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Evaluation of wood characteristics of tropical post-mid rotation plantation *Eucalyptus cloeziana* and *E. pellita*: Part (a) Natural durability of timber

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Evaluation of wood characteristics of tropical post-mid rotation plantation *Eucalyptus cloeziana* and *E. pellita*: Part (a) Natural durability of timber

Prepared for

Forest and Wood Products Australia

by

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Executive summary

Australian solid wood products industries are facing considerable shortfalls in the supply of traditional hardwood resources as more native forest regions continue to be reserved. To avoid an increased dependence on imported timber, suitable hardwood plantations need to be established without delay. Research to characterise the key properties of plantation hardwood resources intended for high-value applications is essential to support industry development; not only to facilitate continuous quality management and improvement activities of timber producers, but to enable optimum design and end-use of plantation hardwood products.

Currently, there are few mid to final rotation hardwood plantations in Australia that are managed for sawlog production. As a consequence there is very limited timber available for fundamental research. Therefore, soon after Cyclone Larry struck North Queensland during March 2006, 74 stems were salvaged from two damaged hardwood plantations for evaluation of their timber quality, processing and performance characteristics. The stems that were salvaged appeared sound and represented two provenances of 19-year-old *Eucalyptus cloeziana* (Gympie messmate) and two provenances of 15-year-old *Eucalyptus pellita* (red mahogany). These species are of interest for future hardwood plantation establishment and their age and growth performance reflected expectations for mid to final rotation plantations established in north Queensland.

Studies were undertaken to evaluate wood and mechanical properties[1], accelerated seasoning[2] and veneer and plywood production[3] for the *E. cloeziana* and *E. pellita* stems salvaged. Field and laboratory tests were implemented to evaluate the natural durability of these resources, and are described in this report.

Above-ground and in-ground durability field tests were established at three locations in Queensland. Ground proximity tests and L-joint tests were installed to gather data applicable to above-ground, weather-exposed end-use applications, and stake tests were installed to gather data applicable to in-ground, weather-exposed end-use applications. These field tests were implemented to:

- Evaluate the natural durability of timber produced from the *E. pellita* and *E. cloeziana* stems salvaged from tropical north Queensland
- Determine if there is any significant difference between the natural durability of the *E. pellita* and *E. cloeziana* tested and the natural durability of traditional mature native hardwoods
- Evaluate the effect of different exposure configurations on the natural durability of the species tested
- Evaluate the effect of environmental conditions on the natural durability of the species tested

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[1] McGavin, R.L., Bailleres, H. and Hopewell, G.P. (2007) The wood quality and structural properties of two tropical plantation eucalypts in north Queensland: 19-year-old Gympie messmate, and 15-year-old red mahogany DPI&F PR-3228. Report submitted October 2007 to FWPA (PN 07.3022) www.fwpa.com.au, and DTRDI (MN 86629).

[2] Redman, A.L. and McGavin, R.L. (2007) Accelerated seasoning of plantation grown *Eucalyptus cloeziana* and *Eucalyptus pellita* DPI&F PR-3188. Report submitted October 2007 to FWPA (PN 07.3022) www.fwpa.com.au, and DTRDI (MN 86629).

[3] Hopewell, G.P., Atyeo, W.J. and McGavin, R.L. (2007) The veneer and plywood potential of tropical plantation eucalypts in north Queensland: 19-year-old Gympie messmate, *Eucalyptus cloeziana*, and 15-year-old red mahogany, *Eucalyptus pellita* DPI&F PR-3187. Report submitted October 2007 to FWPA (PN 07.3022) www.fwpa.com.au, and DTRDI (MN 86629).

- Provide essential data for calibration and refinement of performance-based durability models that are necessary to enable more accurate service life prediction for timber products
- Examine the potential for using the performance of low-durability eucalypts (*e.g. Eucalyptus regnans*) at a particular location, as an indicator of the performance of high-durability eucalypts (e.g. *E. pellita* and *E. cloeziana*) at that location
- Examine the potential for using the performance of timber species exposed at high-hazard field sites to model the performance of those species at lower-hazard sites

Given that many years are required before field test samples of high-durability timber species begin to yield useful data, accelerated decay bioassays were also established to provide an earlier, qualitative indication of the relative natural durability of the *E. cloeziana* and *E. pellita* tested. A standard soil jar bioassay and a novel vermiculite burial test were implemented and are expected to be completed by April 2008.

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1 Introduction

Australian hardwood resources

Australian solid wood products industries are facing considerable shortfalls in the supply of traditional native forest resources. Approximately $1 billion worth of sawn timber is produced from Australian native forests each year, with an additional $1 billion generated through further processing and associated products. Under current native forest management policies, however, the estimated total sustainable log availability is expected to fall by 36% (776,000 m^3) from Australia's public forests between 2001 and 2039, and by 25% (115,000 m^3) from private forests (Nolan *et al.*, 2005).

In addition to optimising sustainable management of available native forest resources, it is essential that suitable hardwood plantations be established promptly. In their review of eucalypt plantations for solid wood products in Australia, Nolan *et al.*, (2005) pointed out that most of Australia's current plantation hardwood estate was established for wood fibre production and will not produce logs of suitable quality for profitable solid wood products industries. Consequently, unless further plantations are established swiftly for the production of hardwood sawlogs, Australian markets will have to meet the demand for high-quality hardwood with increased imports. Furthermore, many of the 32,000 Australians employed in solid wood products industries may face an uncertain future. Nolan *et al.*, (2005) concluded that it is highly likely that a solid wood products industry can profitably process and sell material from a future plantation hardwood resource, provided that a high proportion of high quality logs with significant clear wood are produced.

The success of emerging Australian hardwood plantation industries engaged in the production of high-value timber will be influenced strongly by levels of awareness and confidence amongst end-user market stakeholders regarding the qualities of plantation hardwood products.

