Borescope-Aided Inspection May Be Useful in Some Drywood Termite Detection Situations

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Abstract

Detection and delimitation, usually accomplished via visual inspection, are primary tactics used for integrated pest management of drywood termite infestations, helping to determine whether whole-structure or localized treatment will be required. Borescopes, fiber-optic devices enabling views within voids, represent alternative or supplemental inspection tools, potentially increasing accuracy and efficiency. We observed and recorded successes of seven participants, with varied levels of termite inspection experience, when asked to identify sample items evidential of drywood termite infestation or likely to be confused with such items. Identifications were made in the laboratory, where samples were protected from view by a physical division, and in a simulated field environment, where samples were placed within inaccessible wall voids, some of which contained insulation material and were therefore designated as ''external'' voids. Identification accuracy was 80.6 percent overall, highest in the laboratory and lowest in external voids in the field. Differences due to participant became evident in the field, where accuracy ranged from 35.7 to 78.6 percent. Differences in identification accuracy due to sample type were important in both the laboratory and the field. In some cases, participants were able to achieve levels of identification accuracy comparable to those previously observed with alternative inspection devices such as acoustic emission and microwave. Borescope-aided inspection may be useful (but should not be solely relied upon) in cases where structural/environmental impediments are few, inspectors are experienced and physically able, and infestations are large enough to produce evidential items such as dead alate termites and accumulations of termite pellets.

Various species of drywood termites are known to attack sound structural timbers and woodwork of buildings throughout tropical, subtropical, and some temperate regions of the world (Potter 2011). In California, *Incisitermes minor* (Hagen), the western drywood termite, is the most economically important of the five species of endemic and introduced drywood termite species [*I. arizonensis* (Snyder), *I. banksi* (Snyder), *I. fruticavus* Rust, *I. minor* (Hagen), and *I. snyderi* (Light); Su and Scheffrahn 1990]. In some regions of California, almost half of wooden structures have historically been infested (Ebeling and Wagner 1964, Brier et al. 1988), and it is estimated that up to one-fifth of the annual costs (>$300 million) of termite management and damage in California can be attributed to this species (Lewis et al. 2004). Unlike most subterranean termites, drywood species do not require any contact with the soil to survive (Bennett et al. 1997). Therefore, preventive soil treatments with insecticides, mainstays in subterranean termite management, are of no benefit (Potter 2011).

Preventive measures, such as screening, caulking, painting, and chemical treatment of wood surfaces, may help to exclude drywood termites, but they are expensive and difficult to put into use and to maintain (Potter 2011). Additionally, once drywood termites have been detected, management options depend, in part, upon the extent of infestation: whole-structure infestations usually require

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expensive and complicated application of the fumigant sulfuryl fluoride or logistically difficult heat treatment (Lewis and Haverty 1996), while localized infestations may be managed via various chemical and nonchemical ''spot treatments'' (Lewis et al. 2009).

Detection and delimitation of drywood termite infestations are primary tactics used within structural integrated pest management (IPM) programs (Lewis 2003). Most commonly, this is accomplished through visual inspections of the structure, using a flashlight and a metal probe (Scheffrahn et al. 1993), to search for signs of infestation, such as the presence of characteristic fecal pellets, which are small (1 mm long), hard, and oval, with rounded ends and six indentations along the sides (Potter 2011). The accuracy and precision of such visual inspections are unknown and will vary depending on the experience of the inspector and the structural variations of buildings. Josof (1996) reported that faulty inspections were a primary reason for customer dissatisfaction and treatment failures in the structural pest management industry, and Lewis et al. (1997) reiterated this assessment in reference to drywood termite inspection failures in California.

Alternative inspection methods for drywood termites, including acoustic emission detection devices (Fujii et al. 1990, Lewis et al. 2004), microwave technology (Evans 2002), canine detection (Brooks et al. 2003), electronic odor detection (Lewis et al. 1997), thermal imaging (infrared), and X-ray devices (Potter 2011), have been proposed and demonstrated to have varying degrees of success (Zahid et al. 2012). A possibility for expansion of visual inspection exists through use of borescopes, which allow users to view termites, termite fecal pellets, and/or associated damage within wall voids. These devices were originally developed for inspection of gun barrels (i.e., bores; Careaga and Careaga 1920) but have been adapted for use in tubular aircraft structures (Lyon 1926), tanks and barrels (Baer 1933), and engineering drums and pipes (Crampton 1948). Borescopes function by channeling visible light through a flexible, hollow tube, inserted into otherwise inaccessible hollow spaces, such as via holes drilled in wood members. Such technology has only recently been in use within the pest management industry (first reported by Potter 1997); a rigorous and scientific performance evaluation has yet to be reported.

