Population Ecology and Movement of the American Cockroach (Dictyoptera: Blattidae) in Sewers

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J. Med. Entomol. 48(4): 797–805 (2011); DOI: 10.1603/ME10255

ABSTRACT The population size, age-class structure, and movement of the American cockroach, *Periplaneta americana* (L.) (Dictyoptera: Blattidae), were studied in three sewers in Penang, Malaysia, from September 2008 to October 2009. Eighteen to 20 glass-jar traps (two per manhole) were deployed for a 24-h period during each sampling occasion at each sewer. Adults and nymphs were active throughout the study period, with an average monthly trap catch of 57–97 adults and 79–99 nymphs. The mean proportions of adults and nymphs at the three sewers ranged from 0.47 to 0.57. Of the 2,177 male and 2,717 female cockroaches marked and released over the three sewers, recapture rates were 29.4–45.8 and 30.8–47.0%, respectively. The proportion of marked males and females did not differ significantly from the proportion of recaptured marked males and females. However, the mean number of times a marked female was recaptured was significantly greater than that of males. Of the 783 males and 1,030 females that were marked and recaptured, 19.4 and 24.7%, respectively, had moved between manholes, and significantly more females than males moved between manholes. Of the 406 recaptured marked adults that moved between manholes, 90.4% moved a distance of 2–20 m from their initial release site; one male moved 192 m, the longest distance recorded. Trap catch on each sampling occasion was positively correlated with daily mean temperature. The number of cockroach movements between manholes also was correlated with the mean daily minimum temperature.

KEY WORDS *Periplaneta americana*, sewage system, population ecology, age-class structure, mark–recapture

The American cockroach, *Periplaneta americana* (L.) (Dictyoptera: Blattidae), is an insect pest of great medical and economic importance. Besides leaving stains and an unpleasant odor, *P. americana* is a potential mechanical vector of various pathogenic organisms, and it contains allergens that may responsible for allergies and asthma (Roth and Willis 1957, 1960; Gore and Schal 2007; Rust 2008; Lee and Ng 2009). In Southeast Asia, *P. americana* is a predominant domiciliary pest cockroach, and it also is able to thrive in large numbers in outdoor environments such as sewers and bin chutes, where conditions are favorable for its development (Lee and Lee 2000, Lee 2007, Lee and Ng 2009).

Concerns about the close association of *P. americana* with human wastes and the potential for this pest to be a carrier of enteric pathogens led to several mark–recapture studies of the dispersal of *P. americana* in and from sewers. In an experiment conducted in Arizona, Schoof and Siverly (1954) found no dispersal of *P. americana* within sewers, and only one radioactive-tagged cockroach was discovered in a trap placed outside a house 18 m away from the four manholes where 6,500 radioactive-tagged *P. americana* had been released. However, in another experiment conducted in Texas, Eads et al. (1954) reported that enamel-painted American cockroaches released in manholes were able to disperse within sewers and enter houses as far as a block away. Jackson and Maier (1955, 1961) demonstrated that seasonal and carrying capacity factors played a role in the dispersal of *P. americana* within sewers and from sewers into yards and houses in experiments conducted in Arizona. These early studies provided insight into the dispersal activity of *P. americana* in and from sewers, but they did not provide detailed information about population ecology of this species. Such information, including trap catch data, age-class structure, and movement rates, are crucial for a better understanding of this pest cockroach.

Studying the population ecology and behavior of pest cockroaches that are well adapted to the human environment is crucial to developing effective management strategies. For example, mark–recapture studies conducted on outdoor populations of smokybrown cockroaches, *Periplaneta fuliginosa* (Serville),

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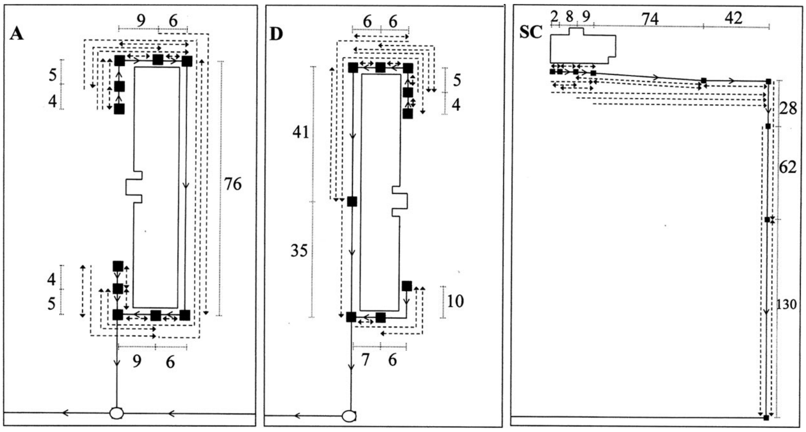

Fig. 1. Diagrams of the three sewers (sewers A, D, and SC) and the direction and distances moved between manholes by *P. americana* at Universiti Sains Malaysia, Penang. Numbers with dotted lines indicate distance (meters) between manholes; dashed lines indicate direction of cockroach movement; solid lines with arrows indicate sewer lines and direction of sewer flow; ■, manhole with traps; ○, manhole without trap; □, building).

identified their primary harborage sites, season of peak population size, and activity, and they also revealed that adult cockroaches were mobile, with an estimated home range of 108–300 m^2 (Fleet et al. 1978, Appel and Rust 1985, Brenner 1988). Brenner (1988) and Brenner and Pierce (1991) suggested that smoky-brown cockroach invasion into houses is a function of population size and the distance between primary outdoor harborage sites and houses. Mark–recapture studies of German cockroach, *Blattella germanica* (L.), demonstrated that the presence of common plumbing connections resulted in significant intra- and interapartment movements by cockroaches, and the movements were independent of population size (Owens and Bennett 1982, Runstrom and Bennett 1984, 1990). Information obtained from population ecology studies on *P. fuliginosa* and *B. germanica* provided valuable information about coverage areas of cockroach management program, the role of an outdoor reservoir population to fuel indoor invasion, and the significance of landscape and structural features that are conducive to cockroach infestation (Fleet et al. 1978, Owens and Bennett 1982, Runstrom and Bennett 1984, Brenner and Pierce 1991, Smith et al. 1995). Such information is necessary for designing effective pest management strategies.

In the current study, we used the mark–recapture technique to study population size, age-class structure, and movement of *P. americana* in three sewers that service buildings on the Minden Campus of Universiti Sains Malaysia, Penang, Malaysia.

Materials and Methods

Study Sites. The study was conducted on the Minden Campus, Universiti Sains Malaysia, (5° 21′ N, 100° 18′ E), Penang, which is located on the northwestern coast of Peninsular Malaysia. Penang has a tropical climate with high temperatures and rainfall throughout the year. Mean daily temperatures during the day range from 30.4 to 32.2°C and from 23.2 to 24.2°C during the night. The average annual rainfall of 2,408 mm is distributed throughout the year; wet weather condition occurs more frequently during southwest monsoon from April to September (http://app2.nea.gov.sg/asiacities_malaysia.aspx). Based on a survey of the cockroach infestation levels in sewers on the Minden Campus, Universiti Sains Malaysia, three sewers with heavy infestation of *P. americana* were selected for this study (Koay 2002). One sewer services a sports complex (SC), and the other two service the Aman (A) and Damai (D) student dormitories (Fig. 1). Unlike the common tightly sealed manhole covers, the unsealed type manhole cover present in the selected sewers made it feasible for us to study the sewer population of *P. americana.* To access the sewer manholes, the square-shaped metal manhole covers were removed using the flattened end of a crowbar (45 cm in length) applied to the side of the cover. Sewer A consists of 10 manholes and sewers D and SC consists of nine manholes (1-m-diameter manhole shaft). The mean depth of the manholes in sewers A, D, and SC was 1.13, 1.07, and 1.62 m, respectively.

Sampling and Marking Technique. Traps consisted of 0.45-liter glass jars baited with one-fourth slice of beer-soaked bread. A layer of petroleum jelly/oil (3:1) mixture was smeared on the inner upper 3 cm of the glass jar to prevent escape of trapped cockroaches. Masking tape was used to cover the outer layer of the glass jar to increase trap efficacy because nymphs (first–fifth instars) are unable to climb a vertical glass surface (Willis et al. 1958, Granovsky 1983). A sheet of transparent polyvinyl chloride (15 by 10 cm) was folded over the opening of the glass jar and secured by inserting two protruding edges (3 by 2 cm) into the opening. This was used to exclude rain that flowed into the manhole. Two glass-jar traps were placed at the bottom half of each manhole shaft either on the floor or on the rungs of a ladder (U-shaped bars attached on the inner wall of manhole used as a ladder for access).

Therefore, 20 traps in total were deployed at sewer A, whereas there were 18 traps each in sewers SC and D during each sampling occasion. Traps were set up in the morning (between 0900 and 1200 hours) and examined after 24 h. The drains delivering the sewage flow were ≈30 cm in diameter. Each sewer was sampled three times per month (interval 7–14 d) from 16 September 2008 to 27 October 2009, for a total of 37 samples per sewer.

