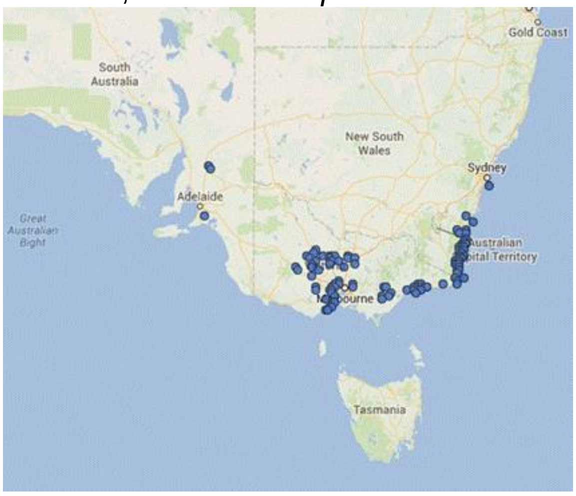
Figure 1: Natural distribution of selected durable eucalypts
(http://avh.chah.org.au/) (*continued*)

Gum, spotted – *Corymbia maculata*

Gum, sugar – *E.cladocalyx*



Ironbark, red – *E.tricarpa*



Mahogany, southern – *E.botryoides*

Stringybark, yellow – *E.muelleriana*

Tallowwood – *E.microcorys*

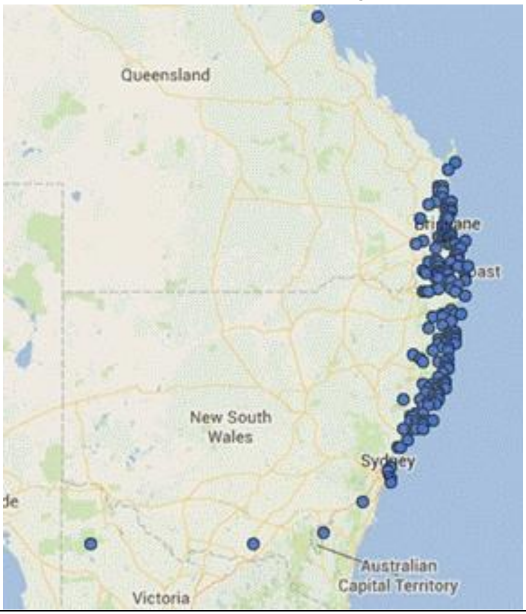


Table 2: Tree description in its natural environment

Species	Appearance	Height/diameter	Form	Rate of growth
Eucalyptus pilularis (blackbutt)	Very tall tree with smooth bark, rough bark at base.	Up to 70 metre height and 300 cm diameter	Very good form with bole 60-70 of crown height	Capable of fast growth >20 m^3/ha/year
Eucalyptus bosistoana (coast grey box)	Tall tree with subfibrous bark tending toward smooth on upper bole and branches	Up to 40 metres height and 150 cm diameter	Good form, with bole to crown height ratio 50-60%	Moderate growth rate around 10 m^3/ha/year
Eucalyptus quadrangulata (white-topped box)	Tall tree with subfibrous bark on bole, persisting to small branches	Up to 45 metre in height and 150 cm diameter	Good form, with bole to crown height ratio 40-60%	No reliable information, but would expect up to 10 m^3/ha/year
Eucalyptus melliodora (yellow box)	Moderate height tree with subfibrous bark tending toward smooth on upper bole and branches	Up to 30 metre height and 100 cm diameter	Large spreading crown, with bole to crown height ratio typically 30-50 %	Slow growth, generally < 5 m^3/ha/year
Eucalyptus saligna (Sydney blue gum)	Tall tree with smooth bark	Up to 55 metre height and 200 cm diameter	Very good form with bole 60-70% of crown height	Capable of fast growth >20 m^3/ha/year
Eucalyptus camaldulensis (river red gum)	Large bole with large spreading crown, smooth dappled bark	Up to 20 metres height and 200 cm diameter	Often poor form with low bole to crown height ratio	Can grow fast, but limited due to repeated defoliation
Corymbia maculata (spotted gum)	Clean, long, straight bole with dappled (spotted) bsrk.	Up to 35-40 metre 100-130 cm diameter	Very good form with very high bole to crown height ratio	Extremely variable, depending on site, maximum of 15m^3/ha/year
Eucalyptus cladocalyx (sugar gum)	Medium tree with dappled bark. Open crown with distinctive clumped foliage	Can grow to 35 metre height and 100 cm diameter	Can be good form. Bole typically 50-70% of crown height	Slower growing, depending on moisture availability
Eucalyptus tricarpa (red ironbark)	Medium sized tree with open crown. Dark, thick fissured bark on bole	Up to 30 metre height and 100 cm diameter	Large spreading crown, with bole to crown height ratio typically 30-50 %	Slow growth rate can be misleading due to extreme bark thickness
Eucalyptus botryoides (southern mahogany)	Variable form, depending on site, rough bark persisting on bole up to minor branches	Up to 30-40 metre height and 100 cm diameter	Can be good form, with bole 50% of crown height. Spreading crown with dense canopy	Capable of fast growth >20 m^3/ha/year
Eucalyptus muelleriana (yellow stringybark)	Stringybark, straight bole	25-40 metre height and 100 cm diameter	Good form, bole 50% crown height	Generally 10-15 m^3/ha/year
Eucalyptus microcorys (tallowwood)	Tall tree with persistent sub-fibrous bark	Up to 60 metres in height and 200 cm diameter	Good form with bole to crown height ratio typically 60-70%	Generally 10-15 m^3/ha/year

Table 3: Site requirements

Species	Climate requirements	Minimum temperature (^{0}C)	Moisture requirement	Soil type	Comments
Eucalyptus pilularis (blackbutt)	Coastal NSW, warm humid climate	Very frost susceptible	900-1750 mm	Prefers well-drained loam to sandy loam soils on gentle slopes	
Eucalyptus bosistoana (coast grey box)	Coastal east Victoria and southern NSW, warm temperate, moderately humid climate.	Moderate frost resistant	700-1200 mm	Prefers better, well-drained soils, such as loams over limestone.	
Eucalyptus quadrangulata (white-topped box)	Coastal slopes of NSW northern tablelands, warm temperate, moderately humid climate.	Moderate frost resistant	900-1700 mm	Moderate heavy soils, shale or volcanic origin	
Eucalyptus melliodora (yellow box)	Inland of dividing range, Victoria and NSW. Temperate, sub-humid climate	Moderate to good frost tolerance	500-900 mm	Best on alluvial loams and sandy loams found on gentle slopes and foothills	
Eucalyptus saligna (Sydney blue gum)	Coastal regions of NSW and southern Qld	Mild frost tolerance	900-1800 mm	Prefers well drained alluvial sandy loams	
Eucalyptus camaldulensis (river red gum)	Endemic across most of mainland Australia, adapted to a wide range of climates.	Mild frost tolerance	250-600 mm	Sandy alluvial soils in river valleys. Not suited for calcareous soils	Wide number of provenances to meet site requirements
Corymbia maculata (spotted gum)	Coastal NSW, warm humid climate	Frost susceptible	750-1750 mm	Wide range, moderately heavy, moist, well drained valley slopes	
Eucalyptus cladocalyx (sugar gum)	Flinders Range, South Australia. Limited natural distribution	Mild frost tolerance	380-650 mm	Capable of growing in shallow skeletal or podsolic soils	
Eucalyptus tricarpa (red ironbark)	Inland of dividing range with coastal outliers, Victoria Temperate, sub-humid climate	Moderate to good frost tolerance	500-900 mm	Capable of growing on poor shallow soils on ridge tops, including clays, ironstone and sands	Very closely related to *E. sideroxlon*, occurring in NSW
Eucalyptus botryoides (southern mahogany)	Narrow distribution, coastal belt of southern NSW and far eastern Victoria	Low frost tolerance	700-1300 mm	Prefers moderate fertile loams of river valleys. Capable of growing on poor sandy soils	
Eucalyptus muelleriana (yellow stringybark)	Far south east Australia, coastal and coastal foothills	Sensitive to frost damage	700-1200 mm	Prefers deep clay loams, sheltered slopes and valleys	
Eucalyptus microcorys (tallowwood)	Coastal northern NSW and southern Queensland. Warm, humid climate	Poor frost tolerance	1000-2000 mm	Requires moist fertile soils.	

Susceptibility to attack by biological agencies

A wide range of defoliators have evolved, adapted exclusively to eucalypts. A list of major insect defoliators known to be a problem in Victorian plantations is shown in Table 4 and Table 5 provides a further summary of insect defoliators relative to the species listed in Table1a. Crysomelid beetles, including Christmas and Paropsis beetles and Psyllid (lerps) cause the most wide-spread damage across a very broad range of eucalypt species. In addition, ambrosia beetle is known to attack the wood of some species, such as *E.pilularis* and *E.muelleriana*. This can significantly reduce the strength properties and appearance attributes of infected sawn products (Figure 2).

Figure 2: Typical Ambrosia borer holes

Silvicultural operations, regular thinning and ensuring maintaining tree vigour and air flow through a plantation is the best defence for numerous fungal agencies which can attack eucalypt foliage. However the looming threats of Guava Rust (*Puccinia psidii*) and Myrtle Rust *(Uredo rangelii*) are other factors which will be needed to be taken into account, with a number of the species listed as being susceptible to this disease which predominantly attacks young foliage and shoots (http://www.anbg.gov.au/anpc/resources/Myrtle_Rust.html). Most species other than *E.muelleriana* are not regarded as being susceptible to Dieback Disease (*Phytopthera cinnamoni*).

Most of the species have been established in either Australia or New Zealand in plantations. However, some species, particularly the box type species have had only limited development and it is as yet unknown as to the effect of development of a monoculture may have on future attack by biological agencies.

