CONTROL OF FORMOSAN SUBTERRANEAN TERMITE INFESTATIONS USING BAITS CONTAINING AN INSECT GROWTH REGULATOR

Nan-Yao Su, Edward Freytag, Edgar S. Bordes and Roman Dycus

Summary—*Baits containing an insect growth regulator, hexaflumuron, were used in the historic Presbytere and the Creole House of the Cabildo, in the French Quarter of New Orleans, Louisiana, to control infestations of the Formosan subterranean termite, Coptotermes formosanus Shiraki. As with many historic structures in the French Quarter, these two landmarks have sustained chronic infestations by C. formosanus for the last three decades. Baits were applied using both above-ground and in-ground stations between late 1996 and early 1997. Termite activity was monitored using an acoustic emission detector and in-ground monitoring stations. After consuming ≈0.4-1g hexaflumuron during the three to nine month baiting period, the target populations of C. formosanus in these two buildings were eliminated. No dispersal flights were observed in the springs of 1997 and 1998 from these historic buildings.*

Introduction

St Louis Cathedral is perhaps the most prominent structure facing Jackson Square in the French Quarter of New Orleans, Louisiana. To the southwest of the cathedral is the Cabildo, which was built between 1795 and 1799 to house Louisiana's Spanish governing council (Figure 1). The mansard roof of the Cabildo is the oldest example of Second Empire architecture in the United States [1]. In 1803. the Louisiana Purchase was signed in the Cabildo's council chamber, or Sala Capitular. To the northeast of the cathedral stands the Presbytere (Figure 1), which was built between 1791 and 1813 as a residence for the Capuchin monks, but was never used as such [2]. In 1819, when the noted architect, B.H. Latrobe visited New Orleans, he wrote in his *Impressions Respecting New Orleans*, 'The public square [Jackson Square], which is open to the river, has an admirable general effect, and is infinitely superior to anything in our Atlantic cities as a water view of the city .... The whole of the side parallel to the river is occupied by the Cathedral in the center and by two symmetrical buildings on each side. That to the West is called the Principal [Cabildo], ... That on the East is called the Presbyter[y] ...' [1]. As in the days of Latrobe, these three imposing buildings today form magnificent landmarks facing Jackson Square.

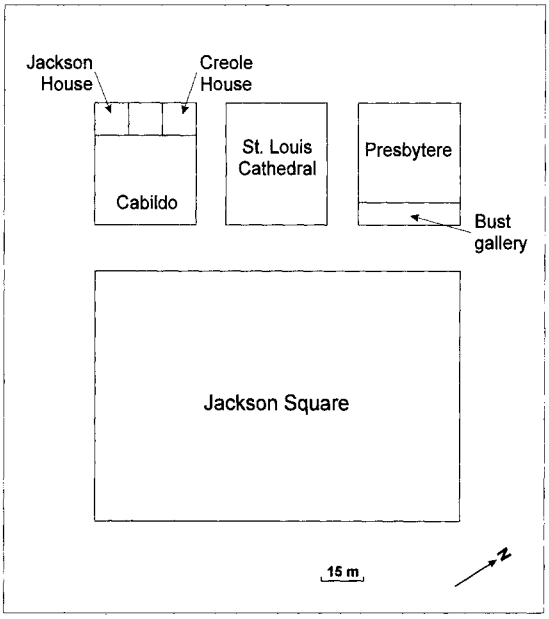

Figure 1. Relative positions of the Cabildo (including Creole House and Jackson House), St Louis Cathedral, and the Presbytere (and the Bust Gallery) in relation to Jackson Square.

Indigenous to southern China, the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, is the most destructive termite species wherever it occurs [3]. It was discovered in the United States in the late 1950s in coastal ports such

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as Charleston, South Carolina, Houston, Texas, and Lake Charles and New Orleans, Louisiana. Currently *C. formosanus* is found in most of the states of the southeastern United States. Of these locations, New Orleans is especially heavily infested by this aggressive termite pest, and the damage to the historic French Quarter is particularly alarming because of the abundance of wood used in the old structures and the irreplaceable nature of these historic landmarks [4].