Trapped cockroaches were brought back to laboratory in polyethylene containers (1,000 ml) closed with a perforated cover; the inner side of the containers was smeared with a layer of petroleum jelly/oil (3:1) mixture to prevent escape of cockroaches. Each container was labeled with the location of capture. For the mark–recapture study, only adult cockroaches were marked because nymphs may lose the tag during molting process. Each adult cockroach was marked with a piece of masking tape (1 by 0.5 cm) that was individually coded with an alphanumeric code written in water-resistant pigmented ink (Ecco pigment fiber tip 0.2 mm, Faber-Castell, Nürnberg, Germany) (Fleet et al. 1978, Appel and Rust 1985). Alphabetical code was used to indicate the manhole from which the cockroaches were first captured, whereas the numerical code was used to record the number of cockroaches that were caught and marked in the respective manhole. Tissue paper saturated with acetone was used to clean the tegmen to remove epicuticular lipids and dirt before the masking tape tag was stuck to the tegmen (Appel and Rust 1985). Tegmen that was covered beneath another tegmen was chosen for tagging because it was protected and may increase tag adherence. An additional layer of transparent cello tape was used to cover the masking tape tag to provide a smooth surface to minimize the adherence of dirt on the rough surface of the masking tape. The marking process was facilitated by anesthetizing cockroaches with CO_2 (10-kPa pressure for 10–15 s). This brief anesthesia on *P. americana* was reported to have no significant effect on their survival and probability of being recaptured and has been used to handle this cockroach species in several studies (Coler et al. 1986, 1987; Smith and Appel 1996; Appel and Smith 1999). After being marked and recorded, all cockroaches were released back into the manhole from which they were captured in the evening.

During each sampling session, the numbers of trapped adult males, females, and nymphs (divided into three size-classes: small, ≤ 10 mm; medium, 11–25 mm; and large, >25 mm long) were recorded. Proportion of each life stage also was determined. The Jolly stochastic model was used to estimate adult cockroach population size for each time point at each sewer (Jolly 1965, Begon 1979). Estimated adult population size, trap catch, and proportion of each life stage were reported on a monthly basis by averaging data from each of the three sampling sessions per month at each sewer. The numbers of movements and longest distance moved by marked adult cockroaches between manholes were recorded. Data on the trap catch and movement of adult cockroaches from the three sewers were pooled to investigate the effect of meteorological factors on these data. Meteorological data were recorded at the Bayan Lepas weather station, located 8.5 km away from the study site, by the Malaysian Meteorological Department.

Data Analysis. The number of recaptures and the number of movements between males and females, and the proportions between adults and nymphs were compared using the nonparametric Mann–Whitney *U* test (Conover and Iman 1981). Proportions of nymphs among the three sewers were compared using nonparametric Kruskal–Wallis test, followed by posthoc comparisons between means using Mann–Whitney *U* test with a Bonferroni adjustment (significant level set at $P = 0.05/3 = 0.017$). Pearson's product-moment correlation was used to examine the relationship between meteorological factors (daily mean, maximum and minimum temperature, and rainfall) and trap catch on each sampling date. Daily maximum and minimum temperature were averaged over the days between sampling interval, and Pearson's product-moment correlation was performed to examine the correlation between these data and number of cockroach movements. Adult population estimates determined between sampling occasions were averaged, and Pearson's product-moment correlation was used to determine whether there was a correlation between these data and the number of cockroach movements. All analyses were performed using SPSS version 11.0 at $\alpha = 0.05$ (SPSS 2002).

Results

The mark–recapture study conducted between September 2008 and October 2009 revealed that *P. americana* was the dominant cockroach species trapped; only one *Pycnoscelus surinamensis* (L.) and one *Periplaneta australasiae* (F.) were trapped during the study. The mark–recapture study showed that the adult population peaked in December 2008 for sewers A and D and in January for sewer SC, with 295, 334, and 599 adult cockroaches, respectively. The lowest estimated adult populations of 100, 82, and 233 cockroaches were recorded in July, January, and May for sewers A, D, and SC, respectively (Fig. 2). Throughout the study period, the mean monthly adult trap catch at sewers A, D, and SC was 75, 57, and 97, and the mean monthly trap catch of nymphs was 99, 79, and 85, respectively (Fig. 2). The mean proportion of nymphs throughout the study at sewers A, D, and SC was 0.56 ± 0.02, 0.57 ± 0.02, and 0.47 ± 0.03, respectively (Fig. 3). The proportion of nymphs was significantly greater than the proportion of adults at sewers A and D (Mann–Whitney *U* test: A, $Z = -3.298$, $P = 0.001$; D, $Z = -3.294$, $P = 0.001$; $n = 12$ each), whereas there was no significant difference between these proportions at sewer SC (Mann–Whitney *U* test, $Z = -1.994$, $n = 12$, $P = 0.05$; Fig. 3). There were significant differences between the mean proportions of nymphs among the three sewers (Kruskal–Wallis test, $H = 7.826$, $df = 2$, $P = 0.02$). The mean proportion of nymphs at sewer A did not

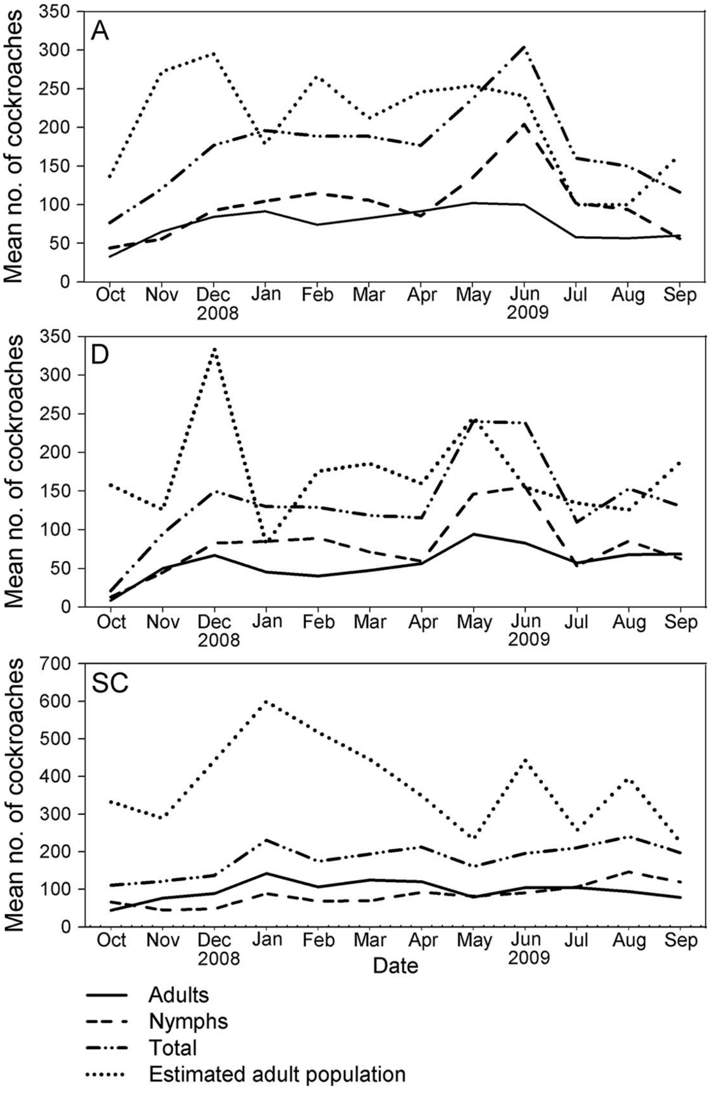

Fig. 2. Monthly estimated adult population and trap catch of *P. americana* found in three sewers (A, D, and SC) at Universiti Sains Malaysia, Penang from October 2008 to September 2009.

differ significantly from that of sewer D (Mann–Whitney *U* test, Z = −0.290, *n* = 12, *P* = 0.772), whereas both the mean proportions of sewer A and D were significantly greater than that of sewer SC (Mann–Whitney *U* test: A versus SC, Z = −2.400, *P* = 0.016; D versus SC, Z = −2.429, *P* = 0.015; *n* = 12 each). In general, the overall proportion of adults and nymphs was 0.47 (56% females) and 0.53 (16% small nymphs and 42% each for medium and large nymphs), respectively.

Of the 2,177 male and 2,717 female cockroaches marked and released over the three sewers, recapture rates were ranged from 29.4 to 45.8% and from 30.8 to 47.0%, respectively. Further analysis revealed that the proportions of marked males and females did not differ significantly from the proportions of recaptured marked males and females at each sewer (A, χ^2 = 1.324, *P* = 0.250; D, χ^2 = 0.093, *P* = 0.760; SC, χ^2 = 0.340, *P* = 0.560; df = 1 each; Table 1). However, the mean number of times a marked female was recaptured was significantly greater than that of males at each sewer (Mann–Whitney *U* test: A, Z = −2.846, *P* = 0.004; D, Z = −3.019, *P* = 0.003; SC, Z = −3.065, *P* = 0.002; Table 1).