Table 4: Summary of principal insect defoliators and their life cycle and host preference in young Victorian eucalypt plantations prior to canopy closure. http://www.dpi.vic.gov.au/forestry/pests-diseases-weeds/pests/insect-pests-of-young-eucalypt-plantations

Insect species	No. generations per year	Damaging part of life cycle	Primary eucalypt host species	Foliage attached	Comments
Wingless grasshopper (Phaulacriduium vittatum)	One	Nymphs and adults (mid-summer to early autumn)	Most spp. of eucalypt at the seedling stage	Juvenile	Attack generally confined to first year after planting during drought years
Autumn gum moth (Mnesampela privata)	One	Larvae (March to August)	E. globulus E. nitens E. dunnii E. bridgesiana	Juvenile	Attack ceases once trees have adult foliage
Leaf blister sawfly (Phylacteophaga froggatti)	Four to five	Larvae (mainly over winter in north-central Victoria)	E. botryoides E. grandis E. saligna	Juvenile	Attack ceases once trees have adult foliage
Steelblue sawfly (Perga affinis affinis)	One	Larvae (April to September)	E. camaldulensis E. globulus E. occidentalis E. melliodora E. viminalis	Juvenile and adult	Attack declines once trees achieve canopy closure
Christmas beetles (Anoplognathus spp.)	One or two	Adults (November to January)	E. grandis E. globulus E. blakelyi E. botryoides E. viminalis	Juvenile and adult	Generally, pre-canopy closure pest in farm areas with susceptible eucalypts
Leaf beetles (Paropsis spp. and Chrysophtharta spp.)	Two	Larvae and adults (November to March)	E. viminalis E. grandis E. regnans E. melliodora E. globulus* E. blakelyi	Juvenile and adult	Attack lessens once trees achieve canopy closure; usually a problem near forest areas
Brown basket lerp (Cardiaspina fiscella)	Three to five	Nymphs and adults	E. botryoides	Adult	Attack is concentrated adults on lower crowns
Redgum basket lerp (C. retator)	Three to five	Nymphs and adults	E. camaldulensis	Juvenile and adult	Whole crowns are susceptible

***Adult foliage only**

Table 5: Susceptibility to biological attack

Species	Fungal	Insect	Adaptability to plantations	Comments
Eucalyptus pilularis (blackbutt)	Susceptible to Guava Rust	Gum leaf scale (Eriococus spp). Wood can be attacked by ambrosia beetle	No major problems other than site selection.	
Eucalyptus bosistoana (coast grey box)	No known severe pathogen problems	No major problems recorded	Little information of adaptation to plantations, but not expected to be any major pathogen or insect problems.	
Eucalyptus quadrangulata (white-topped box)	No known severe pathogen problems	No major problems recorded		
Eucalyptus melliodora (yellow box)	No known severe pathogen problems	Paropsis attack prior to crown closure	Potential slow growth. Preferred honey species	
Eucalyptus saligna (Sydney blue gum)	Susceptible to Guava Rust	Prone to attack by Psyllids. Juvenile foliage attacked by sawfly.	Highly susceptible to defoliation by many insects, limiting plantation growth	Not recommended by Scion for NZ planting
Eucalyptus camaldulensis (river red gum)	Potentially susceptible to Guava Rust	Every know leaf-feeding creature, from koalas, through to Crysomelid beetles and psyllids	Leaves and leading shoots constantly eaten, reducing vigour and resulting in poor form. Does well in countries free of its natural pests	Difficult to grow in plantations in Australia due to defoliation. Expect same in NZ
Corymbia maculata (spotted gum)	Susceptible to Ramularia spp, causing growing tip die-back	Mild susceptibility to Christmas beetle and Cup moth lavae defoliation. Sapwood prone to lyctus attack	Adapted to a wide range of sites if free of frost	Has shown to be adaptable to farm forestry in Australia
Eucalyptus tricarpa (red ironbark)	No major problems	Foliage can be attacked by psyllids.	Very slow growth, but potentially high value wood	Good form even with wide spacing
Eucalyptus botryoides (southern mahogany)	Suscepibility to Guava Rust may be a future problem	Highly susceptible to psyllid and sawfly attack	Psyllid attack can develop frequently as a major problem	Not recommended by Scion for NZ planting
Eucalyptus muelleriana (yellow stringybark)	Susceptible to *Phytophthora cinnamomi.*	Foliage not highly susceptible. Wood can be attacked by ambrosia beetle	No major problem	Proven success in NZ
Eucalyptus microcorys (tallowwood)	No major problems	No major problems recorded	Site selection may mean limited opportunity in NZ	

Wood characteristics and uses for naturally grown trees

While it can be expected that wood properties will differ with plantation-grown wood; density and strength properties will be reduced, the properties of the existing resource can often be a valuable insight as to the potential product opportunities of growing the same species in plantations, particularly for slower grown species that may require a rotation length of 30 or more years.
Table 6 provides summarised information on wood properties and existing uses, while Table 7 provides summarised information on processing characteristics. Further information on density, strength and durability characteristics of both mature and plantation-grown wood is provided in later Tables.

Commercial processors of listed species in Australia

(Refer to table 6 for species list for each manufacturer)

1. Boral Timbers 89 St Hillers Road, Auburn NSW 2144, ph::: 1800 818 317
2. Hurford Hardware Rifle Range Rd, Tuncester NSW 2480, ph (02) 6621 9886
3. Notaris and Sons Heber St.,South Grafton NSW 2460 ph (02) 6642 3477
4. O'Briens Sawmill 1 Little Forest Ln, Barham, NSW 2732 ph (03) 5453 2905
5. Smart Timbers http://www.smartimbers.com.au/news-services.htm
6. Terra Timbers Powerstation Rd, Bairnsdale, Vic 3875 ph: (03) 5152 6600
7. Hallmark Oaks 110 Princess H'way, Cann River, Vic 3890 ph: 0351586244
8. Talbot Timbers 11 Biltons La, Talbot, Vic 3371 ph: (03) 5463 2300
9. Simmonds Lumber 1 Durham Street, Rosehill NSW 2142 ph: (02) 9638 7333

Some of the selected species, such as *E.botryoides, E.camaldulensis* and *E.bosistoana* have now limited availability as most of the resource has been included in forest reserves and no longer available to industry.
Other species, such as *E.tricarpa* and *E.melliodora* are more scattered in distribution and likewise also have been incorporated into reserves, although examples of small scale sawmilling still exist, primarily for local farmer use.

Damage caused by wild animals and livestock

There is nothing in the literature to indicate that any one of the listed species is more at threat than others, but rather, damage is more a wide-spread problem

Livestock damage can largely be controlled by the grower. Eucalypt foliage is unpalatable to livestock, so most of the damage created is mechanical and most will be in the early years of establishment, particularly when it may be desirable to introduce livestock to control competing vegetation. While sheep are little problem, once seedlings are established, cattle in particular beef cattle can cause considerable stem damage to most eucalypts by rubbing themselves against trees, separating the cambium, which is unlikely to be noticed until well after the damage took place.

Browsing by possums and rabbits (and wallabies and koalas in Australia) is not so easily controlled and baiting and deterrent chemicals provide the only real solution (Montague et al 1990)

Table 6: Natural forest wood description and uses

Species	Colour	Characteristics	Traditional uses	Commercial processors
Eucalyptus pilularis (blackbutt)	brown	Open texture	Heavy construction, flooring	1,2,3,9
Eucalyptus bosistoana (coast grey box)	Light brown	Fine texture with interlocking grain	Poles, railway sleepers, construction timbers	9
Eucalyptus quadrangulata (white-topped box)	Pale yellow-brown	Fine	Heavy construction uses	
Eucalypt s melliodora (yellow box)	Yellow-brown	Fine texture	Sleepers, poles, cross-arms. Difficult to machine	
Eucalyptus saligna (Sydney blue gum)	Light to dark red	Straight grain with coarse texture	General construction uses, flooring and decking	1,2,3
Eucalyptus camaldulensis (river red gum)	Medium to dark red	Interlocked, fine grained wood, with numerous kino pockets and veins	Piles and poles, sleepers, flooring and decking and general construction uses	4.9
Corymbia maculata (spotted gum)	Light grey to tan	Wood usually straight grain	Piles and poles, sleepers, flooring and decking and general construction uses	1,2,3,9
Eucalyptus cladocalyx (sugar gum)	Pale yellow-brown	Fine, but interlocking grain	Posts, poles, decking and general construction	5.8
Eucalyptus tricarpa (red ironbark)	Dark red	Fine, interlocking grain	Posts, decking and flooring, furniture and general construction	8
Eucalyptus botryoides (southern mahogany)	Deep pink to red	Medium texture with interlocking grain	Sleepers, general construction, decking	6,7
Eucalyptus muelleriana (yellow stringybark)	Yellowish-brown with pink tinge	Straight grain with some interlocking. Fine texture	Wide range of uses; flooring, decking, poles	6,7
Eucalyptus microcorys (tallowwood)	Reddish-brown	Coarse, interlocking grain, kino veins	Railway sleepers, general construction	1,2,9

Table 7: Wood working characteristics

Species	Sawing	Drying	Adhesive properties	Machining/turning	**Comments**
Eucalyptus pilularis (blackbutt)	Moderate distortion and splitting during sawing	No known problems	Good bond strength for most adhesives	No known problems	
Eucalyptus bosistoana (coast grey box)	No known problems	No known problems. Will develop surface checking if dried too fast		Fine grain, believed to turn and machine well.	Fine grain of box eucalypts has application for high-end furniture.
Eucalyptus quadrangulata (white-topped box)	No information	No specific information. Expect surface checking if dried too fast	No information. Expect to perform same as other box species	Expect would machine and turn well	
Eucalyptus melliodora (yellow box)	No known problems	Surface checking if dried too fast		Fine grain box. Machines and turns well.	Takes finishing treatment and polish very well
Eucalyptus saligna (Sydney blue gum)	Log end-splitting and distortion during sawing	No problems if use low drying rate schedule		Coarse grain, but machines and turns well	Versatile species with many uses
Eucalyptus camaldulensis (river red gum)	Log end-splitting and distortion during sawing	Needs mild drying schedule. Wood prone to collapse during drying	No known problems	Can have considerable interlock grain causing chip-out on machining	
Corymbia maculata (spotted gum)	Moderate distortion during sawing	Easy to dry with little danger of surface checking	Bond strength is a major problem with phenol based adhesives	Machines and turns well	Adhesive bond OK with fresh machined surface. Isocyanate adhesives successful
Eucalyptus cladocalyx (sugar gum)	No known problems	Mild schedule required to reduce surface checking	Can be a problem with phenol based adhesives	High wear on cutters and blades	Good results for use for decking
Eucalyptus tricarpa (red ironbark)	No known problems	No known problems	Good bond strength with both PVA and phenol based adhesives	No problems with machining and turning	Popular wood for high-end furniture, when available
Eucalyptus botryoides (southern mahogany)	Moderate log end-splitting and distortion during sawing	Danger of severe surface checking. Can suffer distortion during drying	No known problems	Can have some problem with grain angle and chipping out	