Consumers and construction industry stakeholders, including regulators, builders, architects and engineers, need to be well informed of the positive environmental credentials of sustainably-managed hardwood plantations. Furthermore, it is essential that key properties of plantation timber resources are scientifically characterised to ensure that quality end products can be appropriately designed to function as desired in-service. Key timber properties that influence product performance in-service include dimensional stability, workability, mechanical properties, appearance, and durability.

Natural durability

This report describes the implementation of field and laboratory tests to characterise the natural durability of 19-year-old *Eucalyptus cloeziana* F.Muell (Gympie messmate) and 15-year-old *Eucalyptus pellita* F.Muell (red mahogany) salvaged from two plantations after cyclone Larry struck tropical north Queensland. Parallel evaluation of these resources was also undertaken to evaluate wood and mechanical properties (McGavin *et al.*, 2007), accelerated seasoning (Redman and McGavin, 2007), and potential veneer and plywood production (Hopewell *et al.*, 2007).

Natural durability is defined as the inherent resistance of a timber species to decay and insect attack (Standards Australia 2005a). Australian Standard AS 5604-2005 Timber – Natural durability ratings, lists mature native *E. cloeziana* as a durability class 1 species for both above-ground and in-ground weather-exposed applications (Table 1). *E. pellita* is also listed in AS 5604 – 2005 as a durability class 1 species for above-ground weather-exposed applications, but is listed as a durability class 2 species for in-ground weather-exposed applications (Table 1).

Table 1 Timber durability classification (Standards Australian, 2005a)

Durability Class	Probable in-ground life expectancy[a] (D^{ag}) (years)	Probable above-ground life expectancy[a] (D^{ig}) (years)
1	Greater than 25	Greater than 40
2	15 to 25	15 to 40
3	5 to 15	7 to 15
4	0 to 5	0 to 7

[a] Notes:
1. As further evidence becomes available these ratings may be amended
2. The heartwood durability of an individual piece of timber may vary from the classification nominated for that species
3. Above-ground conditions equate to outside above-ground subject to periodic, moderate wetting when ventilation and drainage are adequate.

Considerable uncertainty currently surrounds the durability of timber products that are exposed to the weather in-service. Consequently, unless the key serviceability properties of plantation resources are appropriately characterised for different applications, access to dynamic contemporary building markets may be impeded. The main limitation of the current durability classifications listed in AS 5604-2005, is that for each species only two wide-ranging service-life estimates are provided; one for all above-ground applications, and the other for all in-ground applications. Rates of biodeterioration, however, are known to vary considerably for similar timber products in-service at different locations throughout the country (Cookson and Trajstman, 2000; Francis and Norton, 2006; Leicester *et al.*, 2003). Furthermore, the likelihood and consequence of biodeterioration varies between different structural components (Brischke and Rapp, 2007; Leicester *et al.*, 2003).

Modern performance-based design and engineering regulations and practices continue to be developed to facilitate innovation, trade and sustainable building practices (Foliente, 2000a). In contrast with conventional prescriptive design and engineering systems, however, the performance-based approach requires the 'in-service performance' of building products to be specified in terms of their probability of failure or non-performance (Foliente *et al.*, 2000b). Consequently, timber durability needs to be characterised in terms of the rates at which biodeterioration typically initiates and proceeds under various exposure conditions. For the purposes of performance-based design and engineering, timber durability information currently available in AS 5604-2005 is not adequately sensitive (Francis *et al.*, 2007; Leicester *et al.*, 2003; Standards Australia 2005a). To address this issue, the Australian Design for Durability research program[4] was initiated to develop performance-based timber engineering models incorporating durability factors to provide more accurate timber service-life estimates (FWPRDC, 2003).

The field and laboratory tests described in this report were established to evaluate the natural durability of timber produced from salvaged *E. cloeziana* and *E. pellita* logs. A range of tests were implemented to provide essential data for calibration and refinement of performance-based timber durability and engineering models:

- inner, intermediate and outer heartwood regions were sampled to examine their relative natural durability
- field tests were established at three locations to evaluate the effects of different environmental conditions on timber durability

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[4] Supported and / or undertaken by the Forest and Wood Products Research and Development Corporation (FWPRDC) now Forest and Wood Products Australia (FWPA), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Timber Queensland (incorporating the former Timber Research and Development Advisory Council (TRADAC), with above-ground durability data supplied by DPI&F.

- several configurations of field test samples were installed to evaluate the effect of different exposure conditions on timber durability

Accelerated decay bioassays were also implemented to provide a more immediate qualitative indication of the relative natural durability of the *E. cloeziana* and *E. pellita* sampled.

Durability evaluation

Currently, there are no Australian standard procedures or guidelines for evaluating the natural durability of timber. Tests designed for assessment of timber preservative treatments are therefore used as the basis for natural durability evaluation.

Field tests are considered necessary to evaluate the performance of treated timber intended for weather-exposed applications, as the relationship between standard accelerated decay tests and the durability of timber in the field is poorly understood and suspected to be limited. Whilst field tests are designed to be more conducive to biodeterioration than most service conditions, more than twenty years exposure may be required before reliable data are available for modelling the performance of high-durability species (Francis *et al*., 2007).

A variety of laboratory methods have been developed for more rapid assessment of timber durability. Soil jar bioassay is the most widely used method in Australia and North America (Morrell, 2007), and a similar test is used throughout Europe, where an agar support medium is used rather than soil (Comité Européen de Normalisation, 1996). Both methods involve the exposure of small representative timber blocks to pure cultures of known decay fungi growing on a support medium in pre-prepared jars. After 12 to 16 weeks incubation, any mass loss resulting from exposure of sample blocks to decay fungi is recorded as an indication of the decay resistance of the timber tested. Given that this method is most common, a conventional soil jar bioassay was established to provide an indication of the relative decay resistance of the *E. cloeziana* and *E. pellita* sampled.