If borescopes can be used to accurately identify and delimit infestations, they will facilitate IPM efforts to be localized, reducing the economic and environmental costs associated with insecticide applications, while maintaining an acceptable level of control. The purpose of our investigation was to explore, under laboratory and simulated field conditions, the accuracy of a commercially available borescope to distinguish between signs of drywood termite infestation and other, visually similar samples within areas inaccessible to traditional visual inspection, over a range of different users and different conditions within wall voids.

Materials and Methods

Laboratory measures of detection accuracy

Accuracy of drywood termite detection using a fiber-optic borescope (ProVision, CML Innovative Tech., Inc., Hackensack, New Jersey) was first measured in the laboratory. Seven individuals, whose experience with termite inspections varied from none to extensive (decades of professional experience), participated in this investigation. Participants were asked to identify unknown samples that were hidden from view by a cardboard divider while using the borescope device. Samples included commonly encountered materials and dead insects indicative of infestation: drywood termite fecal pellets, either 0.5 or 2.0 g, arranged in a pile; debris (mixture of mineral soil, arthropod parts, cobwebs, and wood shavings) containing both drywood termite workers and fecal pellets; drywood termite workers, soldiers, or alates; subterranean termite workers or alates; workers of two species of carpenter ants, *Camponotus* spp.; workers of the Argentine ant, *Linepithema humile* (Mayr); and drywood termite workers mixed with subterranean termite workers. Also included were materials that could be mistaken for drywood termite fecal pellets: grains of brown rice, celery seeds, fennel seeds, sesame seeds, raw sugar, wood shavings, and sand mixed with vermiculite. Another sample type was an empty plastic dish, bringing the total number of different sample types to 20.

All samples were presented in a 5.5-cm-diameter plastic dish and could only be observed via use of the borescope. The borescope was affixed to a wooden board (Fig. 1) that could be freely moved around by the participant to improve visibility and comfort. All participants completed a 42-item identification quiz that required them to assign unknown samples to one of the 20 sample types listed above. Total time required to complete this quiz (trial duration) was recorded for each participant. In order to document the inherent optical capabilities of the borescope device, standard digital images were taken of all sample materials through the eyepiece (Fig. 2) from one of two viewing distances, 2 or 4 cm.

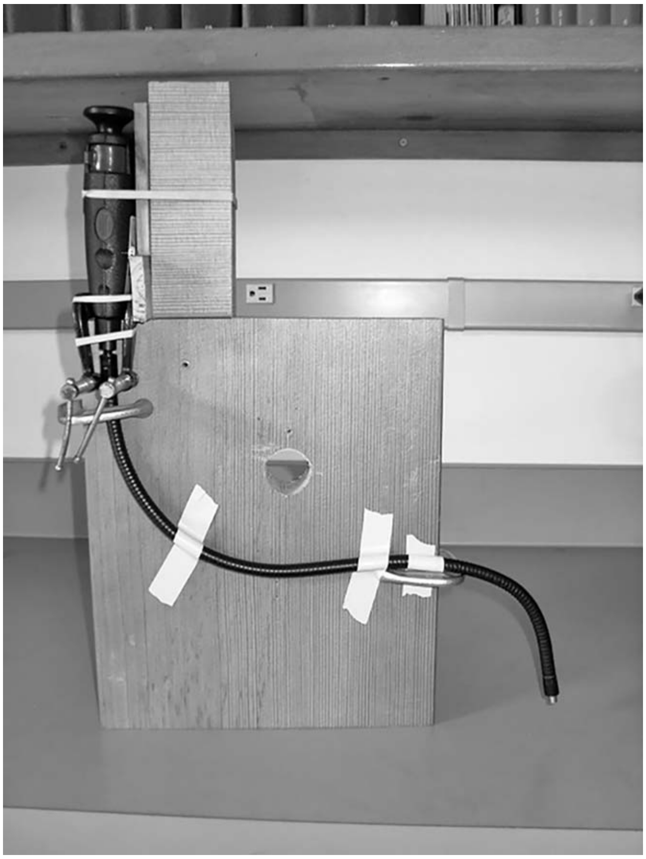

Figure 1.—Fiber-optic borescope device and setup used for laboratory measurement of identification accuracy for selected items.

