Comparison of Localized Injections of Spinosad and Selected Insecticides for the Control of *Cryptotermes brevis* (Isoptera: Kalotermitidae) in Naturally Infested Structural Mesocosms

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ABSTRACT We investigated the efficacy of various chemical injections against *Cryptotermes brevis* (Walker) (Isoptera: Kalotermitidae) in hardwood shipping pallets. We had three principle interests: efficacy in whole structures, relative efficacy of the active ingredients, and whether acoustic evidence augmented treatment site selection. Infested pallets were delineated into boards with four monitoring sites each. Six chemical treatments were compared: chlorpyrifos aerosol, aqueous disodium octaborate tetrahydrate (DOT), resmethrin aerosol, distilled water (control), and two treatments of spinosad SC (one treatment applied based upon visual and the other treatment upon acoustic [AE] evidence). Individual boards were split apart; efficacy was determined by percentage mortality and pre- and posttreatment AE counts. Injections were constrained to a single point per board with the greatest level of termite activity. In whole pallets, mean percentage mortality ranged from 53.3 to 58.7% for the visual and AE spinosad treatments, respectively, whereas water averaged 6.8%. Remaining treatment mortalities were 33.2, 30.4, and 18.1% for chlorpyrifos, DOT, and resmethrin, respectively. Analysis of whole-pallet data indicated that none of the insecticides produced commercially acceptable mortality; localized injections of insecticides were not comparable with whole-structure treatments. We delineated independent groups of board sections (sectional aggregates; SA) that were connected by galleries. When treated SA were analyzed, spinosad and DOT treatments were significantly different from controls, whereas remaining treatments were not different from controls or spinosad and DOT. AE readings and visual termite evidence were compared with presence or absence of termites in SA, and it was determined that both AE and visual evidence were effective predictors of termite presence.

KEY WORDS drywood termite, acoustic emissions, spinosad, sodium borate, resmethrin

Drywood termites are often more common in structures in the southern United States than subterranean termites, despite their relative lack of notoriety (Rust et al. 1988, Scheffrahn et al. 1988). Although subterranean termite structural infestations may involve a single large external colony, structures infested with drywood termites can contain literally thousands of small- to medium-sized colonies (Su and Scheffrahn 1990). Additionally, these colonies occur inside of various wooden items, often with few outward signs of their presence (Su and Scheffrahn 2000). Thus, the principle complicating factor in remedial localized control of drywood termites is finding and treating all of the colonies within a structure. Whole-structure treatments have the advantage of minimizing this variable, because they encompass all colonies within structures. As demonstrated in numerous studies, fumigation is extremely effective at controlling drywood termites on a whole-structure basis (Bess and Ota 1960, Scheffrahn and Su 1992, Lewis and Haverty 1996). Although many technologies, such as heat (Lewis and Haverty 1996, Woodrow and Grace 1998), cold, electricity, and microwaves (Lewis and Haverty 1996, Lewis and Haverty 2001) have been developed, chemical treatments are still most commonly used for localized control of drywood termites (Lewis 2003). Recent reviews by Lewis (2003) and Su and Scheffrahn (2000) summarize much of the efficacy data for the various chemistries, whereas recent studies include those by Ferster et al. (2001) and Scheffrahn et al. (1997, 1998). Although insecticides are sometimes applied directly to the wood surface, intragallery injections are generally more efficacious (Scheffrahn et al. 1998, 2001; Ferster et al. 2001).

An alternative to attempting to inject toxicants into galleries containing active termites is to place toxicant residuals into the galleries with the assumption that termites will eventually contact the treated area as they move through their gallery system. Conventional, fast-acting termiticides are often either immediately repellent or may have a secondary repellent affect due to the accumulation of dead termites in the treated

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area, as observed in some subterranean termites (Su et al. 1982). To overcome these potential repellent factors, several slow-acting toxicants have been developed and tested in laboratory and field simulations. Slow-acting toxicants have the additional possible benefit of transfer between foragers and their nestmates (Kofoid and Williams 1934, Ferster et al. 2001). An early study by Randall and Doody (1934) evaluated the efficacy of a delayed toxin, Paris green (copper arsenate) dust, which was injected at 0.91-m (3-ft) intervals in heavily infested utility poles. Although hitting an active termite colony was a hit-or-miss proposition, these researchers found that significant mortality could be achieved when the toxicant was injected into any part of the gallery system. Although arsenicals are not used in current practice, a modern and more acceptable alternative that may have similar activity is spinosad (Dow AgroSciences, Indianapolis, IN). This information led us to postulate that treatment of a limited number of sights with a delayed toxicant might offer control that extends beyond the treated zone.

