Comparative in-ground natural durability of white and black cypress pines (*Callitris glaucophylla* and *C. endlicheri*)

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Summary

Stakes composed of outer heartwood of *Callitris glaucophylla* (white cypress pine), *Callitris endlicheri* (black cypress pine), *Corymbia maculata* (spotted gum) and *Eucalyptus regnans* (mountain ash) were exposed to in-ground accelerated testing for 280 weeks (5.4 y). The time for each stake to reach unserviceability (loss of 60–75% of cross-section) due to microbial attack was recorded. The time for *Ca. glaucophylla* was not significantly different ($P > 0.05$) from that of *Co. maculata*. Both these Class 2 timbers were significantly different in durability from *Ca. endlicheri* which, in turn, was significantly different ($P < 0.05$) from *E. regnans,* a less durable Class 4 timber. Calibration with long-term field test results for *Ca. glaucophylla* and *Co. maculata* suggested that *Ca. endlicheri* should remain Class 2. The sapwood of both *Callitris* species showed evidence of higher natural durability than that of *Pinus radiata*. Other comparisons demonstrated that no significant difference was found in time to unserviceability of *Ca. glaucophylla* from two sites (Forbes and Gilgandra, both NSW), and similarly for *Ca. endlicheri*. Also, no significant correlation between time to unserviceability and density was found.

Keywords: durability; decay; simulation; calibration; classification; cypress pine; spotted gum; mountain ash; *Callitris endlicheri*; *Callitris glaucophylla*; *Corymbia maculata*; *Eucalyptus regnans*

Introduction

Timber products can deteriorate during service because of decay fungi and insects. The inherent ability of timber species to resist deterioration is called natural durability, and in Australia four classes are recognised: Class 1 timbers are most durable and Class 4 timbers are non-durable. Natural durability ratings are based upon the outer heartwood, which is often more durable than inner heartwood, while sapwood is generally considered to be non-durable. The natural durability ratings of the outer heartwood of *Callitris glaucophylla* J.Thompson and L.J.Johnson (white cypress pine) and *Ca. endlicheri* (Parl.) F.M.Bail. (black cypress pine) have been controversial. Based on experience and expert opinion, Bootle (1981) considered heartwood of both species to be of natural durability Class 1. The CSIRO tentative durability ratings considered only *Ca. glaucophylla* and that species was rated as Class 2 (Thornton *et al.* 1983). In later publications, Bootle (1983) and Smith *et al.* (1991) reallocated *Ca. endlicheri* to Class 2 and retained *Ca. glaucophylla* as Class 1. The CSIRO in-ground stake test at five sites confirmed that *Ca. glaucophylla* was a Class 2 timber (Thornton *et al*. 1997; Cookson 2005). *Callitris endlicheri* was not included in that field test; but both species are now listed as Class 2 in-ground timbers in the Australian Standard on natural durability, AS 5604-2005 (Standards Australia 2005).

Very little research has been carried out to compare the natural durability of these *Callitris* species. Rudman (1966) recorded the mass loss caused by a brown rot fungus attacking heartwood blocks cut from six *Ca. endlicheri* and ten *Ca. glaucophylla* trees. From his laboratory study, he concluded that *Ca. glaucophylla* was highly resistant to attack while *Ca. endlicheri* was only moderately resistant. More recent research has concentrated on the production of a natural wood preservative using extracts of waste wood from *Ca. glaucophylla* (Powell *et al*. 2000).

Here we report a study that compares the in-ground durability to decay of the two *Callitris* spp. The durability of these species is compared with that of several 'yardstick' timbers whose rating for natural durability is known.

Material and methods

Exposure

Unsterile sandy loam soil collected from our natural durability test site at Walpeup (Victoria) was used as a test medium. A stainless steel tank, 1770 mm long, 620 mm wide and 740 mm deep, was used to contain the test. On the bottom of the tank a layer of gravel, 100 mm thick, was placed to assist in drainage and prevent waterlogging. On top of the gravel was 350 mm of soil from the B horizon which, in turn, was topped with 150 mm of soil from the A horizon and humus. The soil was kept moist throughout the study and the test stakes were installed vertically with 75 mm of their length buried. The stakes were arranged in a duplicated resolvable row × column design consisting of five rows by eight columns. Spacing of 100 mm was maintained between stakes in a row and between columns.