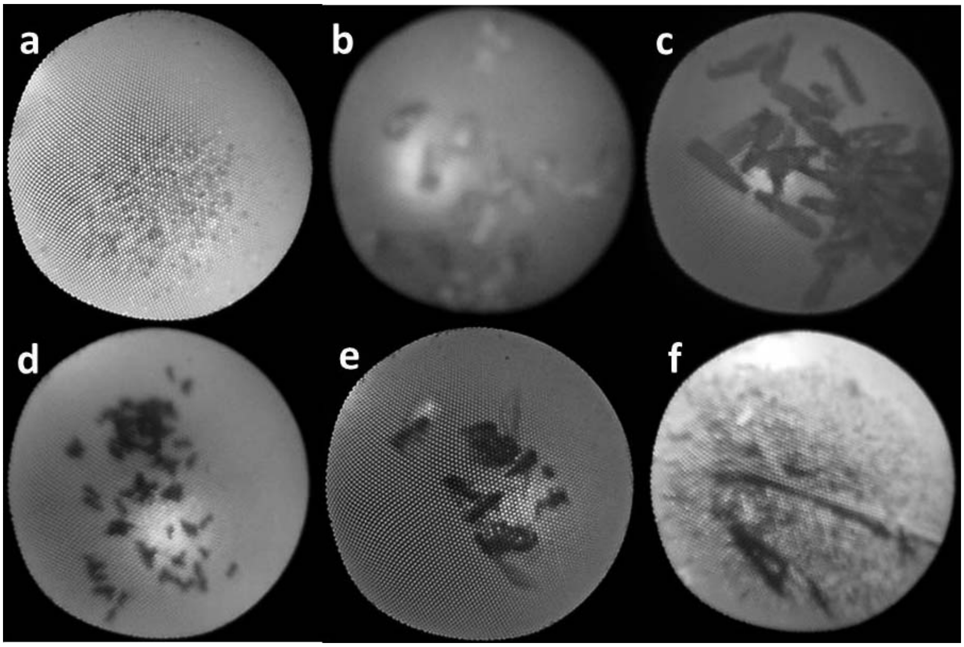

Figure 2.—Some materials used for laboratory assessment of identification accuracy: (a) drywood termite pellets, (b) dead drywood termite workers, (c) dead drywood termite alates, (d) dead Argentine ants, (e) dead carpenter ants, and (f) organic debris. Images are as seen through the fiber-optic borescope device (ProVision, CML Innovative Tech., Inc., Hackensack, New Jersey).

Simulated field measures of detection accuracy

For the simulated field portion of this study, the accuracy of detection was evaluated in the Villa Termiti, an experimental structure built at the University of California, Berkeley's Richmond Field Station in 1993 for the purpose of evaluation of nonchemical termite management methods. The building has a symmetrical, square footprint (6.1 m per side; 37.2 m^2; 154 m^3) and is composed of an attic, a drywall area, and a subarea (Lewis and Haverty 1996). The structure contains wood members of varying lumber species and dimensional sizes, and exterior wall coverings of various materials, representing multiple building situations seen in the field in California. All wall cavity spaces (voids) have fire blocking wood members.

