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Non-destructive Detection of an Invasive Drywood Termite, *Cryptotermes brevis* (Blattodea: Kalotermitidae), in Timber

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Abstract

Reliable drywood termite detection in structures is challenging but is critical for effective management. A microwave-based non-destructive method was evaluated for detecting termite activity. This study evaluated factors affecting the ability of this device to reliably detect *Cryptotermes brevis* in timber. The device displayed a high probability of successfully detecting *C. brevis* in naturally infested boards. The system detected termites 97% of the time when used at the highest sensitivity level, while producing few false positives. The number of termites did not affect detection ability, and detectable signals were produced even when a single termite was present. Detection success decreased with both increasing wood density and testing perpendicular to the grain in abrupt transition timber species. The device detected termites to a maximum depth of 45 mm in southern pine (*Pinus* spp.), but sensitivity declined with increased wood density with the detection limit declining to only 20 mm in denser Tasmanian oak (*Eucalyptus* spp). The device could only detect termites in samples with densities between 392 to 511 kg/m^3 in 38 mm thick radiata pine samples. The results support the ability of microwaves to reliably detect *C. brevis* in timber.

Introduction

Drywood termites (Kalotermitidae) occupy unique niches not available to other xylophagous termites (Evans et al., 2013). Unlike many subterranean termite species that attack wood above the ground by carrying moisture upwards into the timber, drywood termites have evolved to thrive at the low wood moisture contents typical of these environments (Evans, 2010). These adaptations allow drywood termites to attack timber with no direct soil contact, making them difficult to detect and costly to control (Lewis et al., 2014).

Among the most important drywood termites globally is the West Indian drywood termite *Cryptotermes brevis* (Walker). Although first described in the Caribbean, the species is thought to have originated from deserts in Chile or Peru, where it evolved to attack dry wood at low moisture contents (<12-15% EMC) (Evans et al., 2013; Scheffrahn et al., 2009). *Cryptotermes brevis* has since been transported globally in various wood articles and is considered invasive in many countries. The species is currently found in multiple locations in Southeast Queensland, Australia (Peters, 1990).

Their cryptic nature, relatively slow rate of colony growth, and small colony sizes make *C. brevis* detection difficult in the early stages of an infestation. The traditional method for eliminating *C. brevis* infestations has been whole-house fumigation, usually with sulfuryl fluoride (Lewis et al., 2014). The process is costly and does not prevent re-infestation. Heating wood to achieve internal temperatures of at least 50 °C for an hour or more has been proposed as an alternative treatment method (Lewis & Haverty, 1996). However, wood is an excellent insulator, and whole-house heating requires substantial energy inputs. A complicating

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factor in many older structures is the absence of exterior insulation that might increase heating efficiency, especially in the sub-tropical locations where this termite is found, such as Southeast Queensland. Spot treatment with injectable pesticides also has potential, but requires the ability to accurately detect infestations.

While *C. brevis* infestations can be extensive in some structures, most are smaller colonies present in distinct building assemblies. These infestations might be more easily controlled using directed heating systems instead of the whole-house approach or by injection of insecticides in nests. Spot treatment could markedly reduce the costs of dealing with minor infestations (Perry, 2019; Scheffrahn & Su, 1997; Woodrow & Grace, 1997); however, it requires the ability to reliably detect colonies. Detecting even advanced infestations can be challenging, with inspectors searching for frass expelled through kick holes or sounding surfaces to detect cavities beneath (Evans, 2002). The use of localized treatments will depend on accurately detecting active infestations in timbers in many different configurations without causing excessive damage to the substrate.

