# Baiting *Reticulitermes* (Isoptera: Rhinotermitidae) Field Colonies with Abamectin and Zinc Borate-Treated Cellulose in Georgia.

by

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ABSTRACT

Field trials of subterranean termite bait efficacy require interpretation of descriptive statistics more often than application of the scientific method. The cryptobiotic life history of subterranean termites, their loosely defined colony territories containing several loci of activity, and current research tools for their study often precludes definitive conclusions. Five locations with observed termite activity in and around structures in Georgia were included in baiting studies using a cellulose powder bait matrix with either abamectin or zinc borate hydrate against *Reticulitermes* spp. These experiments are described in the form of case studies. The data collected at two sites only involved observations of termite activity. At the other three sites, numbers of termites, wood consumption, and bait consumption were recorded from established termite monitors. Interpretation of the data collected varied in relation to the amount of information collected at each site and results ranged from complete reductions in termite activity following bait removal to bait removal followed by no indication of reductions in indices of termite activity. The problems associated with constructing a cause and effect relationship between bait applications and recorded changes in indices of termite activity are discussed. These include verification of colony associations, verification of bait consumption by one of several colonies within the baiting area, determination of colony movement or fractionating, and separation of normal variation in activity indices versus impact of bait removal.

INTRODUCTION

Subterranean termites from the genus *Reticulitermes* are significant economic insect pests in the United States (Su & Scheffrahn 1990). Despite their economic importance, aspects of the biology and control of subterranean termites have not been addressed in field studies. These include determination of what constitutes a subterranean termite colony and the field biology of the recognized species in the

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variety of habitats found across the continental United States.

Recommendations for control of subterranean termites are shifting from ground applications of termiticides to a more integrated approach incorporating baiting strategies, building modifications, and remedial, structural treatments (French 1994). Studies have indicated the potential of termite baiting techniques, yet the measures of field efficacy vary between researchers making direct comparisons difficult (Randall & Doody 1934, Ostaff & Gray 1975, Esenther & Beal 1978, Jones 1989, Su 1994, Henderson & Forschler 1996).

Field trials of termite bait efficacy do not readily lend themselves to statistical analysis. The cryptobiotic nature of termite biology and current research tools can provide only a partial view of any subterranean termite colony in the field. The data collected can include notations on the presence or absence of termite activity, number of termites collected at monitoring stations, food consumption at monitors or bait sites, indications of related use of known loci of termite activity based on mark-release-recapture, live worker body weights, and species determinations from soldier or altate caste members (Beard 1974, Forschler & Ryder 1996). The unpredicatable nature of termite visitation to monitoring stations, the difficulty in determining age, size, and even the undefined nature of what is a colony make it impossible to find true replicate colonies for testing. Therefore, much of the data generated is more anecdotal than scientific. In this paper I relate my experiences using abamectin or zinc borate hydrate in a proprietary bait matrix against *Reticulitermes* colonies in Georgia. I present results, in the form of case studies, from field tests with the aforementioned active ingredients only as illustrations of the problems confronting researchers attempting to measure the impact of bait treatments on subterranean termite colonies and to provide a forum for discussion of research needs in this area.

## GENERAL METHODS AND MATERIALS

A total of 6 subterranean termite colonies were baited. Termite activity was located using wooden survey stakes, although at two of the sites termite activity was observed in the structure and not at nearby survey stakes. When termites were located in wooden portions of a structure but not at nearby survey stakes, termite activity was recorded as presence or absence of termites and amount of bait removed. Stakes with termite activity were replaced with termite monitors consisting of 16 cm lengths of 10cm diameter polyvinyl chloride (PVC) pipe containing 60 to 90g of oven dried pine wood (Forschler & Townsend 1996). Measures of termite activity were recorded during monthly visits to each site. Measures of activity included numbers of termites collected, wood consumption rates from each monitor, worker live weights, and presence or absence of marked termites following release of marked termites into specific monitors. Termite species identification was made using alates associated with each group of termites (Weesner 1965).

The termite bait matrix used at all sites consisted of a proprietary cellulose powder provided by Whitmire Research Laboratories, St. Louis, MO. Baits were prepared by the manufacturer with different concentrations of either abamectin or zinc borate hydrate as the active ingredient in the aforementioned bait matrix. The amount of bait removed was determined by visually estimating the percent of bait remaining. This method was used because soil and fecal material were often brought into baits by termites and complicated obtaining true bait weights.

## CASE STUDIES

Two separate *Reticulitermes* colonies (Case Studies 1 & 2), observed only in structural lumber, were baited in the spring of 1993 using 0.001% abamectin baits (w\w). Because these termites were not found associated with termite activity in the soil, treatment efficacy was determined by observation of termite activity in infested structural members at and away from the baiting sites within the structures. Case Study 3 included one or more *Reticulitermes flavipes* (Kollar) colonies which were observed using termite monitors and baiting was conducted with 0.0005% abamectin placed in one of two monitors known to be visited by termites. In Case Studies 4 and 5 termites also were visiting termite monitors, but baiting was attempted using 1% zinc borate hydrate placed in 50ml centrifuge tubes within 0.3m of active termite monitors.

### Case Study 1.

The site was located in Barnesville, Lamar County, Georgia. The infested structure was a garage framed in 0.6cm plywood on three sides and open across the front (Fig. 1). *R. flavipes* were observed in two 10 X 10cm vertical support beams, one in the front corner (bait site 1.1), and the other inside the structure, 1.8m from the front of the building (bait site 1.2). In addition, termites were feeding in a 10 X 10cm sill plate (bait site 1.3) along the same wall as location 1.1 and along the back of the structure in the plywood siding (bait site 1.4). Termites also were located outside the structure at survey stakes along the wall adjacent to bait sites 1.1 and 1.3 (monitors #1 & #2). The termites in these monitors were marked with Nile Blue A and then released, but marked termites were never collected from sites in the structure. The termites in monitor #1 were initially smaller than those collected from the structure or monitor #2 (average live worker weights 1.6mg compared to 3.1mg from monitor #2) but by August, 1993 the termites in monitor #1 also were the same size as the *R. flavipes* collected at monitor #2 indicating a shift in activity by that termite colony to include both monitors.

Termites were presented with 1.5g of dry bait in 4 dram shell vials (1.8cm diameter, 7cm length). Vials with bait were placed into infested lumber by drilling a 2cm diameter hole 0.5cm deep and placing the vial into the hole. Vials were covered with paper sleeves to prevent light entry and allow bait tube inspection without removal of the bait tube.

Three bait tubes were placed at bait site 1.1 and one vial was placed at bait site 1.2 in May, 1993 (Fig. 1). In June, 1993 bait was provided at bait sites 1.3 and 1.4. Bait was presented at the latter two sites in a 9cm diameter #1 Whatman filterpaper disk folded around 2g of dry bait. The filterpaper/bait disk was moistened with 2ml of distilled water and placed over shelter tubes at bait site 1.4 and into the infested sill plate at bait site 1.3. Termite activity was recorded at all sites on a monthly basis from March 1993 to the present.

At the time of the July inspection termites were present at all bait sites with the exception of bait site 1.4. During that inspection, bait sites 1.1 and 1.3 provided evidence that bait was removed by termites. The amount of bait removed was estimated to be 0.5g from both sites combined. Bait site 1.2 had termite carton covering the entrance to the vial with no sign of bait removal. Termites were not seen at any location in August and the structure has not shown termite activity in the past two years. Both termite monitors provided evidence of termite activity until March of 1995 when they were destroyed during homeowner landscape improvements.

**Case Study 2.**

The structure was a 50yr old tenant shack measuring 6 X 6 m located approximately 3km from Aldora in Lamar County, Georgia. The structure was supported by combination brick and cinderblock piers with pine 5 X 15cm floor joists. *Reticulitermes virginicus* (Banks) activity was observed at two locations with termite shelter tubes on brick supports near the front porch, along cinder blocks under the kitchen floor, and in a floor joist under the kitchen. Two grams of 0.001% abamectin bait were provided in folded filter paper as previously described along broken shelter tubes against the brick and cinderblock supports. A 2cm diameter hole was drilled into the infested 5 X 15cm floor joist and approximately 2g of bait placed directly into the hole in June, 1993.