As with many structures in the French Quarter, *C. formosanus* infestations in the Presbytere and the Cabildo probably started as early as the 1960s [5]. On several occasions since the 1970s, the walls and ground floors of the Presbytere and the Cabildo were drilled and injected with liquid insecticide to treat *C. formosanus* infestations [6]. Drill marks on these historic buildings are vivid reminders of past efforts to protect the structures from *C. formosanus* infestations. Despite such repeated treatments, *C. formosanus* continued to cause damage to these buildings. One year after devastation by fire, the restoration of the Cabildo began in 1989. During the restoration project, most of the floor joists in the Cabildo were found to be totally excavated from the brick walls by *C. formosanus*, and steel supports had to be installed to maintain structural integrity. In 1993, a large number of *C. formosanus* alates swarmed during a reception in the Quarter Guardroom of the Cabildo. In 1995, additional *C. formosanus* infestations were found in wooden floors of the Bust Gallery of the Presbytere and the Creole House of the Cabildo complex (Figure 1). The Creole House, located in the northern portion of the complex, and the Jackson House (western portion), occupy a site behind the Corps de Grade (police station) which was the forerunner of the Cabildo. During the Spanish colonial period in the 1760s, the site was occupied by a *calabozo*, or prison.

Insecticidal barrier treatment has been the most commonly used method for subterranean termite control for the last half century. A large quantity of liquid insecticide is applied into trenches and drill holes in an attempt to drench the soil beneath and surrounding an infested building to create a barrier for the exclusion of soil-borne termites. An uninterrupted barrier of treated soil is extremely difficult to produce beneath an existing structure. Because a single colony of *C. formosanus* may contain up to several million termites that forage up to 100 meters in search of food, and large proportions of termites are usually unaffected by soil insecticide treatments [7], re-infestations are inevitable, as has been demonstrated by the experience of many structures in the French Quarter.

In recent years, baits containing the insect growth regulator, hexaflumuron, have been successfully used to eliminate subterranean termite populations in and/or near structures [8-13]. Applications of hexaflumuron baits in historic landmarks such as the Statue of Liberty National Monument demonstrated that subterranean termite populations could be eliminated with minimum disruption to historic landscapes [14]. At the request of the Louisiana State Museum, this project was initiated to control *C. formosanus* infestations in the Cabildo and Presbytere using baits containing hexaflumuron.

Materials and methods

Survey of termite population and activity in the Presbytere and Cabildo

Visual inspections conducted in the spring of 1996 revealed live termite activity in wooden (bald cypress, *Taxodium distichum* (L.) Rich) floor panels of the Bust Gallery on the second floor of the Presbytere and in similar wooden floor members of the second floor of the Creole House in the Cabildo.

Termite activity in these wooden floors was quantified using an acoustic emission detector (AED) as described by Scheffrahn *et al.* [15]. The detector consisted of a main

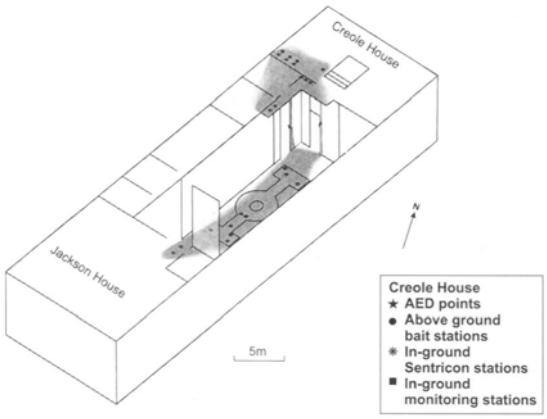

Figure 3. Foraging territory (shaded area) of a C. formosanus colony extended from the Jackson House entrance to the courtyard and the second floor of the Creole House of the Cabildo complex, as determined by a mark-recapture procedure.