The tank was located in the Accelerated Field Simulator (AFS), a room kept at a temperature of about 28°C and 85% relative humidity.

Test material

Foresters supplied billets, 300 mm long, cut from the bottom of the butt log of *Ca. glaucophylla* and *Ca. endlicheri* trees that would otherwise have been used to produce standard grade or 'run-of-mill' sawn timbers. Leaves and fruits were also collected to confirm species identity. The billets came from major areas of cypress pine production in New South Wales and Queensland. Oversize stakes (40 mm × 40 mm × 150 mm) were cut from the outer heartwood of the green billets, slowly air dried and then cut to a final dimension of 20 mm × 20 mm × 100 mm.

Tables 1 and 2 show the sources and characteristics of the *Callitris* test material. Heartwood stakes from 16 *Ca. glaucophylla* and 14 *Ca. endlicheri* trees and, in each case, six geographical sources, were included in the study, along with sapwood stakes from two *Ca. glaucophylla* and two *Ca. endlicheri* trees. Heartwood stakes from two trees of both *Corymbia maculata* (Hook.) K.D.Hill and L.A.S.Johnson (spotted gum) and *Eucalyptus regnans* F.Muell. (mountain ash) were included as typical representatives of Durability Classes 2 and 4 respectively. Sapwood stakes from two trees of *Pinus radiata* D.Don (radiata pine) were also included. In all cases the stakes were of clear wood and two replicate stakes were included from each tree.

Inspection method

At intervals of eight weeks, each stake was removed from the tank, scraped free of soil and inspected with a scalpel to determine the depth of decay. The condition of the stake was rated at the most severely decayed cross-section. Scores ranged from 8 (sound, no loss of cross-section) to 0 (failed, total loss of cross-section) in integer steps. A stake was considered unserviceable when it rated 3 (loss of 60–75% of cross-section) or less. Thornton *et al*. (1991) give a full description of the rating system.

Statistical analyses

Wood types (species, heartwood or sapwood) were assessed using Minitab (Release 12) and S-PLUS (Version 4.5) according to the following criteria: nonparametric Kaplan–Meier survival curves, hazard curves and median time to unserviceability. The survival and hazard curves provide an overall visual assessment of performance of the wood types, and median time to unserviceability is an index that can be used to characterise the performance of a wood type. Survival time was the time for a stake to reach unserviceability. As some specimens had not reached a condition of unserviceability before the end of the study, it was necessary to take data censoring into account. It should be noted that the size of samples for all wood types other than *Ca. glaucophylla* heartwood and *Ca. endlicheri* heartwood are rather small (i.e. four replicates, Table 3).

The two-way ANOVA, with replicates as blocks, was used to compare the time to unserviceability of *Ca. glaucophylla* heartwood from Forbes, NSW, with *Ca. glaucophylla* heartwood from

Table 1. Sources and characteristics of *Callitris glaucophylla* billets from which outer heartwood stakes were prepared

Tree No.	Geographical source		Diam.[1] (mm)	Sapwood thickness[2] (mm)	Heartwood		Estim. age[4] (y)	Mean rating at 4 y[5]
	Nearest town	State forest/ compartment			Diam.[3] (mm)	Air-dry density (kg m⁻³)		
1	Western Creek, Qld		134	15–17	92	715	?	3.2
2			124	10–16	92	678	?	
3			130	7–12	110	748	?	
4	Dalby, Qld	Dunmore	148	28–32	89	721	~70	4.5
5	Gilgandra, NSW	Eura/34	117	10–15	80	830	>80	5.2
6		Eura/34	127	11–14	101	927	>80	
7		Eura/430	130	12–14	106	795	>80	
8	Baradine, NSW	Wittenbra/274	158	16–18	116	690	~40	5.2
9		Wittenbra/274	142	15–17	110	716	~40	
10		Wittenbra/274	140	15–21	101	724	~40	
11	Forbes, NSW	Strahorn	160	21–29	116	739	~90	3.8
12		Strahorn	145	12–15	120	904	~90	
13		Strahorn	149	18–24	114	735	~90	
14	Griffith, NSW	Jimberoo	131	14–17	96	790	?	4.5
15		Jimberoo	115	11–12	95	860	?	
16		Jimberoo	125	14–18	104	846	?	