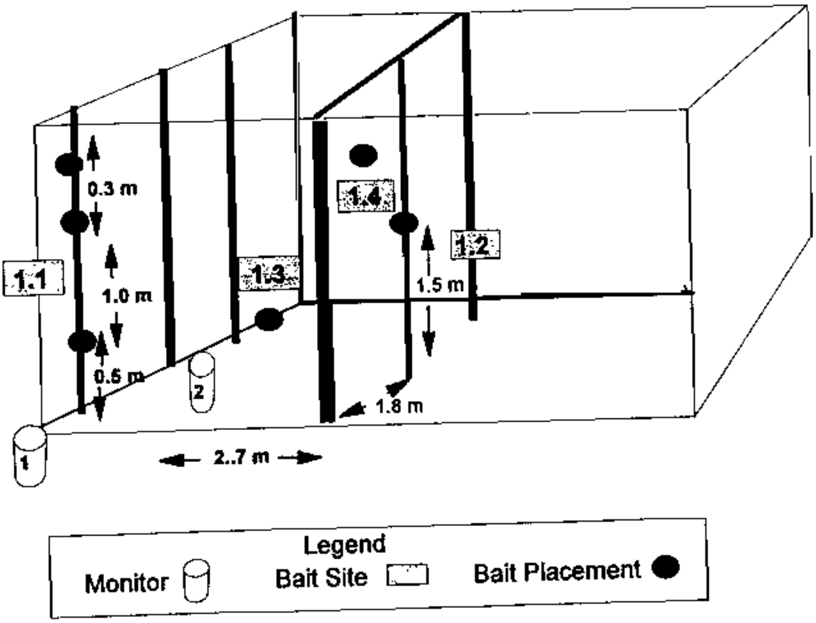


Fig. 1. Diagramatic representation of garage in Barnesville, Georgia showing relative positions of infested structural lumber, termite monitors, and bait placements by baiting site for Case Study 1.

Termite activity at this site was recorded from April 1993 through August 1993.

At the time of the first post-baiting inspection, termites had rebuilt shelter tubes around or through baits placed on shelter tubes with no evidence of termite feeding on the bait. In addition, termites had placed mud and/or fecal material over bait in the floor joist with no signs of bait removal from that location. Termite shelter tubes were again broken and baits repositioned over the same termite trails in both July and August. Termites rebuilt shelter tubes around baits between each monthly inspection with little to no feeding on baits at these locations. There was evidence of limited termite feeding on bait in the floor joist but termite activity continued at all sites into September when site inspections and the baiting study were discontinued in favor of recommendation to conduct a soil termiticide treatment.

**Case Study 3.**

The termite colony at this site was initially located in the wooden framing members of the crawlspace doorway at the rear of a single family residence in Milner, Lamar County, Georgia. The infested framing members were removed in February 1993 at the same time that survey stakes were placed around the entire structure. One month later, termites were located on two survey stakes approximately 0.5m from the crawlspace entrance and monitors #1 and #2 established (Fig. 2).

The colony of *R. flavipes* at this site was first baited in June, 1993. Baiting was accomplished by placing 0.0005% abamectin bait in monitor #1. Monitor #2, known to beused by the same group of termites, from spray paint marking, was left unbaited (Fig.2). Bait was presented by spreading 2g of abamectin-treated cellulose powder on the corrugated side of a 15 X 40cm piece of single faced cardboard which was then rolled up and placed inside a 4cm diameter section of PVC pipe. The baited cardboard was moistened with 5ml of water. All termites found in monitor #1 at the time of bait application were returned to monitor #2. Termite activity (number of termites collected and wood consumption rates) at those monitors and nearby stakes was recorded monthly beginning in April 1993 and continued through March 1995.

In July 1993 there was evidence of limited (<10% removed) termite feeding on the cardboard rolls. During that inspection it was noted that termite tubes leading from the baits into the soil, at the bottom of the termite monitor, were lined with bait matrix. Monitor #2 had evidence of termites (i.e. mudtubes on the termite sandwiches) but no termites were present. No termites were found in either monitor from July 1993 until May 1994 (Fig. 3). However, wood consumption data showed

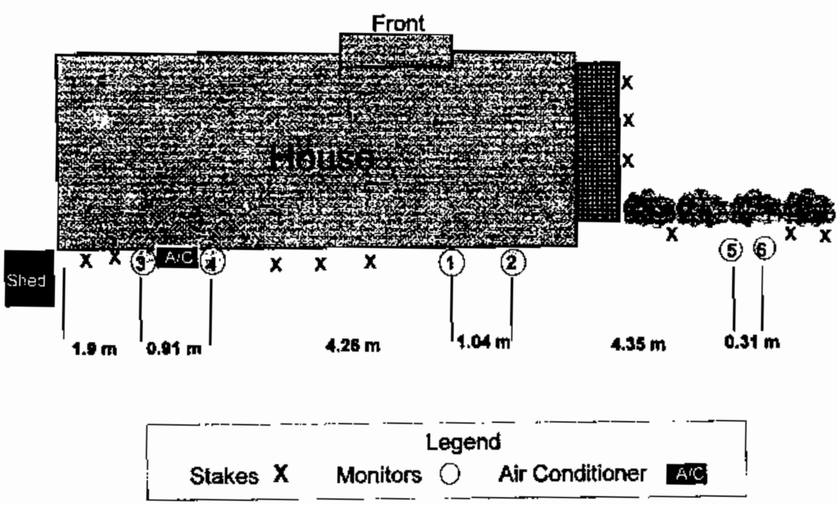


Fig. 2. Map of termite bait Case Study 2 test site in Milner, Georgia showing relative positions of the structure, wooden survey stakes, termite monitors, and other features of the site.

feeding at the baited monitor (monitor #1) in February and April 1994, and at monitor #2 in August 1993. (Fig. 4).

In September 1993, termites attacked two stakes within 5m of the baited monitor and two new monitors (monitors #3 & #4) were established (Fig. 2). Termites from Monitor #3 were returned to the laboratory and stained with Nile Blue A. The stained termites were released into monitor #3, in October 1993, to determine related use of the monitors. In March 1994, another stake on the opposite side of the building, 9m from monitors #3 and #4, was attacked by termites and a monitor established (monitor #5). At that time approximately 2,000 termites were collected and one was stained with Nile Blue indicating relatedness to monitors #3 and #4. However, over the next 12 months three separate spray paintings of these two groups at opposite ends of the building indicate that they did not intermingle, therefore, they were considered separate colonies.

In May 1994, termites were again found in Monitors #1 and #2 (Figure 3). Spray painting showed them to be the same group that was visiting monitors #3 and #4 (Forschler 1994). In July, 1994, baits were again placed in monitor #1 as previously described. Termites were not found in either monitor #1 or #2 from August through April of 1995 at which time the test was terminated because monitors #5 and #6 were destroyed during new construction at the site. In March 1995, we retrieved a primary pair with immature termites and workers from monitor #4. These were not returned to the monitor before the test was terminated.