Standard soil jar and agar jar bioassays do, however, have several limitations. Mass loss results are difficult to interpret as it is widely accepted that some fungi cause substantial structural effects on wood at weight losses that would be considered to be too low to be of significance in standard laboratory tests (Wilcox, 1978). Furthermore, subtle changes in the characteristics of the soil support medium, particularly moisture holding capacity, can have dramatic effects on the ability of specific fungi to cause wood mass loss (Morrell, 2007). Alternatively, the more precisely constituted agar support medium is sometimes criticized as it provides the test fungus with sugars that can affect the rate of fungal attack (Morrell, 2007; Raberg *et al*., 2005).

To address the limitations of standard accelerated decay methods, researchers have explored alternative techniques to evaluate the effects of fungal attack on wood quality. Vermiculite has been used as a non-nutritional support medium as it provides a uniform water holding capacity. Alternative methods to evaluate timber samples after exposure to decay have also been investigated. These include destructive compression tests and bending tests, as well as non-destructive vibration-impulse excitation techniques. Rather than measuring mass loss to provide an indication of resistance, such methods measure the effects of fungal decay on mechanical properties such as stiffness[5] and strength[6].

Compression and bending tests are relatively straight-forward since losses in mechanical properties can be directly related to fungal attack on wood polymers. Vibration-impulse techniques evaluate the response of a timber sample to a reproducible pulsed wave generated by a light elastic tap delivered by a small hammer. Vibration-impulse methods offer a more

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[5] Modulus of elasticity (MOE)

[6] Modulus of rupture (MOR)

indirect measure of timber properties, and several studies have revealed that a strong relationship exists between MOE measured by direct destructive testing and MOE calculated using vibration-impulse techniques (Alfredsen *et al*., 2006; Brancheriau and Bailleres, 2003; Machek *et al*., 2003). Despite their potential, however, alternative accelerated decay test methods remain largely experimental. These methods might prove useful as a means for predicting changes in wood quality over a fungal exposure period and could help provide a more meaningful measure of decay effects to the engineering community.

To take advantage of emerging methods for accelerated decay testing, outer heartwood samples of the *E. cloeziana* and *E. pellita* salvaged from north Queensland were included in a novel vermiculite burial test being refined as part of durability research underway within the Cooperative Research Centre for Wood Innovations (CRC-WI). This test employs a vermiculite support medium to maintain the required moisture content within incubation boxes. Mini beams are inoculated with a pure culture of decay fungus, and after a period of incubation, each beam is subjected to a bending test to determine its stiffness and strength. A vibration-impulse method is being used in parallel with the bending tests to evaluate the feasibility of using this non-destructive technique to measure and monitor the MOE of mini beams.

2 Materials and methods

2.1. Sample material

Despite the urgent need to characterise the key properties of plantation hardwood timber to support industry development, there are currently few post-mid to final rotation plantations in Australia that are managed for sawlog production. Consequently, there is little timber available for testing. Therefore, soon after Cyclone Larry struck North Queensland in March 2006, DPI&F seized the opportunity to salvage suitable logs from two damaged hardwood plantations for essential research and development activities.

Whilst both plantations were destroyed by the cyclone, many of the *E. cloeziana* trees were blown over with their root ball intact and minimal or no apparent damage to their merchantable bole. In contrast, many of the *E. pellita* trees had snapped along the merchantable bole. DPI&F officers assessed the cyclone-damaged plantations and determined that a total of 42 *E. cloeziana* stems and 32 *E. pellita* stems were of suitable condition for timber research. Specific details of the plantation and silvicultural histories for logs selected are provided by Hopewell *et al*., (2007). Both species are of interest for future hardwood plantation establishment and their age and growth performance reflected expectations for mid to final rotation plantations established in north Queensland.

Logs salvaged represented two provenances of 19-year-old *E. cloeziana* and two provenances of 15-year-old *E. pellita*. Where possible, a butt log of approximately six metres in length and a top log of at least three metres in length were cut from each stem. Each log was end-sealed with a proprietary brush-on treatment prior to transport to Salisbury Research Centre[7] for final merchandising and sampling.

A representative selection of logs were initially selected to provide billets for veneer and plywood manufacture and testing, which is described by Hopewell *et al*., (2007) (Table 2). Remaining logs were separated into two groups: the first group contained a representative selection of 41 *E. cloeziana* logs and 26 *E. pellita* logs intended for evaluation of wood and mechanical properties, including natural durability tests; the remaining 16 *E. cloeziana* logs and 12 *E. pellita* logs were processed for accelerated seasoning and shrinkage evaluation, which is described by Redman and McGavin (2007). Research to evaluate wood and mechanical properties is described by McGavin *et al*. (2007).

Table 2 Distribution of logs for various research activities

Research focus	**Number of logs selected**	
	E. cloeziana	***E. pellita***
Veneer and plywood manufacture and testing	15	15
Evaluation of wood and mechanical properties (including natural durability)	41	26
Accelerated seasoning and shrinkage	16	12
Total	**72**	**53**

All logs selected for wood and mechanical properties evaluation (including natural durability tests) were processed to provide boards representing approximate inner, intermediate and outer heartwood zones. Each heartwood zone was designated to occupy 1/3 of the heartwood radius

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[7] Salisbury Research Centre in Brisbane is DPI&F's forest products processing research facility.

(Figure 1), and 38 x 100 mm boards were cut from each region. Samples for natural durability tests were prepared from these boards (Figure 2 and Table 3). The original size of the logs sampled is summarised in Table 4 and Table 5.

Samples were prepared for a range of field and laboratory tests (Table 3). The presence and extent of any defects described in AS 2796.1 Timber - Hardwood - Sawn and milled products Part 1: Product specification and AS 2796.2 Timber - Hardwood - Sawn and milled products Part 2: Grade description, were recorded so that any subsequent effects on sample durability can be evaluated (Standards Australia, 1999; Standards Australia, 2006).

