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PROJECT NUMBER: PRB287-1112 January 2015

Establishing the comparative durability of African mahogany (Khaya senegalensis) in weather exposed above-ground applications

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Project No: PRB287-1112

This work is supported by funding provided to FWPA by the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF).

ISBN: 978-1-925213-06-5

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Establishing the comparative durability of African mahogany (*Khaya senegalensis*) in weather exposed above-ground applications

Final report

Condition of plantation African mahogany durability test specimens after one year of exposure

This publication has been compiled by Rod Vella and Lesley Francis of Forestry Science, Department of Agriculture, Fisheries and Forestry for African Mahogany Australia Pty. Ltd. (AMA)

Contents

Summary

This study was established to evaluate the natural durability of ten- and twenty-year-old plantation-grown *Khaya senegalensis* (African mahogany) above ground.

Whilst mature African mahogany heartwood is expected to last five to 15 years in ground, Australian natural durability standards and specifications do not currently provide information on the durability performance of African mahogany when used above ground.

A ground proximity field test was installed at DAFF's South Johnstone Research Facility in north Queensland and modified ground proximity tests were also installed in a fungal cellar at DAFF's Salisbury Research Facility near Brisbane.

Whilst the plantation African mahogany tested appears more durable than pine, it is not yet possible to determine if its' durability is consistent with expectations for durability class 3 or durability class 2 timbers above ground. Minimal decay of test specimens had occurred after 12 months and more time is required before reliable conclusions can be drawn. Data gathered, however, are vital for any future durability modelling for plantation African mahogany, to calculate the lag for decay initiation and rates of decay.

Introduction

Natural durability is defined as the inherent resistance of a timber species to decay, or insect or marine borer attack (Standards Australia 2008). Mature heartwood of *Khaya senegalensis* (African mahogany) is classified as in-ground durability class 3 in Australian Standard AS 5604-2005 Timber – Natural durability ratings (Standards Australia 2008). Durability class 3 species have a probable life expectancy of five to 15 years when used in contact with the ground and exposed to the weather (Table 1). This standard, which is a reference document for the Building Code of Australia (BCA), does not provide an above-ground natural durability rating for African mahogany. Data on African mahogany is not listed in Construction Timbers in Queensland which is referenced in the Queensland amendment of the BCA (CTIQ, 2013).

Information about the natural durability of African mahogany is scarce, even in other publications than Australian standards and specifications. The "Timber Answers" online database (http://www.timberanswers.com) only lists in-ground durability for African mahogany. Reports of the performance of this species in other countries vary. Bolza and Keating (1972) reported that the African mahogany can last from eight to twenty years in ground. Chudnoff (1980) reported African mahogany to be moderately durable, lasting ten to 15 years in-ground.

It is unclear whether the natural durability of plantation-grown African mahogany will differ from that of mature native African mahogany.

The absence of information on the durability performance of plantation-grown African mahogany above ground impedes product development.

Table 1 Timber durability classification

Durability Class	Probable life expectancy[a]	
	In-ground (D_{ig}) (years)	Above-ground (D_{ag}) (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

Objectives

The aim of this study was to evaluate the natural durability of plantation-grown *K. senegalensis* for above-ground weather-exposed applications. Two tests were established to achieve this: (i) an accelerated test intended to provide a comparative estimate of natural durability, and (ii) a long-term field test to provide information required for national durability specifications.

Methods and materials

Test formats and locations

Two test formats were used:

1. Ground proximity test in north Queensland

A ground proximity test was established at the Department of Agriculture Fisheries and Forestry's South Johnstone Research Facility (SJRF, DAFF) according to the specifications set out in the American Wood Protection Association Standard E18-12 (AWPA 2012). Blocks measuring 20 x 50 x 125 mm were placed on concrete masonry blocks and covered with shade cloth to reduce drying (Figure 1). A total of 190 specimens were installed including control species representing each of the four above-ground durability classes (Table 2). The field test site at SJRF is located approximately 100 km south of Cairns in north Queensland and is known to present a very high decay hazard. This location was selected as durability data will be available sooner than at other locations. Specimens will be assessed periodically to provide durability performance data that can be used in timber engineering models to determine the probable life expectancy of timber products.