For efficacy to extend beyond the treated area, it is essential that toxicants be placed in active termite galleries. Although conventional doctrine dictates that visible evidence is used to locate drywood termite activity, visually finding colonies is often problematic. As an aid to toxicant placement, acoustic emission detectors have been developed and investigated by a number of authors (Fujii et al. 1990, Scheffrahn et al. 1993, Lemaster et al. 1997, Lewis et al. 2004). This technology has proven to be a useful research tool for locating drywood termites (Scheffrahn et al. 1997) and may serve to ensure optimal placement of delayed toxicants.

Field and laboratory studies with drywood termites have confirmed that the delayed toxicant spinosad is effective in control. In laboratory simulations, Scheffrahn et al. (1997) demonstrated that *Cryptotermes brevis* (Walker) and *Incisitermes snyderi* (Light) will forage from untreated areas into areas treated with spinosad suspension concentrate (SC) in simulated gallery systems. These authors also observed significant mortality from spinosad SC, whereas other conventional materials, including disodium octaborate tetrahydrate (DOT) (dust and 10% aqueous), calcium arsenate (35% dust), and chlorpyrifos (0.5% aerosol) had only marginal levels of mortality. In field studies, they also tested these treatments, minus calcium arsenate, in 55 separate natural infestations among two buildings and evaluated efficacy in this part of the study by using AE activity. Although short-term reductions in AE counts were observed with DOT and chlorpyrifos, only spinosad SC produced continued progressive reductions in AE activity over the entire 12-mo period. Conversely, a similar structure in this same study was fumigated, producing rapid and sustained cessation of any AE activity. Scheffrahn et al. (1998) conducted further investigations of DOT and spinosad injections in mature colonies of *I. snyderi* in dead trees or branches and *C. brevis* in lumber. In this study, they subdivided naturally infested wood into individual experimental units, which were then assigned to treatments. This study found that single-point injections of spinosad SC and DOT yielded high levels of mortality after 1 and 3 mo, respectively (Scheffrahn et al. 1998). The progressive mortality from spinosad exposure as seen in these studies is consistent with the hypothesis that toxicity of delayed toxicants may extend beyond the point of injection.

Conventional localized injection has been hampered not only by the cryptic nature of drywood termites but also by the nature of structures themselves. Modern construction techniques use double-wall construction that creates wall voids, for example, which are difficult to inspect and impossible to spot treat. Although the previous studies made significant inroads into the use of spinosad, they did not analyze for this structural effect. Scheffrahn et al. (1997) presumably made multiple injections into gallery systems, because they were injecting whenever they found positive AE evidence. They also studied buildings where they had complete access to the wooden members. Under these ideal conditions, spinosad was shown to be superior to the other conventional materials. Although Scheffrahn et al. (1997) examined naturally infested boards over 3-mo periods, no study has been conducted on naturally infested structures, which evaluated this partial accessibility factor. A similar study by Thoms (2000) investigated spinosad injections in 44 naturally infested structures in Florida, in which colonies were completely delineated with AE evidence and were generally completely accessible. They observed a significant reduction in AE counts over the 6-mo duration of the study.

The previous work discussed herein suggests that nonrepellant compounds with delayed toxicity, such as spinosad, are superior to other materials when used for localized control of accessible drywood termite infestations. However, little is known about the efficacy of these materials at the level of the entire structure. The main difficulty that has limited direct measurement of termite mortality on this scale is the practical inability of destructively sampling structures for the sake of research. As a result, structural studies have used AE evidence alone to evaluate efficacy. Although we were not able to overcome this limitation directly, we chose to approach this problem by reducing the scale of our structures. This enabled us to replicate and study a number of naturally infested microstructures, as simulations of macro-structures, or buildings. We chose to use naturally infested hardwood shipping pallets as manageable and uniform mesocosms (Peterson and Hastings 2001), which could be experimentally manipulated. Pallets contain a level of structural complexity not examined in previous studies (connected boards in three dimensions) and could be destroyed at the end of the trial to directly assess mortality. We also limited injections to a single point per board to simulate limited access. We assumed that control was achievable under this scenario given the results of Randall and Doody (1934) who achieved significant mortality in utility poles, injected at 0.91-m (3-ft) intervals.