A variety of non-destructive tools such as acoustic monitoring have been evaluated for detecting termite infestations, but most are of limited value because they are affected by wood variables such as density or grain direction (Lewis, 2009). Another non-destructive approach uses microwaves (radar) for detecting movement, a temperature sensor for detecting surface temperature, and moisture sensors for detecting changes in moisture levels (Termatrac™, Ormeau, QLD, Australia, Taravati, 2018). Temperature and moisture sensing are likely to be less useful in this application since the termites do not appreciably alter moisture content and any possible temperature changes will be buffered by the surrounding wood. However, radar has the potential to detect *C. brevis* movement within cavities. The radar emits a stream of microwave signals into the timber which are then reflected back to the device. A moving termite can be detected via changes in the reflected waves which are interpreted on a screen in the form of a moving bar and line graph (Recil et al., 2016). This technology is increasingly used for detecting subterranean termite infestations in structures within a variety of substrates (Evans, 2002). Active subterranean termite attack; however, is characterized by higher degrees of activity with more workers in a given area and moisture content increases as workers transport moist soil into the timber, sharply increasing the probability of detection. Conversely, *C. brevis* colonies are often small, ranging from as few as ten to upwards of several hundred and they are less active in the wood compared to subterranean termites. These characteristics may make them more difficult to detect. The purpose of this study was to evaluate factors affecting the ability of the radar function to detect *C. brevis* activity. We hypothesized that wood characteristics related to density and grain orientation as well as termite abundance would affect detection capability.

Materials and Methods

Termite infested timber: Timber containing *C. brevis* was collected from a building in Maryborough, QLD. The timber consisted primarily of aged hoop pine floorboards (*Araucaria cunninghamii* Ait. & D. Don) but also included plywood, door panels, and stiles, as well as millwork. Because *C. brevis* is listed as a notifiable pest within the Queensland Biosecurity Act 2014, the infested boards were cut into shorter lengths and placed into sealed containers (40 ×20×25 cm) for safe transport to a secure laboratory in Brisbane. The materials were stored at 26 °C and 75% relative humidity and removed for assessment as needed. While moisture content has been shown to affect microwave sensitivity (Recil et al., 2016), the moisture levels in this study were low (~12-15 %) and consistent, making them less likely to affect results.

Detection of C. brevis in infested boards: All tests were performed using a Termatrac™ T3i unit which provided data directly to a mobile phone (Termatrac™, Ormeau, QLD, Australia). The ability of the device to detect termites in the timber was assessed in a series of tests on both naturally infested boards as well as boards with artificial galleries to which a specific number of termites were added. In some cases, it was necessary to agitate boards prior to testing to stimulate termite movement.

Depending on the size of the board, a grid consisting of ~30-36 cm squares was marked on one face of each board. Boards were placed, one at a time, on a laboratory worktable. The device was placed with the sensor directly on a given grid section for at least 15-20 seconds per reading. An additional three boards were examined by moving the instrument in 30 mm overlapping increments with a 15 second pause between movements. Termite activity, as indicated by motion detection on either the line graph or bar output on the display screen, was recorded by board location. The device can be used at intensity levels (Gain) ranging from 1 to 10, with ten being the most sensitive. Evaluations were performed at intensity levels 2, 6, and 10. Each piece of timber was carefully dissected using a chisel and hammer immediately after a reading to confirm the presence or absence of termites in each section of the board. If present, termites were collected and counted. The results from the evaluation and termite collections were used to determine four possible outcomes:

1. Negative: Termites absent and not detected
2. False positive: Termites absent but detected
3. False negative: Termites present but not detected
4. Positive: Termites present and detected

Effect of termite numbers on detection: The small size of most *C. brevis* colonies makes detecting even a few termites important. The ability of the instrument to detect differing numbers of termites at increasing depths in the wood was assessed by drilling a 4 mm deep hole in the wide faces of three radiata pine boards (*Pinus radiata*) (20×50 ×80 mm) to create a small chamber to which 1, 5 or 10 pseudergates were added. A five mm thick wafer of *Eucalyptus nitens* (5×50×100 mm) was clamped on top of the radiata pine board, and the instrument, set at the maximum gain, was placed on top of the *E. nitens* board directly over the chamber with the termites. The ability of the device to detect termites was assessed, and then additional 5 mm thick layers were sequentially added until the device was unable to detect termite activity. Each termite number/detection depth was assessed on three samples.

In the second trial, pseudergates were placed on roughened filter paper in an open, clear plastic container (diameter: 4 cm; height: 5.5 cm), and a 5 mm thick *E. nitens* wafer was placed directly on top. The instrument was placed on the wafer directly beneath the active termites. Additional 5 mm thick wafers were sequentially added and tested until activity was no longer detectable (Fig 1a). The test was repeated three times with 1, 5 or 10 termites in the plate.

