Surface and subsurface sensor performance in acoustically detecting the western drywood termite in naturally infested boards

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Abstract

Field-collected boards showing visual signs of damage by the western drywood termite, *Incisitermes minor*, were searched with a portable acoustic emission (AE) device. Depending on cross-sectional size, boards were either searched with a flat sensor that was hot-melt-glued to the wood surface or a subsurface sensor that was threaded 20 mm into the wood. The number of AE-monitored locations varied with length; however, at least three 1-minute AE recordings were collected for each board. In total, 108 boards were treated to control termites with 1 of 5 different treatment methods. These boards were AE monitored at 3 days, and at 1, 2, and 4 weeks post-treatment. Thirty-two boards were AE monitored but not treated. Boards were later dissected and live and dead termites were counted. Of the boards searched by AE prior to treatment, 94 percent (102 of 108) contained termites upon dissection. The volume, number of AE monitoring sites, pretreatment AE counts, and number of termites found in boards upon dissection were not significantly different among the five different treatments. Post-treatment AE counts corresponded well with boards containing survivors. Regarding sensor performance, there were no significant differences in AE counts between threaded subsurface and flat surface-attached sensors. Regression analyses revealed a statistically significant correlation between increasing AE counts and termite numbers for boards, although the association was low. Untreated boards that were determined by AE to contain live termites (test for false positives) upon dissection were successfully detected 100 percent (13 total) of the time. Untreated boards, determined by AE to not contain live termites (test for false negatives), were successfully detected 78.9 percent of the time (15 of 19). Comparisons of means suggest AE counts of ≥ 4 per minute can detect survivors from failed treatments. Results of this study support the ability and reliability of the AE device to detect live termite infestations in naturally infested boards.

Drywood termites attack wood structures and are serious pests on most continents (Su and Scheffrahn 2000). Around the world, the family Kalotermitidae contains 21 genera and several hundred species of economic importance (Pearce 1997, Su and Scheffrahn 2000). In North America, there are 14 species of drywood termites of which 5 have economic importance (Su and Scheffrahn 1990). Each year the damage caused by drywood termites is considerable and represents > 20 percent of the several billion dollars spent on termite detection, control, and repairs of damage in the United States (Lewis and Haverty 1996; Su and Scheffrahn 1990, 2000).

Before drywood termites can be controlled, they must first be detected. The primary inspection tools are visual

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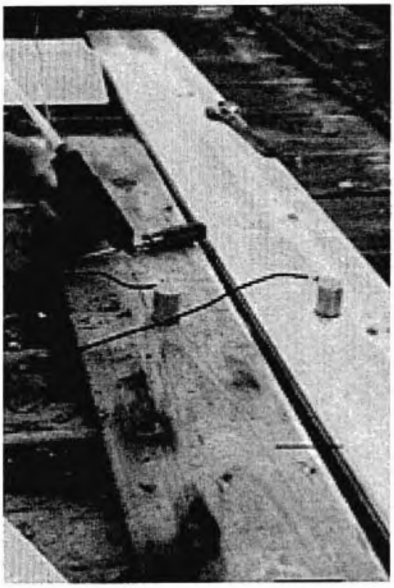

Figure 1a. — Surface-mounted sensor for AE termite detection device. Boards in the background are 3- by 20-cm (1- by 8-in.) ponderosa pine.

Figure 1b. — Threaded subsurface sensor for AE termite detection. In foreground is a 10- by 10-cm (4- by 4-in.) redwood pier post.

searches in conjunction with a metal probe and flashlight (Scheffrahn et al. 1993). Missed inspections have been reported (Lewis et al. 1997). The following other detection methods have been tested: sound (Pence et al. 1954); dog (Lewis et al. 1997, Brooks et al. 2003); electronic odor detector (Lewis et al. 1997); and acoustic emission (AE) (Fujii et al. 1990, Noguchi et al. 1991, Scheffrahn et al. 1993, Lemaster et al. 1997).

AE is defined as the elastic energy that is spontaneously released by materials undergoing deformation (Lemaster et al. 1997). This energy transfers through the material as a stress or strain wave and is typically detected using a piezoelectric transducer, which converts the surface displacement to an electrical signal (Lemaster et al. 1997). This wave energy is released in the ultrasonic range (> 20 kHz). AE was originally developed for detecting stress failures in machinery (Dornfeld and Kannatey-Asibu 1980). However, AE has also proven reliable in detecting termites (Fujii et al. 1990; Noguchi et al. 1991; Scheffrahn et al. 1993, 1997; Lemaster et al. 1997; Lewis 1997). AE devices reportedly detect termites as a result of their pulling of wood fibers during feeding (Fugii et al. 1995, Matsuoka et al. 1996, Scheffrahn et al. 1993).