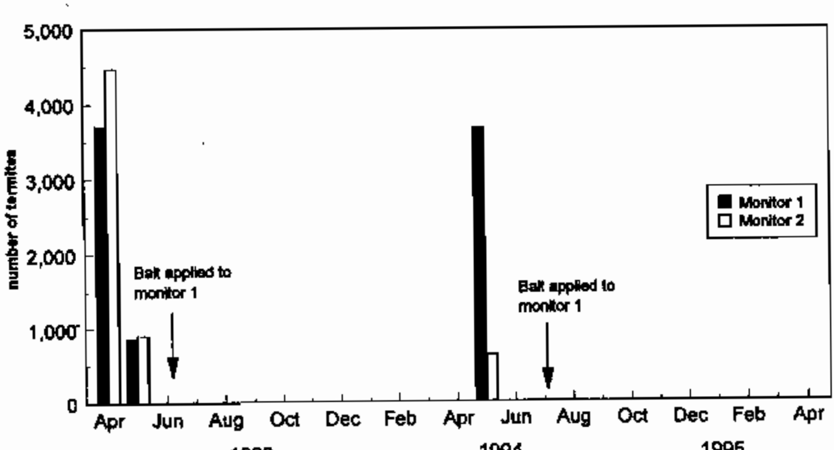


Fig. 3. The number of termites collected by monitor and month from *R. flaivpes* termites visiting monitors #1 and #2 during Case Study 2.

It would appear that baiting monitor #1 affected the colony at that location. It is my opinion that the remaining termites moved to and established feeding sites at monitor #3 and #4 that fall. This opinion is based on the fact that those survey stakes had been in place for 8 months without indicating termite activity. Although it could be coincidence that termite activity was recorded within 3 months of baiting termites 4 m distant, my experience suggests that they were the same group of termites. In general, when stakes have been in place for over 6 months without signs of termite activity and those stakes show termite activity shortly after termite activity ceases at a nearby site, there is a strong suspicion of relocation rather than demise of one group and invasion of another. The assumption of termite colony movement seems to have been strengthened by the reappearance of termites (one year later) in monitors #1 and #2 and topical marking indicating they were the same group using monitors #3 and #4.

It also appears likely that an additional group broke off from that same colony in the spring to establish monitors #5 and #6 because of the presence of the one dye-marked termite recovered at that site when the only marked termites were released into monitor #3. These two groups or now colonies of termites (monitors #3 and #4 and monitors #5 and #6) remained separate from that time on as indicated by repeated spray painting of termites in these monitoring stations. Termites at monitors #3 and #4 eventually returned to the feeding sites at monitors #1 and #2 where the second baiting episode again impacted that group (Figs. 3-6).

Recovery of the primary reproductives from monitor #3 indicates that the bait treatments did not affect the reproductives. The fraction of the colony that established at monitors #5 and #6 appeared to have been unaffected by the second baiting as indicated by both the wood consumption rates and numbers of termites collected per month (Figs. 7 & 8). Although the number of termites collected and wood consumption data are lower in April 1995 than that recorded for the same month the previous year (Figs. 3-8)and could simply be the affects of weather and seasonal activity (Haverty *et al.* 1974). This reinforces the notion that they were functionally separate groups. The number of termites found at each monitor and the wood consumption rates also supports the contention that the second baiting of monitor #1 affected the termites at monitors #3 and #4. (Figs. 5 & 6).

Close examination of termite activity does indicate that the second baiting impacted the termites at monitors #1 through #4 more than those at monitors #5 and #6 (Figs. 3-8). The total number of termites collected from August 1994 through April of 1995 from monitors #5 and

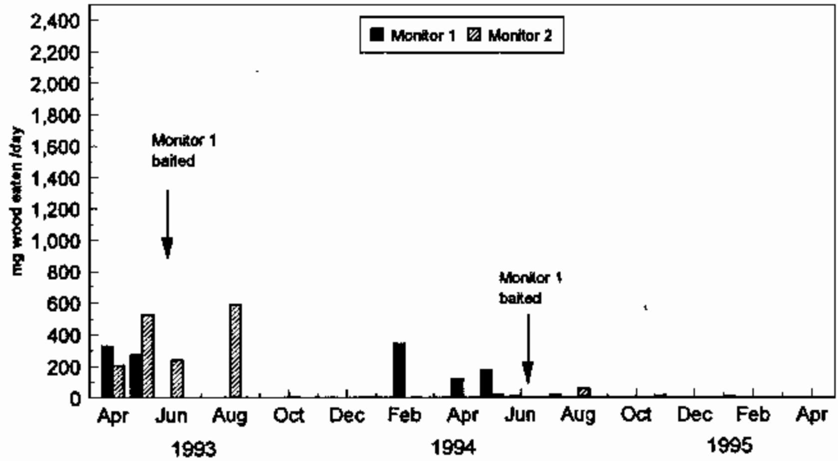


Fig. 4. Amount of wood consumed per day, in mg, by monitor and month from *R. flavipes* termites visiting monitors #1 and #2 during Case Study 2.

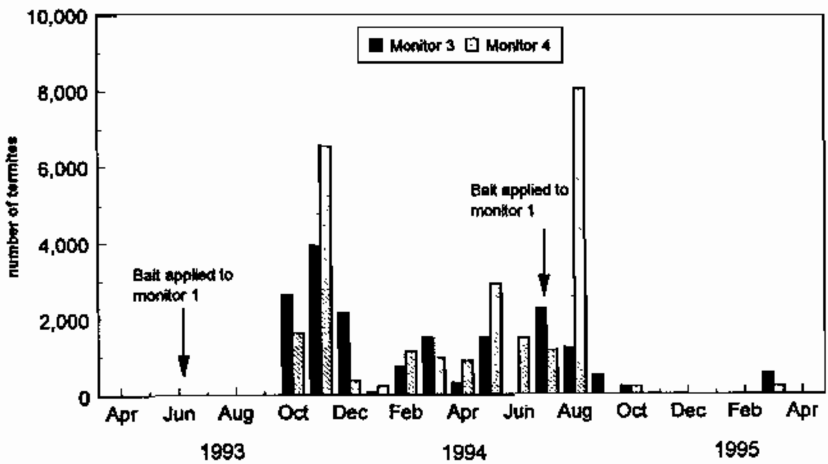


Fig. 5. The number of termites collected by monitor and month from *R. flaivpes* termites visiting monitors #3 and #4 during Case Study 2.

#6 was approximately 27,000 (Fig. 7). The number of termites collected from monitors #3 and #4, during the same time, was approximately 10,000 (Fig. 5). There were no termites collected from monitors #1 and #2 over the same time period (Fig. 3). The record of wood consumption showed a more dramatic reduction in activity. Total wood consumption recorded from monitors #5 and #6 from August 1994 through April 1995 was 280 g (Fig. 8). Total wood consumption from monitors #3 and

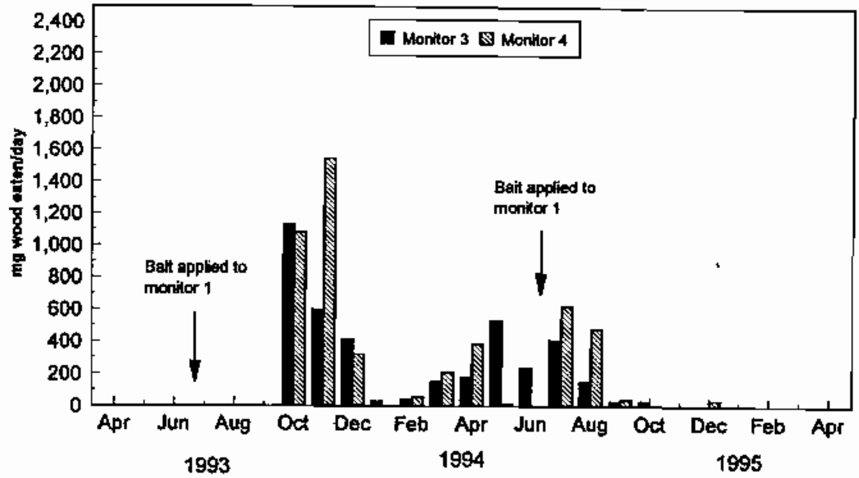


Fig. 6. Amount of wood consumed per day, in mg, by monitor and month from *R. flavipes* termites visiting monitors #3 and #4 during Case Study 2.