Finally, 5 mm thick wafers were sequentially added to the top of an infested board where the Termatrac™ indicated that termites were present in 1 or 2 locations (Fig 1 b). The device was assessed at these locations as 5 mm thick *E. nitens* wafers were sequentially added until activity could no longer be detected.

Ability to detect C. brevis galleries: The ability of the device to detect galleries within the wood in the absence of live termites was determined by oven drying three infested boards for 3 hours at 102 °C to kill any termites that might still be present. The boards were divided into a grid of 35 one cm squares that were examined using the Termatrac™. Control boards with no prior infestation were similarly assessed. The infested boards were then dissected, and the tunnels were mapped.

Effect of wood density on detection ability: The device claims to be capable of detecting termites up to 40 mm from the surface but makes no mention of the possible effects of wood density on detection. Wood density varies widely between and even within a given species. The effect of wood density on detection was evaluated by placing five termites on roughened filter paper in an open, clear plastic container as previously described and clamping boards of the same thickness but with densities ranging from ~ 400 to 800 kg/m^3 to the container. The device was placed directly over the termites and readings were taken at the maximum gain setting. Each density was assessed three times.

In a second trial, 38 mm thick *P. radiata* boards of varying densities were selected. Each board was placed on the top of the container with termites. The device was placed directly over the termites and readings were taken at the maximum gain setting. Each density was assessed three times using fresh termites.

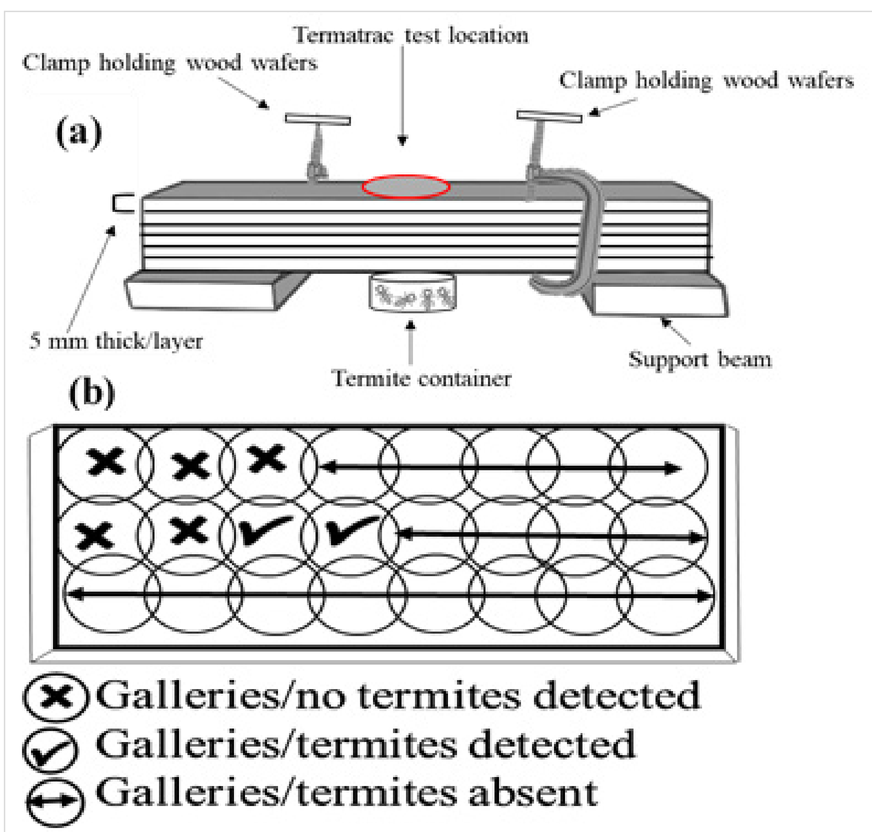

Fig 1. Setup used to determine detection depth and effect of *C. brevis* number on device signal strength (a) (side view) and an example of the sampling pattern on a naturally infested board used to determine depth detection showing presence (√) and absence (X) of *C. brevis* in different sections (b) (top view).