Figure 1 Typical allocation of inner (blue), intermediate (red) and outer (yellow) heartwood zones.

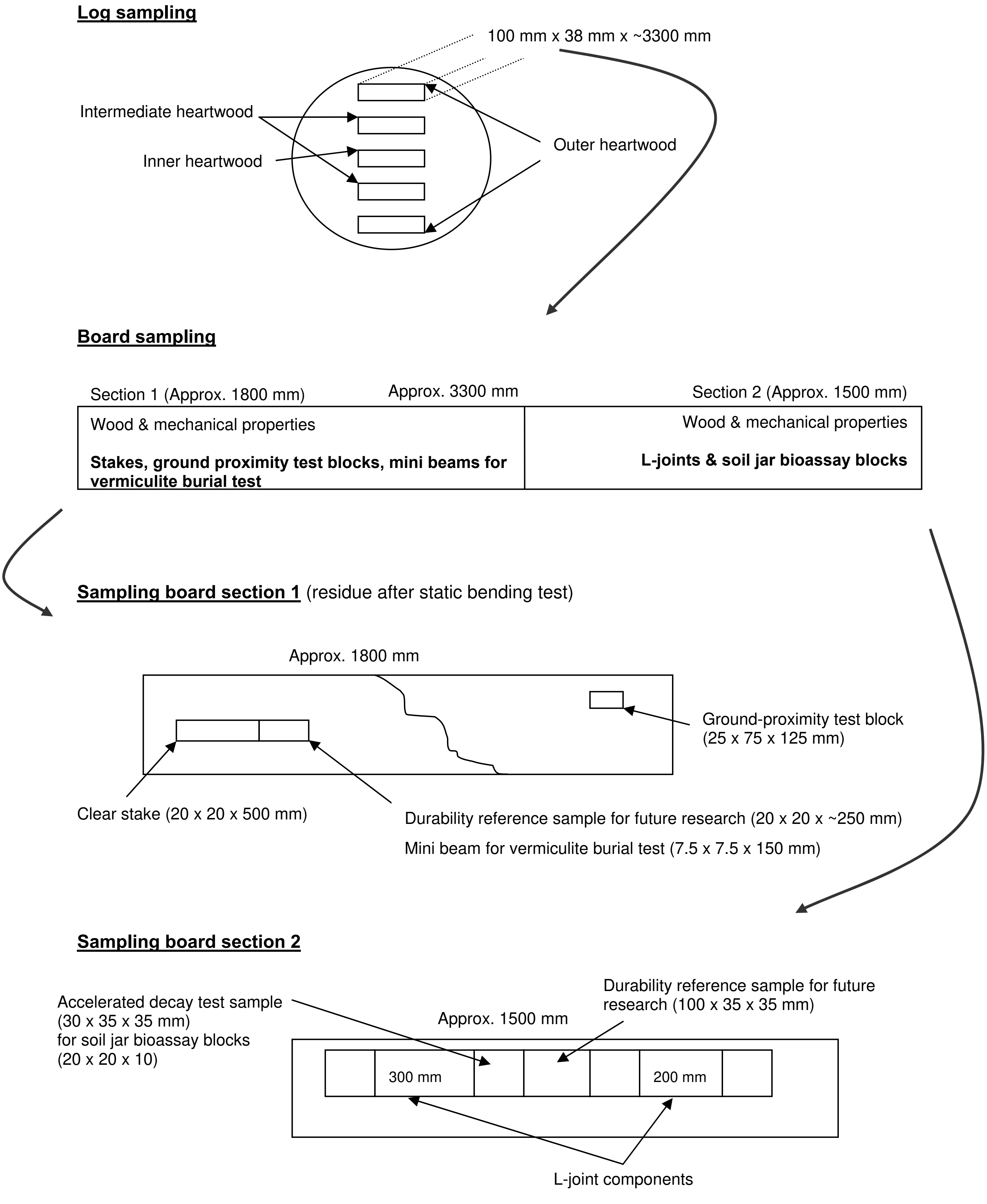

Figure 2 Schematic diagram of sampling for durability tests after evaluation of wood and mechanical properties.

Table 3 Summary of tests for natural durability evaluation

Test	Summary	Purpose
Ground proximity test	Field test 20 mm x 50 mm x 125 mm blocks exposed above-ground on concrete blocks under shade cloth to accelerate decay	Determine the natural durability of the plantation-grown *E. cloeziana* and *E. pellita* tested Facilitate performance-based design and engineering practices through provision of essential data for more accurate modelling of the durability of plantation hardwood products intended to be used for: • Uncoated above-ground end-use applications, such as decks (ground-proximity test) • Painted above-ground joinery applications, such as window frames (L-joint test) • In-ground applications, such as utility poles (stake test) Examine the potential for using the performance of low-durability eucalypts as an indicator of the performance of high-durability eucalypts at a particular location Examine the potential for using the performance of a timber species exposed at a high-hazard field site to model the performance of that species at lower-hazard sites
L-joint test	Field test Painted L-joints (mortise: 35 x 35 x 200 mm, tenon: 35 x 35 x 300 mm) exposed above-ground on racks designed to accelerate decay	
Stake test	Field test 20 mm x 20 mm x 500 mm stakes exposed with 250 mm buried below ground level	
Soil jar bioassay	Accelerated laboratory test Based on mass loss in 20 x 20 x 10 mm test blocks after exposure to pure cultures of decay fungi	Provide a rapid qualitative indication of relative natural durability of the plantation-grown *E. cloeziana* and *E. pellita* tested
Vermiculite burial test	Accelerated laboratory test Based on strength loss in 7.5 x 7.5 x 150 mm mini beams after exposure to pure cultures of decay fungi	Provide a more accurate rapid qualitative indication of relative natural durability of the plantation-grown *E. cloeziana* and *E. pellita* tested
Durability reference samples	Archived	Intended for future research to evaluate improved accelerated decay tests and novel techniques to evaluate timber durability, such as near infrared reflectance spectroscopy (NIRS)