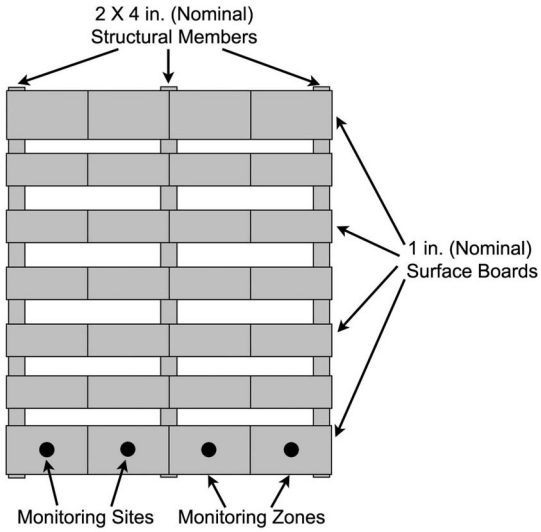

Fig. 1. Hardwood shipping pallet with basic structural components, monitoring zones, and monitoring sites.

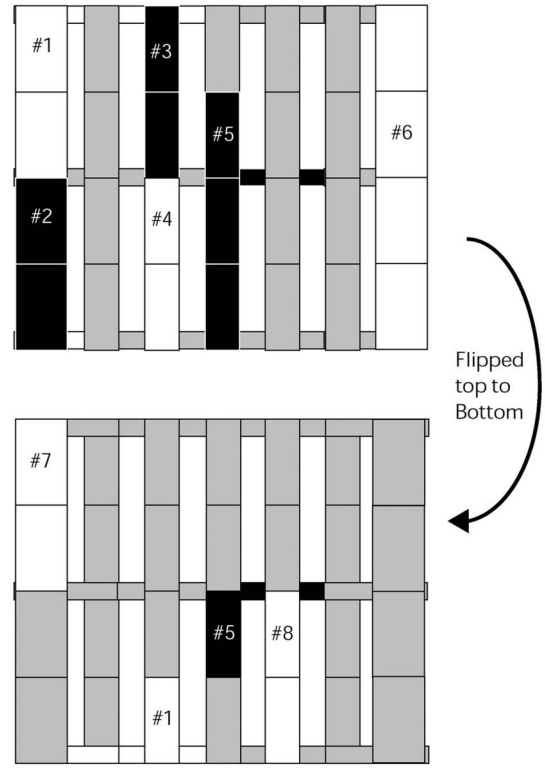

Fig. 2. Diagrammatic example of a specific hardwood shipping pallet used in the study, with separate independent interconnected aggregates of sections (sectional aggregates) represented by numbers.

We posed three principle areas of investigation relative to spinosad and other conventional injectable toxicants: efficacy in whole structures, relative efficacy, and whether acoustic evidence augmented treatment site selection over conventional visual assessment. We hypothesized that there would be significant and progressive mortality produced by spinosad over a 1-yr period, compared with limited efficacy of conventional toxicants; and that the AE technology would augment the selection of treatment sites and improve efficacy, when coupled with spinosad.

Materials and Methods

Forty unfinished, hardwood shipping pallets were preselected based on visual evidence of infestation (i.e., fecal [frass] pellets, kick-out holes used to expel fecal pellets, and open galleries) from a large collection of pallets located at the Pearl Harbor Naval Shipyard, Pearl Harbor, HI. Typical hardwood shipping pallets consisted of two to four 5- by 10.2-cm (nominal 2- by 4-in.) structural members and a number of 1.9–2.5-cm (0.75–1-in.)-thick outer surface boards, which were between 10.2 and 20.3 cm (4 and 8 in.) in width and either 101.6 or 121.9 cm (40 or 48 in.) in length (Fig. 1). Individual boards within the pallets were each given a unique label, and then four equally spaced 25.4- or 30.5-cm (10–12-in.) monitoring zones were delineated; broken boards were delineated into section lengths equal to that of the unbroken boards on the same pallet. Monitoring sites were centered in the monitoring zones and were labeled on each board (Fig. 2). All pallets were oriented so that surface boards were horizontal, whereas support members were vertical.

