Susceptibility of Coconut Wood to Damage by Subterranean Termites (Isoptera: Mastotermitidae, Rhinotermitidae)

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Two field trials were conducted with untreated coconut wood ("cocowood") of varying densities against the subterranean termites *Coptotermes acinaciformis* (Froggatt) and *Mastotermes darwiniensis* Froggatt in northern Queensland, Australia. Both trials ran for 16 weeks during the summer months. Cocowood densities ranged from 256 kg/m^3 to 1003 kg/m^3, and the test specimens were equally divided between the two termite trial sites. Termite pressure was high at both sites where mean mass losses in the Scots pine sapwood feeder specimens were: 100% for *C. acinaciformis* and 74.7% for *M. darwiniensis*. Termite species and cocowood density effects were significant. Container and position effects were not significant. *Mastotermes darwiniensis* fed more on the cocowood than did *C. acinaciformis* despite consuming less of the Scots pine than did *C. acinaciformis*. Overall the susceptibility of cocowood to *C. acinaciformis* and *M. darwiniensis* decreases with increasing density, but all densities (apart from a few at the high end of the density range) could be considered susceptible, particularly to *M. darwiniensis*. Some deviations from this general trend are discussed as well as implications for the utilisation of cocowood as a building resource.

INTRODUCTION

The coconut palm *Cocos nucifera* L. is a distinctive crop due to its large variety of uses (Subramanian 2003). Besides the various products from the coconut itself, the trunk of the palm has important commercial uses, including as a building product. In the Pacific region, large areas of coconut palm have senesced, and consequently copra yields are greatly reduced. The cost and phytosanitary implications of clearing senile palms are real impediments to replanting. For example, felled palms have to be removed immediately from a plantation; otherwise they become a breeding refuge for the coconut rhinoceros beetle *Oryctes rhinoceros* (L.), which can in turn damage living palms (Peek 1994). The production of high value flooring, bench tops, and furniture from senile stems has been proposed as a solution to this problem while providing an income to farmers from the senile palms (Marino 2010). This would in turn cover the cost of removing the older dead palms and freeing the land for productive use once again. Stems can reach a height of up to 20 m in 70 to 80 year old palms, with usable quality wood available after 50 years.

Cocowood is different from traditional wood in that it is a monocotyledon (belonging to the grass family) and not a dicotyledon as are traditional wood-producing

trees. As such, it is not botanically speaking wood. One of the significant differences relative to true wood is that the stem is made up of tightly packed vascular bundles surrounded by parenchyma (ground tissue). This is most evident in the high density wood, which is the material suitable for building applications. There is a gradient running from the low density core to the high density peripheral fibre (Hopewell *et al.* 2012). The advantage of this characteristic is that cocowood is not subject to normal wood quality degrading effects, such as knots. On the downside the presence of thick-walled sclerenchyma fibres and a high loading of minerals makes sawing difficult and very hard on processing equipment and wood-working tools (Subramanian 2003). The cocowood density is correlated with "bundle pattern", which is equivalent to the number of vascular bundles per unit area and their size (Hopewell *et al.* 2012). Generally in high density cocowood the typical pattern can be either large darker bundles and medium concentrations or smaller bundles in high concentrations. The reverse is the case with medium to low density cocowood. It is true that the density can vary within individual lengths of cocowood due to how widespread or congested the bundles (each bundle has its own density) are at any point. The density of an individual piece of cocowood can only be considered an "average" density.

There is very high demand for flooring products in Asia, America, and Europe. This market was estimated globally at $5.4B in 2004 with predictions for strong growth (Arancon 2010). Generally, however, while market demand is increasing, the supply of suitable resources is decreasing, particularly for hard, dark timbers from sustainable resources. Market appraisals by Australian companies indicated that the unique attractive appearance of cocowood, combined with its hardwearing properties and sustainable plantation origins, will ensure high levels of consumer demand. It has long been recognized that cocowood is an attractive material, highly suitable for aesthetic applications (Hopewell *et al.* 2012).