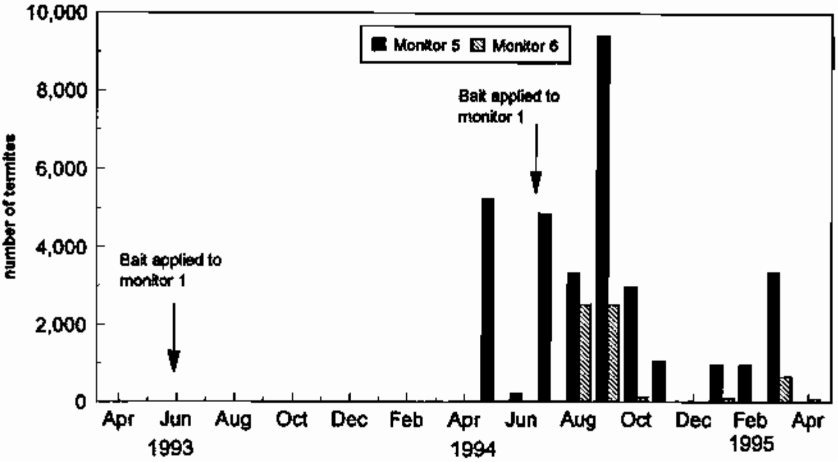


Fig. 7. The number of termites collected by monitor and month from *R. flaivpes* termites visiting monitors #5 and #6 during Case Study 2.

#4 for the same time period was 28g and there were only 3g eaten at monitors #1 and #2 (Figs. 4 & 6, respectively).

**Case Study 4.**

The termite colony at this site was known to be visiting 5 different termite monitors at the rear of the Conference Room at the Coastal Area Extension and Research center near Savannah in Chatham County (Fig. 9). One percent zinc borate hydrate baits were provided in 50ml

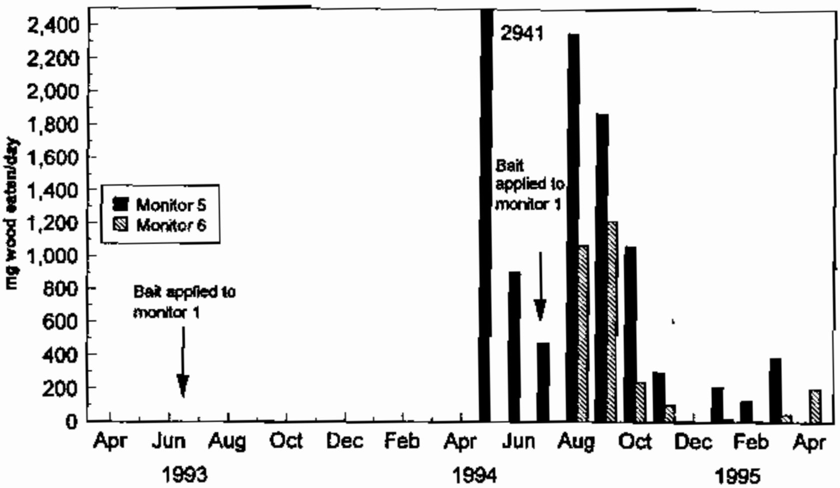


Fig. 8. Amount of wood consumed per day, in mg, by monitor and month from *R. flavipes* termites visiting monitors #5 and #6 during Case Study 2.

centrifuge tubes (3cm diameter) that had 2mm diameter holes drilled around the circumference (20 total). Bait tubes were placed within 30cm of four of the five monitors in August 1995 (Fig. 9). Termite activity at the monitors and bait tubes was recorded monthly from June 1994

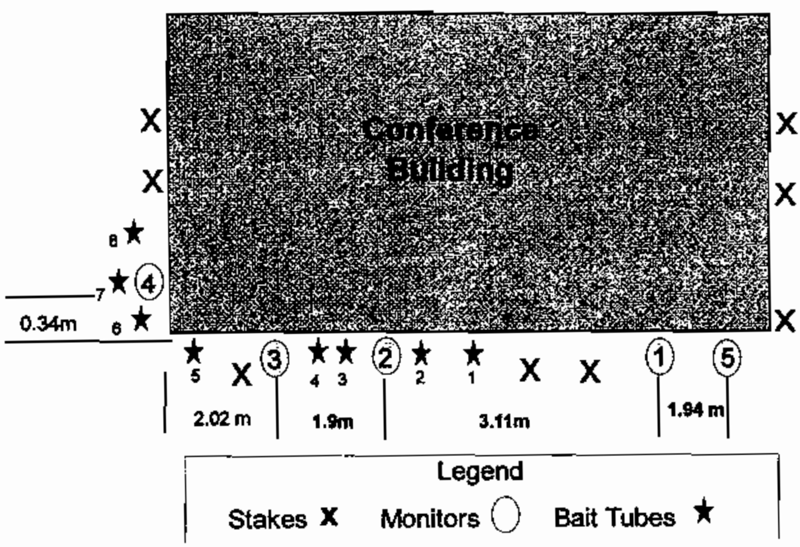


Fig. 9. Map of termite bait Case Study 3 test site from the Coastal area Extension and Research Center in Savannah, Georgia showing relative positions of the structure, wooden survey stakes, termite monitors, bait tubes, and other features of the site.

to April 1996. Bait tubes were replaced only after 50% or more of the bait was removed.

Baits were consumed on an erratic schedule with two bait tubes (tubes 4 & 5) providing evidence of limited feeding (<5% removed) two months after initial bait placement and tube 6 had 20% of the bait removed (Fig. 9). During November 1995 bait tube #6 had 80% of the bait removed. During December 1995, 30% of the bait was removed from bait tube 4. In February 1995, 10% was removed from bait tube 2 and a *R. flavipes* delate pair was recovered from bait tube 6 with evidence of <5% of the bait removed in April 1995.

Termite activity, recorded through May 1995, at all monitors, with the exception of monitor #4, was not obviously suppressed following the limited removal of bait (Figs. 10-13). Termite activity at monitors #3 and #4 was reduced following bait removal, however, the impact of the recorded bait consumption on this termite colony is confounded by the variable nature of monitor visitation. It would appear from both indices of termite activity that this colony abandoned monitor #4 after bait removal because no termites were recovered from that monitor from October, 1995 through April, 1996 (Fig. 12). Wood consumption at monitor #4 averaged approximately 600mg of wood eaten per day from April, 1995, through October, 1995 (Figure 13). The feeding rate at this monitor was reduced to less than 50mg per day from October through December, 1995 and no evidence of feeding was recorded from January through April of 1996 (Fig. 13). The activity at monitor #3 also was reduced for several months but had rebounded by April, 1996 (Fig. 12 & 13). The wood consumption averaged approximately 700mg per day from April through November of 1995 but no feeding was recorded from December, 1995 through March of 1996 (Fig. 13). In April, 1996 termites were again consuming 700mg of wood per day from monitor #3 (Fig. 13).

The numbers of termites collected and wood consumption rates for the other monitors visited by this *R. flavipes* colony displayed a typical erratic pattern associated with seasonal and weather related activity (Figs. 10 & 11).

**Case Study 5.**

Two *R. flavipes* colonies known from monitors #1, #2, and #3 and one *R. virginicus* colony from monitor #4 were identified behind the offices of the Marine Institute on Sapelo Island in McInstosh County, Georgia (Fig. 14). Baits were placed around the three monitors visited by the two *R. flavipes* colonies, as described for site four, in August 1995 (Fig. 14). Activity was monitored from October 1994 to April 1996.