For field testing, 28 of these interior wall voids were randomly assigned to represent either an interior wall (without insulation) or an exterior wall (with insulation added: Ecotouch R-19, 38.1 by 236 cm; Owens Corning Insulation Systems, Toledo, Ohio) situation. These "interior" and "exterior" wall voids were all then assigned to receive one of seven sample types: debris (mineral soil, arthropod parts, cobwebs, and wood shavings), debris containing drywood termite fecal pellets, 0.5 g of pellets dropped from 1.5 cm, 0.5 g of pellets dropped from 1 m, 2 g of pellets dropped from 1.5 cm, 2 g of pellets dropped from 1 m, or nothing. Each sample type was represented twice within both exterior and interior void groups. The same seven participants from the laboratory accuracy trial were provided with a fiber-optic borescope device (same manufacturer and model as noted above) and a metal probe and were asked to inspect each wall void, identify the sample type within, and to record their answers. Holes were drilled at the center of each void 5.1 cm above the mudsill plate to facilitate insertion of the distal end of the scope. Stud bays were closed in order to block the participant's view with a combination of cardboard and plyboard or drywall (Fig. 3). Total time required to inspect all 28 voids (trial duration) was recorded for each participant.

Statistical analysis

Responses of the participants to both the laboratory and simulated field trials were scored as either incorrect identification or correct identification. Detection accuracy was then determined for each participant as a percentage of the total number of sample presentations. The probabilities that outcomes were affected by participant, sample type, or location (laboratory, interior void, "exterior" void) were determined via likelihood ratio contingency analysis. In order to tease out sources of variation within the data set, mixed model analysis was performed, considering participant, sample type, and location as random variables. Mean handling times (seconds per trial item) were determined for each participant by dividing the total duration of a laboratory or field trial by the number of sample items within that trial. The correlation of handling time and detection accuracy was described using linear regression. All statistical analysis was performed using the statistical software package JMP (SAS Institute 2007).

Results and Discussion

When considering data from all participants, sample types, and locations, mean detection accuracy was 80.6 percent (Table 1). Overall, there were no statistically significant differences among participants in terms of accuracy ($\chi^2 = 8.60$, df = 6, $P = 0.197$), although overall accuracy among participants ranged from 72.9 to 87.1 percent. Mean handling time for the laboratory quiz and field inspection combined ranged from 34.3 seconds per item to 120 seconds per item. There was a negative relationship observed ($R^2 = 0.33$, $F_{1,12} = 5.85$, $P = 0.03$) between handling time and detection accuracy, with

Figure 3.—View of bore holes used for borescope insertion into experimental wall voids used for the simulated field assessment of identification accuracy. Each void was designated either as an internal void or an external void containing insulation materials and held one of seven sample types within.

accuracy generally decreasing as more time was spent per item.

Mean accuracy was highest in the laboratory trials (mean of 91.8% with a range of 85.7% to 97.6%), with no significant effects due to participant ($\chi^2 = 8.80$, df = 6, $P = 0.185$). Mean handling time was 46.9 seconds per item, with a range of 28.6 to 85.7 seconds per item. In the laboratory, sample type had a highly significant effect on mean accuracy ($\chi^2 = 147.3$, df = 25, $P < 0.0001$), with an extremely wide range in accuracy from 38.1 to 100 percent (Table 1). Identification accuracy was 100 percent for drywood termite soldiers, subterranean termite alates, subterranean termite workers, Argentine ants, the mixture of drywood and subterranean workers, brown rice grains, fennel seeds, raw sugar, the sand and vermiculite mixture, sesame seeds, wood shavings, and the empty plastic dishes. Identification accuracy was lowest for celery seeds (38.1%).

Statistically significant differences in participant accuracy became evident when considering simulated field data ($\chi^2 = 14.4$, df = 6, $P = 0.026$), where mean accuracy was 63.6 percent, ranging from 35.7 to 78.6 percent (Fig. 4), and mean handling time was 91.8 seconds per item, ranging from 42.9 to 171.4 seconds per item. These lower levels of participant accuracy and uniformity were mainly influenced by participant performance in exterior wall voids that contained insulation material (mean of 59.2% with a range of 21.4% to 85.7%; significant differences due to participant: $\chi^2 = 14.7$, df = 6, $P = 0.023$). When only considering interior wall voids, which did not contain insulation material, there were no statistically significant differences attributable to participants ($\chi^2 = 4.83$, df = 6, $P = 0.565$). In the simulated field portion of the study, the effect of location (interior vs. exterior wall) was highly significant ($\chi^2 = 61.2$, df = 2, $P < 0.0001$) with an average of 68.0 and 59.2 percent of the identifications accurate in interior or exterior walls, respectively. Accuracy was 79 percent for empty wall voids in the field environment (84.6% for interior walls and 71.3% for exterior walls). Debris containing pellets was accurately identified only 42.9 percent of the time, and 0.5 g of pellets, dropped either from 1.5 cm or 1 m above the viewing area, were accurately identified an average of 46.4 percent of the time (Table 1).