Figure 1 Ground Proximity field test at South Johnstone research facility

2. Modified ground proximity tests in fungal cellar

Modified ground proximity tests were established at Salisbury Research Facility (SRF, DAFF) according to the specifications set out in the American Wood Protection Association Standard E18-12 (AWPA 2012) with the following modifications: test assemblies were installed on and adjacent to soil beds in a controlled environment room (fungal cellar), where conditions are maintained at 25°C and 75% relative humidity (Figure 2). Specimens remain uncovered and were wet weekly with rain water using a trigger spray. These conditions were intended to promote decay and provide an indication of the relative natural durability of *K.*

senegalensis sooner than conclusions may be drawn from the performance of specimens in the field test. A total of 167 specimens were installed including control species representing each of the four above-ground durability classes (Table 2). In contrast to the field test, the modified tests can only be used to determine if test species perform better or worse than the reference timber species of known durability, rather than providing service life data.

Figure 2 Modified ground proximity tests at Salisbury Research Facility (left – SRF on soil, right – SRF on shelf)

Test specimens

African mahogany

Eighteen *K. senegalensis* billets were supplied, nine from twenty-year-old trees and nine from ten-year-old trees. Twenty-year-old trees were sourced from Clare, Queensland (near Ayr). Ten-year-old trees were sourced from Mutarnee, Queensland (near Townsville). Durability test specimens (20 x 50 x 125 mm) were obtained from all nine billets from twenty-year-old trees. Only four of the billets from ten-year-old trees were large enough to provide heartwood specimens of the required size.

This study will provide indicative information on the natural durability of timber that would be produced by conventional milling of trees that are less than 20-years-old, as is currently preferred for plantation timber production.

Whilst it was requested that billets have a heartwood diameter of at least 200 mm, this was rarely possible. Given the smaller size of the billets provided, it is likely that timber sampled from ten-year-old trees contained a large proportion of juvenile heartwood. It is also possible that some juvenile heartwood was present in timber sampled from twenty-year-old trees.

The properties of juvenile heartwood (also known as inner heartwood) are known to vary from that of mature heartwood. Durability in particular is commonly reduced, as highlighted in AS5604-2005, which states that the inner heartwood (the first few growth rings around the pith), generally, has lower natural durability than the rest of the heartwood (Standards Australia, 2008). Juvenile heartwood is poorly understood and consequently not well defined. There are no methods to identify juvenile heartwood.

If the natural durability of the juvenile heartwood of African mahogany is found to be too low for use above ground outdoors but mature heartwood is adequate for some purposes, there may be potential for new processes and products to be developed. For example, further research may enable higher-durability timber to be separated and used in engineered wood products, while lower durability timber may be used for indoor furniture production.

Reference species

Reference timbers were included in each test with one species representing each durability class above ground (D_{ag}): *Corymbia citriodora* (spotted gum) ($D_{ag}1$), *Eucalyptus marginata* (jarrah) ($D_{ag}2$), *Eucalyptus obliqua* (messmate) ($D_{ag}3$), *Pinus elliottii* (slash pine, sapwood) ($D_{ag}4$) (Table 2). All reference specimens had no visible defects, evidence of mould, stain, decay or insect attack.

Table 2 Durability test specimens installed

Trade name	**Species**	**Details**	**Durability class above-ground (D_{ag})** (AS5604-2008)	**Specimens installed**		
				Ground proximity test (E18-13)	**Accelerated ground proximity test**	
					Masonry base on soil	Masonry base not on soil (on shelf)
African mahogany	*Khaya senegalensis*	20-year-old plantation, heartwood	-	102	50	48
African mahogany	*Khaya senegalensis*	10-year-old plantation, heartwood	-	40	15	6
spotted gum	*Corymbia citriodora*	DC1 control, native forest, heartwood	1	12	6	6
jarrah	*Eucalyptus marginata*	DC2 control, native forest, heartwood	2	12	6	6
messmate	*Eucalyptus obliqua*	DC3 control, native forest, heartwood	3	12	6	6
slash pine	*Pinus elliottii*	DC4 control, plantation, sapwood	4	12	6	6

Assessment of test specimens

Blocks were assessed according to the criteria presented in Table 3 (AWPA 2013). Decay and termite attack were assessed separately. The depth of deterioration into each face of test blocks was also recorded for future durability modelling.