Of the 1,813 recaptured marked adults, 406 adults (22.4%) moved between manholes, and 90.4% of the movements were restricted within the range of 2–20 m; one male moved a distance of 192 m, which was the longest distance recorded (Fig. 1 and Table 2). Based on the proportion of recaptured marked males and females, significantly more females moved compared with males (χ^2 = 5.511, df = 1, *P* = 0.019; Table 2). Mean number of movements per recaptured female was significantly greater than that of

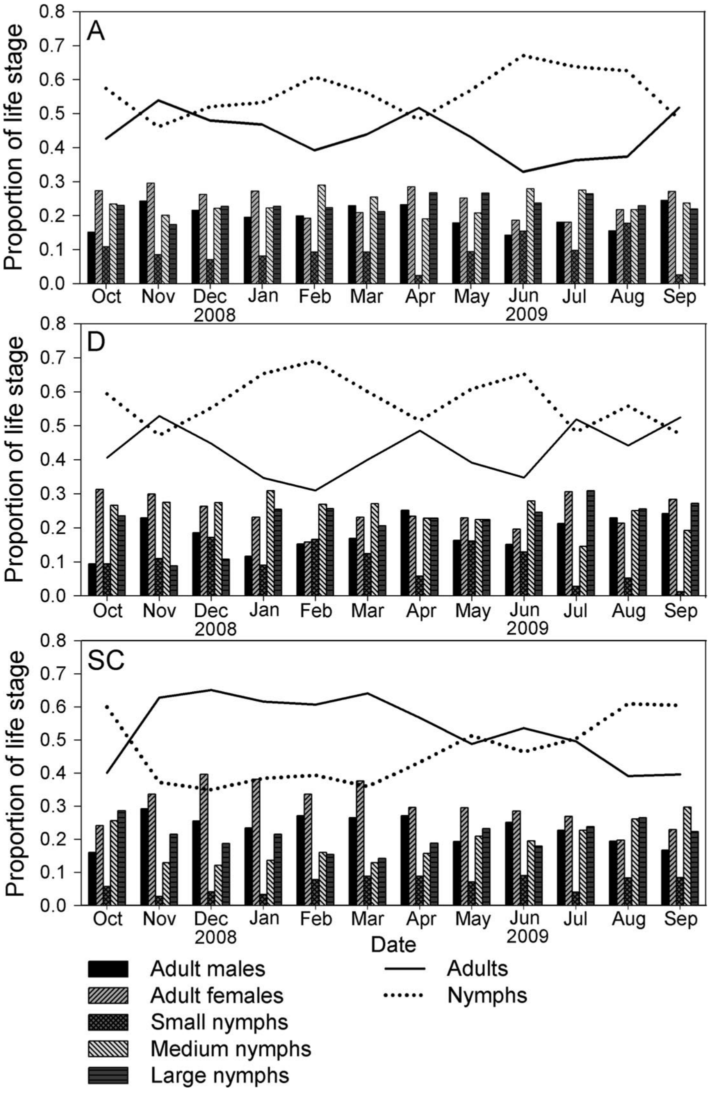

Fig. 3. Proportion of *P. americana* life stages in three sewers (A, D, and SC) at Universiti Sains Malaysia, Penang.

recaptured males (Mann–Whitney *U* test, Z = −2.849, *P* = 0.004; Table 3).

There was no correlation between population sizes and the number of cockroach movements at each sewer (Pearson's correlation coefficient: A, *r* = 0.071, *P* = 0.690; D, *r* = 0.310, *P* = 0.075; SC, *r* = −0.004, *P* = 0.984). Daily mean temperature (25.4–29.2°C) was positively correlated with the number of trap catch

Table 1. Summary of mark–recapture data for adult *P. americana* at three sewers

Sewer	Sex	No. marked cockroaches	No. recaptured marked cockroaches (n)	% recapture	No. times an individual marked adult was recaptured						No. recaptures	No. (mean ± SE) of recaptures/recaptured adult
					1	2	3	4	5	6		
A	♂	730	277	37.9	203	64	9	1	0	0	362	1.31 ± 0.03
	♀	864	359	41.6	227	105	20	5	1	1	528	1.47 ± 0.03
D	♂	489	224	45.8	165	43	12	4	0	0	303	1.35 ± 0.04
	♀	619	291	47.0	179	75	23	12	2	0	456	1.57 ± 0.03
SC	♂	958	282	29.4	218	50	13	1	0	0	361	1.28 ± 0.03
	♀	1,234	380	30.8	253	95	25	5	2	0	548	1.44 ± 0.03
Overall	♂	2,177	783	36.0	586	157	34	6	0	0	1,026	1.31 ± 0.02
	♀	2,717	1,030	37.9	659	275	68	22	5	1	1,532	1.49 ± 0.02

Table 2. Percentage and number of adult *P. americana* that moved in the various ranges of distances between manholes

Sex	Distance travelled by individual cockroach from their initial release site (m)										No. recaptured marked cockroaches	No. recaptured marked cockroaches that moved	% recaptured marked cockroaches that moved
	2–5	6–10	11–15	16–20	21–24	35–47	58–74	82–90	116–135	192			
♂	58	71	5	8	1	2	1	2	3	1	783	152	19.4
♀	105	78	22	17	2	7	9	8	4	0	1,030	254	24.7
Total	163	149	27	25	3	9	10	10	7	1	1,813	406	22.4
% of cockroaches in each range of distance travelled	40.6	36.9	6.7	6.2	0.7	2.2	2.5	2.5	1.7	0.2			

(Pearson's correlation coefficient, $r = 0.400$, $P = 0.014$). The number of movements recorded for adult cockroaches was correlated with mean daily minimum temperature (23.5–24.5°C, Pearson's correlation coefficient, $r = 0.491$, $P = 0.002$).

Discussion

The study of pest cockroach populations is an important way to understanding their biology and behavior in the field. Trapping and mark–recapture techniques that allow assessment of the status of a population and its dynamics are widely used for this purpose. In the current study, the mean proportion of nymphs that ranged from 0.47 to 0.57 was lower than the 0.77 (based on the total number of cockroaches removed by trapping and a vacuum cleaner) reported for a green house population of *P. americana* by Coler et al. (1987). On the contrary, the value was higher than that documented from an outdoor population of *P. americana* (0.22) by Appel (1986). Differences in experimental design such as sampling technique and trap placement may partly explain variation in age-class structure. Placement of traps had been reported as a factor that affected the composition of trap catch. Traps placed near to harborage sites and areas with more concealment caught significantly more nymphs than other sites in the mark–recapture studies of *P. fuliginosa* (Fleet et al. 1978, Appel and Rust 1985). In our study, significantly lower nymphal proportion was recorded in the larger manhole shaft of sewer SC compared with the other two sewers; in this sewer, the traps might not have been reached so easily by most of the relatively less mobile nymphs that stay close to their harborage sites. Compared with sampling cockroaches in sewers, traps can be directed and placed at areas of cockroach activity (e.g., along the wall or near food sources) or near harborage sites in aboveground sampling. This may partly explain the relatively higher proportion of nymphs reported by Coler et al. (1987) for a green house population of *P. americana* where cockroaches were removed by glass-jar traps placed at corners and along the perimeter in addition to the aid of a vacuum cleaner that eventually captured a greater number of nymphs compared with our study. In addition, interspecific competition is also one of the factors that affect trap catch of cockroaches. *P. fuliginosa* nymphs were demonstrated to repel nymphal and male *P. americana* and their presence in glass-jar traps was found to affect the trapping of *P. americana* (Appel 1994). This interspecific competition may explain the relatively lower proportion of *P. americana* nymphs documented by Appel (1986) in an outdoor environment where *P. fuliginosa* occurred as a dominant species.

Several mark-recapture studies of *P. fuliginosa* and *P. americana* reported that marked females were more likely to be recaptured than marked males (Appel and Rust 1985, Appel 1986, Coler et al. 1986, Brenner 1988, Brenner and Pierce 1991). However, in our mark–recapture study, the proportion of marked and released males and females did not differ significantly from the proportion of recaptured marked males and females, indicating that the probability of recapture for marked males was not different to that of marked females. However, the number of times a female was recaptured was greater than that of males. Our finding is similar to the results of Fleet et al. (1978) who reported on *P. fuliginosa.* Coler et al. (1986) demonstrated that glass-jar traps were not biased toward trapping either sex of adult *P. americana* in their laboratory experiment. Nevertheless, trapping results from their field experiment showed that marked *P. americana* females were more likely to be caught than that of the marked males. Differences in behavior and physiology between males and females may explain differences in recapture rates and number of times a marked individual being recaptured. In outdoor activity studies of cockroaches, Appel and Rust (1986) and Appel (1986) reported differences in height-spe-

Table 3. Number of movements made between manholes by adult *P. americana*

Sex	No. recaptured marked cockroaches (n)	No. movements recorded for each individual cockroach				No. movements	No. movements/ recaptured adult
		0	1	2	3		
♂	783	631	145	7	0	159	0.20 ± 0.02
♀	1,030	776	219	29	6	295	0.28 ± 0.02
Total	1,813	1,407	364	36	6	454	0.25 ± 0.01

cific distribution between males and females in *P. fuliginosa* and *P. americana.* They found that males occupied significantly higher position (averaged 2.3–2.8 m) than females (averaged 0.4–0.8 m). Schal (1982) hypothesizes that height-specific distribution of males and females is a mate-finding strategy. A similar height-specific distribution of males and females was reported in his study in a few tropical cockroach species; males perched higher than females on vegetation during their active period. He suggested that micrometeorological gradients facilitated upward movement of volatile sex pheromones. Males positioned at higher level were able to detect sex pheromones released by females located at lower position. In the current study, the placement of traps close to or on the floor of the manhole shaft may have resulted in the higher frequency of recapture of females due to differences in spatial distribution between the sexes. In addition, Bell et al. (2007) found that male cockroaches had lower amounts of gut contents and narrower diets compared with females; they suggested that food intake by females may be related to the reproductive cycle and nutrient requirement for oogenesis or embryogenesis. Therefore, it is possible that a female may visit food-baited jar traps more frequently than males in those mark–recapture studies. Sampling period in Fleet et al. (1978) (16 mo) and our (12 mo) studies were longer compared with those mark–recapture studies (2–21 d). It is possible that longer sampling period may allow more marked individuals to be recaptured and contribute to the equal probability of recapture between males and females reported in Fleet et al. (1978) and our studies.