[1]Diameter inside bark when green; mean of maximum and minimum diameters
[2]Minimum and maximum sapwood thickness when green
[3]Mean of minimum and maximum heartwood diameters when green
[4]Age of tree estimated by field foresters
[5]Based on a 0–8 rating scale, where 8 is sound, 3 unserviceable and 0 totally destroyed

Table 2. Sources and characteristics of *Callitris endlicheri* billets from which outer heartwood stakes were prepared

Tree No.	Geographical source		Diam.[1] (mm)	Sapwood thickness[2] (mm)	Heartwood		Estim. age[4] (y)	Mean rating at 4 y[5]
	Nearest town	State forest/ compartment			Diam.[3] (mm)	Air-dry density (kg m⁻³)		
17	Western Creek, Qld		130	20–24	86	673	?	0.0
18	Dalby, Qld	Dunmore?	153	17–23	112	665	~50	3.5
19	Gilgandra, NSW	Eura/34	127	11–18	134	812	<80	2.8
20		Eura/34	143	12–14	112	763	<80	
21		Eura/34	132	16–19	92	723	<80	
22	Baradine, NSW	Wittenbra/382	138	14–17	117	686	~40	0.7
23		Wittenbra/382	148	17–22	92	650	~40	
24		Wittenbra/382	151	17–21	110	688	~40	
25	Forbes, NSW	Killonbutta	150	17–22	111	714	~80	2.2
26		Killonbutta	138	7–13	127	772	~80	
27		Killonbutta	152	17–21	118	687	~80	
28	Griffith, NSW	Jimberoo	127	20–24	86	721	?	0.7
29		Jimberoo	129	14–18	92	668	?	
30		Jimberoo	123	20–24	78	748	?	

[1]Diameter inside bark when green; mean of maximum and minimum diameters
[2]Minimum and maximum sapwood thickness when green
[3]Mean of minimum and maximum heartwood (green) diameters
[4]Age of tree estimated by field foresters
[5]Based on a 0–8 rating scale, where 8 is sound, 3 unserviceable and 0 totally destroyed

Table 3. Median time to unserviceability of *Callitris* and yardstick timbers under test conditions

Timber type	Median time to unserviceability (weeks)	Estimated 95% confidence interval of the median (weeks)		Number of replicates studied	Number of replicates serviceable after 280 weeks
		Lower	Upper		
Ca. glaucophylla heartwood	256	234	278	32	11
Ca. glaucophylla sapwood	130	79	181	4	0
Ca. endlicheri heartwood	192	179	206	28	1
Ca. endlicheri sapwood	156	105	207	4	0
Corymbia maculata heartwood	243	209	277	4	0
Eucalyptus regnans heartwood	35	1	69	4	0
Pinus radiata sapwood	87	53	121	4	0

Gilgandra, NSW, and *Ca. endlicheri* heartwood from Forbes with *Ca. endlicheri* heartwood from Gilgandra. The analysis was based on six replicates from each species and site.

Finally, the effect of density on time to unserviceability of *Ca. glaucophylla* and *Ca. endlicheri* heartwood was examined by Spearman rank correlation analysis (Siegel 1956). At the time the analyses were carried out, the in-ground test had run for 280 weeks (5.4 y).

Results and discussion

Results of statistical analyses of the cypress pines

A major comparison of interest is between *Ca. endlicheri* heartwood and *Ca. glaucophylla* heartwood, and the survival curves and hazard curves for these wood types are given in Figures 1 and 2. A log-rank test and a Wilcoxon test identified the survival curves for these wood types as significantly different ($P < 0.0001$). To simplify the graph, the 95% confidence intervals for the survival curves were not plotted on Figure 1. However, when these were plotted (elsewhere) the intervals did not overlap any part of the 'Time to failure' axis. Figure 1 indicates that *Ca. endlicheri* heartwood and *Ca. glaucophylla* heartwood had different survival curves. The curve for *Ca. endlicheri* heartwood was much steeper than for *Ca. glaucophylla*, indicating that *Ca. endlicheri* heartwood declined into unserviceability much quicker than *Ca. glaucophylla* heartwood. This is further supported by the hazard curves in Figure 2, which provide estimates of the failure rates over time. In the case of *Ca. glaucophylla* heartwood, the hazard curve is relatively flat compared to the steep ascent for *Ca. endlicheri* heartwood. *Callitris endlicheri* heartwood rapidly declined in serviceability between the end of the third (156 weeks) and fourth (208 weeks) years of study.