Table 3 Assessment criteria for ground proximity test blocks (AWPA 2013)

Rating	Description	Details
10	Sound	No signs or evidence of decay, wood softening, or discoloration caused by microorganism attack
9.5	Trace / suspect	Some areas of discoloration and/or softening associated with superficial microorganism attack
9	Slight attack	Decay and wood softening is present. Up to 3% of any cross-sectional area is affected
8	Moderate attack	Similar to “9”, but more extensive attack with 3-10% of any cross-sectional area affected
7	Moderate / severe attack	Sample has between 10-30%of any cross-sectional area decayed
6	Severe attack	Sample has between 30-50% of any cross sectional area decayed
4	Very severe attack	Sample has between 50-75% of any cross sectional area decayed
0	Failure	Sample has functionally failed. It can either be broken by hand due to decay or the evaluation probe can penetrate through the sample

Data analysis

Statistical analyses were performed using GenStat (V16.1.0.10916, 2013). Kruskal-Wallis one way analyses of variance were used to identify statistically significant differences between timbers in each test group (South Johnstone, SRF on soil or SRF on shelf). When significant differences were found within test groups (P=0.05), Mann-Whitney U pairwise comparisons were performed to further examine these differences (P=0.05).

Results and Discussion

Test specimens in the ground proximity field test at South Johnstone were assessed after 12 months according to the criteria defined in the American Wood Protection Association Standard E18-13 (AWPA 2013).

Test specimens in the modified ground proximity tests in the fungal cellar were assessed after six and 12 months according to the criteria defined in E18-13 (AWPA 2013). Only 12 month inspection data are presented in this report as very little decay had occurred after six months. The modified tests were intended to provide a more rapid indication of the relative natural durability of African mahogany, but decay did not occur more quickly than at the South Johnstone field test site, which presents a very high decay hazard.

Termite attack was not observed for any species tested, including *Pinus elliotii* (slash pine) sapwood, which is known to be susceptible to termite attack. The South Johnstone field test site was selected as it provided the highest decay hazard of any test sites available, but termite activity is known to be variable at this site. We therefore recommend that specimens installed in the fungal cellar at Salisbury Research Facility be moved to the DAFF Redlands field test site, where termite attack is more likely. Given that decay of tests specimens was less severe in the fungal cellar than at South Johnstone, relocating specimens to Redlands should provide useful additional information.

Whilst the plantation African mahogany tested appears more durable than pine, it is not yet possible to determine if its' natural durability is consistent with expectations for durability class 3 or durability class 2 timbers above ground. More time is required before reliable conclusions can be drawn.

Test results are summarised in Figure 3 and Table 4, followed by a discussion of each test in more detail. It is important to keep in mind that mean decay scores after one year's exposure represent small amounts on decay in some of a timber's replicate specimens. The lowest mean decay score was 8.8 for untreated slash pine sapwood at the South Johnstone field test site. A score of nine is assigned to test specimens that are found to have decay affecting less than 3% of any cross-sectional area (Table 3).