Table 4 Size of *E. cloeziana* sawlogs sampled for natural durability testing

	Small end diameter (mm)	**Large end diameter (mm)**	**Log length (m)**	**Log volume[a] (m^3)**
Mean	287	335	3.45	0.260
Standard deviation	62	63	0.02	0.104
Maximum	429	457	3.49	0.486
Minimum	193	231	3.40	0.122

[a] Under bark sawlog volume was estimated using Huber's formula (Plank and Cahill, 1984)

Table 5 Size of *E. pellita* sawlogs sampled for natural durability testing

	Small end diameter (mm)	**Large end diameter (mm)**	**Log length (m)**	**Log volume[a] (m^3)**
Mean	271	315	3.33	0.217
Standard deviation	52	60	0.27	0.090
Maximum	377	454	3.52	0.424
Minimum	194	230	2.64	0.099

[a] Under bark sawlog volume was estimated using Huber's formula (Plank and Cahill, 1984)

2.2. Field tests

Building products intended for above-ground, weather-exposed applications are expected to be a major market for plantation hardwood. Therefore, L-joint tests and ground proximity tests were included in this study to provide essential data for modelling timber durability for different end-use applications. Stake tests were also installed to evaluate durability for in-ground, weather-exposed applications.

Field tests were established at three locations in Queensland (Figure 3) representing a range of climatic conditions. The tests will be used to determine the rates at which biodeterioration typically initiates and proceeds for approximate inner, intermediate and outer heartwood regions of the *E. pellita* and *E. cloeziana* timber sampled.

The field test sites selected were:

- DPI&F Centre for Wet Tropics Agriculture (South Johnstone), approximately 100 km south of Cairns in north Queensland
- Australian Agricultural College's, Dalby Campus, approximately 200 km west of Brisbane
- DPI&F Redlands Research Station (Cleveland), approximately 35 km south-east of Brisbane

These sites represent a range of climatic conditions (Table 6).

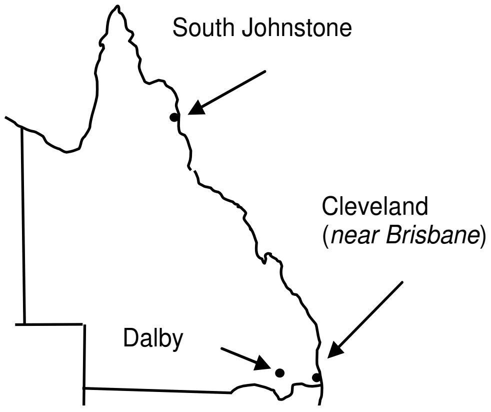

Figure 3 Field site locations

Table 6 Summary of some key climate characteristics for field sites (July 2006 to June 2007)

Key climate characteristics[a]:	**Mean temperature (°C)**		**Rainfall (mm)**	**Percent wet days**
Field site location	**Max**	**Min**		
South Johnstone[b]	27.8	19.4	3323.5	46.4
Dalby[c]	27.8	12.1	369.4	10.4
Cleveland[d]	25.1	14.5	777.5	31.9

[a] Climate characteristics calculated from monthly data provided by the Bureau of Meteorology (BOM).
[b] Data from South Johnstone Exp Stn (BOM site 032037).
[c] Data from Dalby Airport (BOM site 041522).
[d] Monthly data for Redlands HRS (BOM site 040265) incomplete. Climate characteristics calculated as mean over days for which data were available.

Ground proximity tests

Ground proximity tests were based on American Wood Preservers' Association (AWPA) E18-06 Standard field test for evaluation of wood preservatives intended for use category 3B applications exposed, out of ground contact, uncoated ground proximity decay method (AWPA, 2007). All samples were processed as recommended for untreated controls. The level of sample replication was increased.

In summary, a total of 111 *E. cloeziana* and 61 *E. pellita* test samples measuring 20 mm x 50 mm x 125 mm (Table 7) were installed on concrete blocks and covered with a shade cloth lid (Figure 4). A total of 96 control samples were also installed (Table 7). Control species are described in section 4.2.4. Occasional minor defects such as manufacturing flaws, checks and small splits were recorded.

E18-06 advises that all surfaces of each sample should be evaluated periodically (typically annually) using a blunt probe to detect biodeterioration.

For the purpose of this study, annual inspections are considered ideal, however biannual inspections would suffice. It is recommended that both the extent and depth of decay be recorded during inspections to maximise data available for predictive durability models.

Figure 4 Ground-proximity samples installed at Dalby (shade cloth lid removed for photograph)

Figure 5 L-joints installed at Cleveland

L-Joint tests

L-joint tests were based on the Australasian Wood Preservation Committee (AWPC) Protocols for the assessment of wood preservatives, Field test procedures for decay and termites, Hazard Class H3[8], L-joint test. All samples were processed as recommended for untreated controls. The level of sample replication was increased where possible.

In summary, each L-joint was manufactured from two 35 mm x 35 mm lengths of timber which were joined to form an L-shape with a mortise and tenon corner joint. The tenon component of each L-joint extended 300 mm from the joint, and the mortise component extended 200 mm from the joint (Figure 6). All L-joints were painted, end-sealed then installed on to exposure racks as recommended (Figure 5).

Sixty-one *E. cloeziana* and 42 *E. pellita* L-joints were installed to provide durability characterisation data. An additional 98 *E. cloeziana* and 32 *E. pellita* L-joints that were found to contain minor defects, such as manufacturing flaws, checks and small splits, were also installed to maximise the data generated from the limited timber available. Twenty-six *E. pellita* outer heartwood L-joints that contained sapwood were also installed to gather additional information regarding the effect of rapid decay of non-durable sapwood on the durability of adjacent sound heartwood. Durability data subsequently gathered for defective samples is not intended to be included in durability characterisation analysis.