AE readings were taken with an improved AE detector (Dow AgroSciences) before chemical treatment and then 6 and 12 mo posttreatment at all monitoring sites on all pallets. Acoustic evidence was based on counts produced by the AE detector (Scheffrahn et al. 1997). AE readings were recorded for each individual monitoring site over 30-s intervals. AE counts more than five counts per 30 s were deemed positive for the presence of termites.

Pallets from the preselected pool were chosen for inclusion in the study based on the presence of at least one monitoring site that was positive for termites. These pallets were assigned at random to receive one of six chemical treatments: chlorpyrifos 0.5% aerosol (Dursban PT-270, Whitmire Research Laboratories, St. Louis, MO), 15% aqueous DOT (Tim-bor, U.S. Borax, Valenica, CA), resmethrin 0.25% aerosol (Term-Out, Makiki Electronics, Honolulu, HI), distilled water (control), and two treatments of 0.5% spinosad suspension concentrate (Spinosad SC, Dow AgroSciences): one treatment based on visual evidence of termites and the other treatment upon acoustic evidence. Twenty-eight of the original 40 pallets had verifiable termite AE evidence and were included in the study; all of the treatments were replicated in five

separate pallets, except chlorpyrifos, which was assigned to three pallets. For each board with AE activity, a single injection site was assigned to the monitoring site with the highest level of acoustic or visual (visual spinosad) evidence; boards without evidence of infestation were excluded from treatment. At the selected injection sites, holes were drilled with a 2.4-mm (3/32 in) drill until a gallery was located. Prepared aqueous formulations were applied with a veterinary repeater syringe (N. J. Phillips, Somersby, New South Wales, Australia) tipped with an 18-gauge hypodermic needle inserted through a rubber stopper to prevent backflow. All prepared treatment materials were applied until failure or until the material escaped from another location; all quantities were recorded. Aerosol formulations were measured by timing the application then calculating the volume based on previous calibration runs using three separate cans. If no material could be applied in the pallet, then another pallet was selected, and the treatment process was repeated.

After the final 12-mo AE readings, the pallets were partitioned into individual boards. Using a band saw, boards were then cut into four equal, separate sections, corresponding to each of the predetermined monitoring zones (Fig. 2). All individual board sections were split apart using hammer and hand-ax to extract both living and dead termites present; the presence of visible pesticide residues was also noted during extraction. Shriveled bodies and head capsules were counted as dead individuals, whereas termites injured during extraction were counted as living. Gallery connections between pieces were noted, and each piece was then placed in a plastic bag until extraction; board sections interconnected with galleries were termed sectional aggregates (SA).

To evaluate the predictive ability of acoustic and visual evidence, we analyzed the presence or absence of termites within SA against corresponding visual and AE data by using chi-square analysis (SAS Institute 1997). We counted isolated board sections as independent units, whereas SA had to be treated differently owing to the possibility of migration within SA. Because termites were highly concentrated within SAs, we would have severely biased our analysis in favor of the areas where termites were absent if we considered them individually equal to sections, and counting all of the sections within SA would bias in favor of termite presence, because many sections within SA had no termites. Thus, SA were given a section-count based on the number of sites positive for termite presence or sites positive for evidence, whichever was less. We tested the null hypothesis of no significant relationship between visual or acoustic evidence and the presence of termites with chi-square and Fisher Exact test, right-sided (SAS Institute 1997).

To analyze for the effects of the treatments on the entire structure (pallet), the numbers of living and dead termites were summed over the entire pallet, and percentage mortality was calculated from the percentage of dead bodies to living termites at the initiation of the trial [dead/(living + dead)]. To analyze for treatment effects on percent mortality, a general linear models procedure (PROC GLM, SAS Institute 1997) was used. If significance was found, individual Tukey–Kramer means comparisons (SAS Institute 1997) were carried out. Further analysis of whole-pallet data were conducted with a GLM model weighted by the amount of dilution injected, to correct for differences in injection quantity. Similarly, we also analyzed SA as independent experimental units to further resolve the efficacy of individual compounds minus structure-level effects.