Eucalyptus muelleriana (yellow stringybark)	Relatively stable with little distortion. Minimal knotty core	Minimal degrade if use correct drying schedule	No recorded problems	No problems with machining and turning	Very versatile species, many uses
Eucalyptus microcorys (tallowwood)	No known problems	Major problem with surface checking	Can have problems with bond strength with phenol based adhesives	Machines well. Expect would also have no problems with turning	Popular for flooring. Wood has greasy feel

Table 8: Adaptability to plantations grown for solid wood products

Species	Anticipated rotation length	Potential products	Potential growth rate in plantations	Anticipated self-pruning capability	Possible concerns
Eucalyptus pilularis (blackbutt)	20-25 years	Flooring, sawn structural and veneer products, poles	>15 m^3/ha/year	good	Site selection, soils and frost
Eucalyptus bosistoana (coast grey box)	30-35 years	Flooring, decking, furniture and sawn structural product. poles	10-15 m^3/ha/year	Good	
Eucalyptus quadrangulata (white-topped box)	30-35 years	Flooring, decking, furniture and sawn structural product. poles	10-15 m^3/ha/year	Should be good.	
Eucalyptus melliodora (yellow box)	35 years	Flooring, decking, furniture and sawn structural product. Honey	7-12 m^3/ha/year	Moderate	Early insect attack
Eucalyptus saligna (Sydney blue gum)	20 years	Flooring and decking, furniture and sawn structural products, veneer products and decking	>20 m^3/ha/year	Very good, even at wider spacing	Insect attack
Eucalyptus camaldulensis (river red gum)	30 years	Flooring and decking, furniture and sawn structural products	7-12 m^3/ha/year	Poor to moderate	Severe insect attack
Corymbia maculata (spotted gum)	25-30 years	Poles, flooring and decking, sawn structural products	>15 m^3/ha/year	Excellent, even at wide spacing	Frost sensitivity. Adhesive problems
Eucalyptus cladocalyx (sugar gum)	35-40 years	Decking, sawn structural product	5-10 m^3/ha/year	Good	Slow growth
Eucalyptus tricarpa (red ironbark)	35-40 years	Decking and flooring, furniture and sawn structural product	5-10 m^3/ha/year	Moderate to good	Slow growth. Very thick bark
Eucalyptus botryoides (southern mahogany)	20-25 years	Flooring and decking, furniture and sawn structural products	>15 m^3/ha/year	Moderate	Insect defoliation, tree form
Eucalyptus muelleriana (yellow stringybark)	35 years	Posts, poles, decking and flooring, sawn structural product	>15 m^3/ha/year	Moderate to good	Root pathogens, site selection
Eucalyptus microcorys (tallowwood)	20-25 years	Poles, decking	>15 m^3/ha/year	Good	Site selection may limit NZ potential

Adaption to Plantations

Tree growth and performance

Trees growing under natural conditions will provide a first indication regarding how a species may perform when grown in plantations, but only when matched by climatic conditions, soil and topography. However, only some of the species selected do grow naturally as a single species forest and then rarely of a single age, therefore how a tree grows and reacts and competes with trees can be completely different. The absence of a natural understory can have a major influence on self-pruning.
In Table 8, an attempt is made to estimate the performance of the different species growing in a plantation environment and the limited data that is available comparing the characteristics of plantation and mature wood is shown in Table 10 (APP 3). For some species, such as *E.saligna, E.cladocalyx, E.muelleriana* and *C.maculata*, there is already considerable experience with growing these species and there are reliable expectations regarding growth rate and rotation length. However, for some, for example the three box eucalypts; *E.quadrangulata, E.bosistoana* and *E,melliodora*, growth rates and rotation length are more speculative.

Branching and self-pruning characteristics

NZFFA stated: “There is a perception that eucalypts are self-pruning, but this is true only of naturally regenerating stands with an initial stocking rate in the order of 20,000 stems/ha. In planted stands with standardised spacing (1,111 stems/ha), most of the lower branches are retained. At 2,000 stems/ha branch size is severely restricted and reduced, but does not eliminate the need for pruning. Eucalypts require pruning for clearwood production. Pruning should be done in dry weather to minimise entry of decay organisms.”
However, there can still be quite a large difference in self-pruning characteristics between species, with *C.maculata* readily self-pruning, even a wide spacing, while other species such as *E.muelleriana* and *E.pilularis* not exhibiting the same desirable trait. Table 8 information is based on the known performance of particular species in existing plantations and also expectations based on self-pruning in native forests. An attempt to provide a broad classification of self-pruning capabilities is described in Tables 8 and Table 10 (APP 3).

Wood description and properties

Natural durability (in ground use) and insect susceptibility

Durability information on the 12 tree species targeted in this report is extracted from the Australian Standard AS5604 2005: Timber – Natural Durability Ratings and presented in Table 9. Under these criteria, only those species meeting durability class 2 or better for both above and in-ground use, could be classed as durable.
Mature wood of *E.saligna, E.botryoides* and *E.muelleriana* fail to meet this requirement (Table 9), but the NZ Farm forestry Association does rate plantation-grown wood of these species as meeting class 2 requirements (APP 3 Table 10).

The natural durability, termite resistance, sapwood susceptibility to lyctid attack for wood from mature native forests (Australia) and plantations (Australia and New Zealand) are also presented in Table 9.

The results from McCarthy et al. (2009) show that "the low rainfall and farm forestry species tested in this project generally have high natural durability. The heartwood of 30-50 years or older trees of red ironbark, spotted gum, sugar gum, yellow gum and brown mallet all proved to be termite resistant (against *Coptotermes acinaciformis*). Similarly, the same timbers gave at least natural durability class 3 performances against decay, both above ground and in-ground. Most likely, if the decay trials continued, they would prove to have class 1 or 2 naturally durabilities. More variable results were obtained with <25 years old trees, with density providing a useful guide as to likely performance relative to mature timber".

Table 9: Timber - Natural Durability Ratings (AS5604 2005)

1	2	3	4		5
Standard common name and scientific/botanical name	Lyctid susceptibility of sapwood	Termite resistance of heartwood (inside above ground—applicable to H2 in AS 1604 series)	Natural durability class of heartwood		Marineborer resistance of heartwood
			In-ground contact, Dig	Outside above ground, Dag	
blackbutt *Eucalyptus pilularis*	NS	R	2	1	3
box, grey, coast *Eucalyptus bosistoana*	S	R	1	1	3
box, white-topped *Eucalyptus quadrangulata*	NS	R	2	2	-
box, yellow *Eucalyptus melliodora*	NS	R	1	1	-
gum, blue, Sydney *Eucalyptus saligna*	S	NR	3	2	3
gum. red, river *Eucalyptus camaldulensis*	S	R	2	1	2
gum, spotted *Corymbia maculata*	S	R	2	1	4
gum, sugar *Eucalyptus cladocalyx*	S	R	1	1	-
ironbark, red *Eucalyptus tricarpa*	S	R	1	1	2
mahogany, southern *Eucalyptus botryoides*	NS	R	3	2	-
stringybark, yellow *Eucalyptus muelleriana*	NS	R	3	2	3
tallowwood *Eucalyptus microcorys*	S	R	1	1	3

Notes:

Dig = in-ground natural durability class
Dag = above-ground natural durability class
S = Susceptible
NS = Not susceptible
R = Resistant to termite
NR = Not resistant to termite

Natural Durability – Probable Life Expectancy (AS5604 2005)

Durability class	Probable in-ground life expectancy (in years)	Probable above-ground life expectancy (in years)
1	Greater than 25	Greater than 40
2	15 to 25	15 to 40
3	5 to 15	7 to 15
4	0 - 5	0 to 7

Marine Borer Resistance – Probable Life Expectancy (AS5604 2005)

Class	Probable marine-borer-resistance life expectancy in southern waters (years)
1	Greater than 60
2	41 – 60
3	21 - 40
4	0 to 20, usually less than 5

AS 5604 gives natural durability ratings for mature timber only (Table 9), and the need to place data for younger wood should be considered (APP 3 Table 12). Density appeared to account for many of the variations in natural durability found between the different age groups of timber. MaCarthy et al. (2009) recommended that "Standards Australia could be asked whether such additional information can be included in the standard. One approach might be to mention allowable tree ages for each species, while another would be to nominate an acceptable range of density values. The latter method would be easier to trace and monitor in the market place".

Density

Density values vary within trees, between trees, between provenance and sites, and also sampling methods. These need to be kept in mind when inspecting the numbers in Table 12 (APP 3).

Density of plantation wood was often found to be lower than the values for mature wood from native forests. However density of older plantation trees is comparable or even higher than density of mature wood from native forests. For instance, McCarthy et al. (2009) found that *C.maculata* (spotted gum), *E.cladocalyx* (sugar gum), *E.leucoxylon* (yellow gum) and *E.astringens* (brown mallet) trees 30-50 years old had heartwood density values higher than the values for mature trees determined by Kingston and Risdon (1961).

NZFFA stated: "New Zealand-grown eucalypt has similar wood properties to Australian grown material. Although New Zealand-grown eucalypts can have a lower wood density than those grown in Australia, which are often from older trees, the timber is suitable for the same purposes".

Lower densities generally associated with plantation-grown wood for the range of species covered in this review can be an advantage for certain end-uses. The furniture industry prefers wood at about 850 mg/m^3, where strength is generally more than adequate for purpose and the wood readily machined. The mature wood of all of these species exceeds that range, often in excess of 1000 kg/m^3, making the wood more difficult to machine and glue and the end product more heavy than needed.

Engineering properties

Modulus of elasticity (MOE, a measure of stiffness), modulus of rupture (MOR, a measure of strength), and hardness for wood from mature native forests (Australia) and plantations (Australia and New Zealand) are presented in Table 11 (APP 3).

Shrinkage and drying degrade propensity

Shrinkages from green to 12% MC, and unit shrinkage (percentage of change in dimensions with each one percent change in moisture content below fibre saturation point), in radial and tangential directions for wood from mature native forests (Australia) and plantations (Australia and New Zealand) are presented in Table 12 (APP 3).