Mixed model analysis revealed that most data set variation was due to sample type when considering both laboratory data (28.0%) and simulated field data (11.0%). Variation due to participant was much higher in the field simulation (5.42%) than in the laboratory (1.71%).

In our study, seven participants with widely varying levels of experience were able to identify evidence of drywood termites and items potentially confused for evidence of drywood termites using a borescope, although accuracy varied according to sample type, environment, and participant and was nearly always less than 100 percent. Overall, the lack of statistically significant differences among participants, largely attributed to laboratory results, suggests that even inexperienced users can be trained to use a borescope relatively quickly and easily, limited only by physical hindrances such as flexibility and eyesight. Observed accuracy was comparable to that observed for other detection methods: visual searches (Lewis 1997, 70%), use of termite-sniffing dogs (Brooks et al. 2003, 89%; Zahid et al. 2012, 100%), acoustic emission devices (Lewis et al. 2010, 100%; Zahid et al. 2012, 79%), and microwave devices (Evans 2002, 90%; Zahid et al. 2012, 70%). Additionally, borescopes are relatively inexpensive as compared to alternatives such as acoustic emission and

Table 1.—Accuracy of identification and detection for 26 unseen sample types by seven participants using a borescope in the laboratory and in simulated field trials.

Location and sample type	No. of presentations	Correctly identified	
		No.	% accuracy
Laboratory			
Overall	294	270	91.84
0.5 g of drywood termite fecal pellets	21	20	95.24
2.0 g of drywood termite fecal pellets	21	20	95.24
Debris containing drywood termite workers, pellets	14	11	78.57
Drywood termite workers	7	6	85.71
Drywood termite soldiers	7	7	100.0
Drywood termite alates	7	6	85.71
Subterranean termite workers	7	7	100.0
Subterranean termite alates	7	7	100.0
Black carpenter ant workers	14	13	92.86
Red carpenter ant workers	14	11	78.57
Argentine ant workers	14	14	100.0
Drywood termite and subterranean termite workers	7	7	100.0
Grains of brown rice	14	14	100.0
Celery seeds	21	8	38.10
Fennel seeds	21	21	100.0
Sesame seeds	14	14	100.0
Raw sugar	14	14	100.0
Wood shavings	14	14	100.0
Sand mixed with vermiculite	14	14	100.0
Empty (nothing)	42	42	100.0
Simulated field trial (interior wall voids)			
Overall	97	66	68.04
Debris	14	11	78.57
Debris containing drywood termite pellets	14	6	42.86
0.5 g of drywood termite pellets dropped from 1.5 cm	14	6	42.86
0.5 g of drywood termite pellets dropped from 1.0 m	14	10	71.43
2.0 g of drywood termite pellets dropped from 1.5 cm	14	8	57.14
2.0 g of drywood termite pellets dropped from 1.0 m	14	14	100.0
Empty (nothing)	13	11	84.62
Simulated field trial (exterior wall voids containing insulation material)			
Overall	98	58	59.18
Debris	14	14	100.0
Debris containing drywood termite pellets	14	6	42.86
0.5 g of drywood termite pellets dropped from 1.5 cm	14	7	50.00
0.5 g of drywood termite pellets dropped from 1.0 m	14	3	21.43
2.0 g of drywood termite pellets dropped from 1.5 cm	14	12	85.71
2.0 g of drywood termite pellets dropped from 1.0 m	14	6	42.86
Empty (nothing)	14	10	71.43
All locations combined	489	394	80.57