Results and Discussion

Breakdown. Among 28 pallets included in the study, there were 381 boards and 1,514 individual monitoring sections with an average of 13.6 boards and 54 sections, per pallet, respectively (Table 1). There were numerous gallery connections between monitoring sections as well as between boards and structural components of boards. Although it was impossible to determine how many colonies were present in a pallet, it was possible to delineate connections between sections and thus interconnected groupings of sections, which were termed SA. There were a total of 90 SA across the 28 pallets or a mean of 3.2 aggregates per pallet. The number of SA varied, with a maximum of eight separate aggregates found in a single pallet (Fig. 2). In some cases, there were more individual SA within a pallet than there were injections (pallets 20, 30, 3, 27, 38, 4, 8, 33, and 39), indicating that some termite colonies were not detected originally and thus were not treated (Table 1). Conversely, there were 13 SA treated multiple times (pallets 25, 17, 18, 37, 22, 29, 6, 7, 10, 12, 15, 11, and 23).

Some general observations were made about the drywood termite gallery systems within the pallets. Gallery systems consisted of a single or series of excavations connected by narrow cylindrical passages, ≈1 mm in diameter. Relative to the lumber, galleries were generally oriented longitudinally (parallel to the wood grain), with occasional lateral interpenetrations. These observations are similar to those reported by (Rust et al. 1979) for *Incisitermes minor* (Hagen). Heavily infested boards had many interconnected cavities, with paper-thin coverings to the outside, whereas lightly infested boards had galleries that were deeply centralized, often axially located within the lumber and with no obvious external evidence of their presence. This information is consistent with our initial premise that the primary complicating factor in conducting localized treatments is the cryptic nature of drywood termites and thus the difficulty in locating galleries.

Deposition. Liquid dilutions were injected into 108 individual monitoring sites, amounting to a total of 2,433 ml of liquid applied with an average of 86.9 ml per pallet or 22.5 ml per injection. There were 82 monitoring sites that yielded pesticide residues upon breakdown at the termination of the study (Table 1). Dry pesticide residues were most noticeable with the spinosad injections, which left a thick white layer in

Table 1. Summary 12-mo breakdown data from 28 hardwood shipping pallets injected with various chemical treatments

Treatment	Site selection criteria[a]	Pallet no.[b]	Boards[c]	Monitoring sites[c]	Injected vol (ml)	Injection site	Sites with residue	Living termites	Dead termites	SA[d]
Chlorpyrifos	Acoustic	20	17	68	5	1	0	75	0	6
Chlorpyrifos	Acoustic	25	12	48	18	4	0	1,500	388	1
Chlorpyrifos	Acoustic	30	13	48	42	3	1	124	472	4
Spinosad SC	Acoustic	3	13	52	30	1	3	0	24	3
Spinosad SC	Acoustic	17	13	52	76	6	8	356	638	5
Spinosad SC	Acoustic	18	15	60	43	3	6	1,460	168	1
Spinosad SC	Acoustic	27	12	47	5	1	2	21	6	3
Spinosad SC	Acoustic	37	15	60	126	6	10	117	3,507	5
Spinosad SC	Visual	6	12	48	394	9	24	167	843	1
Spinosad SC	Visual	7	11	44	148	6	5	41	192	3
Spinosad SC	Visual	10	15	57	74	6	5	84	8	1
Spinosad SC	Visual	12	15	60	26	3	0	578	4	2
Spinosad SC	Visual	15	17	68	126	5	14	76	899	4
Resmethrin	Acoustic	4	12	48	26	1	0	533	212	6
Resmethrin	Acoustic	8	15	60	67	5	1	351	102	8
Resmethrin	Acoustic	22	15	60	279	10	0	2,755	1,060	3
Resmethrin	Acoustic	29	12	48	54	5	0	216	21	3
Resmethrin	Acoustic	35	10	40	7	1	0	825	25	1
DOT	Acoustic	5	11	44	3	1	0	1,057	23	1
DOT	Acoustic	13	15	60	30	1	0	3	213	1
DOT	Acoustic	19	15	60	75	5	3	18	8	5
DOT	Acoustic	34	14	56	75	2	0	1,563	406	2
DOT	Acoustic	38	15	60	5	1	0	290	1	4
Distilled water	Acoustic	11	15	60	265	9	0	1,545	4	2
Distilled water	Acoustic	23	15	60	270	8	0	1,830	56	1
Distilled water	Acoustic	26	11	44	35	2	0	36	11	2
Distilled water	Acoustic	33	15	58	60	2	0	1,546	11	6
Distilled water	Acoustic	39	12	44	70	1	0	55	4	6
Total		—	381	1514	2433	108	82	17,222	9,306	90