Sensor attachment to wood is critical when using AE for detecting termites. The earliest reported termite sound detection device used a needle-like sensor pushed into wood (Pence et al. 1954). Others report only on surface mounted sensors (Fujii et al. 1990; Noguchi et al. 1991; Scheffrahn et al. 1993, 1997; Lemaster et al. 1997). We know of no papers that compare the relative merits of surface versus subsurface sensors for termite detection. Papers that report results from field-collected boards are also infrequent (Scheffrahn et al. 1993, 1997; Lewis and Haverty 1996, 2001). This is the first report that compares results for surface and subsurface sensors and post-treatment AE evaluations of naturally infested boards that include board dissection.

Materials and methods

Collection of boards

We collected 288 boards with visual signs of damage by the western drywood termite, *Incisitermes minor* (Hagen), from homes, fencing, and decks undergoing remodeling. Boards were collected from 12 cities in California: Concord, Fremont, Fresno, Los Angeles, Novato, Oakland, Riverside, Sacramento, San Jose, San Luis Obispo, San Rafael, and Ventura. Boards varied in dimensional size (3 by 20 cm, 1 by 8 in.; 5 by 10 cm, 2 by 4 in.; 5 by 15 cm, 2 by 6 in.; 5 by 20 cm, 2 by 8 in.; 5 by 25 cm, 2 by 10 in.; 10 by 10 cm, 4 by 4 in.; and 10 by 15 cm, 4 by 6 in.) and wood species (ponderosa pine, *Pinus ponderosa* [Engelm]; redwood, *Sequoia sempervirens* [D. Don]; and Douglas-fir, *Pseudotsuga menziesii* [Mirb.] Franco).

AE device

The detection device used during the study was a Wood-Destroying Insect Detector® (DowAgroSciences, Indianapolis, Indiana). The dual sensor configuration made it possible to record data from multiple locations within a board or from two separate boards (**Fig. 1a**). Paired readings were compared: one from a field-collected board and one from a similar dimensional size and species of kiln-dried board that did not contain termites. The rationale for using dual sensors and kiln-dried boards of similar dimension was that we hoped to better account for background noise and increase the probability of live termite detection. The feature on the device that allows paired comparison is called "Noise Reject." Specifics on the components and electronic capability of the AE device have been reported previously (Scheffrahn et al. 1993).

AE searching of boards

Boards 3 by 20 cm (1 by 8 in.) or less in cross section were searched with a flat sensor (2.8 cm diameter, 4 cm high, 110 g) that was hot-melt-glued to the wood surface (**Fig. 1a**). Simultaneously, a second sensor was attached to a kiln-dried board of similar dimension and wood species. Each sensor was positioned in the center of the board along the long axis and spaced at 91-cm increments (Lewis et al. 1991). Three 1-minute recordings were taken from the center location for each monitored 91-cm section of wood for both boards along their entire length. For boards > 3 by 20 cm (> 1 by 8 in.) in cross section, a subsurface sensor (1.0 cm diameter, 9.3 cm length, 121.7 g) was threaded 20 mm into the wood surface (**Fig. 1b**). For pier post boards (10 by 10 cm, 4 by 4 in.) with cross grain distance > 8 cm, two sets of holes were drilled into wood oriented 180 degrees from each other. Scheffrahn et al. (1993) reported that the maximum distance AE can detect termite feeding across wood grain (tangential orientation) was 8 cm. Three 1-minute record-

Table 1.— Number of live and dead I. minor, by caste, and associated AE counts by wood species, dimension, sensor type, and monitoring sites in untreated, field-collected boards.