Natural durability is the most important feature that determines the quality of wood and is partially related to density (Peek 1994). The varying density levels in the coconut palm from the top to the bottom and from the central core to the periphery is a significant limiting factor in how much of each stem is suitable for building products such as flooring. Only high density material (> 600 kg/m^3) is suitable for load bearing structures such as trusses, floor joists, and floor tiles, while cocowood with a density below 400 kg/m^3 should not be used as a load bearing structural component (Jayabhanu 2011). The density can vary so dramatically in a single stem that it encompasses the entire density range as is found across the timber industry from balsa to ironbark (Marino 2010). Variability can be in the range of more than 500 kg/m^3 (Jourez *et al.* 2011). Cocowood is graded as hard, intermediate, or soft, corresponding to high density (> 600 kg/m^3), medium density (between 400-600 kg/m^3), and low density (< 400 kg/m^3), respectively. It is graded visually using vascular bundle patterns highlighted in the end grain. The variability in density can have a dramatic impact on such processes as machining and drying of cocowood as well as on its resistance to biological degradation, *e.g.* by termites and fungi (Jourez *et al.* 2011).

The cocowood must be carefully segregated into density grades to satisfy product specifications. Only the outer annulus of hard fibre of the coconut palm is suitable as a flooring product with a minimum threshold for air-dry density set at 700 kg/m^3 (Hopewell *et al.* 2012). The wide variation in density can influence the susceptibility of cocowood to fungal and insect damage. A number of studies (Owoyemi *et al.* 2013, Shanbhag and Sundararaj 2013) have shown that on average the higher the density of the

wood the lower the degradation by termites. Termites are known to damage senile coconut palms, but only the less dense portion is generally damaged (Subramanian 2003). It appears that cocowood possesses the same characteristic with respect to density and the propensity for damage by termites. As such, the less dense cocowood flooring product may be prone to termite damage, but the more dense wood may be less prone or even resistant. It has been stated that termites in field and laboratory tests can severely damage low and high density cocowood, but proof of this is lacking. A Philippines report (Gibb 1985) lists a number of subterranean termites, *e.g. Coptotermes vastator* (= *gestroi*) and *Macrotermes gilvus*, that have been recorded as damaging cocowood. These appear to be the result of in-use observations rather than specific field exposures to these termites. While little is known of the resistance of untreated cocowood to termite attack, laboratory bioassays on untreated cocowood to test the resistance against brown and white rot fungi have shown the timber to be quite resistant when compared to beech and Norway spruce (Amartey *et al.* 2006).

Bamboo is also widely grown and used as a construction material around the world (Hapukotuwa and Grace 2011). Bamboo, like cocowood, belongs to the grass family. No previous work has evaluated the natural resistance of cocowood to termite attack in field trials. However the natural resistance of a variety of bamboo species to feeding by subterranean termites has been evaluated in laboratory and field trials (Hapukotuwa and Grace 2011; Lifang *et al.* 2010; Okahisa *et al.* 2006; Mishra and Rana 1992). In contrast to true wood it was found that overall the natural durability of bamboo is not closely related to density, with many specimens lasting less than 2 years in a field exposure (Lifang *et al.* 2010). Dhawan *et al.* (2008) discovered that height and age of some bamboo species can determine the natural resistance against termites, with bamboo harvested after three years of age more resistant than the younger bamboo. This could be due to an increase in fibre percentage and density as the bamboo culm ages. As well, laboratory bioassays with species such as *Bambusa natans* and *Bambusa balcoola* show them to be quite resistant to termite damage (Mishra and Rana 1992). This compares favorably with the heartwood of some economically important Indian timbers such as *Shorea robusta* and *Garuga pinnata*. The outer layer or skin of bamboo appears to be highly resistant to termite damage and harbors a considerable quantity of ash and silica (Mishra and Rana 1992). Cocowood too has an unusually high quantity of minerals, which may play a role in imparting a degree of natural termite resistance, especially where the density is high.

It has been suggested that for indoor use only low density (< 400 kg/m^3) wood needs to be treated against insects while for outdoor use a chemical timber treatment would be necessary (Jourez *et al.* 2012). To evaluate the natural resistance of cocowood to termite damage, test specimens of cocowood flooring material, encompassing a range of densities (low to high) were exposed to the subterranean termites *Coptotermes acinaciformis* (Froggatt) and *Mastotermes darwiniensis* Froggatt in northern Queensland, Australia. *Coptotermes acinaciformis* and *M. darwiniensis* are the most economically important and destructive termites, respectively, in Australia.