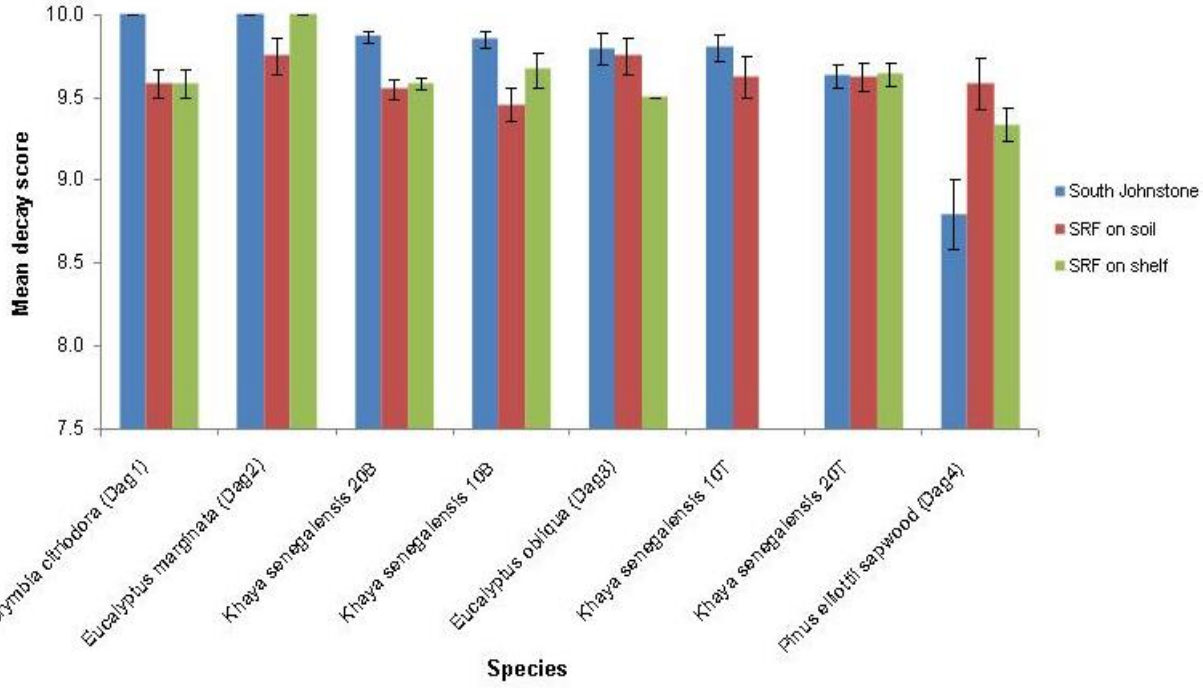

Figure 3 Condition of ground proximity test specimens after one year (mean score +/- SEM)

Table 4 Condition of ground proximity test specimens after one year (mean decay score +/- SEM)

			South Johnstone		SRF - on soil		SRF - on shelf	
			Mean decay score	(SEM)	Mean decay score	(SEM)	Mean decay score	(SEM)
spotted gum	*Corymbia citriodora*	DC1 control, native forest, heartwood	10.0	(0.00)	9.6	(0.08)	9.6	(0.08)
jarrah	*Eucalyptus marginata*	DC2 control, native forest, heartwood	10.0	(0.00)	9.8	(0.11)	10.0	(0.00)
African mahogany 20B	*Khaya senegalensis*	Butt log 20-year-old plantation, heartwood	9.9	(0.03)	9.6	(0.06)	9.6	(0.03)
African mahogany 10B	*Khaya senegalensis*	Butt log 10-year-old plantation, heartwood	9.9	(0.05)	9.5	(0.11)	9.7	(0.11)
messmate	*Eucalyptus obliqua*	DC3 control, native forest, heartwood	9.8	(0.10)	9.8	(0.11)	9.5	(0.00)
African mahogany 10T	*Khaya senegalensis*	Top log 10-year-old plantation, heartwood	9.8	(0.08)	9.6	(0.13)	n/a	
African mahogany 20T	*Khaya senegalensis*	Top log 20-year-old plantation, heartwood	9.6	(0.07)	9.6	(0.08)	9.6	(0.07)
slash pine	*Pinus elliottii*	DC4 control, plantation, sapwood	8.8	(0.21)	9.6	(0.15)	9.3	(0.11)

Ground proximity field test at South Johnstone

A Kruskal-Wallis analysis of variance showed that there was a statistically significant difference in decay scores between the different timbers (H = 36.77, p = <0.001) in the South Johnstone field test group.

Whist it is too soon to draw definitive conclusions, pairwise multiple statistical comparisons suggest that African mahogany specimens cut from butt and top logs of 10- and 20-year-old plantation trees may be significantly more durable than slash pine sapwood ($D_{ag}4$) (Figure 4).

Significant differences are represented by letters at the top of Figure 4. For example, 'ab' above *Khaya senegalensis* 20B (African mahogany specimens cut from the butt log of twenty-year-old trees) indicates that mean decay scores for this timber were not significantly different to any other timbers that have the same letter printed above.

There appears to be a trend emerging in this test suggesting that specimens cut from butt logs may be more durable that those cut from top logs. It is likely that specimens cut from top logs included juvenile heartwood. Juvenile heartwood, which is produced closer to the crown of growing trees, is commonly less resistant to decay. Juvenile heartwood is known to have chemical and structural differences from adjacent mature heartwood, including lower concentrations of extractives (DeBell, Morrell et al. 1999), lower density (Fukazawa 1984) and differences in the size and relative proportions of different cell types (Calonego, Severo et al. 2005).