Termites from the first colony at monitors #1 and #2 did not remove

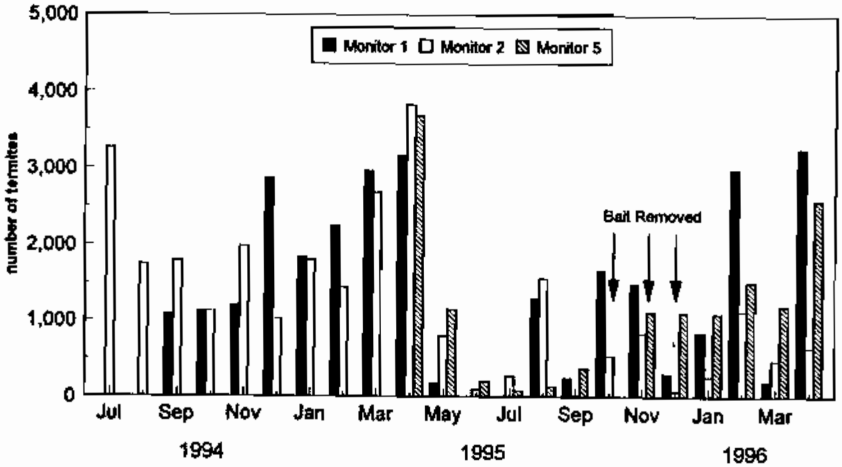


Fig. 10. The number of termites collected by monitor and month from *R. flaivpes* termites visiting monitors #1, #2, and #5 during Case Study 3.

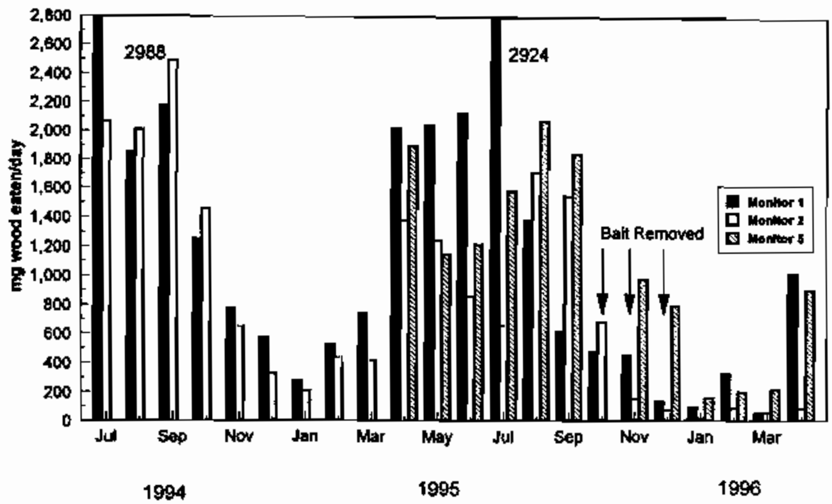


Fig. 11. Amount of wood consumed per day, in mg, by monitor and month from *R. flavipes* termites visiting monitors #1, #2, and #5 during Case Study 3.

any bait during the entire 9 months of the study (Fig. 14). Termite activity at those monitors continued to provide the expected seasonal variations (Figs. 15 & 16). Termites consumed one entire bait tube in November 1994 near monitor #3 and provided limited bait removal from both tubes in January 1995 for an estimated total of 18g of bait removed (Fig. 14). Termite activity at monitor #3 was not affected and remained consistent with expected seasonal variations (Figs. 17 & 18).

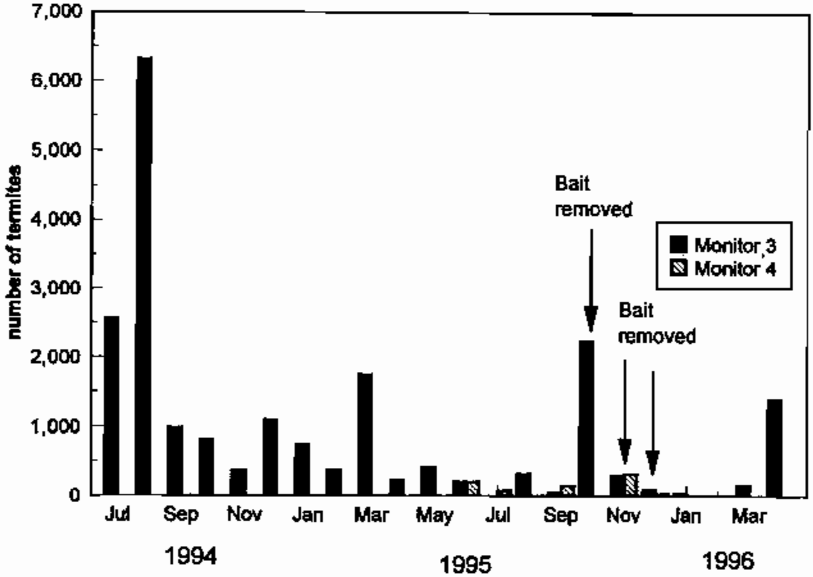


Fig. 12. The number of termites collected by monitor and month from *R. flaivpes* termites visiting monitors #3 and #4 during Case Study 3.

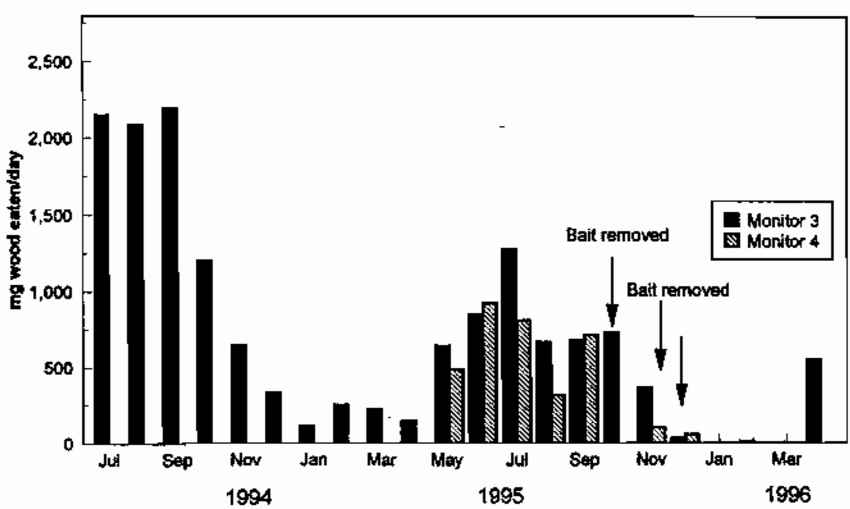


Fig. 13. Amount of wood consumed per day, in mg, by monitor and month from *R. flavipes* termites visiting monitors #3 and #4 during Case Study 3.

Although the average wood consumption rates for that colony in 1996 were below those recorded for 1995 the numbers of termites collected were not appreciably different. Activity at monitor #4 may have been reduced (Figs. 19 & 20). This could indicate the *R. virginicus* colony from

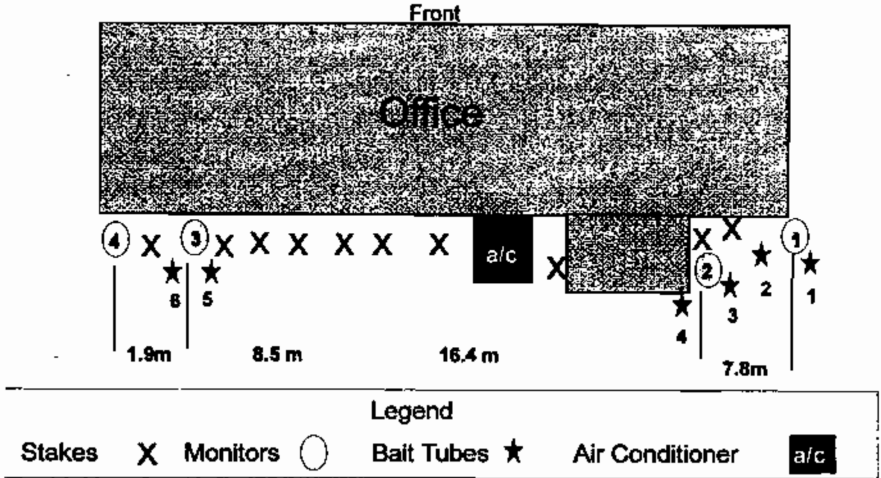


Fig. 14. Map of termite bait Case Study 4 test site from Sapelo Island, Georgia showing relative positions of the structure, wooden survey stakes, termite monitors, bait tubes and other features of the site.