Stem/log growth stresses, log end splitting, brittleheart

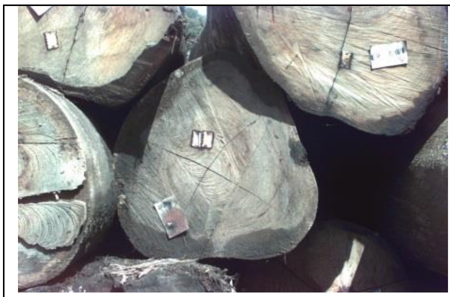
What are Growth stress, log end splits, brittleheart

Growth stresses are self-generated in the cambium during cell maturation and are present in all tree species (Jacobs 1938; Kubler 1987). Strains, as a consequence of relief of growth stresses, are called growth strains. By measuring the strain and modulus of elasticity (MOE), the stress corresponding to that strain can be calculated. Eucalypts that are prone to high levels of growth stresses include *E.delegatensis*, *E.regnans*, *E.globulus* and *E.obliqua* whether from native forests or plantations (Barnacle and Gottestein 1968; Hillis, 1984; Jacobs 1938, Kubler 1987; Nicholson 1973; Waugh and Yang 1993; Yang 2005, 2007). A number of research on eucalypt species has shown that growth stresses vary between and within species (Hillis 1984; Kubler 1987), between provenances (Yang et al. 2001) and highly responsive to growth conditions (Kubler 1987, 1988).

Brittleheart is the wood in the central zone of a tree, which is characterized by the presence of cell wall deformations or compression failures across wood grain, has particularly low impact strength or bending strength, and fails with brash or less splintery fracture (Dadswell and Langlands 1934, 1938; Yang 2001). The cell wall deformations are formed during tree growth when the longitudinal compression stress induced by the longitudinal growth stresses exceeds a certain percentage of the compression strength of the wood. *E.delegatensis, E. egnans* and *E.diversicolor* are known to be susceptible to brittleheart formation (Dadswell and Langlands 1934, 1938; Yang et al. 1995). The severity and radial extent of brittleheart are positively associated with the magnitude of longitudinal growth stresses and tree diameter. The combination of high growth stress and brittle heart are major contributors to log end-splitting.

Radial log end splits as shown in Figure 3 can be mild to highly severe depending on the levels of growth stresses in the trees as shown in below pictures. The loss of both productivity and recovery due to log end splits has been either actually measured (Yang and Pongracic 2004) or estimated (Waugh et al. 1996). Interlocking grain occurring in *E.camaldulensis* and the box eucalypts such as *E.melliodora* will limit the initiation of end-splits, but can still result in distortion during sawing.

Figure 3: End-splitting in eucalypts

		
Mild log end splits Regrowth ash eucalypts in Tasmania, Australia	**Moderate log end splits** Plantation grown *E.saligna*, Australia	**Severe log end splits** Plantation grown *E.saligna*, Australia

Descriptive evaluation of the levels or severity of growth stress, log end splits and brittleheart for log/wood materials from mature native forests (Australia) and plantations (Australia and New Zealand) is given in Table 10 (APP 3).

Main effect of growth stress on wood processing and utilization

Main effect on log/timber processing and wood utilisation are (Yang and Waugh 2001):

1. Loss of sawlog recovery due to log end-splitting
2. Sawn board thickness inaccuracies
3. Sawn board distortion due to stress re-balance
4. Loss of productivity
5. Constraints on log break-down and sawing patterns
6. Drying degrade due to tension wood
7. Weak material in core wood zone caused by brittleheart
8. Heart checks in standing trees
9. Greater effects on conversion of small logs

Limited information on growth stress for the twelve species

There are vast amounts of information on growth stress, log end splits and brittleheart on a number of eucalypt species, which were the species of main economic importance to the regions and countries at the time of the research. However, Information on levels of growth stress, log end splits and brittleheart for the twelve species that are targeted in this report is scarce whether for trees from mature native forests or from plantations in both Australia and New Zealand, with some exception of *E.pilularis*. When high levels of growth stress were reported, they were seldom estimated/quantified through measurements of growth strain on stem surface, but were evaluated/qualified through observations of log end splits and/or estimated loss of sawn recovery (Haslett 1990; Kininmonth et al. 1974; Kubler 1987; NZFFA).

Conclusion

Of the twelve species included in this review, by Australian standards, *E.saligna, E.muelleriana* and *E.botryoides* do not meet the criteria to be classified as 'durable' species as they are classified as Class 3 for in-ground applications

In addition, SCION no longer recommends *E.saligna* and *E.botryoides* for planting due to susceptibility to insect defoliation.

E.camaldulensis should be considered with caution, although durable, when established in plantations, it has been found to be highly susceptible to continuous all year attack by insects. With such a wide geographic distribution, provenance selection and matching to site becomes very important.

As the natural occurrence of *E.microcorys* is confined to warm humid coastal areas in Australia, north of Sydney, it may be that suitable site selection will be very limited in New Zealand. However, this would need to be confirmed with climate and site matching, initially using available software tools such as BIOCLIM. As *E.microcorys* meets all of the essential criteria such as growth rate, form and durability requirements, it certainly should be investigated further.

Where frosts and colder winter months are not going to be a problem, basically north of Rotorua, then there should be sites suited for the establishment of *E.pilularis* and *Corymbia maculata*. Opportunities may exist to expand the range of *C.maculata* with the selection of more frost resistant provenances. Both are fast-growing and durable species with good self-pruning properties. *C.maculata* in particular has proved very successful in Australia in adapting to an agroforestry environment, maintaining good form and self-pruning even at wide spacing. The species is popular in Australia for flooring and decking and new generation adhesives overcome a major past problem for joinery uses.

The remaining five species all have some degree of frost resistance and have broader opportunities for planting on a wider range of sites in New Zealand. E.tricarpa, while having been successfully established in limited plantations in Australia, has never shown very good growth rates. However, it is a very hardy species, capable of handling dry sites and drought, has good form and in Australia, produces a very durable, red, fine textured wood suited for high-value joinery and could be considered for establishment on some sites if other aesthetic and land care values are also taken into account.

The three box eucalypts (*E.bosistoana, E.quadrangulata* and *E.melliodora*) are of interest. They all produce high density, light coloured, fine grain wood which has both high durability and also of interest for high-value appearance use. The wood readily takes finishing treatment and polishing The fact that younger, plantation-grown wood is of lower density will, if anything, enhance opportunities for appearance uses as it should be easier to machine and glue. *E.melliodora* may be more frost tolerant than the other two, but will not achieve the same growth rates and may not have as good form in plantations. However, in Australia, it is noted as the eucalypt that produces the best quality honey, which again could be an important selection factor for agroforestry.

E.cladocalyx has not been left to last for any particular reason. It is frost tolerant and not highly susceptible to insect attack. It has been widely established in the south-west region of Victoria, which is exposed to the cold winds of the Southern Ocean during the winter months, as a windbreak species and has adapted well to that region. The wood is light and fine-grained and meets category 1 for both above and in-ground durability and below average shrinkage for the group of eucalypts included in this review. Plantation-grown wood is currently being used for decking in Australia and is gaining in popularity. Regarding drought-resistance, the species is virtually ‘bullet-proof’.

Of the twelve species reviewed, nine would appear to have opportunities to be grown in New Zealand to produce durable wood. Some may be restricted due to intolerance to frost and others, while producing high-quality wood, may have growth rates unacceptable for commercial forestry, but could gain acceptance for broader agroforestry applications, but it would appear all of these species have some opportunity for adaptation to plantations in New Zealand.

8. Discussion

There is enough evidence in New Zealand and Australia to suggest a place for some of the slower growing but stronger and more durable eucalypt species to be planted in broad scale plantations in NZ.
The benefits have been well documented; strength, stiffness, durability in exposed weather situations.
Some of the risks need noting;
Outside a few species such as *E.globoidea*, and *E.muelleriana* there is not much evidence of larger scale plantings nor trees of maturity in the landscape.

In terms of understanding the likely exposure to variation in soils, climates, environmental extremes and pests and disease, we are only a short way along the domestication pathway.
Our Australian authors also note differences in growth patterns and associated species in the natural situation as opposed to plantations of single species in New Zealand. Often the geographic range of some of the promising new species is small and so full perusal of the genetic resource is advised to gain full exposure to the genetic potential to limit future risk.
Many of the new plantings are young and so there is insufficient growth data to create volume functions and growth models. This means the arguments for expanding plantings have to be advanced on grounds pertaining to durability, strength, sustainability, environmental awareness and long term societal demands.

The accountants will default to IRR of well known species such as *P.radiata*.
The lack of data to construct sound economic arguments will hinder the development of these new species but increasing concern over aspects of *P.radiata* health and its limitations to meet standards for some end uses – e.g. strength may help to engender the motivation to develop some of these alternative species.

<u>Conversion factor / Log Utility</u>

The timber conversion factor for eucalypts will always be lower than pine, despite good advances in sawing and drying technologies. The inherent growth stresses in fast growing hardwoods predispose the fibre toward warping and twist.
Growers would do best economically if they have contracts for both sawlogs and chips, as there will always be a reasonable amount of fibre unsuitable for timber end use. If there is not a pulping facility within economic haul distance then innovative ways of using the un-utilised fibre may need to be developed to justify the venture economically. This could be co-generation energy production or some form of fibre board manufacture.
Note also many of the durable higher density eucalypt species have not proved to be good pulping species.

However if regular volume supply can be established for processors, then the greater strength and density of eucalypt wood should help develop profitable markets in New Zealand as well as in Asia, particularly for the top laminate for engineered flooring.

Carbon sequestration

Whilst the use of timber plantation to store carbon and gain carbon credits has fallen into dis- regard by virtue of low carbon prices, it should not be discounted as another long term revenue earner from plantation eucalypts. An investor can contemplate a much earlier return for a plantation of trees resulting from sequestration and sale of carbon credits.
This reduces the time/cost of money drag that affects all long term investments. Plantation revenue could start from Age 4 years instead of waiting until harvest.
Global groups addressing these carbon issues have to reach some sort of working consensus by 2020 AD.

Some of the on-going research for bio-fuel substrate from trees suggests that hardwoods are more easily broken down enzymatically than pines, so it may develop as another market opportunity in the future.

9. Acknowledgement

I'm grateful to a number of people in the forest industry and SWI for helping with thoughts and expertise contributing toward this paper.

Barry Poole
November 2013

Appendix 1

Brief history of growing plantation eucalypts in New Zealand

Growing and Management

Part of the genesis of *P.radiata* plantations in New Zealand , was to conserve the natural forest resources and offer faster grown alternative wood fibre.
Early houses and the furniture within, were built of kauri, rimu, totara and beech sourced from our native forests.
Once *P.radiata* utilisation began in earnest in the late 1940's, there was still adequate supplies of native wood to fulfil furniture and other more specialised uses of wood.