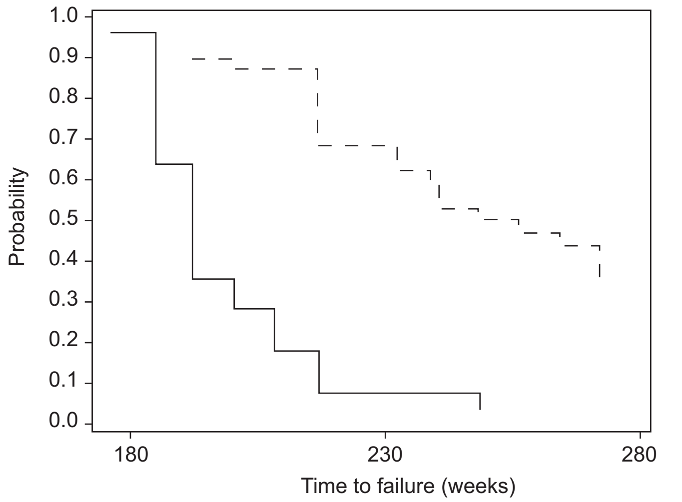

Figure 1. Nonparametric Kaplan–Meier survival plot for time to failure of the heartwood stakes of *Ca. endlicheri* (——) and *Ca. glaucophylla* (- -)

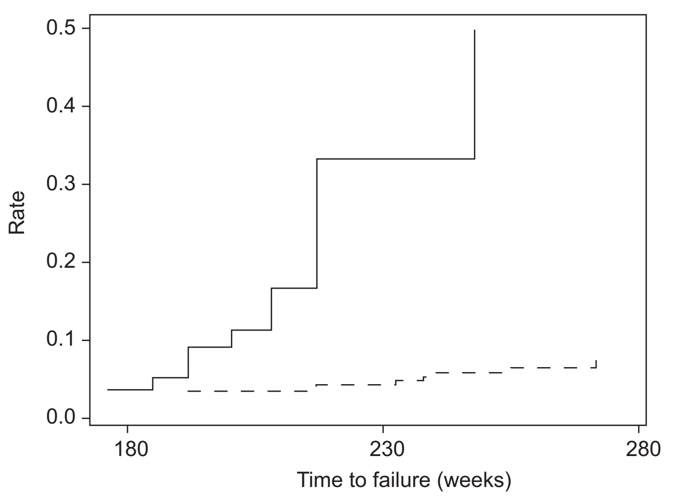

Figure 2. Nonparametric empirical hazard function plot for time to failure, showing failure rate (rate of specimen failure at time *t* given that it has not failed before time *t*) of the heartwood stakes of *Ca. endlicheri* (——) and *Ca. glaucophylla* (- -)

Natural durability ratings

Table 3 presents data on the median time (in weeks) to unserviceability of the timber types included in this study. The durability of *Ca. glaucophylla* heartwood, despite 11 replicates still being serviceable, was not significantly different ($P > 0.05$) from *Co. maculata* heartwood. The results from exposure in the AFS of these species are consistent with results obtained after 35 y at five field test sites. In the field, both species had similar service lives although *Co. maculata* was slightly better in performance, and both were classified as Class 2 timbers (Cookson 2005).