[a] Most treatments were placed according to the results of acoustic emissions evidence (five or more counts/30 s). The remaining treatments were conducted according to visual assessment of drywood termite evidence, i.e., presence of visible galleries kick-out holes, or both.
[b] Arbitrary identification number assigned to pallets at the start of the study.
[c] Number of separate boards or monitoring sites present in each of the pallets (see Fig. 1).
[d] Sectional aggregates are mutually independent groups of board sections, connected by termite galleries, which were delineated after pallets were disassembled.

the galleries in 77 sites in both spinosad treatments. Dispersion of the spinosad SC formulation in the galleries was obvious, with more sites yielding residue than were treated. For the AE spinosad and visual spinosad treatments, 17 and 29 injections yielded 29 and 48 sites with residue, respectively. Residues of the remaining materials were not as obvious, with only one site each in the chlorpyrifos and resmethrin treatments and three sites with DOT. These data suggested that the materials penetrated beyond the point of injection into contiguous board sections.

We further analyzed those pallets treated with spinosad to see whether it penetrated between treated and untreated boards that had interconnecting galleries. There were 277 sections present within pallets treated with spinosad, 240 of which received no injections. Of the 37 sections that were present within treated boards, a majority, $n = 28$ (75.7%) had visible residues. Among the sites on boards that received no injections, there were 48 (20.0%) that had visible residues. The caveat here is that we cannot say how far the materials flowed, because we cannot assume that if the material is not visible that it was not there; no chemical analyses were conducted to quantify deposition. At the very least, we can conclude that spinosad deposited readily within treated sections, whereas in contiguous sections there is some evidence that spinosad did penetrate occasionally in concentrations high enough to produce a visible residue. Because visible residuals were only common within the spinosad sections, we could not evaluate the relative efficacy of the other materials with this information.

Efficacy in Whole Structures. Upon breakdown, 17,222 living termites were collected along with 9,306 dead termites (Table 1). The analysis of whole pallets (Table 2) is most indicative of the potential efficacy of these treatments in typical macrostructures. For whole pallets, mean percentage of dead ranged from 18.1 to 58.7% for the resmethrin and the spinosad treatments, respectively, whereas the water produced 6.8% dead (Table 2). The overall GLM model was not significant ($F = 1.70$; df = 5, 22; $P = 0.176$), indicating that as a whole-structure treatment, all treatments were equivalent and did not differ significantly from the control, regardless of the treatment selection criteria. These results suggest that chemical injections, regardless of the materials used, are not an effective alternative to conventional whole-structural fumigation. Additionally, the similarity of the spinosad treatments indicates that there is no evidence that AE

Table 2. Mean percentages, standard errors, and summary GLM model statistics of percentage of dead *C. brevis* nymphs and soldiers collected from dissected hardwood shipping pallets treated with various injectable compounds after 1 yr

Treatment	Site selection	Pallets		Treated SA[a, b]	
		n	Mean % ± SEM	*n*	Mean % ± SEM
Chlorpyrifos aerosol	Acoustic	3	33.2 ± 23.7	3	33.3 ± 23.7ABC
Spinosad SC	Acoustic	5	58.7 ± 18.5	8	71.9 ± 14.3A
Spinosad SC	Visual	5	53.5 ± 20.0	10	48.3 ± 15.0A
DOT	Acoustic	5	30.4 ± 17.9	4	47.6 ± 22.8AB
Resmethrin aerosol	Acoustic	5	18.1 ± 5.1	11	35.9 ± 10.8BC
Water (control)	Acoustic	5	6.8 ± 4.3	6	5.2 ± 3.8C
F			1.70		16.67[c]
df			5, 22		5, 39
P			0.176		<0.0001

[a] SA are independent groups of board sections, connected by termite galleries, which were delineated after pallets were disassembled.
[b] Grouped according to a Tukey–Kramer mean separation tests (SAS Institute 1997).
[c] Weighted by the quantity of material injected.

evidence augmented conventional visual assessment in whole pallets.

One possibility for the lack of control in whole pallets is the fact that we restricted treatments to a single point per board. If this was so, one would expect mortality to have been higher in treated board sections, than the pallets overall. However, within treated sections mortality was minimal. We analyzed the 108 sections that received an injection; of these there were 58 (53.7%) that contained no termites at the termination of the trial. The remaining 50 were then analyzed for treatment effects. Mean percentage mortalities ranged from 0.55 to 6.01% for water and chlorpyrifos, respectively. An overall GLM model indicated that there was a significant treatment effect ($F = 4.22$; df = 5, 44; $P = 0.003$); individual means comparisons revealed that only a single treatment, resmethrin (5.32%), was significantly different from the water control, which did not represent a commercially acceptable level of control.