As ideas around conserving the natural forest estate grew and conservation issues such as raising the level of Lake Manapouri or utilising the West Coast beech forests began to change public sentiment against utilisation of the natural forest, alternative "special purpose species" came into planners minds.
Thus the interest in eucalypts for wood fibre or "special purposes" did not really begin until the late 1960's and early 1970's.

Perhaps some of the earliest research plantings were initiated by Dr. Harry Bunn of FRI and much of his early interest was in *E.delegatensis* . He also investigated mixed species plantings of eucalypts (Generally *E.delegatensis*) and *P.radiata .*
This prompted organisations such as NZFP to investigate eucalypts as a substitute short fibre source for the local species tawa (*Beilschmiedia tawa)* which was used at Kinleith mill for short fibre pulp.
Early trial plantings by NZFP utilised *E.delegatensis* but quickly moved to *E.regnans, E.fastigata* and *E.nitens* for reasons of growth rate, density , pulping suitability and health status – (*Mycosphaerella sp on E.delegatensis*).

Earlier planting efforts outside the Forest Service or companies, were more serendipitous – gold miners introducing *E.globulus*, McWhannell's nursery introducing *E.viminalis. & E.macarthurii* and a host of NZFS foresters in outlier estates and farm foresters trialling species such as *E.saligna, E.botryoides*, *E. globoidea* and *E.muelleriana* with a view to timber end use rather than pulp and paper. Whilst many of the trial plantings in small NZFS forests may not have had had formal trial layouts and replicated trial design, much of the early indications of growth and adaptability comes from these plantings.

The forerunner of NZFP –NZ Perpetual Forests, established *E.scabra* now named *E.eugenoides* in Kinleith forest (Waikato block) between 1925 -1927, along with redwoods. Working plan records declared 400,000 seedlings were dispatched, though it did not differentiate between the eucalypts and redwoods. As most of this area is now in fourth generation plantation or converted to dairy farm, it is difficult to find evidence of these plantings now days.
There were early plantings in Kaingaroa forest also, and a stand of *E.fastigata* aged 70 years, was harvested a few years ago with substantial yield/ha. This indicates some interest in large NZFS estates from the 1940's.

A number of these species are no longer planted due to insect defoliation, fungal leaf infections, poor fibre characters or other species better suited to end use.

Much of this process is noted as domestication of a species; " identifying and characterising the germplasm of the target species, capture, selection, management and conservation of genetic resources, and then the regeneration and sustainable cultivation of the species in managed ecosystems."

A number of eucalypt species trials were initiated in the 1970's, by FRI staff (Wilcox et al) , Forest Service plantings in various locations, some by Pulp and Paper companies (NZFP & FCL), some by staff at the National Plant Materials Centre and a number of smaller plantings by farm foresters. The objectives in these efforts were mixed –from genetic improvement, suitability for erosion control on Wairarapa hill country, to good timber species and landscape values. All of these efforts have added to our general knowledge of eucalypt species and where they grow well.

A number of the species trials initiated by Dr. M. Wilcox consisted of family seedlot collections of *E.regnans, E.fastigata, E.saligna, E.delegatensis and E.nitens* from Australia, and formed the basis for selection of superior individuals for breeding programmes in these species. Even first generation individuals showed improved domestication in terms of tree health, tree vigour and form. A number of other scientists have continued this work through successive generations despite small programmes and little research monies afforded.

As most trials reported were interested in growth and vigour, the same Monocalyptus species – *E.regnans*, *E.fastigata, E.obliqua and E.fraxinoides,* keep appearing as the best species for vigour. Some of the better timber species such as *E.meulleriana* and *E.globoidea* get a mention but generally as more moderate growth species.

The Wairarapa trials implemented by Hathaway et al. involved a large number of species and were assessed for growth and other factors by Shelbourne et al. at 22 years of age.
The two sites chosen were characterised as dry Wairarapa hill sites and some 52 species were planted and 49 assessed at 12 years and 22 years post planting – generally species known for growth or timber qualities.
Assessment of diameter (DBH), straightness, malformation, crown health and potential number of saw logs indicated species such as. *E.globoidea ;E.muelleriana* ; *E.obliqua, E.fraxinoides, E.regnans, E.cordata, E.delegatensis, E.fastigata, E.sieberi, E.cinerea, E.kartzoffiana* and *E.nitens*, were nominated as the top 12 species.

The significance of this large trial is that by 22 years there is a good expression of growth potential on the site (noting changes in rank from the earlier assessment).
Many of the trees in the non thinned trial site (Kahuiti) were showing good growth (>300mm DBH) and reasonable form by this assessment.

When this information is combined with other trial data from other regions, some broad conclusions on growth and adaptability can be drawn.

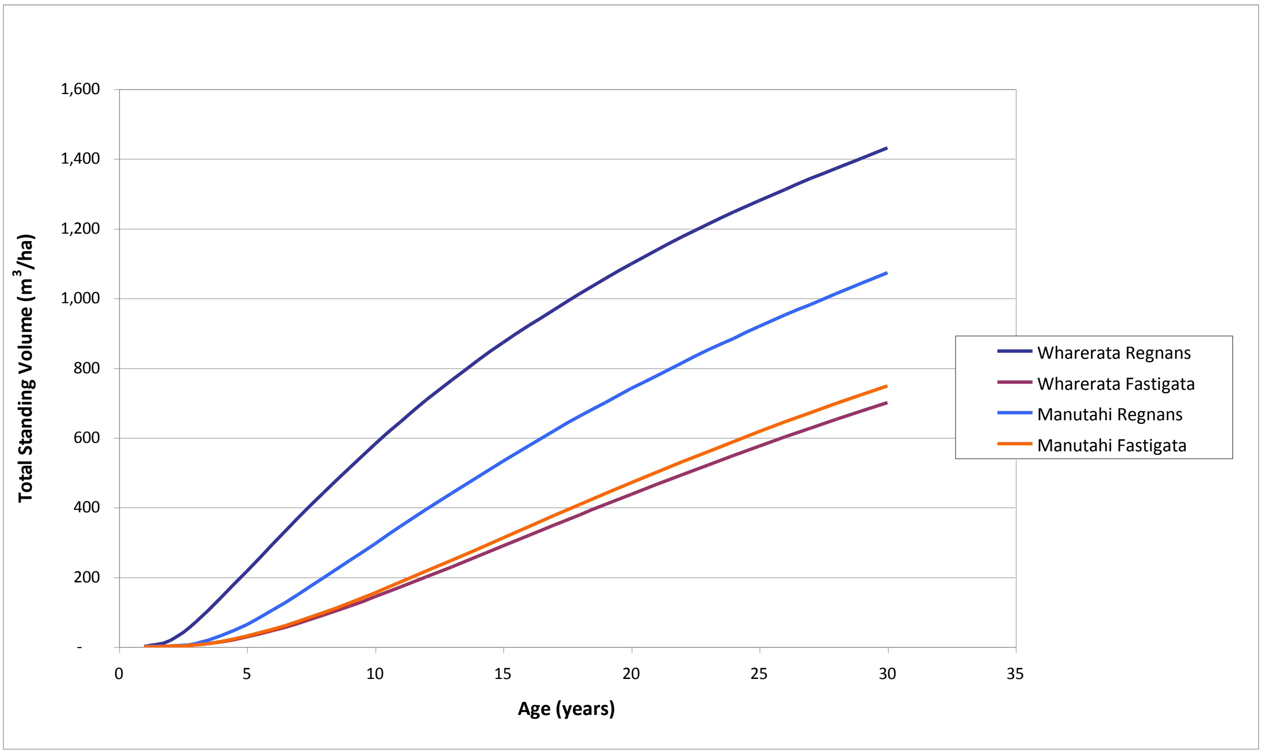
E.regnans, E.obliqua, E.meulleriana, E.globoidea and E.fastigata show good growth potential for the northern parts of the North Island at lower altitudes. There are still fine

examples of *E.saligna* in Northland, but recent insect introductions make it a risky prospect for any future large scale planting.
E.regnans, E.fastigata and *E.nitens* show most potential for the central part of New Zealand, (including the higher central plateau). Species such as *E.fraxinoides* and *E.oreades* also show promise but have not been planted on any scale.
E.nitens, E.delegatensis and E.regnans showed growth potential in the south of the South Island, but relative frost tolerance and lower wood density has discriminated against the latter 2 species in recent plantings.

Some of these species display remarkable plasticity in altitude range - e.g. *E.fastigata* planted at sea level on the Ohiwa Harbour and at around 600m in Walnut Rd., Kinleith Forest.

Recent investigation by Hardwood Management of some of the early NZFS plantings of *E.regnans* and *E.fastigata* in places such as Manutahi forest (Ruatoria) and Wharerata Forest (south of Gisborne) has shown very good growth at altitudes ranging up to around 500m measured at ages 30 and 28 respectively.

Figure 1: East Coast Eucalypts



The predominance of the *Monocalyptus* group species over the *Symphomyrtus* group species is in contrast to most eucalypt plantings around the world and is generally attributed to proximity to Australia, our climate and possible similarity in soil fungal symbionts with the cooler parts of Australia. (Pryor –pers. comm.)
This is probably fortuitous given the greater pest loading on the larger *Symphomyrtus* group and New Zealand's proximity to Australia.

Some of the exceptions in terms of species are *E.maidenii, E.benthamii, E.pulchella* which indicated good growth in trials at Clive;Ohiwa Harbour and Craggy Range, Havelock North (dry site).
Provenance or seed origin can be important as evidenced by *E.benthamii* at Ohiwa Harbour (K.Molony –pers comm.) or some of the early work by Wilcox et al.
There is often as much *variation between a specie provenances,* as there is variation between eucalypt species.