Wood species	Board dimension, *lwh* (cm)	Sensor type[a]	No. of AE sites	Total workers (live/dead)	Total soldiers (live/dead)	Total alates (live/dead)	AE counts max/total[b]
Redwood[c]	115.6 by 15.2 by 5.1	T	2	89/0	0/0	0/0	92/198
Redwood[c]	86.4 by 15.2 by 5.1	T	2	2,923/58	19/0	1/0	105/461
Redwood[c]	181.0 by 10.2 by 10.2	T	2	587/0	26/0	150/0	69/327
Pine[c]	127.0 by 20.3 by 2.54	S	2	43/0	6/0	0/0	20/51
Redwood[c]	246.4 by 10.2 by 5.1	T	3	7/0	0/0	0/0	26/75
Redwood[c]	246.4 by 10.2 by 5.1	T	3	123/0	0/0	0/0	93/218
Redwood[c]	53.3 by 10.2 by 10.2	T	2	99/4	0/0	0/0	24/80
Pine[c]	144.8 by 20.3 by 2.5	S	2	641/6	0/0	0/2	5/11
Pine[c]	170.2 by 20.3 by 2.5	S	2	16/8	1/0	0/0	10/22
Pine[c]	156.2 by 20.3 by 2.5	S	2	28/3	0/0	0/2	6/14
Pine[c]	232.4 by 20.3 by 2.5	S	3	17/0	0/0	0/0	13/38
Pine[c]	215.9 by 20.3 by 2.5	S	3	136/1	1/0	0/0	11/53
Redwood[c]	115.6 by 10.2 by 10.2	T	4	2/1	0/1	0/0	5/32
Pine[d]	177.8 by 20.3 by 2.5	S	2	18/8	0/0	0/0	2/5
Pine[d]	223.5 by 20.3 by 2.5	S	3	1/168	0/5	0/1	1/1
Redwood[d]	233.7 by 10.2 by 6.4	T	3	0/0	0/0	0/0	3/4
Pine[d]	48.3 by 20.3 by 2.5	S	1	0/0	0/0	0/0	0/0
Pine[d]	146.1 by 20.3 by 2.5	S	1	0/0	0/0	0/0	0/0
Pine[d]	70.0 by 20.3 by 2.5	S	1	0/0	0/0	0/0	0/0
Pine	165.1 by 20.3 by 2.5	S	2	0/1	0/0	0/0	1/1
Redwood[d]	87.6 by 15.2 by 5.1	T	4	0/3	0/0	0/0	1/3
Redwood[d]	87.0 by 15.2 by 5.1	T	2	0/1	0/0	0/0	3/4
Redwood[d]	86.4 by 15.2 by 5.1	T	2	0/0	0/0	0/0	1/2
Redwood[d]	157.5 by 15.2 by 5.1	T	2	0/4	0/0	0/0	2/4
Redwood[d]	164.5 by 15.2 by 5.1	T	2	0/2	0/0	0/0	1/1
Redwood[d]	95.3 by 10.2 by 10.2	T	2	0/1	0/0	0/0	4/12
Redwood[d]	81.3 by 10.2 by 10.2	T	2	167/0	2/0	0/0	3/4
Redwood[d]	106.7 by 10.2 by 5.1	T	2	0/0	0/0	0/0	2/2
Pine[d]	153.7 by 20.3 by 2.5	S	2	72/8	0/0	0/0	4/17
Pine[d]	185.4 by 20.3 by 2.5	S	2	0/2	0/0	0/0	2/2
Pine[d]	165.1 by 20.3 by 2.5	S	2	0/53	0/3	0/5	2/6
Pine[d]	261.3 by 20.3 by 2.5	S	4	0/0	0/0	0/0	2/3

[a] All untreated boards revealed visual signs of damage by drywood termites. T = threaded subsurface sensor; S = surface-mounted sensor.

[b] MAX is largest AE count among three 1-minute replicates. Total AE count is summed over three 1-minute recordings.

[c] Boards determined by AE to contain live drywood termites (false negative test).

[d] Boards determined by AE not to contain live drywood termites (false positive test).

ings were collected from a subsurface sensor for each 91-cm section of wood along the entire board length. In total, 140 boards were searched with the AE device and included in the study.

Thirty-two boards were searched with the AE device but not treated. Depending on the cross-sectional size, a surface or subsurface sensor was used. As previously described, three 1-minute readings were taken for each 91-cm increment of board length. Since these boards were not treated, only one reading date was recorded; there were no post-treatment readings. All boards were later dissected and the live and dead termites were counted.