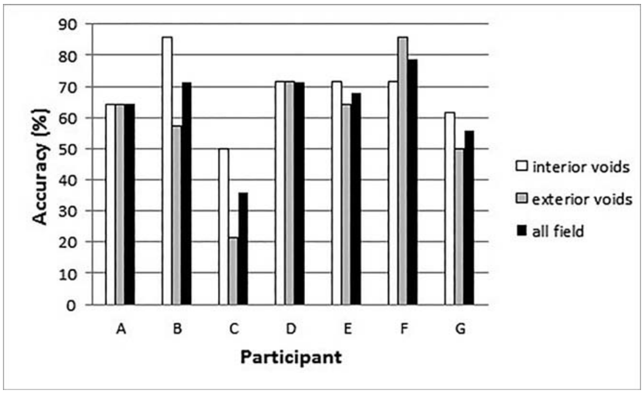

Figure 4.—Overall identification accuracy for each of seven participants when using a borescope during field investigations for evidence of drywood termites. Samples included debris (mineral soil, arthropod parts, cobwebs, and wood shavings), debris with fecal pellets, 0.5 g of pellets (dropped from either 1.5 cm or 1 m), 2 g of fecal pellets (dropped from either 1.5 cm or 1 m), and nothing (empty wall voids). Significant differences in accuracy due to participant were observed when considering all field inspections ($\chi^2 = 14.4$, df = 6, P = 0.026) and when considering only exterior wall voids (those containing insulation materials; $\chi^2 = 14.7$, df = 6, P = 0.023).

microwave devices, and borescope-aided inspection may require less effort and less cost than X-ray and canine detection. These alternative methods, however, are typically nondestructive in that they do not require access holes to be drilled for successful operation.

The primary evidential items sought in wall voids by inspectors are bodies of alate termites from previous swarms, fecal pellets, and potentially the ''kick-out'' holes used by termites to cast out fecal pellets from the gallery. Dead termites and large amounts of pellets may be readily visible when considering large, established colonies, but small and/or incipient colonies may sometimes only be detected by the presence of less-visible kick-out holes, which were not included in this investigation. Therefore, the primary uses of borescopes may be in detecting active infestations of well-established colonies and in evaluating the success of treatments. New infestations by one or more incipient colonies are difficult to detect via visual inspection, and may require up to 5 years to produce definitive evidence (Smith 1995, Potter 2011). Borescope-aided inspection could help to identify these incipient infestations at an early stage, before management becomes more difficult and expensive.

Some structural and environmental attributes of wall voids are expected to limit the utility of borescope inspections in the field, as seen in our study where accuracy fell below 50 percent for several participants when insulation materials were present. Likewise, results will be best within wall voids that are exposed or easily accessible. Inaccessible areas of homes can be as high as 45 percent, when you include roofs and subareas (Lewis et al. 1997). Furthermore, the use of a borescope can be impossible or impractical even within some accessible areas where one might find drywood termite infestations, such as within beams, fascia boards, and through existing siding. The best and most practical uses of borescopes may be along the bottom surface of wall voids where materials accumulate on lower, horizontal surfaces. Finally, despite the potential accuracy and utility of borescope-aided inspections, proper insertion of the probe requires drilling sizable access holes in walls that will usually need to be patched and refinished. Postinspection repairs will further limit borescope-aided inspections behind walls with coverings such as paneling or wallpaper.

Use of a borescope may increase inspection time. The average time for our participants to examine 28 wall voids was 42.9 minutes, or 91.8 seconds per void, not including time spent to drill access holes. Individual abilities and proficiencies of inspectors (i.e., to squat down or stoop in a constrained space to position the tubular borescope probe) are expected to dramatically influence inspection time.

Conclusions

There is a need for detection devices and techniques that are robustly accurate and adaptable to differences in termite species, climatic conditions, and building types encountered (Lewis 2003, Lewis et al. 2009). Future borescope improvements may include better optical lenses and abilities to capture and save digital images for use in later viewing, processing, record-keeping, and client communication. Even though there are limits to borescope-aided inspection for drywood termites, it represents another choice in the array of detection methods and is less expensive than many other devices designed for locating and delimiting infestations. No one detection tool works best for every given field scenario; rather, inspectors should use a combination of devices and techniques to help detect drywood termite infestations, especially within inaccessible areas (Thorne 1993; Lewis 1997, 2003; Lewis et al. 2010) and for finding small or incipient infestations (Smith 1995, Lewis et al. 2010).

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