<u>Species site matching</u>

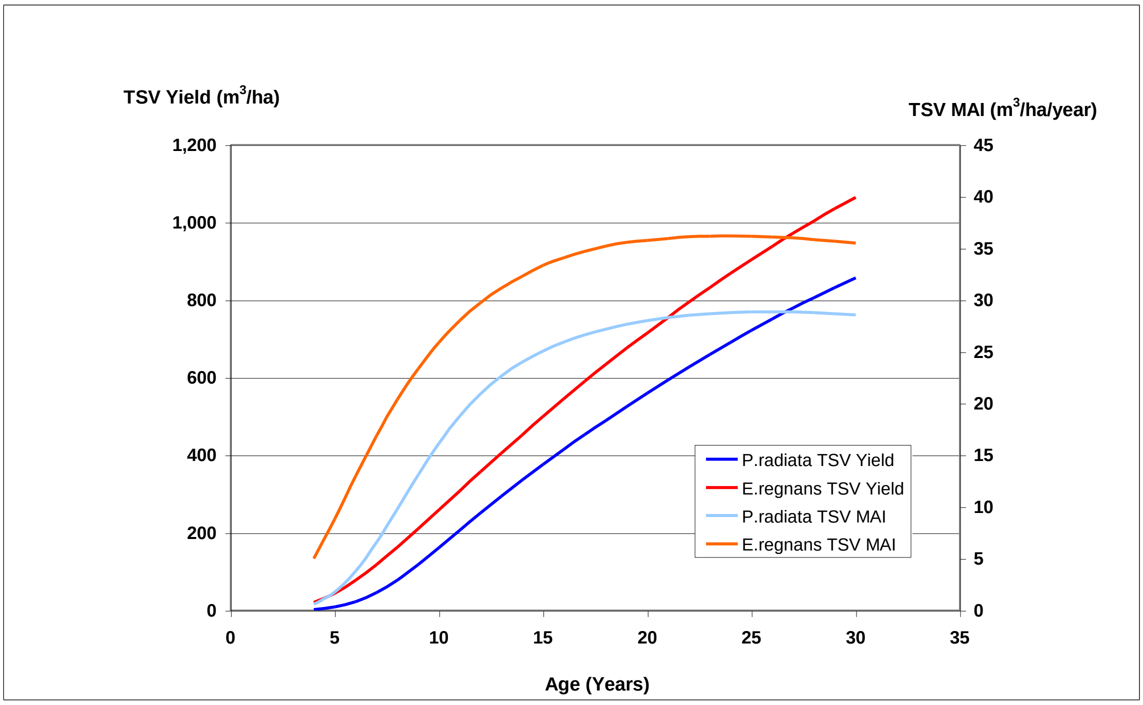
Gradually the idea of matching species to site has gained credence and species/site modelling is gaining ground as data is accumulated to support the importance of correct matching. Computer models such as BIOCLIM ;LENZ and CABALA can indicate the most promising species choices for a particular site and most empirical data to hand supports this.

When the particular eucalypt species is well matched to site, it can perform extremely well as evidenced by examples of *E.regnans* from Pouakani, Manutahi, Wharerata There are similar examples with *E.fastigata* from Kaingaroa, Manutahi, Kapenga and Oakura which suggest these species have the capacity to grow for a long period of time (>50years) at a very productive rate in New Zealand conditions.
There are still impressive stands > 50 years old of *E.regnans* and *E.fastigata* in Waititi, Oakura, Kinleith forest and Newstead near Hamilton.

A recent felling of *E.fastigata/E.nitens* planted close to Rotorua (Kapenga) was harvested for pulp at Age 11years and yielded an average of 248 m3 for *E.nitens* (22.5 m3/ha MAI) (40ha) and 297m3/ha (27m3 MAI) (20ha.) for *E.fastigata* (pers comm).

Invariably growth rate was a major factor in species evaluation and comparison with *P.radiata* growth rates is continual. One of the few examples where most nursery and site factors were the same was a planting monitored and measured in NZFP's Pouakani forests. See Figure 2.

Figure 2 : E.regnans vs P.radiata on Pouakani site –Measured Age 11



Note other examples in Appendix 1.

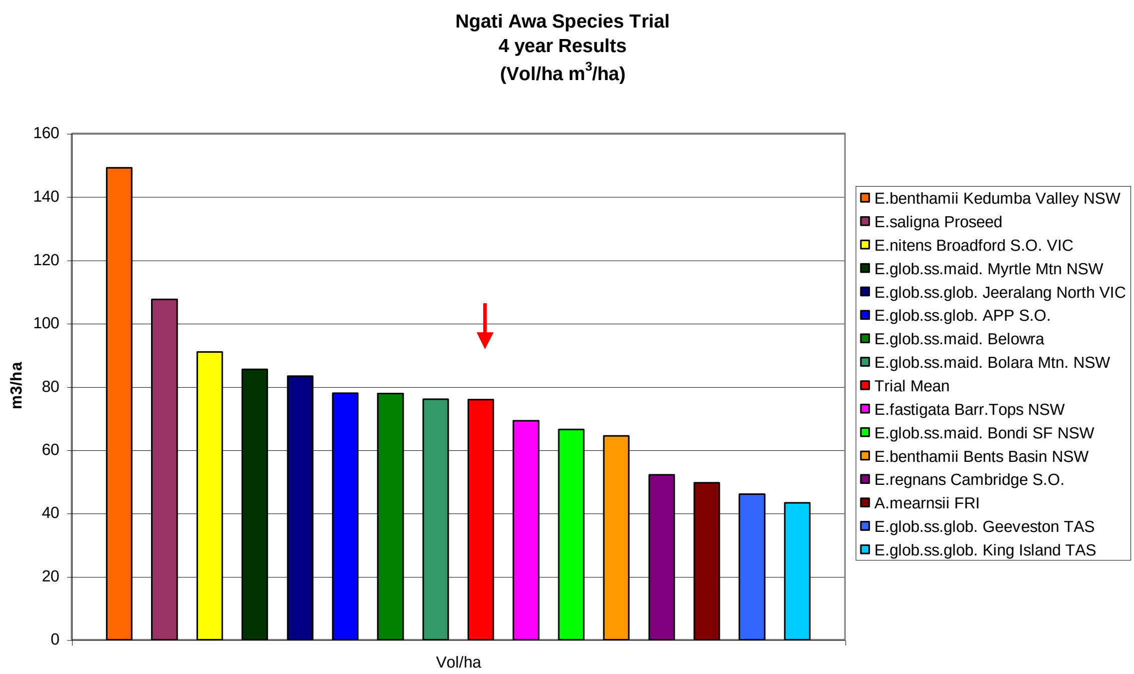
Thus we have eucalypt species which can compete on a number of sites with *P.radiata* in NZ conditions and yet the eucalypt resource area is tiny compared to *P.radiata*? This is in contrast to Australia, Chile, Argentina, Brazil and South Africa where the eucalypt plantation resources have grown considerably in the last 20 -30 years.
The lack of eucalypt plantation resource in New Zealand and the lack of any concentrated plantings outside the pulp and paper companies makes it very difficult to develop wood processing of the species. One cannot guarantee continuity of supply.

At the present time there is very little broad scale planting of eucalypts in New Zealand.
Southwood Exports are still planting *E.nitens* in areas north and west of Invercargill for a chip export operation to Japan. Their current estate is approximately 10,000 hectares.
CHH Pulp and Paper are still establishing eucalypts in close proximity of Kinleith mill as the mill has an annual requirement for around 110,000 tonnes. Major species are *E. nitens, E.fastigata and E.regnans.* Total resource at present covers approximately 3000 hectares. Annual establishment programme averages around 500 hectares.

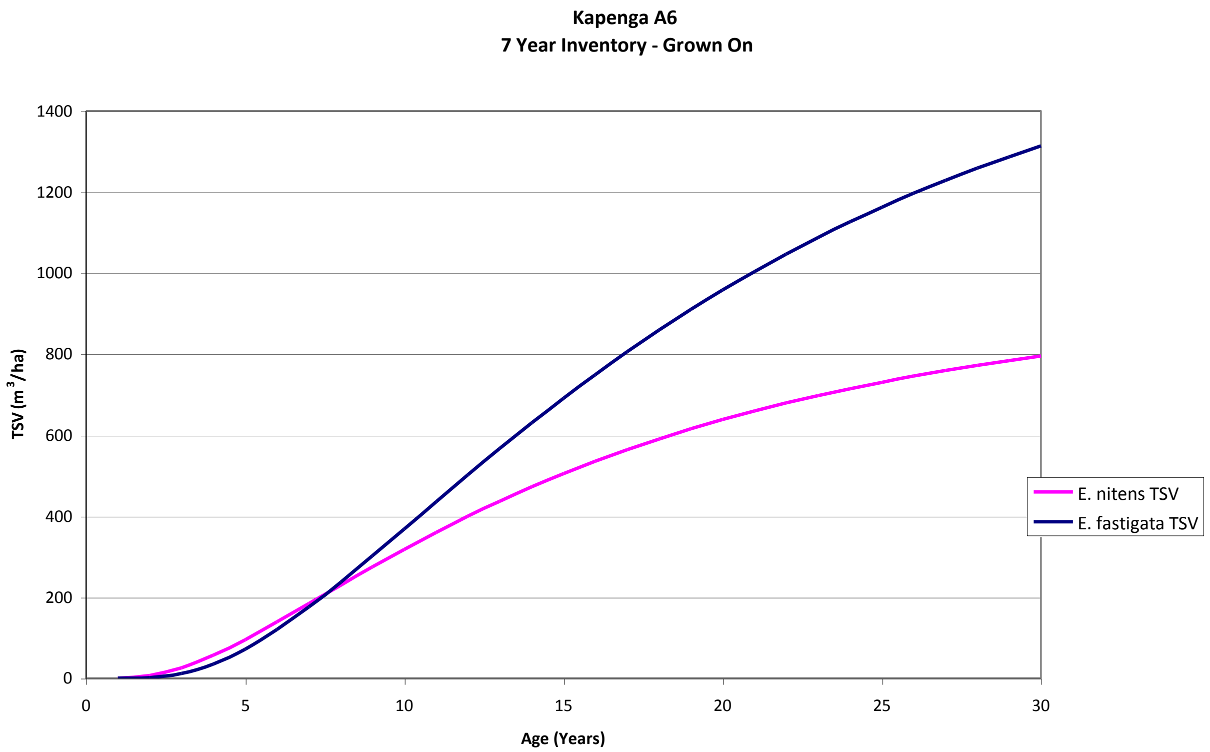
There are still small resources elsewhere in the country as evidenced by the latest NEFD survey - 23,000 hectares nationwide but over 50% is within these 2 estates.

Appendix 2 - Growth information from various sites.