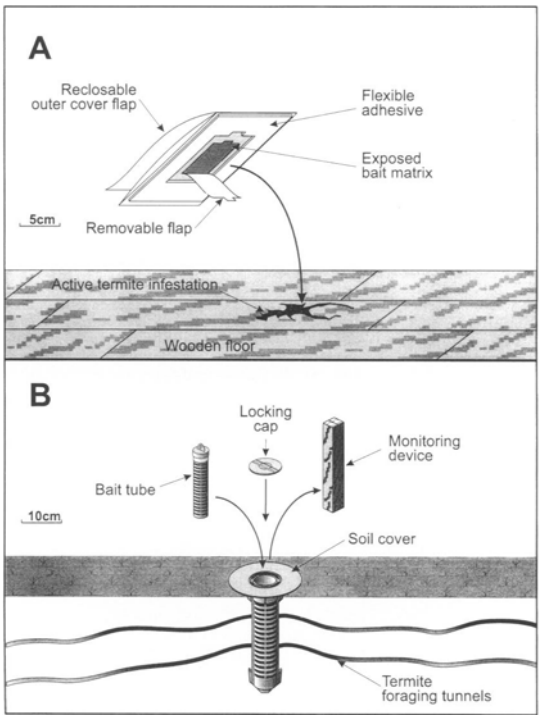

Figure 3. Above-ground bait stations consisting of a flexible laminated pouch containing 15g of 0.5% hexaflumuron bait (A) were placed directly over active infestations of C. formosanus in the wooden floors of the Bust Gallery of the Presbytere and the second floor of the Creole House. In-ground (Sentricon) stations were placed in the soil of the Creole House courtyard to detect termites and deliver hexaflumuron baits (B).

processor compartment (10 × 19 × 3cm) connected by coaxial cables to two resonant acoustic emission sensors. An AED recorded soundwaves of ultrasonic frequency (>20kHz) that were generated when wooden fibers were broken by termite mandibles. Termite feeding activity inside wood was measured at ≈1m intervals along the longitudinally oriented grain of each wood panel of these floors. AED-generated counts recorded during one-minute intervals were plotted using SURFER [16], a grid-based contouring surface plotting graphic software, to represent spatial distribution of termite feeding activity in the wooden floors as a whole.

A stake survey [17] was conducted in the soil of a planter (2.5 × 10m) in the courtyard next to the Creole House (Figure 2). A palm tree in the southern portion of the planter was heavily infested with *C. formosanus*. Spruce stakes (*Picea* sp., 2.5 × 4 × 28cm) were driven into the soil at 3m intervals and were examined monthly to detect termite activity. In-ground monitoring stations were composed of pre-weighed wooden blocks (six pine boards, 7 × 13 × 2cm, nailed together so that four were stacked atop each other and two were attached to the resulting 8cm sides) surrounded by plastic collars (17cm diameter, 15cm high), as described by Su and Scheffrahn [17]. These monitoring stations were placed in the planter soil where termite activity was detected by the stake survey, and were checked biweekly or monthly. Infested wooden blocks were washed to remove debris, dried at 80°C for 48 hours, and cooled in a desiccator before re-weighing to determine the wood consumption rate (mg wood consumed per station per day).

A triple mark-recapture program [7] was done to estimate the foraging territory and population size of the *C. formosanus* colony found in the courtyard of the Creole House. *Coptotermes formosanus* workers collected from a station with heavy activity (>5000 termites collected) were stained with 0.05% (wt/wt) Nile Blue A [18] for three days before being released back to the same station. Monitoring stations in the planters were collected one week after the release. Termites

collected from stations containing marked termites were counted and again stained and released to their respective stations. The mark-release-recapture cycle was repeated three times. The numbers of marked and unmarked workers were recorded for each cycle. A weighted mean model [19] was used to estimate the foraging population and associated standard error. Foraging territories of colonies, defined as the areas encompassed by interconnected stations, were determined by the presence of marked termites.

Applications of hexaflumuron baits

Above-ground bait stations consisted of a flexible laminated pouch containing 15g of 0.5% hexaflumuron bait (Figure 3, A). These were applied in the Bust Gallery of the Presbytere and the second floor of the Creole House to deliver hexaflumuron to termites foraging there. On the front side of the station was a re-closable outer cover flap and on the back was a removable flap surrounded by a 3.5cm-wide collar of flexible adhesive. In the presence of an active infestation, the removable flap was pulled to expose the bait matrix. The exposed bait matrix was moistened with 30-40cm^3 water before being attached over an active infestation using the flexible adhesive so that it was accessible to foraging termites. In addition to visual inspection and manual probing, AED was used to determine sites of termite activity for placement of additional aboveground bait stations. An access hole (≈4mm diameter) was drilled into wood where the AED located termite feeding, to intercept an internal termite gallery. When *C. formosanus* soldiers appeared in the access hole to confirm the presence of live termites in the intercepted gallery, an above-ground bait station was placed directly over the hole. The station was inspected bi-weekly or monthly. When bait was substantially consumed (>50% by visual estimate), the re-closable outer cover flap was removed, and another station was stacked over the old station so that additional bait was available to termites.