Contrary to several other studies that reported limited movements of *P. americana* in sewers, the 22.4% of recaptured marked cockroaches that moved between manholes in this study is high. Although the recapture rates were not adequately addressed, Schoof and Siverly (1954), Eads et al. (1954), and Jackson and Maier (1955, 1961) reported that 0, 0.2, and 0.6–4.3% of marked *P. americana* moved to adjacent manholes when 6500, 1,000, and 300–2,000 marked individuals, respectively, were introduced into the manholes. The experiment in the current study that included various distance ranges (2–192 m) may allow more cockroach movements being recorded. In Jackson and Maier's studies (1955, 1961), the distance of the nearest manhole adjacent to manhole in which the cockroaches were released was ≈50 m. The rate of dispersal in their studies (0.6–4.3%) is similar to the 6.9% of recaptured marked adults that moved within the distance range of 58–192 m in our study. The majority (90.4%) of the movements in our study occurred within the distance range of 2–20 m. Thus, the great distance between manholes in previous studies may have contributed to the relatively low movement rates reported in those dispersal studies. The result from this study provide information for managing *P. americana* in sewers because several studies of insecticide efficacy in controlling *P. americana* in sewers reported possible reinvasion of late nymphs and adults into the treated manholes from nearby sewers (Chadwick et al. 1977, Rust et al. 1991).

In the current study, daily mean temperature was correlated with the number of cockroaches caught in the traps. Fleet et al. (1978) and Brenner (1988) also found a positive correlation between daily maximum temperature and trap catch in outdoor populations of *P. fuliginosa* and *Eurycotis floridana* (Walker). In those studies, the increase in trap catch with increased temperature might have been due to the search for water, because the rate of water loss for *P. fuliginosa* is twice that of *P. americana* (Brenner 1988, Appel 1995, Smith et al. 1999). In sewers, lack of water is not a problem, so searching for water probably does not explain the positive correlation between trap catch and daily mean temperature (25.4–29.2°C). However, it may reflect the temperature preference of *P. americana.* In a temperature preference experiment where cockroaches were allowed to select their resting areas imposed with a thermal gradient, *P. americana* showed their preference for temperatures ranging from 23 to 33°C and were recorded to rest more in areas with 28–30°C (Gunn 1935).

Studies on the dispersal of *P. americana* in sewers showed that population pressure was one of the factors that may influence the movement of cockroaches in and from sewers (Jackson and Maier 1955, 1961). Jackson and Maier (1955) demonstrated that population stress induced by superimposing 1,200 radioactive-tagged cockroaches into a resident population of 300 *P. americana* resulted in 5.9% (71 cockroaches) of the tagged cockroaches caught in traps placed around and inside houses and in adjacent manholes, whereas only 0.8% (four cockroaches) was caught when a normal undisturbed population of 500 *P. americana* were marked and released. In our study, adult population fluctuations were not found to be related to the number of cockroach movements. It is possible that *P. americana* populations were thrived within the carrying capacity of the sewers in our study. Under such condition, population fluctuation may not have an influence on the movement of cockroaches.

In conclusion, the proportions of nymphs and adults among the populations of *P. americana* residing in the sewers studied herein were similar. *P. americana* was mobile in these sewers, and the majority of movements were within the range of 20 m. Temperature was found to be related to trap catch and movement of *P. americana* in sewers.

Acknowledgments

We thank Y.-F. How, K.-B. Neoh, and S.-J. Sam (Universiti Sains Malaysia) for technical assistance in the field. H.-S.T. was supported under an M. Sc. fellowship scheme by Universiti Sains Malaysia. This study was funded by Universiti Sains Malaysia-Research University Postgraduate Research Grant Scheme and DuPont Professional Products (Wilmington, DE).

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Received 29 November 2010; accepted 11 April 2011.

Efficiency of a New Trapping and Marking Technique for Peridomestic Cockroaches (Dictyoptera: Blattaria)

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J. Med. Entomol. 25(6): 489–492 (1988)

ABSTRACT A lightweight baited trap is described for use either at ground level or attached to vertical surfaces for live-trapping cockroaches where nontarget animals are common. Dry distiller's grain in small plastic condiment cups was the bait. Reliability was exceptional: in a trial of 1,500 trap-days (125 traps used over a period of 12 d), only one trap was disturbed. Cumulatively, 15 species of cockroaches have been captured with this baited trap. Trapped cockroaches (adults and nymphs) were marked, and recapture rates for the two most commonly trapped species (*Periplaneta fuliginosa* (Serville) and *Eurycotis floridana* (Walker)) ranged from 38.5 to 75%. Mean number of trap-days between recapture (3.5 ± 0.10) indicated that the release of marked individuals at the point of capture did not result in immediate recapture and therefore did not inflate recapture rates inordinately.

KEY WORDS Insecta, bait, *Periplaneta*, *Eurycotis*

ANY FIELD STUDY on population dynamics of insects, in which movement and population levels are to be estimated, requires reliable methods of trapping and marking individuals. Numerous trapping methods have been developed that use food-based baits, such as beer, bread, raisins, apple, banana, dog food, peanut butter, and dry cat food (Reierson & Rust 1977, Fleet et al. 1978, Rust & Reierson 1981, Ballard & Gold 1982, Appel & Rust 1985). Glass jars of various sizes have been used almost exclusively (Fleet et al. 1978; Owens & Bennett 1982, 1983; Runstrom & Bennett 1984; Appel & Rust 1985). However, these are relatively heavy, fragile, and of little practical use in trapping above ground level. Hagenbuch (1986) designed a lighter, metallic trap from paint cans (0.95-liter capacity) and added a rain-excluding canopy made from aluminum "cavity caps" (normally used in construction of block houses) supported above the can on wire legs pushed into the ground.

Several techniques have been devised for marking cockroaches. German cockroach adults have been marked en masse with dabs of paint (Owens & Bennett 1982), and marked uniquely with bee tags (Runstrom & Bennett 1984). (The term "unique" throughout this paper means that each cockroach has a distinct and unreplicated mark.) Larger species, such as *Periplaneta americana* (L.), have been marked en masse with a radioactive spray (P^{32}) (Schoof & Siverly 1954, Jackson & Maier 1961), or with spray paint (Jackson & Maier 1955). Adults of the smokybrown cockroach, *P. fuliginosa* (Serville), have been marked with uniquely coded pieces of tape affixed to the acetone-cleaned tegmina (Fleet et al. 1978, Appel & Rust 1985). However, in each of these studies, nymphs were not marked, either because of a rapid loss of the mark (Jackson & Maier 1955) and/or because of molting (Owens & Bennett 1982, Runstrom & Bennett 1984).

Our research on behavior and ecology of peridomestic cockroaches (i.e., those living "around" the domestic environment, but not necessarily in it) requires intensive live-trapping over a period of several weeks. Here we report the efficiency of a lightweight reliable trap, a new bait, and a method for uniquely marking adult cockroaches and all but the smallest nymphs.

In preliminary experiments on trapping cockroaches in the peridomestic and feral environments, we used the can trap described by Hagenbuch (1986), with a variety of baits, including bread and beer, bread alone, apple, pear, and cat chow. The traps were placed at ground level and 2 m above the ground on the trunks of trees near homes, as well as in semiferal wooded areas. Traps were checked daily. Although the unmodified can trap was an improvement over heavy jar traps (used in this laboratory for several years), construction of the aluminum canopy, and modification of the trap for aboveground use (wire hooks) was labor intensive, as was the time needed to service large numbers of traps in the field. More importantly, serious problems were encountered with reliability of baits; besides cockroaches, these baits attracted other animals such as cats, dogs, racoons, and wood rats. Consequently, on any given night more than 50%

Mention of a proprietary name in this paper does not constitute endorsement by the USDA.

of the traps were molested, rendering the technique useless for comprehensive studies on population dynamics of cockroaches.

Materials and Methods

Ultimately, the Hagenbuch trap was modified to remedy shortcomings. Modified traps (Fig. 1) were constructed from 0.95-liter capacity, lined paint cans (inner surfaces are painted at the time of manufacture to retard rust) purchased from a local paint factory (Suntech Paint Company, Gainesville, Fla.). A 15-cm strip of Velcro (wool component) was attached to the upper outside circumference with a cyanoacrylic glue that also fills gaps. Two smaller pieces (3 cm) were glued vertically at each end of the larger piece to secure a canopy. The complementary 15-cm strip of Velcro (hook component) was stapled to the substrate being sampled (bark of tree trunk, wood on house, bark of firewood, etc.) to secure the trap in place. A canopy of low density polypropylene (13 by 21.5 cm), designed to exclude rainfall, was attached to the smaller pieces of Velcro on the can with two corresponding strips of Velcro stapled on each end. Thus, the canopy could be removed easily for servicing the trap.