EXPERIMENTAL

Test Specimens

The sampling strategy for the test specimens required a total of 80 palms sourced equally from Fiji and Western Samoa. The palms were senile palms around 60 years of age from old industrial plantations. The samples were processed into 3 meter log lengths per palm from base to fronds, providing around 10 samples as diametrical boards. These boards encompassed the range of densities from the top to the bottom and from the core to the periphery of the palm. They were packed and shipped to Australia for further testing, including for termite exposures. Cocowood test specimens were exposed to termite feeding at two Townsville sites (northern Queensland) for *C. acinaciformis* and *M. darwiniensis* using a method from the Australasian Wood Preservation Committee (AWPC 2007) protocols. Seventy two sections of cocowood ($15 \times 70 \times 190$ mm long) ("test specimens") were cut from boards selected for a range of densities (280 kg/m^3 – 1003 kg/m^3). Untreated Scots pine, *Pinus sylvestris* L., sapwood material (cross section 35×70 mm) was cut into 72 feeder specimens of 190 mm length. The specimens were numbered, oven dried (40 $^\circ$C for 48 h), weighed, and assigned to 12 test containers (Bipa Plastics 6-litre plastic food containers, 210 mm wide $\times$ 90 mm deep $\times$ 310 mm long). The feeder specimens were used to facilitate termite foraging into the test containers and to maintain a high level of termite pressure during the exposure period. Twelve test containers each had six test specimens and five feeder specimens. This was the maximum number of specimens that could be allotted to a container. The test specimens in each test container were selected to represent the range of cocowood densities. Two additional control containers each had seven feeder specimens. Six test containers and one control container were used for each species of termite. The control containers were used as an additional indicator of termite pressure for the period of the trial. Significant mass loss in these containers would be an indicator of strong termite pressure.

Specimen Selection

The test specimen weights were sorted into ascending order. From this sort, alternate test specimens were assigned to either *C. acinaciformis* (Set 1) or *M. darwiniensis* (Set 2). The six lightest test specimens for Set 1 were randomized over Containers 1 to 6. Similarly, the next six lightest were randomized over Containers 1 to 6, and so forth until the 36 test specimens for Set 1 were assigned to Containers 1 to 6. The six test specimens within each test container were then randomly assigned to six positions (Positions 1 to 6). The test specimens for Set 2 were similarly assigned. Each feeder specimens were assigned to six test containers and a control container for exposure to *C. acinaciformis* (Set 1) or *M. darwiniensis* (Set 2). The initial mass values of test specimens were subjected to standard analyses of variance (ANOVA), using StatSoft, Inc. (2006), to partition the variance due to sets, test containers, and the interaction of these variables with respect to test specimens and feeder specimens. Similarly, the difference between the initial mass of feeder specimens due to sets in control containers was also examined.

The ANOVA on test specimens indicated that the mean mass of test specimens in Set 1 (126.1 g) (mean = 632.0 kg/m^3; Standard Deviation (SD) = 212.3 kg/m^3; Range 256.2 - 1002.8 kg/m^3; N = 36) was not different from that of test specimens in Set 2 (128.2 g) (mean = 642.7 kg/m^3; SD = 211.3 kg/m^3; Range 280.2 - 1003.5 kg/m^3; N = 36) ($F_{1, 60} = 0.040$, $P = 0.84$). Similarly, the mean mass of test specimens exposed in

Containers 1 to 6 were not significantly different ($F_{5, 60} = 0.11$, $P = 0.99$). The interaction between sets and test containers was also not significant ($F_{5, 60} = 0.0071$, $P = 1.0$). The ANOVA on feeder specimens indicated that the mean mass of feeder specimens in Set 1 (200.0g) was not different from that of feeder specimens in Set 2 (201.5g) ($F_{1, 48} = 0.26$, $P = 0.61$). Similarly, the mean mass of feeder specimens exposed in Containers 1 to 6 were not significantly different ($F_{5, 48} = 0.29$, $P = 0.92$). The interaction between sets and test containers was also not significant ($F_{5, 48} = 0.79$, $P = 0.56$). The mean mass of feeder specimens in Set 1 (Control) (205.7g) was not different from that of feeder specimens in Set 2 (Control) (196.2g) ($F_{1, 12} = 1.64$, $P = 0.22$).

Termites

Coptotermes acinaciformis occurs in mounds (epigeous nests) in regions north of the Tropic of Capricorn. It occurs on private property near Hervey Range (19° 21' S, 146° 29' E), about 35 km west of Townsville in tropical north Queensland, where the trial was conducted. *Mastotermes darwiniensis*, does not build a mound and occurs on private property at Rowes Bay (19° 13' S., 146° 47' E.), Townsville, where the trial was conducted.