1. Ngati Awa near Ohiwa Harbour. Plot data



2. Kapenga inventory –Age 7 years. Data and graph



Appendix 3

Following:

Table 10 Internal log defects, natural durability, growth stress and related defects in trees from plantations and mature native forests in Australia and from New Zealand-grown plantations

Table 11 Engineering properties at 12% MC of wood (mean and standard deviation in brackets) from plantations and mature natural forests grown in Australia and from New Zealand -grown plantations

Table 12 Density and shrinkage of wood (mean and standard deviation in brackets) from plantations and natural mature forests grown in Australia and from New Zealand-grown plantations

Table 10: Internal log defects, natural durability, growth stress and related defects in trees from plantations and mature native forests in Australia and from New Zealand-grown plantations (to continue).

Species	Ref.	Origin	Age	Internal log defects	Natural durability class		Termite resistance	Lyctid susceptibility of sapwood	Self-pruning	Growth stress	Brittle heart	Log end splitting
					In-ground fungal attack	Above-ground fungal attack						
E. pilularis	8	NSW	Short rotation	-	-	-	-	-	-	-	-	Severe
	1	Australia	Mature native forests	-	2	1	Resistant	Not susceptible	-	-	-	-
	2	North Island, New Zealand	>25	-	-	-	-	Sapwood not durable	-	-	-	-
	7	New Zealand	Plantation	-	2	2	-	-	-	Low	Low	Low
E. bosistoana	1	Australia	Mature native forests	-	1	1	Resistant	Susceptible	-	-	-	-
E. quadrangulata	1	Australia	Mature native forests	-	2	2	Resistant	Not susceptible	-	-	-	-
E. melliodora	1	Australia	Mature native forests	-	1	1	Resistant	Not susceptible	-	-	-	-
E. saligna	1	Australia	Mature native forests	-	3	2	Not resistant	Susceptible	-	-	-	-
	2	North Island, New Zealand	>25	-	-	-	-	Sapwood not durable	-	Severe	High incidence	Severe
	5	Athenree forest, New Zealand	28	-	-	-	-	-	-	Severe	-	Severe
	7	New Zealand	Plantation	-	2	2	-	-	-	-	-	-
E. camaldulensis	1	Australia	Mature native forests	-	2	1	Resistant	Susceptible	-	-	-	-

Table 10: Internal log defects, natural durability, self-pruning, growth stress and related defects in trees from plantations and mature native forests in Australia and from New Zealand-grown plantations (continued)

Species	Ref.	Origin	Age	Internal log defects	Natural durability class		Termite resistance	Lyctid susceptibility of sapwood	Self-pruning	Growth stress	Brittleheart	Log end splitting
C. maculata	6	QLD	30-50	-	At least 3	At least 3	Resistant	-	-	-	-	-
	6	South Australia	80+	-	At least 3	At least 3	Resistant	-	-	-	-	-
	1	Australia	Mature native forests	-	2	1	Resistant	Susceptible	-	-	-	-
	2	North Island, New Zealand	>25	-	-	-	-	-	Very good	-	-	-
E. cladocalyx	4	Murray-Darling Basin, Australia	36	-	-	-	-	-	Good	-	-	-
	6	Vic, South Australia	30-50	-	At least 3	At least 3	Resistant	-	-	-	-	-
	6	Vic	80+	-	At least 3	At least 3	Resistant	-	-	-	-	-
	1	Australia	Mature native forests	-	1	1	Resistant	Susceptible	-	-	-	-
	7	New Zealand	Plantation	-	1	1	-	-	-	-	-	-
E tricarpa	4	Murray-Darling Basin, Australia	40	-	-	-	-	-	Good	-	-	-
	6	Vic	30-50	-	At least 3	At least 3	Resistant	-	-	-	-	-
	6	Vic, South Australia	80+	-	At least 3	At least 3	Resistant	-	-	-	-	-
	1	Australia	Mature native forests	-	1	1	Resistant	Susceptible	-	-	-	-

Table 10: Internal log defects, natural durability, self-pruning, growth stress and related defects in trees from plantations and mature native forests in Australia and from New Zealand-grown plantations (continued)

Species	Ref.	Origin	Age	Internal log defects	Natural durability class		Termite resistance	Lyctid susceptibility of sapwood	Self-pruning	Growth stress	Brittle heart	Log end splitting
					In-ground fungal attack	Above-ground fungal attack						
	1	Australia	Mature native forests	-	3	2	Resistant	Not susceptible	-	-	-	-
E. botryoides	2	North Island, New Zealand	>25	-	-	-	-	Sapwood not durable	-	Severe	High incidence	Severe
	7	New Zealand	Plantation	-	2	2	-	-	-	-	-	-
E. microcorys	1	Australia	Mature native forests	-	1	1	Resistant	Susceptible	-	-	-	-
	7	New Zealand	Plantation	-	2	2	-	-	-	Low	Low	Low

Table 10: Internal log defects, natural durability, self-pruning, growth stress and related defects in trees from plantations and mature native forests in Australia and from New Zealand-grown plantations (continued)

Species	Ref.	Origin	Age	Internal log defects	Natural durability class		Termite resistance	Lyctid susceptibility of sapwood	Self-pruning	Growth stress	Brittle heart	Log end splitting
					In-ground fungal attack	Above-ground fungal attack						
E. muelleriana	3	NSW	Mature native forests	old E. muellerana logs commonly demonstrate larger pipe and “bardi grub” related defects	-	-	-	Not susceptible	-	Low	-	Low
	1	Australia	Mature native forests	-	3	2	Resistant	Not susceptible	-	-	-	-
	2	North Island, New Zealand	>25	-	-	-	-	Sapwood not durable	-	Low	-	Low
	3	Davies-Colley property near Titoki, New Zealand	31	-	-	-	-	Not susceptible	-	Low	-	Low
	7	New Zealand	Plant-ation	-	2	2	-	Not susceptible	-	Low	Low	Low

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Notes: In Haslett, T. 1990, the age of the trees for data measurements is explicitly specified. An educated guess has to be made for this table.

Table 11: Engineering properties at 12% MC of wood (mean and standard deviation in brackets) from plantations and mature natural forests grown in Australia and from New Zealand -grown plantations (to continue).

Species	References	Origin	Age	MOE (GPa)	MOR (MPa)	Hardness (N)			Comments
						Radial	Tangential	End	
Eucalyptus pilularis (blackbutt)	5	QLD	9	10.4 (-)	90 (-)	4890 (-)		-	
	1	NSW, QLD	Mature native forest	18.9 (2.2)	144.1 (16.2)	8985 (1483)	8807 (1431)	9564 (1435)	
	4	North Island, New Zealand	>25	13.4 (-)	114.5 (-)	5900 (-)		-	As reported by Haslett, T. 1990
Eucalyptus bosistoana (coast grey box)	1	Vic	Mature native forest	20.3 (2.4)	163.4 (14.7)	13122 (1279)	12588 (1511)	10142 (1014)	
Eucalyptus quadrangulata (white-topped box)	1	-	Mature native forest	-	-	-	-	-	
Eucalyptus melliodora (yellow box)	1	Vic	Mature native forest	14.1 (2.6)	122.0 (24.7)	13078 (1340)	12944 (1327)	10854 (1438)	
Eucalyptus saligna (Sydney blue gum)	2	Mildura (Victoria)	18	14.7 (2.0)	116.0 (20.6)	-	-	-	
	2	Shepparton (Victoria)	25	14.4 (2.1)	99.4 (26.7)	-	-	-	
	1	NSW, QLD	Mature native forest	15.2 (3.0)	122.0 (22.0)	8719 (894)	7473 (1663)	9074 (1838)	
	4	North Island, New Zealand	>25	11.1 (-)	90.9 (-)	5200 (-)		-	As reported by Haslett, T. 1990

Table 11: Engineering properties at 12% MC of wood (mean and standard deviation in brackets) from plantations and mature natural forests grown in Australia and from New Zealand -grown plantations (continued).

Species	Reference	Origin	Age	MOE (GPa)	MOR (MPa)	Hardness (N)			Comments
						Radial	Tangential	End	
Eucalyptus camaldulensis (river red gum)	2	Mildura (Victoria)	17	11.4 (2.2)	92.1 (21.6)	-	-	-	
	1	QLD, Vic	Mature native forest	11.2 (2.4)	101.4 (23.3)	9742 (2192)	9519 (1333)	10409 (2082)	
Corymbia maculata (spotted gum)	2	Mildura (Victoria)	18	14.1 (1.5)	118.0 (13.8)	-	-	-	
	2	Shepparton (Victoria)	28	17.0 (1.8)	141.0 (22.5)	-	-	-	
	2	Lake Hume (Vic/NSW border)	40	15.2 (1.8)	131.0 (16.7)	-	-	-	
	1	NSW, QLD, Vic	Mature native forest	18.8 (2.7)	142.0 (19.5)	10053 (1382)	10094 (1212)	8407 (1135)	
Eucalyptus cladocalyx (sugar gum)	6	Vic	27	-	-	High		-	
	2	Earlston (Victoria)	40	17.4 (2.9)	137.8 (34.6)	-	-	-	
	2	-	Mature	17 (-)	132 (-)	-	-	-	

Table 11: Engineering properties at 12% MC of wood (mean and standard deviation in brackets) from plantations and mature natural forests grown in Australia and from New Zealand -grown plantations (continued).

Species	Reference	Origin	Age	MOE (GPa)	MOR (MPa)	Hardness (N)			Comments
						Radial	Tangential	End	
Eucalyptus tricarpa (red ironbark)	2	Lake Hume (Vic/NSW border)	40	10.4 (1.4)	94.4 (13.9)	-	-	-	
	1	Vic	Mature native forest	17.0 (3.0)	148.9 (24.9)	12010 (1381)	11832 (1361)	9831 (1204)	
Eucalyptus botryoides (southern mahogany)	1	NSW, Vic	Mature native forest	17.5 (2.2)	130.3 (11.7)	9208 (1289)	9653 (1931)	10542 (1318)	
	3	North Island, New Zealand	>25	11.7 (-)	101.0 (-)	6400 (-)		-	
Eucalyptus muelleriana (yellow stringybark)	1	NSW, Vic	Mature native forest	16.8 (1.9)	131.7 (12.5)	8630 (1467)	8585 (1502)	9341 (1635)	
	3	North Island, New Zealand	>25	10.1 (-)	103.7 (-)	5500 (-)		-	
Eucalyptus microcorys (tallowwood)	1	NSW, QLD	Mature native forest	18.2 (2.9)	137.2 (16.5)	8674 (1128)	8585 (1009)	7740 (793)	

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1. Bolza, E. and Kloot, N.H. 1963.
2. Ashley, P.N. and Ozarska, B. 2000.
3. Haslett, T. 1990.
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5. McGavin, R.L. et al. 2006.
6. Smart Timbers.