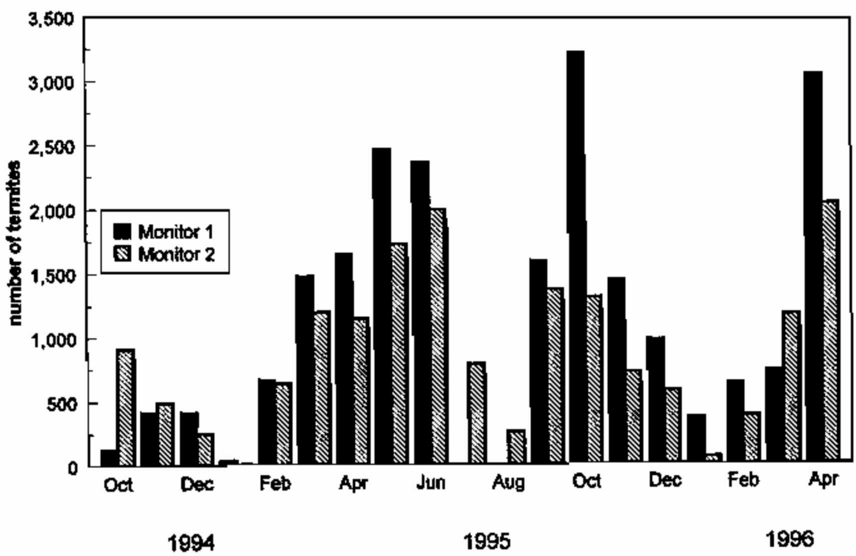


Fig. 15. The number of termites collected by monitor and month from *R. flaivpes* termites visiting monitors #1 and #2 during Case Study 4.

monitor #4 was responsible for the removal of bait from the centrifuge tubes placed nearmonitor #3. However, the erratic visitation at monitor #4 during the previous year obscures verification of a true reduction

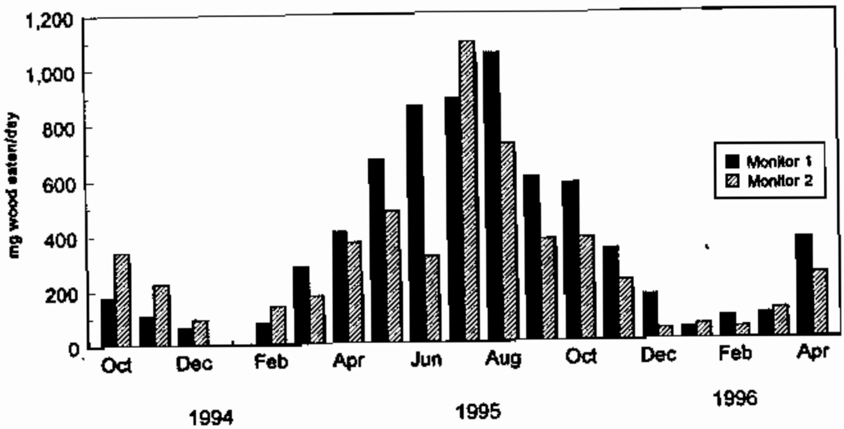


Fig. 16. Amount of wood consumed per day, in mg, by monitor and month from *R. flavipes* termites visiting monitors #1 and #2 during Case Study 4.

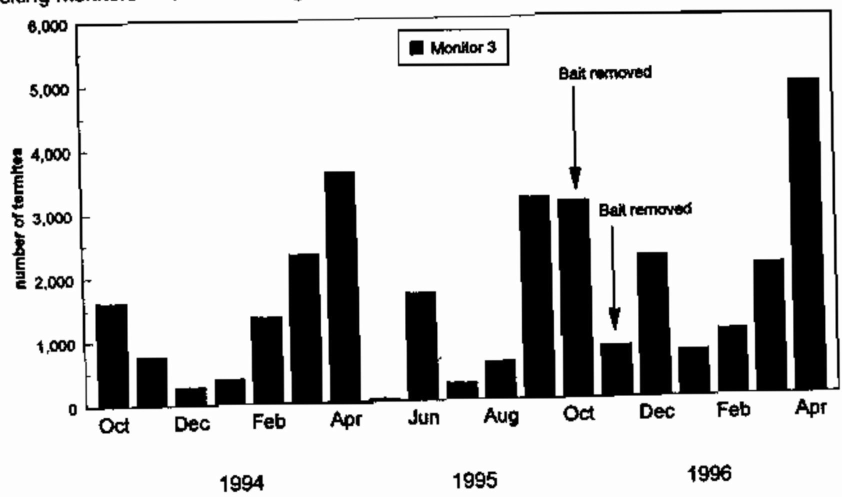


Fig. 17. The number of termites collected by monitor and month from *R. flaivpes* termites visiting monitor #3 during Case Study 4.

relative to bait removal (Figs. 19 & 20).

## DISCUSSION

These studies illustrate several of the problems associated with measuring the efficacy of termite baits in the field. Each of these case studies contains one or more situations where the cryptic biology of termites and the limitations of current research tools precludes definitive explanation. This necessitates conclusions drawn from experience in conjunction with measures of termite activity. Because termite

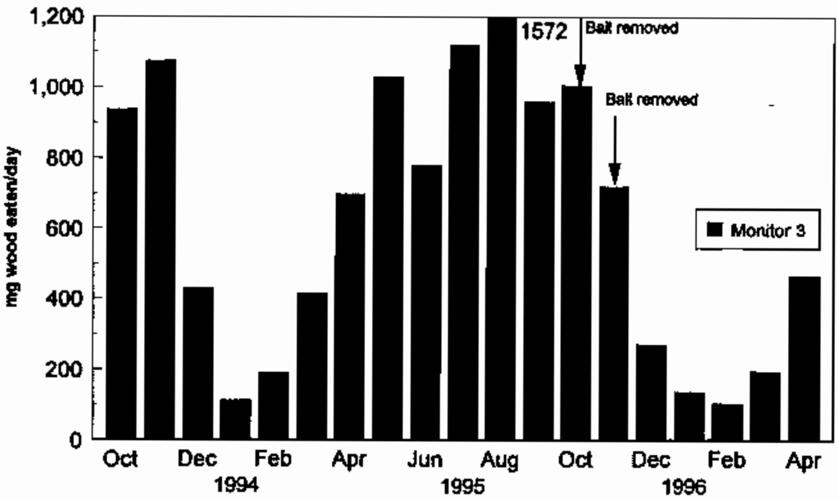


Fig. 18. Amount of wood consumed per day, in mg, by monitor and month from *R. flavipes* termites visiting monitor #3 during Case Study 4.

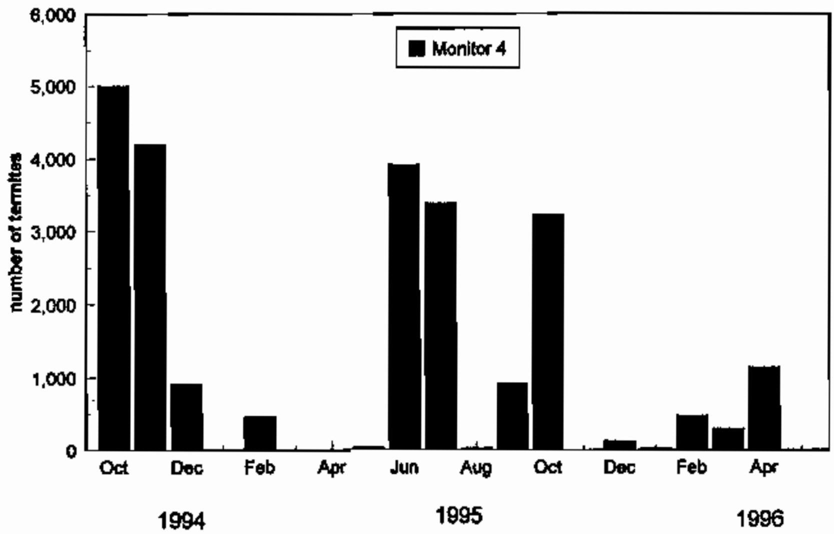


Fig. 19. The number of termites collected by monitor and month from *R. virginicus* termites visiting monitor #4 during Case Study 4.

colony activity also occurs outside of areas where termite activity can be measured, recording several indices of activity at more than one location can only assist in interpreting treatment effects.