In the third trial, 38 mm thick *P. radiata* sapwood samples with densities of ~390 kg/m^3 were clamped to the container with termites, and the device was placed directly over the active termites. Additional layers were added until the device no longer detected the termites

Effect of wood grain orientation on detection ability: Wood sawyers commonly use two methods to cut trees into boards, each revealing a different type of grain. Wood is flat sawn when grain angle is ~45º from the wide face. In contrast, the grain is angled ~ 90º to the board face in quarter sawn wood. Grain direction may be especially important in hardwoods with large earlywood pores resulting in low density in that region or in softwood boards with an abrupt transition that creates a dense band of latewood. The effect of grain orientation on performance in an abrupt transition softwood was assessed using 35 mm thick *P. radiata* blocks cut so that the growth rings were parallel or perpendicular to the microwave signal. Readings were taken at the maximum gain setting, and the experiment was repeated three times using fresh termites each time.

Data Analysis: The data essentially indicates the presence or absence of termites. As a result, the data were percentages of successful detection under a given set of test conditions. The relationship between wood density and maximum detection depth was determined using simple linear regression analysis in Origin Pro software.

Results

Detection of C. brevis in naturally infested wood: The device successfully detected termites whenever they were present, even when subsequent dissection revealed the presence of only one pseudergate (Table 1). Although only one sample was inspected that contained no termites, the device also successfully indicated that absence. The ability to detect relatively low numbers of termites is especially important with *C. brevis* since colony sizes tend to be small and activity levels lower than those found with subterranean termites. It is also notable that the number of positive readings tended to increase with increasing numbers of termites. The results indicated that the device had a high probability of successfully detecting infestations coupled with a low risk of false positives. Results also showed that the device was unable to detect *C. brevis* galleries without active termites.

Table 1. Ability of the Termatrac™ to reliably detect *C. brevis* in different boards in relation to the number of life stages detected by subsequent destructive sampling.

Board #	Board Area (cm^2)	Positive/Negative readings /board		Termites collected/board by life stage				
		Positive	Negative	Pseudergates	Larvae	Soldiers	Reproductives	Total
1	755	2	8	8	-	2	2	12
2	560	6	2	5	7	1	4	17
3	560	8	0	112	34	3	14	163
4	900	10	0	42	18	4	7	71
5	660	7	0	2	17	-	7	26
6	700	5	4	6	-	3	-	9
7	840	2	10	-	-	-	1	1
8	266	0	4	-	-	-	-	0
9	960	10	6	113	47	4	8	172
10	936	7	5	38	7	2	-	47
11	1120	6	10	23	17	1	5	46
12	504	4	11	2	18	1	6	27
13	1080	15	3	96	52	4	5	157

Effect of signal intensity on instrument performance: The device can be operated at different intensities (gain levels) that do not increase the intensity of the radar signal, but only amplify the results. The use of low intensity levels creates the risk that termites will not be detected, while high intensities increase the risk of false positives, leading to unnecessary treatments. This factor can be important if there is a lot of extraneous vibration. Increasing the gain from 2 to 6 resulted in an increase from 10 % to 62% in the ability of the device to detect actual infestations (Table 2). Increasing the intensity to 10 resulted in a further 35 % increase in successful detection. Conversely, using the device at Level 2 intensity resulted in only ~3 % false positives, but that coupled with only 10% detection of actual infestations suggests that this level would be too low to be useful for this species. Increasing the intensity to 6 resulted in 12 % false positives, while increasing the intensity to 10 resulted in 22 % false positives. While detection remains the primary goal of inspection, the results illustrate the trade-off. Inspectors would need to determine which level of false detection was acceptable.

Table 2. Reliability of Termatrac™ detection of *C. brevis* as determined by frequencies of true and false readings for termite infested boards.

Instrument Sensitivity[a]	Frequency (%)			
	True positive	False Positive	True Negative	False Positive
10	97.2	22.0	78.0	2.8
6	62.5	12.1	87.9	37.5
2	10.2	2.9	97.1	89.8

[a]Sensitivity as determined by the amplification of the signal

Effect of colony size on detection: Chambers with one to eleven termites were assessed using the device. Termites were consistently detected when only a single termite was present, although the chamber had to be disturbed by slight banging to get the termite to move (Figure 2). This would be relatively easily accomplished in practice by tapping the wood ahead of placing the device. Termite detection declined with depth in the wood, but a single termite was still detectable up to 20 mm inward from the wood surface. These results were consistent with subsequent thickness tests and illustrated the ability of the device to detect small numbers of termites near the wood surface.