The AWPC L-Joint test protocol advises that each specimen be inspected at least annually, at which time the internal surfaces of the tenon component of each joint (Figure 6) should be evaluated for decay using an internationally recognised system.

For the purposes of this study, it is recommended that both the area and depth of any decay detected by gentle probing the surfaces of the tenon component of each joint be recorded during inspections. Whilst annual inspections would be ideal, biannual inspections are considered adequate.

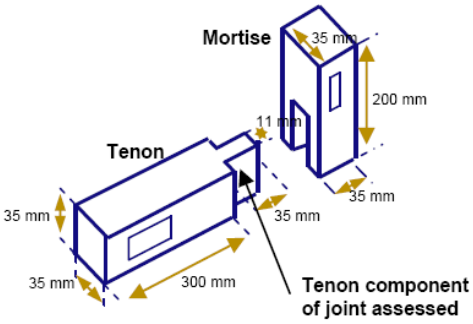

Figure 6 Dimensions of an L-joint

Stake tests

Stake tests were based on the AWPC Protocols for the assessment of wood preservatives, Field test procedures for decay and termites, Hazard Classes H4[9] and H5[10]. All samples were processed as recommended for untreated controls. The level of sample replication was increased. Occasional minor defects such as manufacturing flaws, checks and small splits were recorded.

In summary, a total of 264 untreated 20 mm x 20 mm x 500 mm test stakes (Table 7) were installed into rows spaced at least 500 mm apart to allow grass to be cut between them (Figure

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[8] Six hazard class classifications are provided in AS 1604.1-2005 Specification for Preservative Treatment Part 1: Sawn and round timber. Each hazard class is defined in terms of specific service exposure conditions.
Hazard class 3 (H3) refers to outside, above-ground exposure conditions where products are subject to moderate wetting and leaching. Typical H3 applications include weatherboard, fascia, window joinery and decking (Standards Australia, 2005b).

[9] Hazard class 4 (H4) refers to outside, in-ground exposure conditions where products are subject to severe wetting and leaching. Typical H4 applications include fence posts, greenhouses and pergolas (Standards Australia, 2005b)

[10] Hazard class H5 refers to outside, in-ground exposure conditions where products are subject to extreme wetting and leaching and/or where the critical use requires a higher degree of protection. Typical H5 applications include house stumps, building poles and retaining walls (Standards Australia, 2005b).

7). One end of each stake was buried to a depth of 250 mm. At each field site, rows were prepared using a ripper before stakes were installed (Figure 8). Rows were ripped to a depth of approximately 200 mm then a hammer was used to knock the stakes in to a depth of 250 mm.

The AWPC stake test procedure recommends that for the purpose of preservative evaluation, each stake should be inspected at least annually for the first five years, and rated for decay and termite attack using an internationally recognised system during each inspection.

For the purpose of this project, annual inspections are considered ideal, however biannual inspections would suffice. It is recommended that both the extent and depth of decay be recorded during inspections to maximise data available for predictive durability models.

Figure 7 Stakes installed at Dalby

Figure 8 Rows being ripped before installation of stakes at Dalby

Control samples

Low- and high-durability control samples of commonly available species of mature native hardwood were installed alongside representative samples of the plantation-grown species. The natural durability of the control species is reasonably well known, so control samples were included to help gauge the relative performance of the plantation-grown species. Durability data gathered for the control species will also provide additional information for predictive durability modelling.

Mature native *Corymbia maculata* F.Muell (spotted gum) was included as a high-durability control (Table 1). *C. maculata* is classified as a durability class 1 species for above-ground weather-exposed applications, and a durability class 2 for in-ground applications (Standards Australia, 2005a). Matched ground-proximity test blocks, L-joints and stakes were prepared from eight boards and distributed between the three field sites in equal proportions to maximise additional data available for subsequent inter-site comparison.

Mature native *Eucalyptus regnans* F.Muell (mountain ash) and *Eucalyptus delegatensis* R.T.Baker. (Victorian ash) were included as low-durability controls (Table 1). They are classified as durability class 4 species for both above-ground and in-ground weather-exposed applications (Standards Australia, 2005a). *E. delegatensis* and *E. regnans* are commonly sold as Tasmanian oak, and it was only possible to obtain a mix of the two species for the tests described in this report. In the absence of a suitable method to reliably distinguish between them, matched ground-proximity test blocks, L-joints and stakes were prepared from 23 boards and distributed between the three field sites in equal proportions to maximise additional data available for subsequent inter-site comparison.

Additional *Cardwellia sublimis* F.Muell (northern silky oak) inter-test controls were included in the L-joint tests. *Cardwellia sublimis* is classified as a durability class 4 species for in-ground, weather-exposed applications (Standards Australia, 2005a). No information is available for this species for above-ground, weather-exposed applications (Standards Australia, 2005a). *Carwellia sublimis* L-joints were prepared from two 35 mm x 35mm lengths of timber archived during preparation of an extensive DPI&F above-ground durability field research project in 1987 (Cause, 1994; Francis *et al.*, 2007). Each board was originally obtained from a different source. *Carwellia sublimis* controls were installed to aid comparison of the durability of fast-grown plantation timber with the durability of a range of mature native species tested over the past 20 years, and to allow evaluation of the relative performance of timber exposed over different time periods.

Durability reference samples from each board sampled for field tests (Figure 2) were archived for potential future research, along with a number of full-sized field test samples.