Relative Efficacy. To further resolve the efficacy of the individual compounds, SA were analyzed as independent experimental units, excluding those SA that were not treated (Table 2). Because the amount of material injected was variable (Table 1), and assuming that mortality would be directly proportional to the amount of material injected, we chose to weight the GLM model by injection amount. Visual and AE spinosad treatments produced mortality values (48.3 and 71.9%, respectively) that did not differ significantly from each other or from the control. The resmethrin treatment mortality was again not significantly different from the controls, whereas the DOT treatment mortality came out significantly higher than the control mortality. Chlorpyrifos mortality was only intermediate to and not significantly different from the remaining treatments.

The difference between the analysis of whole pallets and that of the SA demonstrates the difficulties imposed on localized treatments by the cryptic nature of drywood termites. The principle difference between whole pallet and SA results in Table 2 is that we managed to subtract treatment site selection error from the SA column, whereas this error was contained within the pallet column. We were able to substantiate the previous results of Scheffrahn et al. (1997, 1998), because greater mortality was produced by spinosad SC than by the other toxicants (Table 2). These results suggest that delayed toxicity is preferable to fast-acting insecticides. Indeed, the results obtained with spinosad are similar to those noted many years ago with Paris green (Randall and Doody 1934). As in this early study, our results suggest that significant mortality can be obtained given that the material is actually injected into galleries that are accessible to the incipient termite population.

Acoustic Evidence. To analyze for treatment effects of acoustic evidence we compared two treatments of spinosad, one treatment where sites were determined with AE evidence and another site where treatment effects were determined with conventional visual evidence. As discussed previously, there is no experimental evidence that AE evidence improved efficacy of either of the spinosad treatments in whole pallets (Table 2), i.e., AE evidence did not augment the use of localized treatments on a whole-structural basis.

Within treated SA, however, mortality in the AE spinosad treatment was greater in this analysis, although not significantly so; this might suggest a slight advantage of AE treatment sight selection over visual assessment within those SA that were active with termites.

Mean AE counts from pretreatment, 6 and 12 mo posttreatment are contained in Table 3. Although it was initially apparent that all of the materials caused a rapid reduction in AE counts, this effect was not progressive over 12 mo. There was an overall 82.28% reduction in AE counts from pretreatment to 6 mo, whereas that same AE reduction decreased to 45% at 12 mo; we omitted the mean AE counts for visual spinosad because it actually increased 227% above pretreatment counts. This is contrary to Thoms (2000) and Scheffrahn et al. (1997), who both observed progressive reductions in AE counts after spinosad injections. One key difference between their studies and ours is that these authors had access to the infestations they were studying, ensuring complete mortality. In contrast, we limited injection to determine whether

Table 3. Mean and standard error of AE counts per 30 s taken at monitoring sites of whole pallets treated with various toxicants at 0, 6, and 12 mo

Mo	Chlorpyrifos	Spinosad	Visual spinosad	DOT	Resmethrin	Distilled water
0	3.68 ± 0.61	4.08 ± 0.79	0.75 ± 0.16	4.02 ± 0.87	4.47 ± 0.69	5.84 ± 0.78
6	0.26 ± 0.07	0.36 ± 0.10	0.17 ± 0.04	0.34 ± 0.79	1.83 ± 0.44	1.09 ± 0.44
12	0.76 ± 0.31	3.28 ± 0.90	2.46 ± 0.55	2.39 ± 0.59	2.87 ± 0.55	2.90 ± 0.46

the termites, not immediately killed by the initial injections, would gradually forage through the treated areas over time. The AE evidence did not support this hypothesis.

We also sought to evaluate the predictive ability of AE evidence for locating active termite galleries. Throughout the study, a total of 4,542 separate acoustic readings were taken on the pallets, and visual evidence was noted at the termination of the study for every board. Among the 1,121 total observations, termites were present in 432 sites and visual evidence was present in 362 of these; termites were absent in 689 sites, and no visual evidence was found in 600 of these sites. Conversely, among 981 observations where acoustic evidence was recorded, termites were present in 222 sites and AE evidence was present in 135 of them; termites were absent in 759 sites, and no evidence was found in 708 of these sites. Table 4 contains the statistical analyses of the predictive rates of the AE and visual evidence. Both analyses were highly significant, indicating that AE and visual evidence were both equally effective predictors of the presence of termites, and suggesting that routine use of the more time-consuming AE detector does not necessarily improve accuracy.