This modified can trap (hereafter referred to as "lightweight baited trap") was used in several residential neighborhoods in Gainesville, Fla., where cats, dogs, and racoons were common. At each site 85–130 traps were used, depending on property size and ecological diversity. Traps were checked daily, typically for 14 d. These studies were done September–December 1985 and May–June 1986.

A mixture of mineral oil and petrolatum (2:3) was applied to the upper 2 cm of the inside surface of the trap to prevent escape of captured cockroaches. Approximately 2 g dried distiller's grain, a by-product of ethanol production (Kentucky Agricultural Energy Corporation, Franklin, Ky.), was placed inside a 22-ml-capacity plastic condiment cup. A circular piece of aluminum mosquito screening (4 cm diameter) was then pressed into the cup to prevent ingestion of the bait by the cockroaches and to minimize spillage. The prepared bait cup then was placed in the bottom of the trap.

At field sites, each captured cockroach was numbered uniquely using a code scheme similar to that used by the electronics industry for coding resistors. Ten colored water-base paint pens (Painters, Speedball brand, Hunt Manufacturing Company, Statesville, N.C.), representing digits 0–9, were used to apply three marks longitudinally on the dorsum of adults and nymphs. Cockroaches were anesthetized with gaseous carbon dioxide (Fig. 1), removed from the trap, oriented with the head pointed away, and marked from left to right with the appropriate colors; marks extended from the center of the pronotum to approximately three-fourths the length of the abdomen (nymphs and brachypterous species) or wings (Fig. 2). Cockroaches were marked quickly, then returned to the point of capture, either at the base of a trap (ground traps) or on top of the canopy (tree and house traps). On succeeding days, traps were revisited and recaptures were recorded; marks were reapplied as needed.

Fig. 1. Components of the lightweight baited trap showing can with Velcro, canopy, and bait cup containing aluminum screening over 2 g dry distiller's grain (left foreground), an assembled trap (right foreground, and a 2.3-kg tank of gaseous CO_2 fastened to a small Scuba backpack frame.

Results and Discussion

Field tests of the lightweight baited trap containing dry distiller's grain demonstrated the reliability of the technique. Over the course of these studies, 15 species were captured (Table 1), and the proportions of each species at each site were similar to those from visual observations. Reliability of traps at all sites was similar; data from one site are provided here as representative. At this site, 125 traps were used on 12 sampling days (encompassing 16 calendar days) for a total of 1,500 trap-days. Only one trap was found overturned (0.07% trap-days), indicating a high degree of reliability. Thus, use of this bait obviates the need to secure ground-level traps to embedded stakes (Appel & Rust 1985) or to bury traps beneath a layer

Fig. 2. Large nymph of *Eurycotis floridana* with longitudinal marks uniquely identifying the cockroach. Each mark represents a digit (0–9); cockroaches are read from left to right with head distad.

of hardware cloth (Wright & Dupree 1984), to prevent overturning of traps and ingestion of the bait by domestic animals. Other laboratory studies confirmed that dry distiller's grain is at least as attractive as laboratory rat chow or dry cat food (Brenner & Patterson in press). Therefore, we conclude that this bait and trap design are ideal for these research purposes.

The technique used to mark cockroaches proved exceptional. More than 585 cockroaches were marked and released, including many nymphs (Table 2). In each case, cockroaches were alert and active within 10 min of having been marked; no ill effects were observed. The overall recapture rate was 63.9% and is superior to those obtained in other studies using traditional baits (Fleet et al. 1978, Appel & Rust 1985). Rates varied by species and stage, ranging from a low of 38.5% (*E. floridana* males) to approximately 75% (*E. floridana* and *P. fuliginosa* females). Differences between the number of marked males and females may reflect a trap bias or represent actual population proportions at the time of the study (October 1985). The number of trap-days between recapture averaged 3.5 ± 0.10 (SE) for all recaptures, indicating that the release of each marked cockroach at the base or top of the trap did not result in immediate recapture, and therefore did not inflate recapture rates inordinately.

Table 1. Species captured outdoors in can traps baited with dry distiller's grain (Aug. 1985–April 1986)

Blattella asahinai Mizukubo[a]
Cariblatta lutea lutea (Saussure and Zehntner)
Eurycotis floridana (Walker)
Ischnoptera deropeltiformis (Brunner)
Latiblattella rehni Hebard
Panchlora nivea (L.)
Parcoblatta lata (Brunner)
Parcoblatta caudelli Hebard
Parcoblatta divisa (Saussure and Zehntner)
Parcoblatta fulvescens (Saussure and Zehntner)
Periplaneta fuliginosa (Serville)
Periplaneta americana (L.)
Periplaneta australasiae (F.)
Periplaneta brunnea Burmeister
Pycnoscelus surinamensis (L.)

[a] Captured in separate studies near Tampa, Florida; all others captured in Alachua County, Florida.

Table 2. Percentage recapture and time between recaptures of peridomestic cockroaches marked during the first three days of a 12-d marking regimen

Species	Stage	No. marked	% recapture	No. trap-days between recapture[a]: Median	Mean	SEM
Periplaneta fuliginosa	Adult					
	♀♀	102	74.5	3.0	3.5	0.16
	♂♂	44	63.6	3.0	3.4	0.22
	Nymphs					
	Large	98	54.1	3.0	3.5	0.22
	Medium	21	57.1	5.0	5.6	0.41
Eurycotis floridana	Adult					
	♀♀	20	75.0	3.5	3.9	0.40
	♂♂	13	38.5	3.0	3.6	0.60
	Nymphs					
	Large	7	71.4	3.0	3.0	0.32
	Medium	30	66.7	3.0	3.1	0.34
Total		335	63.9	3.0	3.5	0.10

[a] For example, a cockroach marked on day 1 and recaptured on day 4 would have a value of 3.

Nymphal stages of cockroaches often constitute >60–70% of the population (Fleet et al. 1978, Owens & Bennett 1983, Appel & Rust 1985), but a suitable method for marking them has been lacking, and almost nothing has been published on their mobility. This technique allows the marking of nymphs and subsequent collection of data on population size and mobility of these stages.

Walker & Wineriter (1981) reviewed methods of marking insects and recommended a method similar to ours, using various colors of Liquid Paper Correction Fluid (Liquid Paper Corporation, Boston) in a scheme in which color and location on the insect are specific. The direct-marking techniques offer several advantages to the general method of marking insects with tags. Dependence on a single tag adhering to the integument results in complete loss of information if the tag is lost. In contrast, the probability of losing all parts of all three long marks is remote. Also, because these markers contain no caustic solvents, there should be little damage to the integument, and because there is no perceptible weight to these marks, flight ability should not be impaired (Walker & Wineriter 1981).

Laboratory studies indicate there is little chance that marks will be lost during a study; there was no complete loss of a digit in either imaginal or nymphal *P. fuliginosa* cockroaches during a 2-wk period (n = 20). Loss of marks because of ecdysis is a possibility, but the relatively short study period, and the relatively long developmental period (several months) of these species (Cornwell 1968), make this possibility unlikely.

Field observations further exemplified the persistence of these markers. Adults of smokybrown cockroaches and *Eurycotis floridana* were seen in the field with all three marks intact 6 wk after having been marked. Even complete loss of one mark rarely results in a loss of information; because the stage and species has been recorded by number, a cross check of possible numbers with species (or stage) usually reveals the correct number, unequivocally. There were five such records during this test, and all were resolved. Even with some loss, these recapture rates are exceptional and sufficient for making inferences about population dynamics (Brenner in press).

Acknowledgment

We are grateful for the excellent technical assistance of K. Crosby, D. Moore, K. Williams, and J. Milio. Special thanks to P. Koehler, University of Florida, for providing some financial support of technicians. We thank M. Moussa, D. Wojick, and J. Becnel for their reviews of the manuscript. The photograph in Fig. 2 was taken by Barry Fitzgerald and provided by Bob Bjork, USDA Information Service.

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Received for publication 16 October 1987; accepted 21 June 1988.

Evaluation of Trapping and Vacuuming Compared with Low-Impact Insecticide Tactics for Managing German Cockroaches in Residences

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J. Econ. Entomol. 90(4): 976–982 (1997)

ABSTRACT In field studies, sticky traps and vacuum cleaners were evaluated to determine their effectiveness in the control of German cockroaches, *Blattella germanica* (L.), infesting multifamily housing. Trapping and vacuuming treatments were compared with insecticide baiting and residual spraying methods. At 4-wk posttreatment in 1995 tests, the percentage of cumulative population reductions caused by Siege gel bait, Victor Roach Pheromone sticky traps, flushing and vacuuming, vacuuming, and Empire spray treatments reached 82.4, 79.3, 80.2, 72.5, and 72.0%, respectively. There were no significant differences in cockroach catch between treatments at all sampling periods after treatment, indicating that the treatments were equally effective in controlling *B. germanica* infestations. At 8 wk after treatment in 1996 tests, the percentage of cumulative population reductions caused by Knockdown Pheromone Boric Acid bait, Victor Roach Pheromone sticky traps, and Suspend spray treatments reached 83.7, 80.1, and 68.5%, respectively. As in 1995 tests, there were no significant differences in cockroach catch between treatments at all sampling periods after treatment. Trapping with sticky traps and the use of the vacuuming technique led to significant reductions in trap catch at all sampling times after treatments. In total, 7,543 cockroaches were caught on Victor Roach Pheromone traps removed from 11 apartments during the 4-wk test period in 1995. In total, 3,554 cockroaches were caught on Victor Roach Pheromone traps removed from 5 apartments during the 8-wk test period in 1996. The use of the flushing agent before vacuuming led to a greater population reduction and removal of hard-to-reach gravid females. Sticky traps and vacuum cleaners also were effective as monitoring devices and provided acceptable control for *B. germanica*.