Determination of termite bait efficacy from field trials should be based on the anticipated result. The basic premise of termite control is

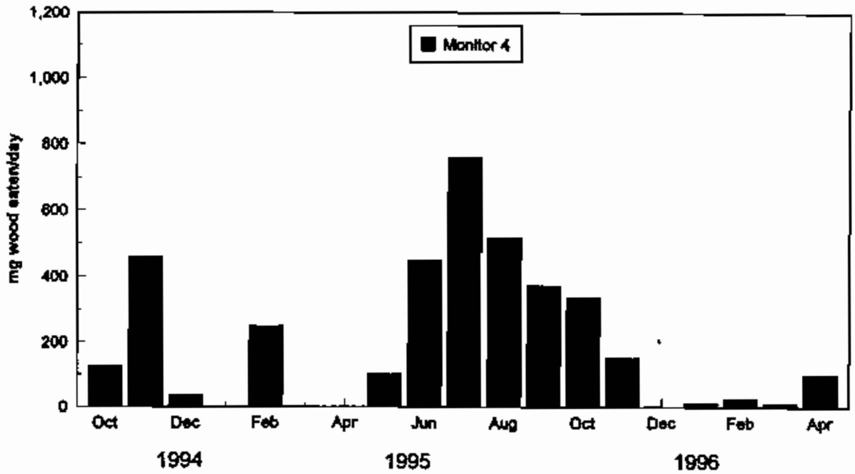


Fig. 20. Amount of wood consumed per day, in mg, by monitor and month from *R. virginicus* termites visiting monitor #4 during Case Study 4.

the prevention or removal of termite infestations - not necessarily colony impacts. Could baits be used to repel termites from a structure? Baits used in that context would simply be a remedial treatment and could be considered a valid use for termite treatment of an infested structure. Under the scheme of a repellent bait, measuring activity in the structure following bait application would indicate success if termites abandoned the structure.

Results from Case Study 1 could be considered successful control within the context of a repellent bait paradigm. Termites were observed infesting the structure. Baits were applied at several locations and bait consumption was recorded. Termites abandoned the structure and have not returned in two years. However, there is no other evidence for a cause and effect relationship between bait consumption and termite abandonment of the structure. Although the infestation was removed, we can not include this case as a scientifically validated successful use of a termite bait for remedial treatment because too many potential explanations for the observed reduction in activity in the structure are possible given the amount of data (presence or absence of termites) recorded at this site.

In Case Study 1, we were unable to establish whether termites observed at monitors near the structure were the same as those infesting the structure. Monitors near the structure remained active after baiting. Therefore, at least three very plausible explanations remain, none of which can be substantiated with the limited data collected. The possible explanations include; first, that the termites infesting the structure and the monitors were the same group of termites and the disturbance (breaking shelter tubes and drilling holes into infested lumber) associated with bait placement changed the status of the structure from an active to inactive feeding site. Second, termites infesting the structure were the same as those in the monitors and the baits killed enough termites to reduce the need for maintaining the structure as a feeding site for the remaining termites. Third, the termites in the structure and in the monitors were two different groups of termites and the baiting decimated or eliminated the group which was using the structure as their feeding site. However, the fact remains that termites abandoned the structure and this baiting could be viewed as a success from a commercial-applicator point of view.

Case Study 2 is easily concluded to be an unqualified failure of the use of a repellent bait. Most of the conditions, infested structural members, baiting infested lumber or termite shelter tubes, abamectin-cellulose bait, and unidentified location of the colony outside of the structure, were similar to Case Study 1. The major difference was the termite species involved (*R. virginicus* vs. *R. flavipes*). Termites at this infestation not only ignored baits placed along shelter tubes, as in Case Study 1, but they also did not consume baits placed into infested lumber. Because the termites in Case Study 2 did not accept the bait, this may suggest that different *Reticulitermes* species have different feeding substrate (bait) preferences. However, the limited data collected (presence or absence of termite activity at the baiting sites and in the structure) and short time frame of this study (6 months) preclude any explanation of this failure to remove termites from that structure.

As demonstrated by Case Studies 1 and 2, it has been my experience that *Reticulitermes* often ignore baits placed to intersect a shelter tube termite trail. A better understanding of termite behavior could help answer why the shelter tube bait placements were ignored in these studies. It could be that termites traveling in shelter tubes are following the trail signal and, if an obstruction is encountered, they react by reopening that trail and not stopping to feed (there is probably a separate signal that says feed). It is certain that termites communicate using chemical signals. Termite behavioral reaction to disruption of a shelter tube may be a repair response more often than a feeding response, each response elicited, in turn, by a different combination of environmental and chemical signals.

It also is possible that the bait in Case Studies 1 and 2 was not as preferred as the already established feeding sites in the structures. Therefore, a bait matrix with a feeding stimulant may have performed better or at least have provided evidence of termite feeding.

Laboratory studies on subterranean termite feeding preferences indicates that termites show preferences when given choices ( Behr *et al.* 1972, Delaplane & La Fage 1987, Waller 1988, Oi *et al.* 1996). This could mean that termite acceptance of baits will be erratic in the presence of alternate food sources, as will most certainly be the case in field situations. To reduce this source of variation, baits should compete with most known indigenous termite food substrates. Although the bait matrix used in these case studies consistently outperformed wood and cardboard in a series of laboratory choice tests, actual acceptance in the field was lower than expected. This lack of correlation between our lab and field results, highlights the need to combine laboratory and field studies of termite bait matrix preference.

In Case Studies 1 and 2 termite activity was measured as simple presence or absence of termite activity within an infested structure. These data could be considered sufficient if removal of termites from a structure were the goal of the baiting strategy. However, observing activity at the baiting site alone provides information confounded by shifts in colony activity unrelated to effects of the treatment on the termite population being baited. Interpreting a reduction in or elimination of a given termite colony would require measuring termite activity at and away from the baiting site to identify treatment effects. Measures of termite activity usually include the number of bait stakes attacked, numbers of termites collected, and/or amounts of food consumed at established termite monitoring stations or known feeding sites ( Beard 1974, Su 1994, Forschler & Ryder 1996). However, these measures of termite activity also warrant careful interpretation.

In research with *Reticulitermes* in Georgia we have found termite visitation to monitors is inconsistent and can be affected by numerous factors that are difficult to measure with any accuracy (Forschler & Townsend 1996). Both the numbers of termites collected and the monthly wood consumption rates by monitor from Case Studies 3-5 were included to illustrate this variability with our system of monitoring *Reticulitermes* activity. Another example of variable termite visitation to monitors involves the discontinuation of monitor use by termites. Approximately one third of the established monitors (active for 9 months during one calendar year) we have observed over the last three years have been abandoned (inactive for 12 consecutive months) by *Reticulitermes* colonies although they are handled the same as other monitors that remain active (Forschler, unpublished data). Therefore, data obtained from termite monitors must be viewed in the context of this variability and should be recorded from as many sites as possible for each separate colony.

The number of termites collected at monitors on the scheduled monthly visits offers only a fortuitous point-in-time picture of termite activity. It does not account for real time movement patterns which may be on a weekly or even daily schedule. Therefore, the number of termites collected during the monthly check of each monitor only gives information concerning termite activity at that time. The absence of termites does not indicate a reduction in colony activity but may only signify a shift in colony activity.