In-ground (Sentricon, Dow AgroSciences) stations were used in the courtyard of the Creole House for delivery of hexaflumuron baits. The in-ground station was composed of a plastic tube on which four columns of 16 rectangular slots each were provided along the entire surface of the tube (Figure 3B). A soil cover made of a plastic ring was affixed to the open end of the housing, and a locking cap was screwed to cover the opening. Stations were inserted in the courtyard planter with soil covers level with the ground surface. A monitoring device (two pieces of wooden slat) was placed in each station before the locking cap was attached (Figure 3B). Stations were inspected monthly or bimonthly to examine termite activity. When termites were found in a station, the monitoring device was replaced with a plastic tube containing 20g bait matrix (0.5% hexaflumuron). Bait tubes that were substantially consumed by termites (>50% by visual estimate) were replaced with new tubes.

At the conclusion of bait application, when termite activity ceased, all above-ground bait stationswere removed. The partially consumed baits were cleaned of soil debris, dried at 60°C for 48 hours, and cooled in a desiccator before re-weighing to determine bait consumption by termites. Bait tubes in the in-ground Sentricon stations were replaced with monitoring devices to detect potential re-infestation.

Results and discussion

Bust Gallery of the Presbytere

The AED located two loci of *C. formosanus* feeding activities in the Bust Gallery on 5 September 1996 (Figure 4). Two weeks after installing nine aboveground stations on 18 September, termite activity in the wooden floor was substantially reduced, but termites were found actively feeding in six bait stations (Figures 4 and 5). Termite feeding activity in the southwestern end of the gallery had been low since 18 September, while activity in the wooden floor in the northeastern corner persisted until 14 October (Figures 4 and 5). On 12 November, termite feeding in the wooden floor of the Bust Gallery ceased, but *C. formosanus* continued to feed on baits in four above-ground stations (Figure 5). Since December 1996, no termite activity has been detected in the wooden floor or in the stations. Termite feeding on the baits lasted three months, during which time a total of 24 above-ground bait stations were used. Termite activity was eliminated after consuming ≈165.8g of bait during the baiting period (Table 1). Although interconnection of the two activity loci in the wooden floor of the Bust Gallery was not confirmed by the mark-recapture procedure, the similarity in body weight of workers (≈3.5mg) collected from these two infestations suggested that they probably belonged to a single colony. A typical colony of *C. formosanus* may forage up to 100m [7], which would have encompassed the entire length of the gallery. The simultaneous cessation of these two termite activity loci also suggests that the *C. formosanus* colony that caused the infestation was eliminated after consuming ≈825.8mg of hexaflumuron (Table 1).