Table 7 Details of all field test samples installed

Test samples	**Species (heartwood position) D^{ag}, D^{ig}**	**Number of samples installed at each site**		
		Cleveland	**South Johnstone**	**Dalby**
Ground-proximity blocks (above-ground) Total = 268	*E. pellita* (inner)	3		
	E. pellita (intermediate) **1, 2**	14	13	
	E. pellita (outer) **1, 2**	16	15	
	E. cloeziana (inner)	15		
	E. cloeziana (intermediate) **1, 1**	16	16	16
	E. cloeziana (outer) **1, 1**	16	16	16
	E. regnans / E. delegatensis **4, 4**	16	16	16
	Corymbia maculata **1, 2**	16	16	16
L-joints (above-ground) Total = 382	*E. pellita* (inner)	9 [3][a]		
	E. pellita (intermediate) **1, 2**	12 [11]	11 [10]	
	E. pellita (outer) **1, 2**	10 [22]	[12]	
	E. cloeziana (inner)	10 [4]	[11]	
	E. cloeziana (intermediate) **1, 1**	14 [14]	[14]	[14]
	E. cloeziana (outer) **1, 1**	12 [13]	12 [14]	13 [14]
	E. regnans / E. delegatensis **4, 4**	14	14	14
	Corymbia maculata **1, 2**	14	14	14
	Cardwellia sublimis **-, 3**	13	13	13
Stakes (in-ground) Total = 353	*E. pellita* (inner)	11	9	
	E. pellita (intermediate) **1, 2**	16	16	16
	E. pellita (outer) **1, 2**	16	16	16
	E. cloeziana (inner)	16	16	13
	E. cloeziana (intermediate) **1, 1**	16	16	16
	E. cloeziana (outer) **1, 1**	16	16	16
	E. regnans / E. delegatensis **4, 4**	16	16	16
	Corymbia maculata	16	16	16

D^{ag} Above-ground durability of mature native heartwood (Standards Australia, 2005a)

D^{ig} In-ground durability of mature native heartwood (Standards Australia, 2005a)

[a] numbers in brackets indicate L-joints with minor defects, most being a gap at the top of the mortise component of the joint measuring > 0.5 mm

2.3. Accelerated decay bioassays

To gain an early qualitative indication of the relative durability of the plantation species, two accelerated decay bioassays are also being undertaken. A standard soil jar bioassay is underway, along with a novel vermiculite burial test.

Soil jar bioassay

A standard soil jar bioassay was established to determine the relative decay resistance of inner, intermediate and outer heartwood regions of the *E. cloeziana* and *E. pellita* sampled. This bioassay is being undertaken in accordance with the AWPC Protocols for the assessment of wood preservatives, Laboratory test procedures for decay and termites, Hazard Class H3/4/5 Laboratory decay test.

Whilst the American standard procedure, ASTM D 2017-05 Standard method for accelerated laboratory testing of natural decay resistance of woods, prescribes a soil jar procedure, the AWPC method was chosen as it includes a prior accelerated weathering procedure (ASTM, 2005; AWPC, 2007).

In summary, six timber samples were selected to represent inner *E. cloeziana*, intermediate *E. cloeziana,* outer *E. cloeziana,* inner *E. pellita*, intermediate *E. pellita*, outer *E. pellita*, and each of the eight control species listed in Table 8. Three replicate test blocks measuring 20 x 20 x 10 mm were cut from each timber sample to provide one test bock for subsequent exposure to each of three decay fungi growing in soil jars.

In preparation for the addition of test blocks, jars were approximately half-filled with a soil support medium then autoclaved. Two sterile 'feeder strips' of low durability sapwood were placed on top of the soil in each jar then inoculated with a pure culture of one of three decay fungi: *Fomitopsis lilacinogilva* (Berk.) J.E. Wright & J.R. Deschamps (brown rot fungus), *Trametes versicolor* (L.) Lloyd (white rot fungus), or *Lopharia crassa* (Lév.) Boidin (white rot fungus). After accelerated weathering, test blocks were weighed then sterilised by gamma irradiation ready to be added to pre-inoculated jars.

Following incubation of the pre-inoculated jars to promote vigorous growth of decay fungi, two test blocks of *E. cloeziana*, *E. pellita* or a control species will be added to each jar. After a further 12 to 16 weeks of incubation, the test blocks will be dried and weighed. Any mass loss resulting from the exposure of test blocks to decay fungi will be used as an indication of the relative decay resistance of the timber tested.

The following specific modifications were made to the AWPC test procedure:

- Test blocks of *E. cloeziana, E. pellita* and control species were prepared to measure 20 mm (radial) x 20 mm (tangential) x 10 mm (longitudinal), rather than 20 mm (radial) x 10 mm (tangential) x 20 mm (longitudinal), so that the largest faces were end-grain. The higher proportion of end-grain over the surface area of the blocks is expected to facilitate decay, and is recommended in ASTM D 2017-05 (ASTM, 2005).
- Additional control species were included to help gauge the relative performance of the plantation-grown species (Table 8).
- Three decay fungi were used rather than five, as only three replicate test blocks could be cut from each accelerated decay test sample (Figure 2).

The soil jar bioassay is expected to be completed by April 2008.

Table 8 Control species for soil jar bioassay

Species	Durability class (AS 5604 – 2005)	
	In-ground	**Above-ground**
Pinus elliottii Engelm. (slash pine)	4	4
E. regnans & *E. delegatensis* (see 4.2 Control samples for details)	4	3
Eucalyptus grandis W.Hill ex Maiden (rose gum)	3	2
Cardwellia sublimis (see 4.2 Control samples for details)	4	-
Eucalyptus resinifera Sm. (red mahogany)	2	1
Corymbia maculata (see 4.2 Control samples for details)	2	1
Eucalyptus tereticornis Sm. (forest red gum)	1	1

Vermiculite burial test

Outer heartwood samples of *E. cloeziana* and *E. pellita* were also included in a new vermiculite burial test being undertaken as part of CRC-WI[11] research. In summary, this test involves exposure of small timber beams (mini beams) to pure cultures of decay fungi. A vermiculite support medium was used to maintain the required moisture content within incubation boxes, and the medium was heaped to support the centre third of the mini beams and focus decay in this region. After incubation, each mini beam will be dried and then subjected to a bending test to determine its MOE and MOR. MOE was also non-destructively measured before exposure to decay by testing each sample within its' proportional limit.