Food consumption rates provide a more continuous record of activity at a monitor. Termite food consumption is, however, subject to the same shifts in colony activity, as well as, weather-related and seasonal feeding patterns. As a result, measuring colony impacts should include both numbers of termites collected and feeding activity overan extended period of time, preferably one calendar year. Taken together, these measures can give a more complete picture of termite colony activity than either one alone. However, interpretation of these data in view of what we don't know about termite field biology is left to the researcher, or reader, based on the weight of information collected during the field study. Therefore, interpretation can only be assisted by accumulation of as much information from as many different sites from each colony.

Case Study 3 provided data on wood consumption and number of termites in monitors over several years, yet interpretation of the data is confounded by the question of how to track termite colony movements and use of monitors by the same colony of termites. In Case Study 3 termites were not observed in structural lumber but were observed only at termite monitors. It would appear that in Case Study 3 the colony was effected by the first baiting and may have split into two separate colonies. A portion of the colony may have moved several meters to stakes where monitors #3 and #4 were established. The appearance of one marked termite in monitors #5 and #6 would seem to indicate that it was the same group of termites which were using monitors #3 and #4 because that is the only location where marked termites were released. However, repeated spray paint marking of termites from both sets of monitors indicated that, after monitor establishment, these groups of termites remained separate.

Current research techniques for deliniation of foraging territories of subterranean termites are confined to use of mark-release-recapture techniques, agonism assays, spacial and temporal patterns, and comparisons of live body weights or soldier morphological characters (Grace 1990, Jones 1990, Su *et al.* 1993, Forschler 1994). Chemical or genetic markers would be useful independent measures for identifying groups of termites as members of the same colony. Definative determination of relatedness of termites within an area is impossible if activity shifts from exclusive use of one location to another, as in Case Study 3. Currently, the only techniques available, aside from mark-release-recapture, involve inferences based entirely on live body weights or soldier morphology. These measures can indicate similar species composition, but not actual functional colony associations.

In Case Study 3, when one marked termite appeared in a newly discovered site of termite activity, repeated mark-release-recaptures failed to verify the connection between the newly established site and the original mark-release site. Does this imply we were dealing with separate colonies? The wood consumption rates from Case Study 3 would seem to verify our assumption that there were two colonies present at that site, but how are we to interpret the appearance of that one marked termite in what was eventually considered a separate colony? There are several explanations which cannot be verified.

The first explanation is that we were dealing with one colony which actually split into two distinct functional colonies. The second is that the one marked termite wandered into another separate colony and was accepted and assimilated into the new colony. An additional explanation could be that movement of termites between separated feeding sites used by the same colony is not rapid and that the spray paint mark, which lasts only weeks, is not capable of verifying movement between feeding sites which occurs over a longer time frame.

For the sake of discussion, I have defined a termite field colony as that group of termites known to be visiting the same monitors as indicated by mark-release-recapture techniques (using both fat soluble dyes and topical spray paint marks in combination). This definition has been tested over the last 4 years in our field studies and independently verified by baiting, morphological comparisons, and agonism assays to the point that I feel confident these mark-release-recapture techniques are, in most instances, reliable indicators of monitor use patterns. However, as illustrated by Case Study 3, mark-release-recapture techniques are inadequate as definitive scientific proof of termite colony associations given our lack of knowledge about termite field biology.

Case Study 4 utilized zinc borate hydrate baits placed into the ground near monitors known to be visited by a single colony of termites. At this site, repeated mark-release-recapture episodes consistently verified the use of these monitors by a single groupof *R. flavipes*. The data collected at this site showed bait consumption coincided with a shift in the location of activity by that colony of termites. Evidence of bait removal was recorded at bait tubes 5 and 6 between monitors #3 and #4 during October and November 1995, after which, activity at monitor #4 (nearest those bait tubes but furthest from the other monitors known to be used by that colony) was reduced to zero (Figs. 9 & 12-13). This seems to indicate that the termites where killed at or near the bait sites and that the remaining termites simply avoided those areas for several months thereafter. This phenomenon can be demonstrated with both abamectin and zinc borate hydrate baits in the laboratory. In laboratory assays with the aforementioned active ingredients, termite mortality occurs at or near the bait site, not throughout the entire test arena, and termite activity in that region of the arena ceases until the cadavers decompose.

Case Study 3 was similar because bait consumption corresponded with a lack of activity near the bait site and a shift of that activity away from the bait site was recorded coincident with bait removal. If termite visitation to a feeding site involves stays of days or weeks, termites feeding at a bait site would die at the baiting site when the time frame for expression of lethal effects was shorter than the pattern of movement between feeding sites.

Alternatively, Case Study 5 shows that termites can consume relatively large quantities of zinc borate hydrate bait and remain active at nearby monitors despite expected detrimental effects. This site consisted of three termite colonies behind a single structure. There were two separate *R. flavipes* colonies, one visiting monitors #1 and #2 and another at #3. The termites at monitor #4 were another species, *R. virginicus*. There were indications that activity at monitor #4 (the *R. virginicus* colony) was reduced following bait removal, but there was no way to verify bait acceptance by this colony at bait tubes located near the *R. flavipes* colony in monitor #3. Bait placements were made in close proximity to active monitors assuming that the termites in that monitor would be the first to locate and feed on the bait. However, it could have been another, unidentified group of termites that removed the bait. This Case Study illustrates the problem of verifying colony participation in bait removal. Perhaps additives which mark termites that have fed on baits could be developed for such a purpose.

The colony known to be visiting monitors #1 and #2 in Case Study five did not remove any bait from tubes placed near those monitors. This colony may have been content with the food provided at the monitors or the baits could have been less preferred and were therefore not accepted. This site is another example of the advantage that a preferred bait substrate or one with a feeding stimulant could provide when attempting to bait a subterranean termite colony. The fact that termite baits will be in competition with alternate feeding sites points out the need to provide the best possible food resource to the termites you are attempting to bait.

The amount of information recorded during a field trial of termite bait efficacy becomes a question essential to establishing proof of a cause and effect. Currently there are several measures of termite activity which can be recorded. Techniques used to estimate the number of termite foragers in a field colony does not provide adequateresolution to provide valid scientific evidence of change within a subterranean termite colony (Thorne *et al.* 1996). Current mark-release-recapture techniques are limited in verifying occurrance of colony formation by fractionation, competetive takeover of feeding sites, or colony merger. The amount of feeding substrate consumed is subject to seasonal and weather related variation and the number of termites collected provides only a limited view of activity. Each of these measures of subterranean termite activity requires long-term data collection to establish colony specific, seasonal, and weather related activity patterns before definitive colony impacts can be accessed. In addition, verification of colony impacts from a termite baiting treatment requires monitoring activity at and away from the baiting site from as many different locations as is feasible for each site.

These studies illustrate the need for a better understanding of termite biology in different habitats and identification of species food preference from field experiments. More information also is needed to identify behavioral differences which may impact termite baiting strategies. Better taxonomic tools for species determination using worker or soldier castes also would aid in these studies. A chemical or genetic colony marker would be an invaluable tool for the study of *Reticulitermes* field biology. Agreement on a definition of what constitutes a termite colony in the field also would assist in assessing termite bait efficacy. Given the techniques currently available for the study of termite biology in the field and the variable nature of termite colony reaction to monitor visitation, field studies of termite bait efficacy should include several baiting and control sites (untreated termite colonies) to properly assess colony effects. In conclusion, these limited case studies indicate that baiting with either abamectin or zinc borate hydrate termite baits will affect only a portion of the colony and usually shift termite activity away from the bait site. This may indicate the utility of these materials as repellent termite baits. However, the unreliability of termite detection technologies limit real-world use of repellent baits by the termite control industry. Accurate and objective termite detection tools are needed to assist in the implementation of new termite control technologies like baiting strategies. Simply moving termite activity away from a baiting site may result in a shift of activity to another part of the structure.

Using this same logic, it also is clear that elimination or reduction of termite colonies in areas of high termite population densities cannot guarantee against shifts in other colony activity into the vacated territory. Therefore, implementation of a termite baiting control program must be centered around a termite monitoring program.

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