Note:

1. In Haslett, T. 1990. Hardness test surface was not specified and is assumed to be the transverse average hardness.
2. In McGavin, R.L. et al. 2006, the test trees thinnings, the strength properties were obtained from small clear specimens, and the hardness is the average transverse hardness.

Table 12: Density and shrinkage of wood (mean and standard deviation in brackets) from plantations and natural mature forests grown in Australia and from New Zealand-grown plantations (to continue).

Species	Reference	Origin	Age	Density (kg/m^3)		Shrinkage (%)				Drying degrade
						Green to 12% MC		Unit shrinkage		
				Basic	12% MC	Radial	Tangential	Radial	Tangential	
Eucalyptus pilularis (blackbutt)	11	QLD	9	528 (?)		2.3 (-)	4.8 (-)	0.16 (-)	0.28 (-)	
	12	QLD	12	590 (-)		-	-	-	-	
	13	QLD	21	567 (-)		-	-	-	-	
	1	NSW	Immature	503 (3.4)	-	4.7 (0.32)	6.4 (-)	-	-	
	1	NSW, QLD	Mature native forest	698 (8.3)	860 (10.6)	3.5 (0.11)	5.8 (0.16)	0.26 (0.008)	0.37 (0.007)	
	6	Puhipuhi, New Zealand	43	-	722 (36.1)	-	-	-	-	Low
	8	Tairua, New Zealand	15	563 (46)	-	-	-	-	-	
	7	North Island, New Zealand	>25	585 (-)	720 (-)	2.9 (-)	5.2 (-)	-	-	Low
	16	New Zealand	-	-	-	2.9 (-)	5.2 (-)	-	-	Low
Eucalyptus bosistoana (coast grey box)	1	NSW, Vic	Mature native forest	875 (13.3)	1084 (10.7)	3.4 (0.17)	6.6 (0.22)	0.31 (0.009)	0.42 (0.013)	
Eucalyptus quadrangulata (white-topped box)	1	NSW	Mature native forest	690 (-)	-	-	-	-	-	
Eucalyptus melliodora (yellow box)	1	NSW, Vic	Mature native forest	899 (9)	1051 (16.3)	2.3 (0.09)	4.6 (0.19)	0.26 (0.014)	0.39 (0.021)	

Table 12: Density and shrinkage of wood (mean and standard deviation in brackets) from plantations and natural mature forests grown in Australia and from New Zealand-grown plantations (continued).

Species	Reference	Origin	Age	Density (kg/m³)		Shrinkage (%)				Drying degrade
						Green to 12% MC		Unit shrinkage		
				Basic	12% MC	Radial	Tangential	Radial	Tangential	
Eucalyptus saligna (Sydney blue gum)	2	Mildura (Vic)	18	-	774 (96.2)	-	-	-	-	
	2	Shepparton (Vic)	25	-	779 (81.4)	-	-	-	-	
	1	NSW, QLD	Mature native forest	655 (14.4)	806 (17.5)	3.7 (0.23)	5.8 (0.30)	0.24 (0.013)	0.34 (0.010)	
	7	North Island, New Zealand	>25	615 (-)	730 (-)	3.8 **(-)**	7.0 (-)	-	-	Low
	6	Athenree, New Zealand	28	-	724 (72.4)	-	-	-	-	Low
	6	Waikato, New Zealand	50-60	-	764 (41.3)	-	-	-	-	Low
	8	New Zealand	3	431 (28)	-	-	-	-	-	
	8	New Zealand	7	420 (31)	-	-	-	-	-	
	8	New Zealand	25	565 (35)	-	-	-	-	-	
	8	New Zealand	44	672 (50)	-	-	-	-	-	
	16	New Zealand	-	-	-	3.8 **(-)**	7.0 (-)	-	-	Low to moderate

Table 12: Density and shrinkage of wood (mean and standard deviation in brackets) from plantations and natural mature forests grown in Australia and from New Zealand-grown plantations (continued).

Species	Reference	Origin	Age	Density (kg/m³)		Shrinkage (%)				Drying degrade
						Green to 12% MC		Unit shrinkage		
				Basic	12% MC	Radial	Tangential	Radial	Tangential	
Eucalyptus camaldulensis (river red gum)	2	Mildura (Vic)	17	-	778 (106.4)	-	-	-	-	
	1	NSW, QLD, Vic	Mature native forest	710 (16.8)	854 (15.4)	2.7 (0.13)	4.8 (0.21)	0.22 (0.015)	0.31 (0.019)	
Corymbia maculata (spotted gum)	2	Mildura (Victoria)	18	-	798 (54.8)	-	-	-	-	
	15	Vic, South Australia	<25	-	834 (106.3)	-	-	-	-	
	2	Shepparton (Vic)	28	-	888 (30.5)	-	-	-	-	
	2	Lake Hume (Vic/NSW border)	40	-	871 (48.5)	-	-	-	-	
	10	Murray-Darling Basin, Australia	40							Low
	15	QLD	30-50	-	1060 (27.7)	-	-	-	-	
	15	South Australia	80+	-	1019 (70.0)	-	-	-	-	
	1	NSW, QLD, Vic	Mature native forest	790 (9.9)	969 (10.3)	3.7 (0.11)	5.0 (0.16)	0.32 (0.005)	0.38 (0.008)	

Table 12: Density and shrinkage of wood (mean and standard deviation in brackets) from plantations and natural mature forests grown in Australia and from New Zealand-grown plantations (continued).

Species	Reference	Origin	Age	Density (kg/m^3)		Shrinkage (%)				Drying degrade
						Green to 12% MC		Unit shrinkage		
				Basic	12% MC	Radial	Tangential	Radial	Tangential	
Eucalyptus cladocalyx (sugar gum)	15	Vic, South Australia	<25	-	1009 (86.6)	-	-	-	-	
	3	Vic	27	-	950-1050	3.4 (-)	8.5 (-)	-	-	
	14	Wail State Forest, Vic	27	752	913	2.6	5.3	0.24	0.37	Moderate
	10	Murray-Darling Basin, Australia	36							Low
	2	Earlston (Vic)	40	-	1032 (45.5)	-	-	-	-	
	9	south-eastern Australia	40	-	-	-	-	-	-	Moderate
	15	Vic, South Australia	30-50	-	1074 (58.7)	-	-	-	-	
	15	Vic	80+	-	1064 (59.3)	-	-	-	-	
	1	Vic	Mature native forest	753 (-)	1035 (54.8)	2.6 (-)	6.2 (-)	-	-	

Table 12: Density and shrinkage of wood (mean and standard deviation in brackets) from plantations and natural mature forests grown in Australia and from New Zealand-grown plantations (continued).

Species	Reference	Origin	Age	Density (kg/m³)		Shrinkage (%)				Drying degrade
						Green to 12% MC		Unit shrinkage		
				Basic	12% MC	Radial	Tangential	Radial	Tangential	
Eucalyptus tricarpa (red ironbark)	15	Vic, South Australia	<25	-	942 (55.7)	-	-	-	-	
	2	Lake Hume (Vic/N.S.W. border)	40	-	934 (63.9)	-	-	-	-	
	10	Murray-Darling Basin, Australia	40							Low
	15	Vic, South Australia	30-50	-	1022 (117.9)	-	-	-	-	
	15	South Australia	80+	-	1144 (25.1)	-	-	-	-	
	1	NSW, QLD, Vic	Mature native forest	886 (14.3)	1060 (17.5)	2.9 (0.32)	4.8 (0.44)	0.27 (0.019)	0.37 (0.013)	
Eucalyptus botryoides (southern mahogany)	1	NSW, Vic	Mature native forest	708 (9.6)	875 (12.2)	4.0 (0.25)	7.0 (0.23)	0.28 (0.017)	0.37 (0.007)	
	6	Waikato, New Zealand	50-60	-	714 (47.1)	-	-	-	-	Low
	7	North Island, New Zealand	>25	625 (-)	765 (-)	2.6 (-)	6.0 (-)	-	-	Low
	16	New Zealand	-	-	-	2.6 (-)	6.0 (-)	-	-	Low to moderate

Table 12: Density and shrinkage of wood (mean and standard deviation in brackets) from plantations and natural mature forests grown in Australia and from New Zealand-grown plantations (continued).

Species	Ref.	Origin	Age	Density (kg/m^3)		Shrinkage (%)				Drying degrade
						Green to 12% MC		Unit shrinkage		
				Basic	12% MC	Radial	Tangential	Radial	Tangential	
Eucalyptus muelleriana (yellow stringybark)	5	NSW	Mature	-	926 (-)	4.3 (-)	7.5 (-)	-	-	High
	4	NSW	Mature	-	-	Low	Low	-	-	Low
	1	NSW, Vic	Mature native forest	697 (9.9)	851 (12.5)	3.2 (0.14)	5.5 (0.23)	0.27 (0.009)	0.37 (0.007)	
	6	Okaihau, New Zealand	25-30	-	684 (56.8)	-	-	-	-	Low
	7	North Island, New Zealand	>25	550 (-)	665 (-)	2.1 (-)	5.2 (-)	-	-	Low
	8	Tairua, New Zealand	15	536 (18)	-	-	-	-	-	
	8	Athenree, New Zealand	45	551 (17)	-	-	-	-	-	
	16	New Zealand	-	-	-	2.1 (-)	5.2 (-)	-	-	Low
Eucalyptus microcorys (tallowwood)	1	NSW, QLD	Mature native forest	796 (8.5)	972 (8.5)	3.3 (0.11)	5.3 (0.10)	0.28 (0.010)	0.37 (0.007)	
	16	New Zealand	-	-	-			-	-	Low

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16. New Zealand Farm Forestry Association (NZFFA).

Notes:

1. When the age of plantation test trees is unknown or unavailable at the time of writing this review report, the word “plantation” is used in the “Age” column.
2. The 12% MC density values are measurements made on after-reconditioned wood (Kingston and Risdon, 1961).
3. In Haslett, T. 1990, the age of the trees for data measurements is explicitly specified. An educated guess has to be made for this table.
4. In Kininmonth et al. 1974, in order to minimize drying degrade, precaution was required which included air drying in sheltered part of the yard, using stack covers and thin fillets to restrict the drying rate.

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