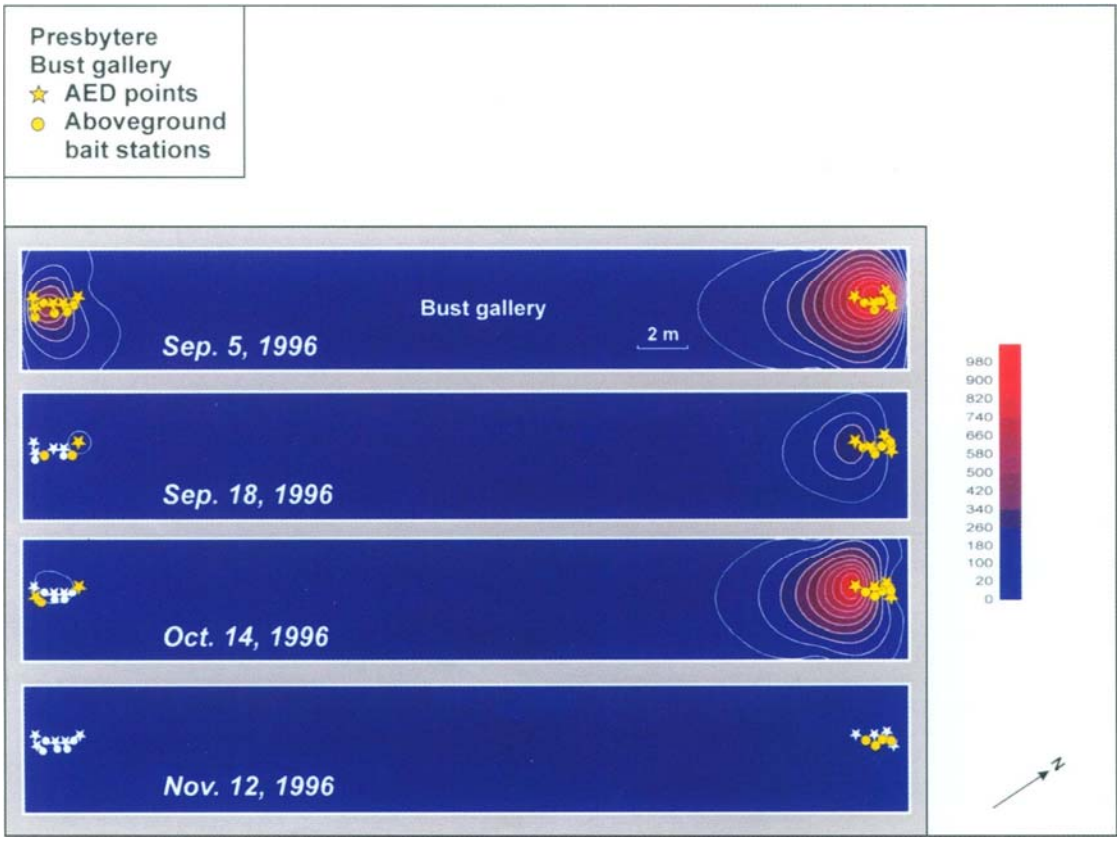

Figure 4. Spatial depiction of C. formosanus feeding activity in the wooden floor of the Bust Gallery of the Presbytere during the baiting period. Stars give positions from which acoustic emission counts were taken and circles represent above-ground bait stations. Symbol colors depict the presence (yellow) and absence (white) of termite activity. Color bar and associated numbers represent AED count per minute.

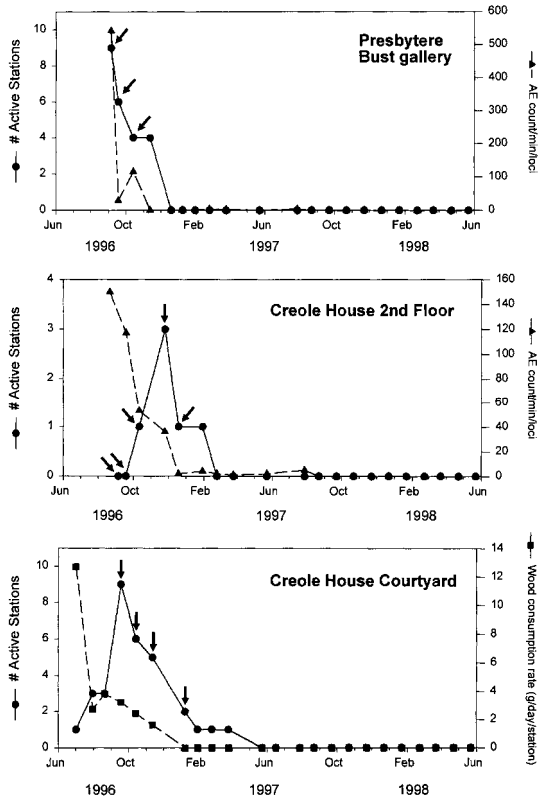

Figure 5. Coptotermes formosanus activities quantified by the number of both monitoring and baiting stations with live termites (circles with solid lines), acoustic emission counts (triangles with dashed line), and wood consumption rates (squares with dashed line) in the Bust Gallery of the Presbytere and the Creole House of the Cabildo. Arrows depict applications of baits containing 0.5% hexaflumuron.