There were 108 additional boards searched by the AE device and later treated to control termites with 1 of 5 different methods: fumigation (sulfuryl fluoride or methyl bromide, at least 22 hours of exposure per label instructions and dosages); excessive heat (temperature for monitored boards exceeding 51°C for at least 1 hr.); liquid nitrogen (applied into wall voids using each of the following dosages: 30 min. @ 1.2 kg/min., 15 min. @ 0.9 kg/min., or 7 min. @ 0.9 kg/min.); microwaves (700 W for a 311-cm^2 spot treated for 8 min.); and electrocution (90,000 V for 7 to 27 min. per treated spot) (Lewis and Haverty 1996, 2001). The criterion used for selecting most of the naturally infested boards for the study was AE readings 3 to 11 counts per minute in at least 1 monitored position within an infested board (Scheffrahn et al. 1993). This minimum AE activity criterion was determined using artificially infested boards containing 20 pseudergates of *I. snyderi* (Light), a drywood termite in Florida similar in appearance and biology to *I. minor* that occurs in California.

After each treatment, all naturally infested boards were removed from the

Table 2. Number of boards tested, board volume, total termites, number of live and dead I. minor, number of AE sites, pretreatment AE counts and post-treatment AE counts (3 days, 1 wk., 2 wk., and 4 wk.) for boards treated with five different control methods and pretreatment AE counts for untreated field-collected boards.[a]

Treatment[b]	No. of boards tested	Board volume Mean ± SEM	Total termites Mean ± SEM	Live termites Mean ± SEM	Dead termite Mean ± SEM	AE sites Mean ± SEM	Pretreatment AE counts Mean ± SEM	3 days post-treatment AE counts Mean ± SEM	1 wk. post-treatment AE counts Mean ± SEM	2 wk. post-treatment AE counts Mean ± SEM	4 wk. post-treatment AE counts Mean ± SEM
		(cm^3)									
Electrocution	18	9351.5 ± 898.1 A	532.1 ± 148.5 A	46.6 ± 19.1 A	485.6 ± 141.6 A	2.3 ± 0.2 A	38.9 ± 9.0 A	3.8 ± 2.2 A	4.1 ± 1.9 A	4.6 ± 1.9 A	2.4 ± 1.2 A
Fumigation	36	9610.1 ± 664.8 A	219.6 ± 53.3 A	0.9 ± 0.8 A	218.7 ± 53.0 A	2.4 ± 0.2 A	23.1 ± 4.6 A	0 B	0.1 ± 0.3 B	0.03 ± 0.2 B	0.07 ± 0.1 A
Heat	18	11036.7 ± 795.0 A	356.3 ± 63.6 A	0 A	356.3 ± 63.6 A	2.7 ± 0.2 A	27.4 ± 5.9 A	0 B	0.2 ± 0.7 B	0 B	0.1 ± 0.2 A
Liquid N_2	27	11704.0 ± 955.1 A	559.7 ± 119.9 A	76.9 ± 42.8 A	482.9 ± 104.1 A	2.7 ± 0.3 A	22.4 ± 3.8 A	0.01 ± 0.3 B	0.5 ± 0.5 B	0.9 ± 0.6 B	0.7 ± 0.7 A
Microwave	9	9067.5 ± 934.4 A	198.9 ± 76.6 A	5.3 ± 3.5 A	193.6 ± 73.6 A	2.4 ± 0.3 A	15.7 ± 4.5 A	4.0 ± 2.6 A	0.3 ± 0.5 B	2.4 ± 1.4 AB	0.9 ± 1.2 A
Untreated	32	10912.7 ± 1702.2	172.7 ± 96.2	161.7 ± 94.7	11.0 ± 5.8	2.3 ± 0.13	51.6 ± 18.6				

[a] AE counts were averaged among three 1-minute recordings per monitored location. Means followed by the same capital letter within each column and parameter are not significantly different ($p > 0.05$; *Ryan-Einot-Gabriel-Welsch multiple range test [PROC GLM* SAS Institute 1994]). Untreated boards were not included in the analysis.

[b] Treatments included electrocution (90,000 V for 7 to 27 min. per treated spot); fumigation (sulfuryl fluoride or methyl bromide, at least 22 hr. exposure per label instructions and dosages); heat (temperature for monitored boards exceeding 51°C for at least 1 hr.); liquid nitrogen (applied into wall voids using each of the following dosages: 30 min. @ 1.2 kg/min., 15 min. @ 0.9 kg/min., or 7 min. @ 0.9 kg/min.); and microwaves (700 W for a 311 cm^2 spot treated for 8 min.).

testing structure and stored in a glass greenhouse at ambient temperature. Boards were acoustically monitored at 3 days, and at 1, 2, and 4 weeks post-treatment. At 4 weeks post-treatment, the boards were cut into small lengths (approximately 10 cm) and carefully dissected. Each section of board was split with a hammer and wood chisel until it was clear there were no more termites in every gallery and chamber in the board. Live and dead termites were counted and sorted by caste (alate, soldier, and nymph/pseudergate). Only AE detection results will be reported in this paper. Mortality results have been previously reported (Lewis and Haverty 1996).