Field Assay

The six test containers and one control container were attached to a *C. acinaciformis* mound, via hollow concrete bricks established adjacent to one another along a section of a trench (Fig. 1). Radiata pine, *Pinus radiata* D. Don, feeder stakes were driven into the ground within the gaps of the bricks to facilitate movement of the termites from the ground to the test specimens, according to the method of Peters *et al.* (2008). Each test and control container was covered with insulating material secured with soil (Fig. 2). Similarly, containers were exposed to *M. darwiniensis*, with the containers being placed atop a trench that had previously been filled with a large amount of feeder timber to facilitate sustained termite foraging (Fig. 3). As with *C. acinaciformis*, these containers were also covered with insulating material. Following exposure for 16 weeks (Australasian Wood Preservation Committee 2007), the specimens were harvested, visually assessed for termite damage, oven dried (40 $^{°}$C for 48 h), and the mass losses determined and analysed (using StatSoft, Inc. 2006).

Fig. 1. Containers placed on top of bricks connected to a mound of *C. acinaciformis* near Townsville

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Fig. 2. Each test container was covered with insulating material secured with soil

Fig. 3. Containers placed on top of bricks sitting atop a trench of aggregated *M. darwiniensis* near Townsville

RESULTS AND DISCUSSION

Termites entered all containers and were present at harvest. Mass losses in the Scots pine sapwood feeder specimens were: *C. acinaciformis*, 100% (Fig. 4) and *M. darwiniensis*, mean was 74.7% (SD = 15.8%; Range 40.9% - 100%). Differences in *M. darwiniensis* feeding in the six test containers, with respect to feeder specimens, were not significant ($F_{5, 24} = 2.6$, $P = 0.051$). Mean mass loss due to *M. darwiniensis* feeding in the control container was 80.6% (SD = 14.9%; Range 62.2% - 100%). Accordingly, termite feeding pressure was strong and more than adequate for a valid trial. Damage to the cocowood test specimens by *C. acinaciformis* and *M. darwiniensis* in the field trials supports previous observations (PCARRD 1983) of subterranean termites damaging cocowood. The percentage mass loss data of test specimens were transformed (using arcsin-squareroot) to normalize these data (Kolmogorov-Smirnov d = 0.155, $P \leq 0.10$). The transformed data were analysed using multiple regression techniques to partition the

variance due to termite species, cocowood density, container, and position effects (StatSoft, Inc. 2006). Termite species ($F_{1,\,67} = 96.0$, $P < 0.0001$) and cocowood density ($F_{1,\,67} = 72.2$, $P < 0.0001$) effects were significant, whereas container ($F_{1,\,67} = 0.75$, $P = 0.39$) and position ($F_{1,\,67} = 0.82$, $P = 0.37$) effects were not significant.

Mastotermes darwiniensis fed more on the cocowood than did *C. acinaciformis* (Fig. 4) despite consuming less of the Scots pine sapwood feeder specimens than did *C. acinaciformis*. This would be considered unusual, as *M. darwiniensis* is considered by far the most destructive Australian termite due to its size and ability to feed on many different materials (Hill 1942). However the percentage consumption was still sufficiently high to discount a low vigour colony, and this is supported by the amount of damage to the cocowood test specimens.
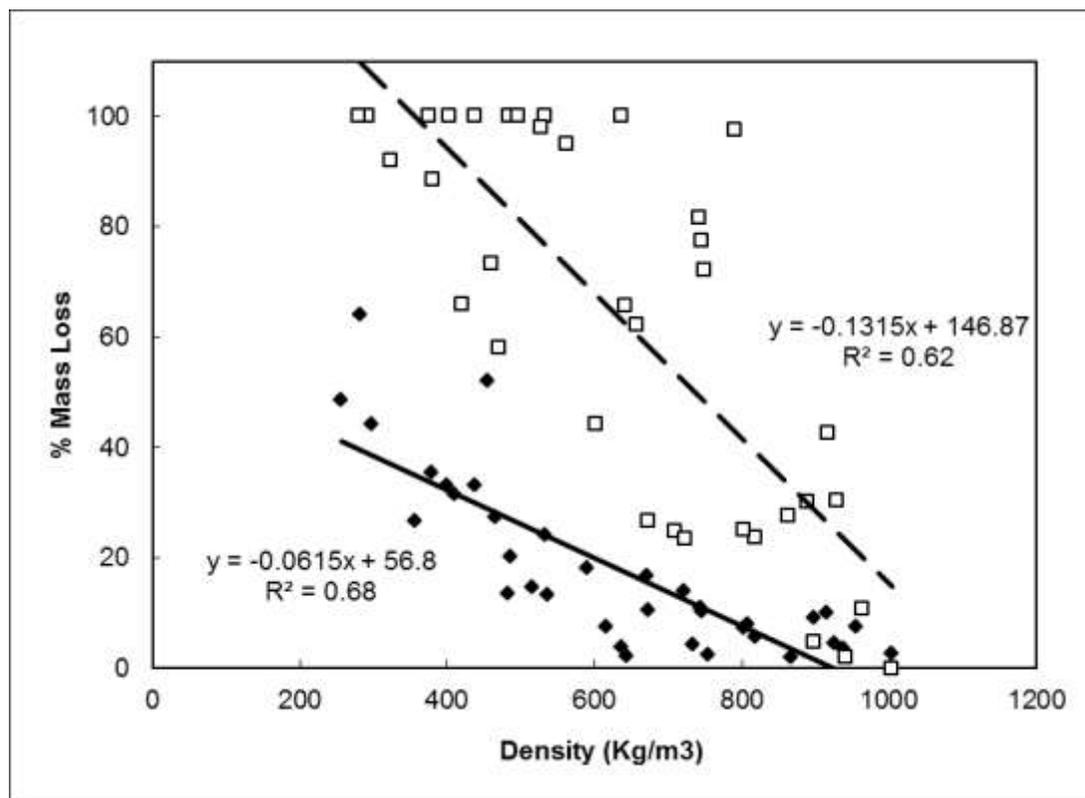