Creole House of the Cabildo

Coptotermes formosanus activity was found throughout the planter in the courtyard of the Creole House. The AED also detected termite feeding activity in the wooden floor near the entrance of the Jackson House and in the door frames near the northern corner of the courtyard (Figure 2). Marked termites released in one of the in-ground monitoring stations in the planter soil appeared in several of the above-ground bait stations placed on the wooden floor of the second floor of the Creole House, thus confirming the interconnection of these two infestations. It appeared that the foraging territory of this *C. formosanus* colony, with an estimated population of 777,089 ± 53,372 (SE) foragers, extended from the ground floor of the Jackson House and courtyard to the second floor of the Creole House (shaded area, Figure 2). Old damage, suspected to be caused by this *C. formosanus* colony, was found in many wooden structures in the Creole House, including wooden joists, trusses, and staircases.

Termite feeding was most extensive in the wooden balcony of the second floor of the Creole House when acoustic emission counts were measured on 20 August 1996 (Figure 6). Several aboveground bait stations were placed over active infestations in September, but termites did not start feeding on baits until 11 October. By 12 November, termites were actively feeding on baits in the three above-ground stations, and the termite activity in structural wood had declined (Figures 5 and 6). This tendency of increased termite feeding in bait stations with the decrease of termite activity in structural wood was similar to that observed in the Bust Gallery of the Presbytere (Figures 4 and 5). By 19 December, only negligible numbers of acoustic emission counts were recorded from the wooden floor, and termites found in the bait stations exhibited apparent symptoms of hexaflumuron intoxication such as sluggish movement and marbled coloration [14]. Since March 1997, no termite has been found on the second floor of the Creole House (Figures 5 and 6). A total of 10 aboveground bait stations were

Table 1. Summary of bait applications to control C. formosanus populations

Site*	Bait type†	No. bait tube used	No. AG station used	Bait matrix consumed (g)	AI consumed (mg)	Period baited (mo)
PRB	A	—	24	165.8	828.8	3
CR2	A	—	10	78.0	390.0	6
CRC	G	15	—	205.0	1025.0	9

*PRB = Bust Gallery of the Presbytere, CR2 = the second floor and CRC = the courtyard of the Creole House in the Cabildo, New Orleans, Louisiana.

†A = above-ground bait station, G = in-ground Sentricon station.

used in the Creole House during the six-month baiting period, during which 78g of bait matrix (and 390mg hexaflumuron) were consumed by the *C. formosanus* population on the second floor (Table 1).

Coptotermes formosanus fed extensively (≈13g/day/station) on the first wooden block in the in-ground monitoring station placed in the courtyard in July 1996 (Figure 6). This feeding rate declined to ≈2-3g/day/station when two additional stations were placed in the planter soil in August. On a windy day in late August, the termite-infested palm tree in the planter fell and the termite-laden tree was removed, but *C. formosanus* remained active in all stations. Following the detection of *C. formosanus* in several Sentricon stations in September, baits were introduced and termite activity gradually declined. By January 1997, no termite feeding was recorded in any of the in-ground monitoring stations in the courtyard, but termites continued to feed on hexaflumuron baits in some other Sentricon stations at the site (Figure 6). Between February and April 1997, only one Sentricon station contained *C. formosanus* workers, and these workers showed apparent symptoms of hexaflumuron intoxication. Since June 1997, no termites have been found in the courtyard. A nine-month baiting period and 15 bait tubes were required to eliminate termite activity in the courtyard, during which a total of 205g bait matrix (≈1025mg hexaflumuron) was consumed. Because the termites in the courtyard and those found in the second floor of the Creole House belonged to the same colony, we believe the *C. formosanus* colony of ≈777,000 foragers was eliminated after consuming a total of 1425mg hexaflumuron (Table 1).