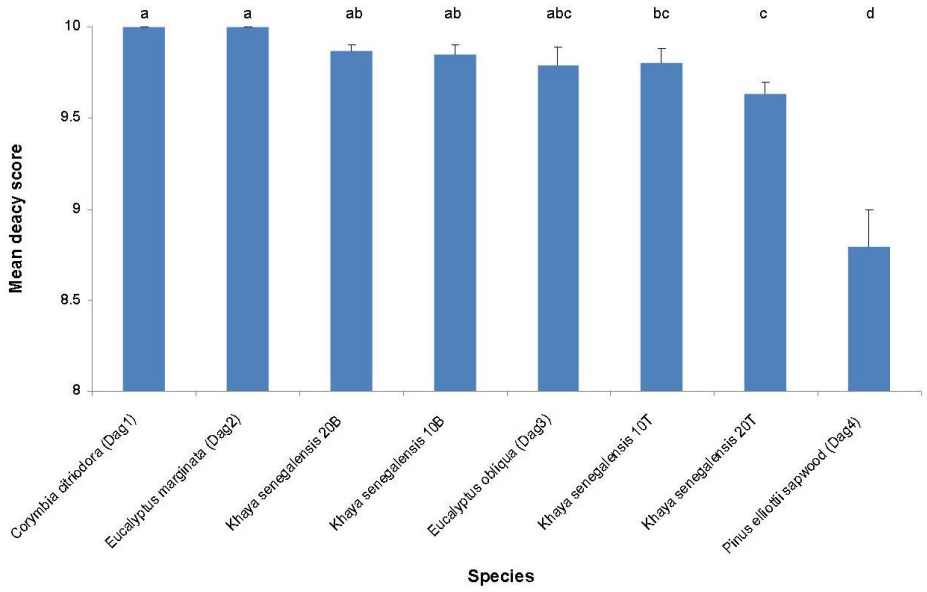

Figure 4 Condition of test specimens at South Johnstone after one year (mean score +/- SEM)
Letters at the top of the graph summarise pairwise comparisons to determine where differences lie

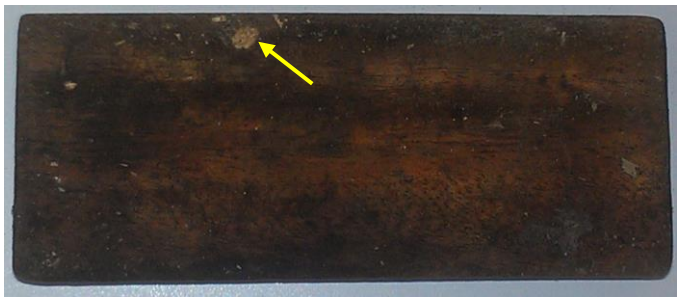

Figure 5 Small decay pocket on the underside (top left) of an African mahogany specimen cut from a butt log of a twenty-year-old tree (specimen 10-1484). Exposed at South Johnstone field test site.

Figure 6 Discolouration caused by incipient (early) decay on the underside of a pine control specimen exposed at the South Johnstone field test site

Modified ground proximity in fungal cellar – on shelf

A Kruskal-Wallis analysis of variance showed that there was a statistically significant difference in decay scores between the different timbers ($H = 15.27$, $p = <0.001$) in the fungal cellar SRF-on shelf test group.

Whilst pairwise multiple comparisons were possible, interpretation is not particularly meaningful in terms of longer-term durability, considering the low levels of decay observed (small patches of surface decay that may or may not ever become more severe).

At this stage, specimens have not been exposed for long enough to determine the relative natural durability of timber cut from plantation African mahogany butt logs and top logs.

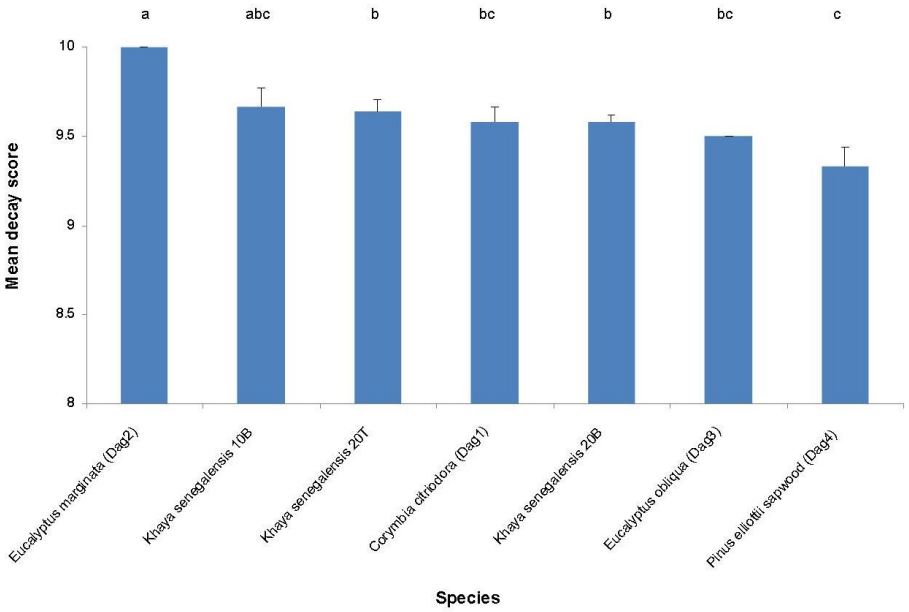

Figure 7 Condition of test specimens on shelving in the fungal cellar at Salisbury Research Facility (SRF) (mean score +/- SEM)