Statistical analysis

For data analysis, we assumed that pretreatment AE counts represented live termites irrespective of treatment outcome. For pre- and post-treatment searches, AE counts were adjusted by subtracting background noise levels obtained from kiln-dried boards of similar dimension and wood species prior to statistical analyses.

Summary statistics for wood species, board volume, total termites, number of live termites, number of dead termites, number of AE sites, pretreatment AE counts, and post-treatment AE counts for treated boards were derived with the MEAN procedure (PROC MEAN, SAS Institute 1994). Similar statistical procedures were used to derive AE means for kiln-dried boards of similar dimension (PROC MEAN, SAS Institute 1994). Means ± SE (standard error) for sensor type, wood species, board volume, total termites, number of live termites, number of dead termites, number of AE sites, pretreatment AE counts, and post-treatment AE counts for treated boards were analyzed for significant differences using the Ryan-Einot-Gabriel-Welsch Q multiple range test (PROC GLM, SAS Institute 1994). Regression and regression coefficient for termite number and AE counts were calculated using linear regression (PROC REG, SAS Institute 1994). Post-treatment comparisons of AE counts for boards with survivors were conducted using a t-test procedure (SAS Institute 1994).

Results and discussion

Untreated boards

Boards determined by AE to contain no live termites were correctly identified 78.9 percent of the time (15 of 19) (**Table 1**), while boards determined to be active with termites were correctly determined 100 percent of the time (13 of 13). Untreated boards were similar to treated boards in volume, number of AE sites, and pretreatment AE counts (**Table 2**). As expected, the number of live termites for untreated boards was much larger compared to the treated boards. Healthy colonies consisted primarily of pseudergate-workers (> 90%) and had a low percentage of dead individuals. Comparable studies to ours are difficult to find; however, live drywood termites (*I. snyderi*) were found in all four naturally infested logs when searched with a similar AE device and later dissected (Scheffrahn et al. 1993). Of course logs have much greater volume and numbers of termites compared to infestations found in structural lumber.

Treated boards

AE counts for treated boards can be characterized as having high values prior to treatment with considerable variance. Termite AE activity in boards was similar among boards (**Table 2**). Mean AE values ranged from 16 to 52 counts per board per monitored site, roughly a three-fold difference. Although, due to high variance among means (as much as 30%), no statistical differences were found. Mean number of termites dissected from boards also reflected a three-fold difference, and also no statistical difference. The natural variance associated with drywood termite feeding and subsequent AE production has already been reported as highly variable due to lack of knowledge of gallery structure, internal radical depth of wood, forager behavior, and forager distribution (Scheffrahn et al. 1993, 1997). However, the majority of boards for the current study, 102 of 108 (94%), contained termites. The total number of termites counted for all 108 treated boards was 40,803. Assuming 1 colony per board, the average colony size among boards that contained termites was 377.80 ± 46.13. Caste proportions appeared in the normal range and were heavily skewed towards pseudergate-workers, > 95 percent of the total.

The mean AE count for all treated boards was 21.5 ± 2.48. By comparison, kiln-dried boards of similar dimension and wood species had mean AE counts of 0.67 ± 0.14 and were significantly lower ($t = -8.38$, $df = 107$, $p < 0.0001$) compared to treated boards. Neither wood species nor sensor type had a statistically significant effect on AE counts prior to treatment ($F = 0.26$, $df = 2$, $p > 0.05$; $F = 2.95$, $df = 1$, $p > 0.05$,) even though the threaded subsurface sensor had 35 percent more AE counts compared to the flat sensor, 6.81 ± 1.32 versus 4.43 ± 0.67.

There is very little information in the literature on AE counts for drywood termite detection. Scheffrahn et al. (1993) using artificially infested boards reported AE counts of 3 to 11 per minute for 20 drywood termites (*I. snyderi*) as the minimum detection threshold for the device used in their study. Reviewing **Table 2** of this paper, all pretreatment AE values exceeded this minimum active threshold range. Except for liquid nitrogen, at least one of the post-treatment AE search dates for those treatments that had survivors fell within the minimum 3 to 11 active threshold range. Obviously, treatment application and active ingredient influence drywood termite behavior, and thus AE counts.