Conclusions

According to the maintenance manager, M.B. Weber of the Louisiana State Museum, the spring of 1997 was the first time in 15 years that *C. formosanus* did not swarm in the Presbytere or the Cabildo. Before this project, baits containing hexaflumuron were used in 1995 and 1996 to control *C. formosanus* populations in Jackson Square and the nearby Upper Pontalba building [20]. A population survey of *C. formosanus* was conducted for the entire French Quarter in the spring of 1998 using sticky traps placed under street lights to catch swarming termites [4]. The survey results indicated a significantly lower catch in traps placed near Jackson Square than in those placed in any other part of the French Quarter [21]. The baiting done in 1995-96 in Jackson Square [20], as well as those reported in this study in the Cabildo and the Presbytere, probably contributed to the population reduction of *C. formosanus* surrounding the Jackson Square, as no other treatment programs were conducted there during this time.

As repeatedly demonstrated by many field evaluation studies, subterranean termite colonies that received hexaflumuron baits were suppressed to the point of inactivity or 'functionally eliminated' [8-14, 20]. As with the cases of the Presbytere and the Cabildo, most of these field sites had histories of chronic termite infestations. A direct observation to confirm the death of all termites in a subterranean colony may be difficult to accomplish, but the prolonged absence of termite activity in soil previously occupied by one or more persistent foraging populations presents strong evidence that the baited populations or colonies have probably been eliminated [22].

As shown from our results, after consuming 1-2kg of hexaflumuron, *C. formosanus* populations were eliminated from these two historic buildings. Our baiting program provided better results than previous soil barrier treatments that typically used >10kg of insecticide. A baiting program is also less intrusive than the soil barrier approach, which is an important consideration for historic landscapes. Because the city of New Orleans, and especially the French Quarter, is heavily infested with *C. formosanus* populations [4], the termite-free zones created by the applications of hexaflumuron baits may eventually be invaded by nearby populations. A rigorous monitoring program must be continued to protect these historic landmarks from re-infestation by this destructive pest.

Acknowledgements

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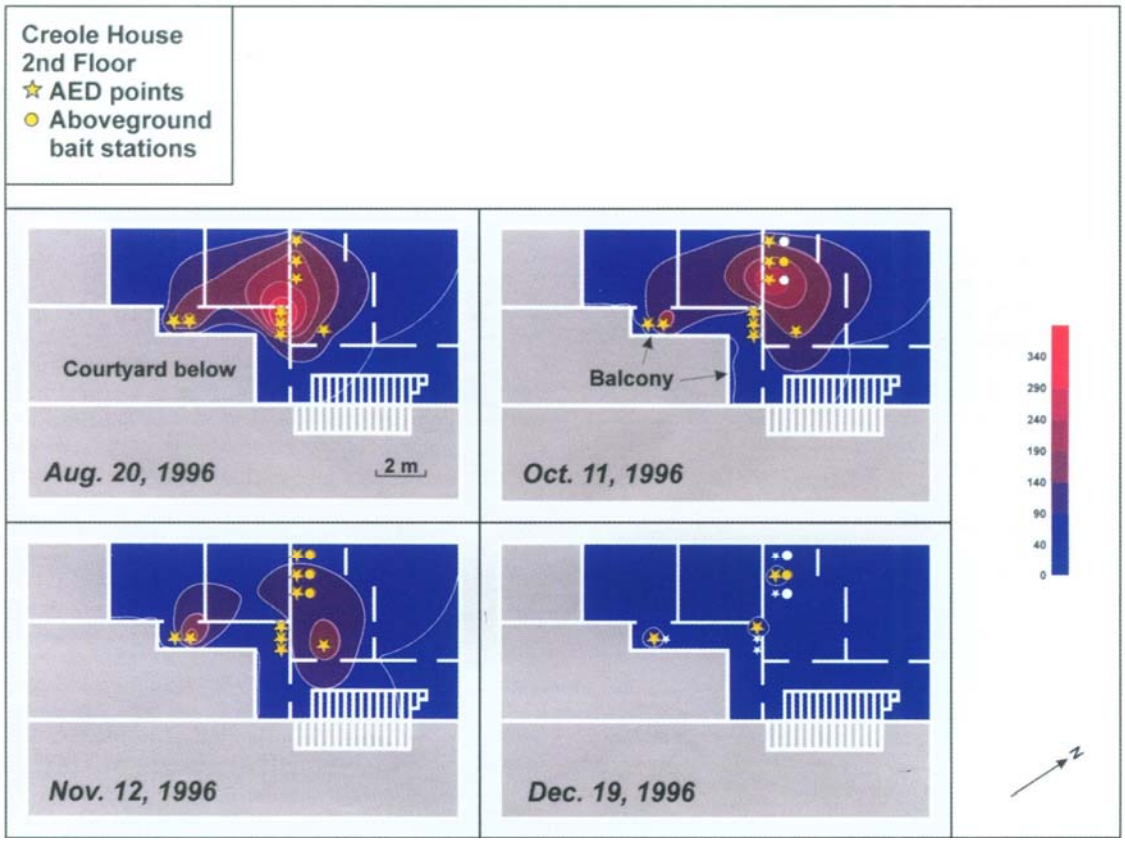