KEY WORDS *Blattella germanica*, vacuum cleaner, sticky traps, baits, flushing, nonchemical control

EVEN WITH THE promotion of integrated pest management programs for the German cockroach, *Blattella germanica* (L.), the pest control industry has generally relied on the use of chemically based synthetic insecticides as the key, direct control technique in these integrated pest management (IPM) programs (Gold 1995). Cockroaches are behaviorally, physiologically, and genetically adaptable, and it is unlikely that a single approach to their control will be effective through time; it takes a combination of approaches to reduce *B. germanica* populations below levels where they are considered pests. Currently, there is significant interest in the control of structural pests without the use of pesticides (especially residual spray formulations) and surprisingly, many consumers are inquiring of pest management professionals as to the feasibility of controlling *B. germanica* with nonchemical pest control strategies (e.g., vacuuming, caulking, trapping, air movement) or by using low-impact insecticide techniques (e.g., baiting, flushing).

Sticky traps are used primarily as sampling, detection, and monitoring tools. However, there has been an interest in the use of sticky traps as control tools (Burgess et al. 1974; Piper et al. 1975; Baker and Southam 1977; Barak et al. 1977; Ballard and Gold 1982, 1983; Kaakeh and Bennett 1996a, b). Traps have been advocated as an alternative to chemical methods and their use has increased with the implementation of IPM programs (Gold 1995). It also has been reported that traps are incapable of removing a significant portion of *B. germanica* populations in the field (Barak et al. 1977; Reierson and Rust 1977; Ballard and Gold 1982, 1983, 1984; Owens and Bennett 1983).

Vacuum cleaners have been used for capturing live *B. germanica* for laboratory testing (Wright 1966, Ross and Wright 1977). Recent articles have reported the use of vacuum cleaners for direct physical removal of cockroaches from their harborages in an attempt to reduce cockroach populations (Christensen 1995, Frishman 1995). However, quantitative data regarding the potential benefits from the use of vacuum cleaners, alone or in conjunction with other methods, for cockroach control were lacking.

This research project was initiated to determine the effectiveness of 2 non-chemical tools (vacuuming and trapping) compared with low-impact insecticide applications (flushing and vacuuming, baiting) and residual sprays, in controlling *B. germanica* populations in heavily infested apartments.

Materials and Methods

Test Site. Field tests were conducted during May–July 1995 and June–August 1996 in a heavily infested multifamily housing complex (Munsyana Homes) operated by the Muncie Housing Authority (Muncie, IN). Faulty construction, generally poor sanitary conditions, and absence of effective pest management programs in this complex favored the development of high cockroach populations. Before the summer of 1994, Demon WP insecticide (AI = cypermethrin; Zeneca, Richmond, CA) had been used for 8 yr by the housing authority on a complaint–response basis. Cockroaches in all infested apartments were highly resistant to cypermethrin (Scharf et al. 1997). During the summer of 1994, the housing units had been a test site in efficacy evaluations of insecticidal sprays and baits. All insecticide applications (other than those made by residents) had been concluded at least 4 wk before the initial sampling in this study.

Population Sampling. Lo-Line cockroach sticky traps (180.5–cm^2 sticky area) (Agrisense, Fresno, CA) were used to estimate cockroach populations weekly in each apartment and to measure the impact of the treatments on these populations. Five treatments (spraying, baiting, vacuuming, flushing and vacuuming, and trapping) were conducted in 1995. Four treatments (baiting, trapping, spraying, and flushing and vacuuming) were conducted in 1996.

The kitchens and bathrooms (20–25 m^2) in each apartment were divided into 6 monitoring–treatment zones—the cabinet under the kitchen sink, the cabinet above the sink, under or adjacent to the stove, under and behind the refrigerator, adjacent to the utility area where water heater and furnace are located, and on the floor behind the bathroom toilet. One trap was placed in each zone against walls or other vertical surfaces and in corners to ensure maximum sampling efficiency. All traps were placed in each apartment for 1 night each week (same night) for the 4-wk monitoring period in 1995 and for 8 wk in 1996. Trap catch was recorded within 3–4 h of trap retrieval noting the number of adult males, adult females, adult females bearing oothecae, large nymphs (4th–5th instars), and small nymphs (1st–3rd instars).

Treatments were assigned randomly to a number of buildings (2-story construction) within the apartment complex before inspection. After collecting the Lo-Line traps, every apartment in each building (6–12 apartments each) received the same treatment, thus every apartment in the complex was treated whether or not it was monitored as a test site. A total catch of 12 cockroaches in the 6 traps was required for any apartment to be included in the test as an observation unit. At least 12 replicate apartments were established for each treatment. This sample size varied after treatment because of apartment vacancy or a lack of tenant cooperation. The number of monitoring–treatment sites requiring treatment contributed to the variation in the amount of materials and vacuuming time in any given apartment. Weekly trappings after the initial treatments were made, using 6 Lo-Line traps, to monitor the cockroach populations, determine trap catch reductions, and eventually determine the success of each treatment.

Treatment Strategies. Spray treatments were made using a 3.79-liter (1-gal) B&G compressed air sprayer (Plumbsteadville, PA). In 1995, applications of Empire 20 (20% microencapsulated chlorpyrifos; DowElanco, Indianapolis, IN) were made at day 1 at the rate of 38 ml (1.3 fluid ounces)/3.78 liter of water (0.2% concentration of spray mixture). In 1996, applications of Suspend SC (4.75% deltamethrin; DowElanco) were made at the rate of 45 ml (1.5 fluid ounces)/3.78 liter of water (0.06% concentration of spray dilution).

Treatments were directed into the cracks and crevices in which cockroaches hid or through which they may have entered an apartment or a building. In addition, all obvious harborages (along and behind baseboards; beneath and behind sinks, stoves, refrigerators, and cabinets; behind plumbing and electrical installations) were treated. A range between 0.75 and 1.0 liter of Empire 20 or Suspend SC dilution was applied to each test apartment.

Baiting treatments were made using Siege gel bait (AI = 2% hydramethylnon; American Cyanamid, Wayne, NJ) in 1995 and Knockdown Pheromone Boric Acid bait stations with an aggregation pheromone (AI = 47% boric acid; Woodstream, Lititz, PA) in 1996. The Siege gel was applied from the Xactadose Precision Baiting System (American Cyanamid) and calibrated according to the manufacturer's directions. The bait applications were regulated at or near 150 mg per placement; 100 placements were made (15 g of bait per test apartment). The number of harborage sites requiring treatment (based on sanitation level and initial visual inspection) contributed to variation in the amount of bait placed in any apartment. Bait placements were distributed only throughout the kitchen and bathroom as follows (approximate number of placements in parentheses): kitchen: below the sink (20), above the sink (15), refrigerator (20), stove (10), utility area (10), others (10); bathroom: general area (10) and below the sink (5).

Twelve Knockdown Pheromone Boric Acid bait stations were placed in each test apartment and left in place for 8 wk in 1996. Bait stations were allocated as follows (number in parentheses): the cabinets under the kitchen sink (2); the cabinets above the sink (2); under and adjacent to the stove (2); under, behind; and adjacent to the refrigerator (3); under and adjacent to the utility area where the water heater and furnace were located (2); and on the floor behind the bathroom toilet (1).

Vacuuming treatments were made using the Back Pack vacuum model of Li'L Hummer (Miracle Marketing–Manufacturing, Salt Lake City, UT). Cockroach harborage areas were identified and vacuumed on day 1 and again 7 d later. Because the use of a vacuum cleaner or repellent flushing pyrethroids (or both) can alter the spatial distribution and movement patterns of *B. germanica* substantially (Owens and Bennett 1982), a follow-up treatment was made at day 7 after the initial vacuuming. Potential harborages under and behind baseboards, beneath and behind sinks and stoves, under refrigerators, floors of the cabinets, and behind plumbing and electrical installations were vacuumed. Li'L Hummer's microcleaning tool kit was used to clean hard-to-reach areas.

Two types of vacuum bags were used for each apartment. The Ultra Stat closed bags, which filter 98.2% at 1 μm to 100% at 8 μm, were used in each test apartment at day 1. According to the manufacturer, the Ultra Stat bags filter out allergens, dust mites, pollen, and hazardous materials; the bags also are treated with a bactericide–fungicide that inhibits growth of microorganisms that could cause respiratory problems for humans. The conventional paper open bags, which filter at 10 μm, were used at the follow-up treatment (2nd vacuuming) at day 7. All bags were labeled after vacuuming, and all cockroaches picked up by the vacuum cleaner were counted in the laboratory, noting the sex and developmental stage.

In the flushing and vacuuming treatments, vacuuming was combined with the use of a flushing agent. Because *B. germanica* are able to hide in cracks and crevices and may withstand the suction of the vacuum cleaner in certain harborage sites, a synergized pyrethrin was used in areas where visible inspection was limited (under the refrigerator, splash boards, behind cabinets and stoves). The use of this flushing agent forced the cockroaches to enter open areas within 2–3 min after application, where they could be vacuumed. Vacuuming was discontinued when no cockroaches were observed outside their harborages. This treatment was made at days 1 and 7 as in the vacuuming treatment. In 1995, the flushing agent PT 565 Pyrethrin Insect Fogger (Whitmire, St. Louis, MO) was applied with a pressurized aerosol can. This agent contained 0.5% pyrethrins, 1% technical piperonyl butoxide, and 1% n-octyl bicycloheptene dicarboximide.