There was a significant regression between AE counts and termite numbers. The regression for AE counts and termite number was significant among treated boards; $F = 37.29$, $n = 108$, $p < 0.0001$. However, the strength of the association was low, $r^2 = 0.26$. Seventy-four percent of the variance was unexplained by the regression. We agree with other workers that the variance noted in AE counts may be due to termites partitioning their nest sites into zones, as well as variation in feeding behavior and other activities (e.g., brood chambers) (Scheffrahn et al. 1993). Sensor type also affected the regression. The threaded subsurface sensor displayed a statistically significant regression between termite number and AE counts ($F = 25.01$, $n = 67$, $p < 0.0001$, $r^2 = 0.28$). The flat surface mounted sensor did not display a significant regression ($F = 3.45$, $n = 41$, $p > 0.05$). Similar regression coefficient values for flat surface mounted sensors have been reported (Scheffrahn et al. 1993). However, for the current study, the regression was best for redwood boards searched with a threaded subsurface sensor ($F = 21.92$, $n = 50$, $p < 0.0001$, $r^2 = 0.31$).

Wood is a variable medium. Ring angle, moisture content, and wood species can interfere with the propagation of signals through wood (Quarles 1990), thereby reducing the association between termite number and AE counts. Movement and intermittent feeding and tearing of wood by termites can also increase variability in AE signal (Lemaster et al. 1997). Data from our study suggest subsurface sensors have a greater potential for detecting and predicting the intensity of termite numbers compared to surface sensors. Improvements are needed in smaller diameter screws that are less destructive to wood and drywall, because current surface mounted AE sensors cannot reach the wood surface behind wall coverings.

Post-treatment

AE counts in treated boards displayed a precipitous drop post-treatment (**Table 2**). Most treated boards resulted in > 75 percent reduction in AE counts irrespective of treatment. Termite survivorship in treated boards post-treatment revealed a parallel reduction in numbers, 40,800 to 2,993. There were no statistical differences in mean AE counts for boards with survivors and their corresponding kiln-dried boards of similar dimension and wood species at 3 days, 1, 2, or 4 weeks ($T = -1.57$, $df = 23$, $p > 0.05$; $T = -1.55$, $df = 23$, $p > 0.05$; $T = -1.91$, $df=23$, $p > 0.05$; and $T = -1.23$, $df = 23$, $p > 0.05$). However, comparing AE means among treatment groups, those boards with survivors were significantly different from boards without survivors (**Table 2**). Of the 108 boards treated, upon dissection, 25 contained survivors. Most of these were boards treated with electrocution, the lowest dosage of liquid nitrogen, and microwaves. Number of survivors varied from 1 to 994. Using the criterion of ≥ 4 counts per minute for one spot in boards, AE searches successfully identified 22 of 25 infested boards (88%) at least once during four post-treatment searches. Scheffrahn et al. (1993) previously reported that 20 individuals is the minimum number of drywood termites for a good likelihood (80%) of detection. For the current study, 14 of 25 boards contained ≥ 20 survivors. Twelve of 14 boards in the category (86%) were successfully detected at least once during the four post-treatment searches. From the data, it appears that drywood termite survivors behave differently when treated, irrespective of the chemical or nonchemical method used. For post-treatment evaluations, additional visits over an extended period of time may be needed to detect failed treatments. This additional time may be needed for colonies to return to normal foraging and feeding behaviors.

Conclusions

Using AE for field-collected boards can produce varying results depending on whether a drywood termite colony has been treated or not. The varying AE counts could be due to behavioral changes in termite feeding post-treatment or just a reflection of a colony's attempt to recover from a partial treatment. At lower population levels, the probability of one or more termites feeding or tearing wood is low; therefore, low AE counts or no AE counts would result. Additional studies that include AE monitoring and dissections of naturally infested boards over varying timeframes are needed.

Wood fibers breaking around the subsurface sensor is also a source of background noise that could confound results. The techniques used in this study suggest that to successfully detect drywood termite colonies of ≥ 20 individuals at least 80 percent of the time, boards may need to be left undisturbed for at least 2 to 4 weeks before statements on survivorship or complete kill can be made. This inspection routine suggests repeated visits or "control service agreements" versus a single treatment visit by a pest control operator. The appearance of pellets, live workers, or alates can also aid in the final determination. Advances in sensor sensitivity and attachment will be needed to improve detection performance.

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