Effect of wood density and grain orientation: The device could detect termites to a maximum depth of 43 mm in southern pine, but this figure declined steadily with increased wood density to a maximum depth of only 20 mm in *E. obliqua* which had a density approaching 650 kg/m^3 (Table 3). The termites used in these studies were primarily in hoop pine, which has relatively low density (~530 kg/m^3). It is unclear whether they can attack denser timbers, but the results indicate that the device has a limited ability to detect infestations in denser timbers. While this would be a limitation in larger timbers and poles (Brodie et al., 2021), it poses less of an issue in building components.

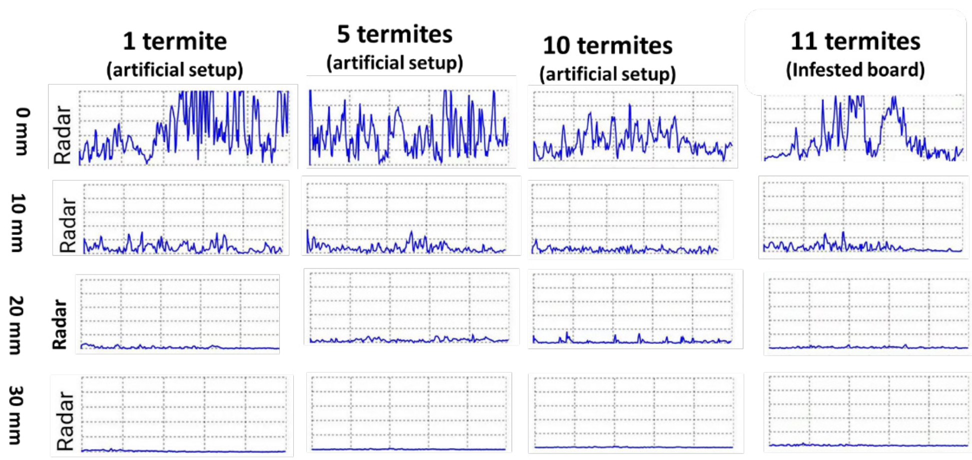

Fig 2. Examples of Termatrac™ output as affected by the number of termites and their depth in the wood. Lines above the baseline denote termite movement (i.e. detection). Note the decline in signal with increasing depth with a given number of termites but no signal change with increasing termite numbers.

Subsequent trials using 38 mm thick radiata pine samples with densities ranging from 392 to 781 kg/m^3 showed that the device could only detect termites in samples with densities less than or equal to 512 kg/m^3 (Table 4). The maximum depth of detection in *P. radiata* was 45 mm when the density of tested samples was 392 kg/m^3. Increasing wood density was negatively correlated with detection illustrating the potential detection limitations associated with wood density (Figure 3).

Grain orientation of the radiata pine block markedly affected the detection ability of the device. The device failed to detect termites through 35 mm thick radiata pine blocks when the test was performed perpendicular to the growth rings (i.e. radially) but successfully detected the same termites when the microwave beam was transmitted tangentially. These results indicate that care needs to be taken when using the device on timbers with an abrupt earlywood to latewood transition.

Table 3. Maximum Termatrac™ detection depth in wood species with different densities.

Sr. No.	Density (kg/m^3)	Maximum detection depth (mm)	Wood material
1	432	43.6	Southern Pine (*Pinus*spp)
2	511	35	Shining gum (*Eucalyptus obliqua*)
3	548	33	QLD maple (*Flindersia breyleyana*)
4	600	30	Tasmanian Oak (*E. obliqua*)
5	660	29	Shining gum (*E. nitens*)
6	776	20	Tasmanian Oak (*E. obliqua*)

Table 4. Ability of the Termatrac™ to detect *C. brevis* through 38 mm thick *Pinus radiata* samples of increasing density.