Letters at the top of the graph summarise pairwise comparisons to determine where differences lie

Modified ground proximity in fungal cellar – on soil

A Kruskal-Wallis analysis of variance did not reveal any statistically significant difference in decay scores between the different timbers at this early stage of testing for blocks above soil in the fungal cellar (Figure 8).

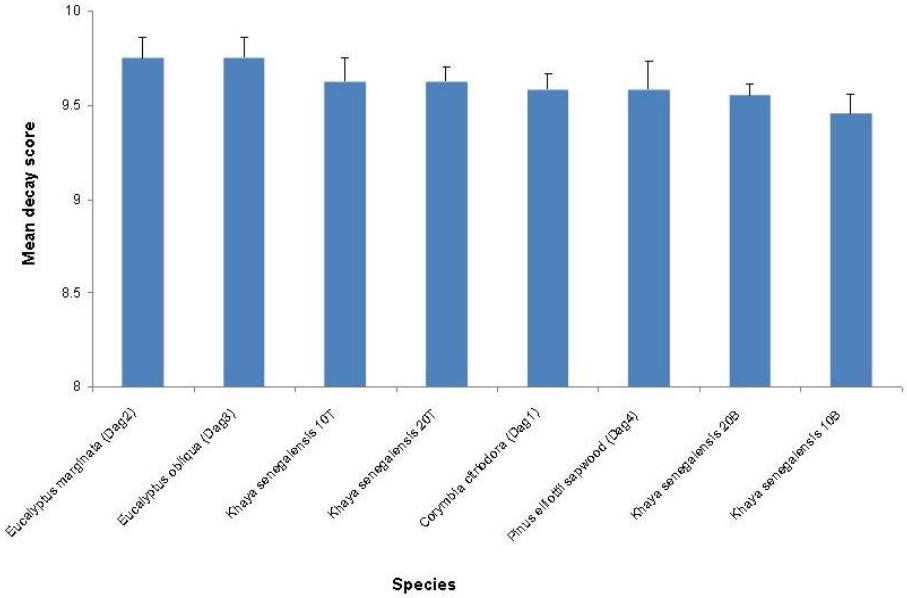

Figure 8 Condition of test specimens on soil in the fungal cellar at SRF (mean score +/- SEM)

Letters at the top of the graph summarise pairwise comparisons to determine where differences lie

Conclusions

Documents referenced by the Building Code of Australia currently do not provide durability performance information for mature *Khaya senegalensis* (African mahogany) heartwood used for above-ground weather-exposed applications. The Australian Standard Timber—Natural durability ratings only provides information for mature African mahogany heartwood used in ground, where it's probable life expectancy is seven to 15 years.

Whilst ten- and twenty-year-old plantation-grown African mahogany tested in this study appears more durable than pine (durability class 4), it is not yet possible to determine if its durability is consistent with expectations for durability class 3 or durability class 2 timbers above ground.

Minimal decay of test specimens had occurred after 12 months and more time is required before reliable conclusions can be drawn. Data gathered, however, are vital for any future durability modelling for these plantation timbers, to calculate the lag for decay initiation and rates of decay.

Termite attack was not observed for African mahogany nor the control species tested, including *Pinus elliotii* (slash pine) sapwood. It is recommended that specimens exposed in the fungal cellar at Salisbury Research Facility be relocated to DAFF's Redlands timber durability field test site, where termite attack is more likely.

The tests discussed in this report to measure the natural durability of 10- and 20-year-old plantation African mahogany will continue to provide valuable data over time. Subsequent assessment of test specimens is subject to a new agreement being established between DAFF and AMA.

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Acknowledgements

We gratefully acknowledge the contributions of: Mr Jack Norton for designing and establishing this project, Dr Andrew Hayes for assistance with data analysis and Mr Gary Hopewell for reviewing this report.

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