Other Localized Treatments. Aside from chemical injection, various physical or environmental control methods have been used for localized drywood termite control. Although chemical injection is limited to the galleries in which injections are made, physical control strategies are generally less localized. Woodrow and Grace (1998) found that, despite the existence of temperature gradients in large structural members, lethal high temperatures could readily be achieved under commercial conditions. Additionally, localized physical control methods have the advantage of being applied to larger areas, such as rooms, walls, or floors. Injections, however, are made at discrete points, and even if an injection is made into one gallery system, it may miss another gallery system that is not outwardly evident or accessible. The principle limitations of physical control methods are that they may be time-consuming and are not widely available (Lewis 2003).

Commercial Implications. Efficacy under experimental conditions does not necessarily ensure the quality of a given drywood termite treatment under commercial conditions. Many factors, including the ease of use, cost, and a myriad of environmental variables can influence the overall quality of a control method or material. As discussed by Lewis (2003), almost all drywood termite chemical treatment options are highly effective under ideal conditions. Lewis (2003) differentiated laboratory efficacy from what he termed "robustness" as a more realistic measure of whether a particular treatment will achieve a satisfactory result under commercial conditions in the field. Whole-structure treatments are extremely robust because they minimize the most significant variable involved in treating drywood termites, their cryptic nature. Drywood termite colonies can exist for several years without any outward evidence of their presence and can infest any cellulose-containing item in a structure. Treatment and inspection are further complicated by not all areas of a structure being accessible.

Table 4. Number of sections and sectional aggregates with termites present versus not present given 12-mo visual and acoustic evidence, with corresponding relative frequencies (%) and chi-square probabilities for hypothesis of independence of groups and Fisher's Exact test statistics

Counts (%)[a]	Termites		Chi-square test[b]	Fisher Exact test[c]
	Present	Not present		
Visual evidence				
Positive	362 (32.3)	89 (7.9)	$\chi^2 = 554.7$, $P < 0.0001$, df = 1	<0.0001
Negative	70 (6.2)	600 (53.5)		
Acoustic evidence				
Positive	135 (13.8)	51 (5.2)	$\chi^2 = 682.14$, $P < 0.0001$, df = 1	<0.0001
Negative	87 (8.9)	708 (72.2)		

[a] Sectional aggregates are mutually independent groups of board sections, connected by termite galleries, which were delineated after pallets were disassembled.

[b] Counts based 12-mo AE and visual evidence assessment and the presence of living termites collected in board sections at the breakdown of the trial.

[c] Pearson chi-square test statistics (SAS Institute 1997).

[d] Fisher Exact test (right-sided *P* value) for the null hypothesis: no association between the presence of termites and positive evidence, i.e., cell 1, 1 frequency; significant *P* value indicates acceptance of alternative hypothesis of a positive relationship between the presence of termites and evidence (SAS Institute 1997).

In this study, there were some pallets where the number of SA exceeded that of injections, indicating that there were some colonies that did not receive any treatment. This hit-or-miss problem is the principle complicating factor in this study as well as with this form of localized treatment. Within a single board there can be many incipient colonies, and it is simply impossible to treat all of them when a limited number of injections are made. This also was observed by Scheffrahn et al. (1998), who observed high rates of mortality in their field simulations with *C. brevis* but commented that in those samples where there was a lack of efficacy; injections were made into inactive galleries. Regardless of the efficacy of the toxicant under ideal conditions, it cannot penetrate from one gallery to another in situations where there are multiple and separate gallery systems in a single board; this is especially true when there is limited access to the infestation.

Delayed toxicity materials such as spinosad are more robust, presumably because one can treat a portion of a colony and termites will move through the treatment residue and distribute the toxin to nestmates. However, these materials cannot penetrate between galleries when a complex of independent gallery systems exists within a board, whereas heat, cold, and fumigants can do this with a high degree of certainty. Although no locally injected toxicant can offer the level of robustness of these whole-structure treatments, delayed toxins, such as spinosad, can be more efficacious than other conventional contact toxicants, given that the infestation is accessible.

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