Fig. 4. Variation of percentage mass loss of test specimens with cocowood density due to *C. acinaciformis* (♦) and *M. darwiniensis* (□) feeding. Trend lines for *C. acinaciformis* (____) and *M. darwiniensis* (-- --) are included

The susceptibility of cocowood to the subterranean termites *C. acinaciformis* and *M. darwiniensis* decreases with increasing density. This aligns with the findings of Owoyemi *et al.* (2013) and Shanbhag and Sundararaj (2013), who reported that in relation to the natural durability of selected wood species, the higher the density of the wood the lower the degradation. In this regard cocowood is similar to the properties of true wood when it comes to natural termite resistance. In addition, trials by Peek 1994 on the durability of cocowood against white and brown rot fungi showed the mass loss of test specimens was inversely correlated with wood density. But all densities (except a few at the high end of the density range) tested were susceptible, particularly to *M. darwiniensis* (Fig. 5).

Fig. 5. Cocowood test specimens of increasing density after exposure to *C. acinaciformis* (298-938 kg/m^3) (L) and *M. darwiniensis* (380-963 kg/m^3) (R) – test specimen 12 was destroyed

While the overall trend points toward decreasing damage with increasing density of cocowood for both termite species, there were instances where low to medium density (*e.g.* < 650 kg/m^3) was accompanied by relatively low percentage mass loss (2 to 15%), especially for *C. acinaciformis*. Alternatively for *M. darwiniensis* at high densities (e.g. > 700 kg/m^3), there were some rather high percentage mass losses (> 70%) in comparison to the majority of the test specimens. As the overall termite pressure at both sites was strong, there may be particular characteristics of these test specimens causing a shift from the normal trend. This is supported by the fact there were no significant position or container effects. It may be that the specific vascular bundle patterns visible on the end grain of these test specimens are an indicator to this shift. Bailleres *et al.* 2010 detailed the relationship between vascular bundle patterns and high density (> 700 kg/m^3) cocowood, with small bundles in high concentrations a reliable gauge (Fig. 6).
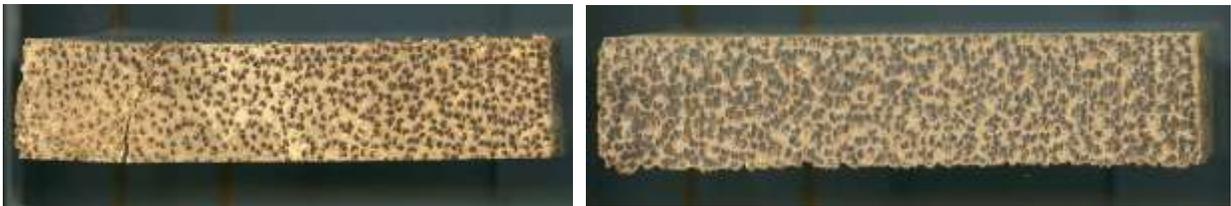

Fig. 6. End grain view of high density cocowood test specimens with densities of 866.5 kg/m^3 (L) and 1003.5 kg/m^3 (R) after exposure to *C. acinaciformis* and *M. darwiniensis*, respectively