On the other hand, *Ca. endlicheri* was less durable than *Ca. glaucophylla*, as the time to unserviceability of *Ca. endlicheri* heartwood stakes was significantly different ($P < 0.05$) from that of heartwood from both *Ca. glaucophylla* and *Co. maculata* (Class 2 timbers). Most *Callitris* spp. stakes became unserviceable due to brown rot fungi. *Callitris endlicheri* was more durable than the Class 4 timber, *E. regnans* heartwood ($P < 0.05$). A representative Class 3 timber was not included in the trial, making it difficult to know whether to reassign *Ca. endlicheri* to this class. However, calibration of the AFS trial with the 35-y stake test (Cookson 2005) suggests that *Ca. endlicheri* should remain a Class 2 timber. The final report of the long-term stake test used the mean of the medians from four of the test sites (excluding Innisfail, Queensland) to determine natural durability ratings. The mean value in the field test for *Ca. glaucophylla* was 18.6 y (967 weeks). The time to median unserviceability for *Ca. glaucophylla* in the AFS was 256 weeks, which is 3.8 times faster than in the field (note that different stake sizes were used in each test). Similarly, the acceleration factor for the other naturally-durable yardstick species *Co. maculata* was more than 4.0, as in the field the mean of the median specimen lives was >16.7 y. Failure of *E. regnans* in the AFS was faster again at 8.3 times faster than in the field, suggesting that acceleration factors in the AFS may increase proportionally with reducing natural durability. The average acceleration factor for the two naturally-durable yardstick species was >3.9. If this factor is applied to the median service life in the AFS of 192 weeks for *Ca. endlicheri*, the service life in the field may have been >749 weeks or >14.4 y. As Class 2 timbers have in-ground service lives of 15–25 y (Standards Australia 2005), for the 50 mm × 50 mm cross-sectioned timbers used in the field test, *Ca. endlicheri* is likely to fall just within the service life range for Class 2 timbers. This classification could be assigned, especially if the acceleration factor for *Ca. endlicheri* lies between 3.9 and 8.3, due to its natural durability being lower (but within the range possible for Class 2) than for *Ca. glaucophylla* and *Co. maculata*.

Another interesting aspect to emerge from this research is that the sapwood of both *Ca. glaucophylla* and *Ca. endlicheri* appeared to have some natural durability, with median specimen lives of 130 and 156 weeks respectively (Table 3). Sapwood is normally considered non-durable, so that it was expected that specimen lives would be closer to those for *P. radiata* sapwood (87 weeks) and *E. regnans* heartwood (35 weeks). However, by applying the >3.9 times factor used above, the service life in the field may have been >507 weeks (>9.8 y) and >608 weeks (>11.7 y) for *Ca. glaucophylla* and *Ca. endlicheri* respectively. This calibration would suggest natural durability ratings of Class 3 for *Callitris* sapwood. In practice, however, there have been a number of early failures (within 2–4 y) of untreated *Ca. glaucophylla* vineyard posts, due to their high sapwood content, especially at ground line when installed small-end down (Johnson unpublished data). Also, Rudman (1966) found in a laboratory bioassay that the sapwood of *Callitris* spp. was susceptible to his brown rot test fungus. Therefore, *Callitris* spp. sapwood should continue to be considered non-durable, although the unexpected result in the AFS is worthy of further investigation. Sapwood with higher-than-usual natural durability has been reported for *Eusideroxylon zwageri* Teijsm. & Binnend. (belian) (Wong and Singh 2001), and has been observed for *Homalium foetidum* (Roxb.) Benth. (malas) (Thornton and Johnson, unpublished data).

Provenance and density

The time to unserviceability of *Ca. glaucophylla* and *Ca. endlicheri* heartwood, each from two geographic sources, was compared. Forested areas near Forbes and Gilgandra, located 200 km apart in north-western NSW, provided samples from trees of similar age and were therefore selected for the comparisons (Tables 1 and 2). Mean ratings for decay after 4 y exposure are provided in Tables 1 and 2. The statistical analysis showed that there was no significant difference at the 5% level between the two provenances within each species.

The Spearman rank correlation coefficient of time to unserviceability and density of *Ca. glaucophylla* and *Ca. endlicheri* was 0.315 and 0.248, respectively. Neither coefficient is significantly different from zero. Hence, within the range included in this study, air-dry density does not have an effect on time to unserviceability of either *Callitris* species. This observation contrasts with the situation reported for the eucalypts, in which greater density resulted in greater in-ground durability, both between species (Chafe 1989) and within species (Johnson *et al.* 1996).

In summary, this research shows that *Ca. endlicheri* heartwood is not as durable as *Ca. glaucophylla* heartwood, although the difference is not sufficient to reduce its rating as a Class 2 timber. This outcome is fortunate, as separation of the two species in the marketplace would be difficult.

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