In 1996, the flushing and vacuuming treatment was made (on day 1 only) in selected, heavily infested apartments previously treated with sprays or traps. The sample density before and 8 wk after treatments with sprays or traps was estimated by Lo-Line trap catch in each of the 8 test apartments. Cockroach populations were sampled 7 d after the flushing and vacuuming treatment was made to estimate any additional population reduction caused by the new treatment. A different flushing agent, PT 565 Plus XLO (Whitmire), was applied with a pressurized aerosol can. It contained 0.25% pyrethrins, 0.25% d-trans allethrin, 1% technical piperonyl butoxide, and 1% n-octyl bicycloheptene dicarboximide.

In the trapping treatments, the Victor Roach Pheromone sticky traps (14.5-cm^2 sticky area) (Woodstream) were used as a control measure. The traps were placed at day 1 in 12 locations in each test apartment and left in place for 4 wk in 1995 and 8 wk in 1996 to obtain the total trap catch and determine population reduction. Traps were positioned against walls and appliances for best results. All filled, missing, or wet traps were replaced with new traps on a weekly basis (at the same time that we placed the 6 Lo-Line traps for weekly monitoring of the population). Locations of the Victor Roach Pheromone traps were the same as for the Knockdown Pheromone Boric Acid bait stations. At the end of the test period, trap catches from the Victor Roach Pheromone traps were determined noting the developmental stage of all cockroaches.

Data Analysis. In 1995 and 1996 tests, apartments were sampled at 1, 2, 3, and 4 wk after the initial treatments. Additional samplings at 6 and 8 wk after initial treatments were made in 1996 tests. The dependent variable in the analysis was the mean number of cockroaches per trap. Two approaches were taken to determine efficacy. One approach involved analysis within time to determine the comparative efficacy among the number of treatments independently at each sample interval. Percentage data were transformed by arcsine $\sqrt{P}$. Analysis was based on a completely randomized 1-way analysis of variance (ANOVA) and followed by multiple comparison tests among treatments by least significant difference (LSD; $P < 0.05$) (SAS Institute 1990). The 2nd approach involved analysis among time periods to determine whether or not the average trap catch (sample density) per apartment was reduced by the treatment. The mean number of cockroaches trapped before treatment was compared with the mean numbers at each interval after treatment by using the UNIVARIATE procedure of SAS ($P \leq 0.10$; SAS Institute 1990).

Results and Discussion

1995 Treatments. The mean number of cockroaches in Lo-Line traps before and after treatments, and the percentage of population reduction, are shown in Table 1. The mean number of cockroaches before treatment ranged from 25.8 to 52.2 per trap. These density estimates were not

Table 1. Mean density of *B. germanica* population, as estimated by Lo-Line trap catch in 1995, following treatments of Siege gel bait, Empire spray, Victor Roach Pheromone traps, vacuuming, and flushing and vacuuming

Treatment	No. apartments	Mean ± SE no. cockroaches trapped at selected dates (% trap catch reduction)					T, Pr > |T|[b]
		Before treatment[a]	1 wk	2 wk	3 wk	4 wk	
Siege Gel Bait	16	50.1 ± 7.7a	18.4 ± 3.7a (63.3)	12.0 ± 2.2a (76.0)	11.5 ± 2.6b (77.0)	8.8 ± 1.8a (82.4)	3.0, <0.01
Victor Roach Pheromone Traps	11	32.4 ± 8.1a	13.9 ± 3.9a (57.1)	10.1 ± 2.1a (68.8)	11.2 ± 2.5ab (65.4)	6.7 ± 1.3a (79.3)	1.8, 0.1
Flushing and Vacuuming[c]	12	34.9 ± 6.8a	16.4 ± 2.6a (53.0)	12.3 ± 2.0a (64.8)	13.3 ± 2.0ab (61.9)	6.9 ± 1.0a (80.2)	2.3, 0.04
Vacuuming[c]	15	25.8 ± 4.6a	11.3 ± 1.9a (56.2)	11.4 ± 1.5a (55.8)	12.2 ± 3.0ab (52.7)	7.1 ± 0.9a (72.5)	3.1, 0.01
Empire Spray[d]	13	52.2 ± 10.6a	24.5 ± 4.2a (53.1)	18.7 ± 3.3a (64.2)	27.5 ± 4.0a (47.3)	14.6 ± 2.0a (72.0)	2.3, 0.04
F		0.8	0.7	0.5	1.8	1.3	—
Pr > *F*		0.5	0.5	0.7	0.2	0.2	—

Within each column (analysis within time), mean densities followed by the same letters were not significantly different (LSD test, $P > 0.05$). Numbers in parentheses represent the percentage of reduction in trap catch compared with the pretreatment sample. Percentage reduction data analysis based on rank transformation of actual percentage data and provided similar statistical differences.

[a] Number of cockroaches per trap ranged from 23.3 to 211 for Siege bait treatment, 5.2 to 193.8 for Victor Roach Pheromone traps, 2.7 to 139 for flushing and vacuuming, 2.2 to 74.3 for vacuuming, and 3.0 to 228.5 for Empire Spray treatment.

[b] The values of T (the Student *t*-value for testing the hypothesis that the mean value for the differences between pretreatment and various samples over time is 0) and Pr > |T| (the probability of a greater absolute value for the Student *t*-value for testing the hypothesis) for the 5 treatments at 4 wk after treatment.

[c] Follow-up treatment was made 1 wk after initial treatment.

[d] Follow-up treatment was made 3 wk after initial treatment.

significantly different ($P > 0.05$), indicating that the infestations in these apartments assigned to each treatment were similar, and, therefore, test conditions were equivalent. The population reductions 1 wk after treatments were >50%. Four weeks after treatment, all treatments provided an acceptable or satisfactory level (>70%) of cockroach reductions under the extreme conditions of the test apartments, but the greatest population suppression occurred with the Siege gel bait to a level of 82.4% of the pretreatment value. Even though the percentage of reduction was numerically higher for the Siege bait 4 wk after treatment, there were no significant differences among the treatments; therefore, all treatments were equally effective at reducing *B. germanica* infestations.

Analysis among time periods indicated that the average trap catch (sample density) was significantly reduced from the pretreatment level by all treatments at all sampling periods after treatment.

Empire spray showed 47.3% reduction in trap catch at 3 wk after in the initial treatment, a degree of reduction that was not satisfactory (<50%). Therefore, a 2nd spray treatment was made 3 wk after the initial application at a rate of 38 ml/3.78 liter of water to decrease the population density. A range between 0.5 and 0.75 liter of Empire 20 was applied to each test apartment. The unacceptable population reduction, at the specified application rate and sampling time, may be related to not having enough residual solution put in the apartment to cause higher than the current reductions under the extreme conditions of the test apartments.

Table 2 shows the average vacuuming time and total number of cockroaches and oothecae vacuumed in the vacuuming and flushing and vacuuming treatments. A significant difference in vacuuming times between the 2 treatments was observed at the initial treatments on day 1 (16.9 ± 1.4 and 31.6 ± 7.0 min [mean ± SE], respectively), but no difference was found at the follow-up treatments on day 7 (9.5 ± 0.8 and 15.8 ± 4.1 min, respectively). At the initial treatments, means of 28.5 ± 7.2 and 76.9 ± 31.2 cockroaches per vacuum bag were found for the vacuuming and flushing and vacuuming treatments, respectively, but

Table 2. Vacuuming time and number of *B. germanica* and oothecae (mean ± SE) in the vacuuming and flushing and vacuuming treatments in 1995

Treatment	*n*	Day 1			Day 7		
		Vacuuming time, min	No. roaches per bag	No. oothecae	Vacuuming time, min	No. roaches per bag	No. oothecae
Vacuuming	15	16.9 ± 1.4a	28.5 ± 7.2a	4.3 ± 1.5a	9.5 ± 0.8a	7.1 ± 1.9a	0.5 ± 0.2a
Flushing and vacuuming	12	31.6 ± 7.0b	76.9 ± 31.2a	10.9 ± 4.0a	15.8 ± 4.1a	32.6 ± 12.3b	4.8 ± 2.0b
F	—	5.2	2.8	2.9	2.9	5.2	5.5
P	—	0.03	0.10	0.10	0.10	0.03	0.03

Means ± SE in the same column followed by the same letters are not significantly different (LSD, $P > 0.05$).

there was no significant difference in these means. At the follow-up treatments, difference in the number of cockroaches vacuumed was observed with mean values of 7.1 ± 1.9 and 32.6 ± 12.3 min for the 2 treatments, respectively. The number of oothecae collected at day 1 doubled with flushing and was 10 times more than in vacuuming alone at day 7.

Sampling densities before trapping with Victor Roach Pheromone traps ranged from 5.2 to 193.8 cockroaches per trap (n = 11). Twenty-four traps (with 62.9 cockroaches each) were replaced from 7 apartments at wk 1, 29 traps (with 56.3 cockroaches each) were replaced at wk 2, and 16 traps (with 51.1 cockroaches per trap) were replaced at wk 3 after trapping . At wk 4, all 132 traps were removed from 11 apartments with a total of 3,581 cockroaches. The use of 12 Victor Roach Pheromone traps per apartment (total of 132 traps), in addition to the traps replaced during the test, removed a total of 7,543 cockroaches during the 4-wk test period.