The vermiculite burial test was established based on the method described by Winandy and Morrell (1993), with the following modifications:

- Smaller samples (7.5 x 7.5 x 150 mm) were used as limited sample material was available.
- A vibration-impulse method of measuring MOE is being evaluated in parallel with the traditional mechanical tests. Each mini beam was tested prior to inoculation and will be tested again before final destructive testing to evaluate the feasibility of this non-destructive technique for measurement and monitoring of the MOE of mini beams.

Given that fungal decay which results in a small mass loss can be associated with a large strength loss (Wilcox, 1978), the vermiculite burial test is expected to yield results sooner than the traditional soil jar bioassay. A relatively long incubation period may still be required for the mini beams, however, to distinguish between higher-durability species, which generally is not possible using soil jar bioassay. The vermiculite burial test is expected to be completed by April 2008.

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[11] Cooperative Research Centre for Wood Innovations, www.crcwood.unimelb.edu.au.

3 Discussion

3.1. Potential application of research

Characterisation of the key properties of timber resources provides essential information required by plantation hardwood producers for quality management and improvement activities, which are especially vital during early stages of industry development. Furthermore, all industry stakeholders, including regulators, consumers, engineers, designers and builders, benefit from more accurate knowledge of the properties of timber products that determine their performance in service.

The comprehensive suite of field and laboratory tests established to evaluate the natural durability of *E. cloeziana* and *E. pellita* salvaged from North Queensland promises to provide much important information. Given that the age and growth performance of the trees sampled reflected expectations for mid to final rotation plantations established in north Queensland, the natural durability of *E. pellita* and *E. cloeziana* resources tested is likely to be indicative for those species grown in similar plantations.

Data from this study may be used to determine if faster growth rates and plantation conditions have any significant effects on timber durability for the resources evaluated. The range of samples and tests selected is expected to provide essential data for calibration and refinement of performance-based durability models.

The durability of the *E. pellita* and *E. cloeziana* L-joints installed will be compared with that of L-joints installed 20 years ago as part of an extensive DPI&F above-ground durability research project established to evaluate the natural durability of a range of mature native species at various locations throughout eastern Australia (Cause, 1994; Francis *et al*., 2007). *Cardwellia sublimis* inter-test controls prepared from timber archived when the DPI&F above-ground durability project was established in 1987 were included in the L-joint tests described in this report. The control species selected for current research were also represented in the earlier tests. It may therefore be possible to model the longer-term performance of the plantation species based on early durability data and the results of the previous research.

The installation of stakes will permit comparison between the performance of plantation-grown *E. pellita* and *E. cloeziana* and the performance of a range of traditional mature native timbers previously tested as in-ground stakes by Thornton *et al.* (1991).

Field test samples were installed at three different locations to evaluate the influence climate factors and environmental conditions on timber durability. This information will also be useful to examine the potential for using the performance of a timber species at a high-hazard location to predict the performance of that species at lower-hazard locations.

Field test samples were distributed to allow their relative performance to be compared between sites. Over time, the possibility of predicting the performance of high-durability eucalypts at a particular location based on the performance of low-durability eucalypts at that location may also be examined.

3.2. Reporting and recommendations

Accelerated decay tests

The results of accelerated decay tests will be published by DPI&F during 2008 through the CRC for Wood Innovations[11].

Field tests

It is recommended that field tests be inspected biannually to provide adequate data for durability modelling. It is considered essential that both the extent and depth of any decay identified is recorded.

Subsequent inspections and maintenance of field tests will be managed by DPI&F. Analysis of field test data will be undertaken progressively and reported by DPI&F when funding permits.

For each site-species combination, representative measures of the time required for biodeterioration to occur and the rate at which it advances should be determined. This information can then be used determine the natural durability of the *E. pellita* and *E. cloeziana* tested and to calibrate timber durability models for performance-based design and engineering practices. Such durability models provide more accurate durability information by accounting for a variety of factors that influence timber durability, including environmental factors, the position of fittings and contact with other building components.

Additional research

In Australia, field tests are considered necessary to evaluate the durability of timber resources as the relationship between standard accelerated decay tests and the durability of timber in the field is poorly understood and suspected to be limited. Whilst field tests are designed to create a higher biodeterioration hazard than most in-service conditions, more than twenty years exposure may be required before data of sufficient reliability for durability modelling become available for high-durability species.

There is an urgent need to develop rapid, reliable, quantitative methods for durability prediction, particularly to support Australia's emerging hardwood plantation industries focused on the production of high-value timber products. Therefore, durability reference samples of *E. cloeziana*, *E. pellita* and control species have been retained for potential future research to evaluate rapid, non-destructive techniques for quantification of timber durability, such as near infrared reflectance spectroscopy. Research to identify and quantify key timber properties that influence durability is also recommended, along with continued improvement of novel accelerated decay tests.

Current techniques for periodic evaluation of field test samples are reasonably subjective and can damage test samples. Investigation of improved objective techniques for evaluation of field tests samples is therefore recommended. A number of full-sized field test samples were retained to serve as unexposed controls for potential subsequent development of quantitative durability evaluation methods, such as non-destructive measurement of sample stiffness.

To address current knowledge gaps concerning the key fungi that are responsible for the decay of timber structures in Australia and to evaluate their particular effects on the properties of plantation hardwood, it is further recommended that microbiology and anatomical studies are undertaken as samples are removed from field tests. Information generated would be valuable for timber durability modelling, for the evaluation of new timber resources and preservatives, and for optimisation of remedial and restorative procedures for timber in-service.

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