Density (Kg/m^3)	Detection
392	Yes
453	Yes
512	Yes
560	No
596	No
641	No
781	No

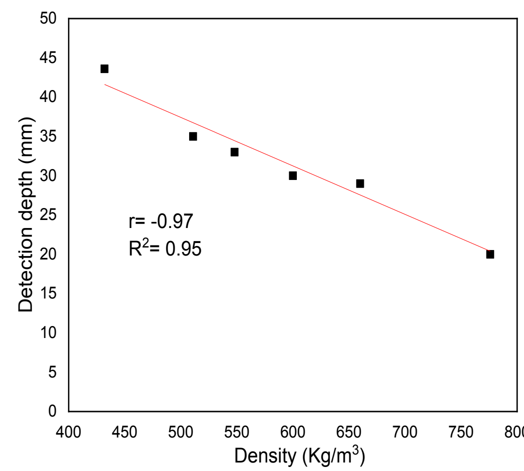

Fig 3. Relationship between maximum detection depth and density of different wood species.

It would also be helpful to ensure proper training of inspectors since interpretations can vary among operators (Zahid et al., 2012). Further studies are recommended on timbers with other anatomical features that might affect the signal.

Discussion

Effective control of drywood termites in structures is highly dependent on accurate inspection results since these species nest exclusively in wood and can be in any part of a structure (Lewis & Lemaster, 1991). Currently, the pest control industry relies heavily on visual signs or destructive methods to locate drywood termites (Evans, 2002).

An effective non-destructive inspection device must reliably detect infestations with a minimum of false detections that lead to unnecessary damage when applying treatments. Our test successfully detected termites whenever they were present. True positives and true negatives were the most common results found at the maximum sensitivity level. Although the highest sensitivity level improved the ability to detect termites, it also increased the probability that other factors such as exterior vibrations could affect output, creating false positives. The successful detection rates were higher than results from previous studies for subterranean and drywood termites (Duarte et al., 2014; Evans, 2002). Separate studies showed that the device also performed better in detecting drywood termites than either acoustic emission or termite dogs, although the dogs only produced a < 1% false positive response (Brooks et al., 2003; Lewis & Lemaster, 1991).

Wood thickness was also an important contributor to signal strength, while the termite number did not affect detection ability. The device detected even a single termite in artificial galleries or naturally infested boards, and termite detection declined with the increased thickness of the wood. These results are consistent with the previous studies on other drywood termite species (Taravati, 2018). Similar observations were recorded previously for a stored grain insect pest where the device output signals were not dependent on insect numbers under observation (Mankin, 2004). Single termites in our tests tended to move more compared to groups of termites that tended to aggregate. This may help explain the higher signal strength observed when using one termite. The factors affecting detection of small vs large numbers merit further study.

Detecting termites in relatively thin wood samples should be simple, but many building elements are thicker and may contain multiple layers. The manufacturer claims the device detects termites up to 40 mm from the surface. However, wood density, grain orientation, moisture content, and wood species can affect microwave propagation through the wood. Maximum detection depth in previous studies has been reported to be 35 and 50 mm in pine and western hemlock (*Tsuga heterophylla*) or Douglas-fir (*Pseudotsuga menziesii*), respectively which have densities similar to hoop pine (Lewis et al., 2009; Taravati, 2018). Wood density affected detection ability in our study and the device could only detect termites in samples with densities ≤511 kg/m^3 with similar thicknesses (38 mm). Moreover, grain orientation also affected detection ability. Similar results were also reported in previous studies (Lewis et al., 2009).

The very high rate of positive *C. brevis* detection makes this device a valuable tool for detecting this termite species in structures. However, in-house or building conditions may be quite different from controlled laboratory conditions with regard to wood thickness, wood species, paints, wall layers, wood density, moisture conditions, and external noise factors (Taravati, 2018). Further in-house or building studies are recommended to validate the laboratory results.

Conclusions

Cryptotermes brevis infestations in structures are very difficult to detect due to their cryptic nature, small colony size, and wood nesting habit. The Termatrac™ successfully detected termites in wood and appears to be useful for detecting infestations for subsequent remedial treatments.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

The first two authors conceptualized, provided resources, and developed the methodology. The third author performed the experiments and the fourth author assisted with method development and validation. All authors contributed to the analysis of the data and preparation of the manuscript.

Data Availability

The authors will provide all data upon request.

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