A closer inspection of some cocowood test specimens reveals that at a low density, where an unexpected small percentage was eaten (483 kg/m^3 and 14% mass loss for *C. acinaciformis*), there was a high concentration of vascular bundles in the remaining portion. Conversely a test specimen with a similar density (454 kg/m^3) had almost 4 times as much eaten (52%). This specimen exhibited a low concentration of vascular bundles in the remaining portion (Fig. 7).
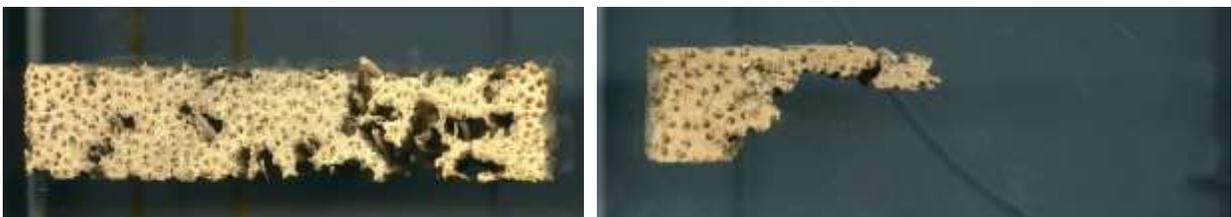

Fig. 7. End grain view of cocowood test specimens with densities of 483 kg/m^3 (L) and 454 kg/m^3 (R) after exposure to *C. acinaciformis*

Similarly for *M. darwiniensis*, considered a more voracious termite than *C. acinaciformis,* a cocowood test specimen with a medium density of 673 kg/m^3 had a percentage mass loss of 27% compared to a test specimen of similar density (636 kg/m^3), which was destroyed by the termites. Again an end grain view of the uneaten portion of the cocowood test specimen showed a high concentration of vascular bundles (Fig. 8).

Fig. 8. End grain view of a cocowood test specimen (density 673 kg/m^3) partially eaten by *M. darwiniensis* with a high concentration of vascular bundles in the uneaten portion

From these results it is apparent that the designated density of a cocowood test specimen is not always a true indicator of its susceptibility to termite damage. The "vascular bundle pattern" will have a significant bearing on how much of the test specimen is damaged by the termites, and this will in turn vary between the two species of termites. As an example, with *M. darwiniensis,* a cocowood test specimen with a density as high as 916 kg/m^3 showed a mass loss greater than 40%. This is much higher than what was recorded with cocowood test specimens of similar density exposed to *C. acinaciformis* (914 kg/m^3 and 10% mass loss). It is suggested this is a response to the variation in size of the termite workers (M. *darwiniensis* 10-12 mm; *C. acinaciformis* 5-6mm) (Hadlington 1996) and the ability of *M. darwiniensis* workers to overcome the tight vascular bundle pattern when feeding. No other effects, *e.g.* due to container or position within the container, were significant. In this trial only test specimens above 1000 kg/m^3 remained uneaten or with negligible feeding by either species of termite.

Cocowood with density above 1000 kg/m^3 would not require treatment to prevent termite damage, should it be used in a situation where it is at risk of termite attack. Similar conclusions were drawn with respect to the susceptibility of cocowood to white rot fungi and suitability for exterior use (Peek 1994). Anything below this level would require treatment, based on these preliminary results, especially where the cocowood is exposed to *M. darwiniensis*. If one were to rely on the natural durability, based on density, of cocowood to prevent termite damage, then the visual grading would have to be very precise to understand the relationship between cocowood density, bundle patterns, and position within the coconut stem (Bailleres *et al.* 2010). Additional field trials would be required to galvanize the relationship between "very" high density (> 1000 kg/m^3) and natural durability in the event of termite attack. It may be that insufficient cocowood can be sourced at these "very" high densities to make the use of untreated cocowood commercially viable.

CONCLUSIONS

1. The susceptibility of cocowood to the subterranean termites *C. acinaciformis* and *M. darwiniensis* decreases with increased density.

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2. All densities except those above 1000 kg/m^3 (where there was none or negligible damage) were susceptible, particularly to *M. darwiniensis*, which is considered the more voracious of the two species due to a much larger worker caste.

3. Based on these results untreated cocowood could not be classified as termite resistant unless the density is > 1000 kg/m^3.

4. For Hazard Class H2 and above and where the density is < 1000 kg/m^3, cocowood would need to be pre-treated to mitigate termite damage.

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