Figure 6. Spatial depiction of C. formosanus feeding activity in the wooden floor of the second floor of the Creole House during the baiting period. Stars give positions from which acoustic emission counts were taken and circles represent above-ground bait stations. Symbol colors depict the presence (yellow) and absence (white) of termite activity. Color bar and associated numbers represent AED count per minute.

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Résumé—*Des pièges-appats contenant un régulateur de croissance des insectes ont été utilisés au Presbytère et à la Maison Créole de Cabildo, dans le quartier français de la Nouvelle Orléans, en Louisiane, afin de contrôler les infestations du termite souterrain de Formose, Coptotermes formosanus Shiraki. Comme c'est souvent le cas dans les structures historiques du quartier français, ces deux édifices ont subi des infestations chroniques entre la fin 1996 et le début 1997. L'activité des termites était contrôlée au moyen d'un détecteur d'émission acoustique et par des stations de contrôles enfouies dans le sol. Après avoir consommé environ 0,4 à 1 g d'hexaflumuron durant une période de 3 à 9 mois de piégeage, les populations cibles de C. formosanus présentes dans les deux immeubles ont été éliminées. On n'a pas observé de vols d'essaimage à partir de ces édifices aux printemps 1997 ni 1998.*

Zusammenfassung—*Hexaflumuron, ein Wirkstoff zur Wachstumskontrolle von Insekten, ist in Lockstoffen enthalten, die in dem historischen Presbyterium und dem Kreolischen Haus der Cabildo im französischen Bezirk von New Orleans in den USA zur Kontrolle des Befalles mit Formosa-Termiten (Coptotermes formosanus Shiraki) dienen. Wie viele der historischen Hinterlassenschaften in New Orleans waren diese beiden Wahrzeichen in den letzten drei Jahrzehnten einem chronischen Befall mit Formosa-Termiten ausgesetzt. Zwischen Ende 1996 und Anfang 1997 wurden über- und unterirdisch die oben beschriebenen Köder aufgestellt. Die Aktivität der Termiten wurde mit einem Schallemissionsdetektor und mit unterirdischen Beobachtungsstationen überwacht. Nach dem Verzehr von 0.4-1.0g Hexaflumuron während der drei- bis neunmonatigen Köderperiode waren die gezielt bekämpften Populationen der Formosa-Termiten in den beiden Gebäuden beseitigt. Zu Beginn der Jahre 1997 und 1998 konnte keine Verbreitung der Insekten aus den beiden genannten Gebäuden beobachtet werden.*

Resumen—*Un regulador de crecimiento de insectos, hexaflumurona, contenido en cebos, fué usado en el Presbytere y en la Creole House del Cabildo, del French Quarter de Nueva Orleans, Louisiana, con el fin de controlar las plagas de la termita subterránea de Formosa, Coptotermes formosanus Shiraki. Como en muchas de las construcciones históricas del French Quarter, estos dos edificios prominentes han padecido infestaciones crónicas de C. formosanus durante las tres últimas décadas. Los cebos se colocaron en sitios sobre el terreno y dentro del terreno entre finales de 1996 y principios de 1997. La actividad de las termitas se monitorizó usando un detector de emisión acústica y estaciones de monitorización dentro del terreno. Después de ser consumido ≈0.4-1g de hexaflumurona durante los 3-9 meses de periodo de los cebos, las poblaciones a tratar de C. formosanus en estos dos edificios fueron eliminadas. No se detectaron vuelos de dispersión en las primaveras de 1997 y 1998 en estos edificios históricos.*