Composition of the total population caught in traps varied from week to week during the test period. Victor Roach Pheromone traps removed from the test apartments during the test period yielded a trap catch ratio (adults/nymphs) of 1:6, 1:5.5, 1:7, and 1:5.5 at 1, 2, 3, and 4 wk after trapping, respectively. Lo-Line traps removed weekly after the 24-h catch period yielded a trap catch ratio of 1:4 before treatment and 1:3, 1:1.5, 1:2, and 1:1.5 at 1, 2, 3, and 4 wk after trapping, respectively. Based on these preliminary data, it seems that Victor Roach Pheromone traps caught more nymphs than Lo-Line traps. A reduction in the frequency of nymphs in the population is an indication of restriction in population growth.

1996 Treatments. The mean number of cockroaches before and after treatment and the percentage of population reductions are shown in Table 3. The mean numbers before treatment ranged from 11.1 to 53.5 cockroaches per trap and were not significantly different ($P > 0.05$), indicating that the infestations in these apartments assigned to each treatment were similar. Similarly, there were no significant differences among the treatments at any sampling periods after treatment. Six weeks after treatment, all treatments provided an acceptable or satisfactory level (>70%) of cockroach reductions. Eight weeks after treatment, Knockdown Pheromone Boric Acid bait, Victor Roach Pheromone traps, and Suspend spray caused population reductions of 83.7, 80.1, and 68.5%, respectively.

Analysis among time periods indicated that the average trap catch was significantly reduced by the 3 treatments at all sampling periods after treatment (except at 1 wk after treatment).

Sampling densities before trapping with Victor Roach Pheromone traps ranged from 2.8 to 126.5 cockroaches per trap (n = 6). Twenty-three traps with a total of 2,345 cockroaches (102 cockroaches

Table 3. Mean number of *B. germanica*, as estimated by Lo-Line trap catch in 1996, following treatments of Knockdown Pheromone Boric Acid bait, Victor Roach Pheromone traps, and Suspend spray

Treatment	No. apartments	Mean ± SE no. cockroaches trapped at selected dates (% trap catch reduction)							T, Pr > |T|[b]
		Before treatment[a]	1 wk	2 wk	3 wk	4 wk	6 wk	8 wk	
Knockdown Pheromone Boric Acid Bait	8	53.5 ± 14.6	33.4 ± 7.6 (37.6)	29.2 ± 8.2 (45.4)	18.8 ± 4.6 (64.9)	12.4 ± 3.1 (76.8)	10.5 ± 2.9 (80.4)	8.7 ± 1.9 (85.0)	3.3, >0.01
Victor Roach Pheromone Traps	6	37.5 ± 10.9	20.5 ± 7.1 (45.4)	13.4 ± 3.8 (64.3)	9.6 ± 3.5 (74.4)	8.4 ± 2.8 (77.6)	9.3 ± 2.7 (75.2)	7.1 ± 2.1 (81.1)	2.8, 0.04
Suspend Spray	8	11.1 ± 3.9	4.5 ± 1.6 (59.5)	5.9 ± 2.2 (46.8)	6.0 ± 1.7 (45.9)	5.0 ± 2.2 (55.0)	3.3 ± 1.5 (70.3)	3.5 ± 0.9 (68.5)	2.7, 0.04
F	—	1.4	2.3	2.4	2.0	1.1	1.2	0.8	—
P	—	0.3	0.1	0.1	0.2	0.4	0.3	0.5	—

Means ± SE were not significantly different between treatments before treatment or at any observation period after treatments (LSD, P = 0.05).

[a] Number of cockroaches per trap ranged from 2 to 259.7, 2.8 to 126.5, and 2 to 27.2 in the Knockdown Pheromone Boric Acid bait, Victor Roach Pheromone traps, and Suspend spray, respectively.

[b] The values of T (the Student t-value for testing the hypothesis that the mean value for the differences between pretreatment and various samples over time is 0) and Pr > |T| (the probability of an absolute value for the Student t-value for testing the hypothesis) for the 3 treatments 8 wk after treatment.

Table 4. Effects of flushing and vacuuming treatment in reducing *B. germanica* populations in heavily infested apartments previously treated with sprays or traps; mean density was estimated by Lo-Line trap catch in 1996

Apartment[a]	No. of roaches/trap at		% population reduction at wk 8	No. roaches and oothecae vacuumed at wk 8		No. roaches/trap 7 d after treatment (wk 9)[b]	% population reduction at wk 9
	wk 0	wk 8		No. roaches	No. oothecae		
1	289.8	43.2	85.1	136	28	22.7	92.4
2	138.3	20.2	85.4	54	11	11.7	91.5
3	114.2	20.5	80.1	57	8	8.8	92.3
4	154.7	53.0	65.7	131	15	34.5	77.7
5	87.8	22.7	74.1	45	10	14.7	83.3
6	93.0	15.8	83.0	47	11	10.7	88.5
7	49.2	18.7	62.0	35	9	12.7	74.2
8	126.5	23.5	81.4	55	18	13.8	89.1
Mean ± SE/ apartment	132.8 ± 24.4	27.2 ± 4.7	79.5 ± 3.2	70 ± 14.1	13.8 ± 2.3	16.2 ± 3.0	87.8 ± 12.2

[a] Apartments 1–5 were treated with pyrrole formulations, apartments 6 and 7 were treated with cyfluthrin formulations, and apartment 8 was treated with sticky traps.

[b] Number of cockroaches per trap 7 d after the 8-wk treatment of spray formulations and sticky traps in the 8 apartments.

per trap) were replaced from 3 apartments during the first 6 wk of the study. Eight weeks after treatment, 1,209 cockroaches caught on 44 traps (28 cockroaches per trap) were removed from 5 apartments. Therefore, the total number of cockroaches caught during and at the end of the test reached 3,554 (53 cockroaches per trap).

The effect of the flushing and vacuuming treatment in reducing *B. germanica* population in apartments previously treated with sprays or traps is shown in Table 4. The mean number of cockroaches for the 8 test apartments before treatment was 132.8 ± 24.4 cockroaches per trap (range, 49.2–289.8) and the percentage of population reduction 8 wk after treatment averaged 79.5 ± 3.2% (range, 62.0–85.5%). Use of a flushing agent and vacuum cleaner 8 wk after treatment resulted in population reduction by 8.3% (to 87.8%). In addition to this additional population reduction, an average of 70 ± 14.1 cockroaches (range, 35–131) and 13.8 ± 2.3 oothecae (range, 8–28) was vacuumed from each apartment. Forcing gravid females from their deep and hard-to-treat harborages and the physical removal of these females is an important step in reducing cockroach population reproduction and growth.

Vacuuming treatment significantly reduces cockroach populations to a low level but does not eliminate them because there is no residual, and the remaining cockroach populations tend to rebound in 3–4 wk (Frishman 1995). Vacuuming should be directed into cracks and wall voids, sides of cabinets, behind baseboards, and potential harborage in appliances and furniture. In addition to the physical removal of cockroaches, vacuum cleaning removes food sources, cast skins, fecal materials, as well as dead and live specimens from normally inaccessible sites, and always adds stress to cockroaches. According to the manufacturer, the vacuum cleaner introduces a 300-mph wind that creates high stress to individual cockroaches, forces them out of their preferred habitats, and makes these areas less suitable for survival or reproduction. This type of stress places cockroaches at greater risk to the effects of insecticides and other biotic and abiotic control tactics (Gold 1995).

The flushing and vacuuming technique is very useful in a control program where high cockroach numbers are present. Also, hard-to-reach gravid females are more vulnerable to being caught by the flushing and vacuuming technique than by other tested methods. Gravid females are more important than males and nymphs from the standpoint of long-term population reduction (Moore and Granovsky 1983).

Using the Victor Roach Pheromone traps led to a significant reduction in trap catch at all sampling times after treatment. This trapping technique has potential application as a mechanical monitoring and control tool for *B. germanica*. Proper trap placement, suitable trap design, and the size of the sticky surface area play important roles in affecting the trap catch (Ballard and Gold 1982). Improved adhesives and food attractants and the effects of enlarging the proportional size of the Victor Roach Pheromone trap and its openings are being made by Woodstream to increase cockroach catch.

Public perception is an important factor in determining the value of various nonchemical control strategies. Whenever new techniques and technologies are developed, it is important to ensure public acceptance and development of proper safety procedures, in addition to reducing the application of unnecessary pesticides and achieving acceptable, cost-effective cockroach control. Additional field testing should be conducted using nonchemical control methods (traps, vacuum cleaners, sanitation), in conjunction with low-impact pesticide techniques (baits), to develop the information and strategies for using these technologies in an integrated pest management system that will enable the implementation of environmentally sensitive pest control in infested residences.

Acknowledgments

We express appreciation to J. Neal, C. Sadof, and Mike Scharf (Purdue University) for critical review of the early version of the manuscript. Steritech Group, Incorporated, and Woodstream provided partial funding for this research. This is Journal Paper No. 15278 of the Agricultural Research Programs of Purdue University, West Lafayette, IN.

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Received for publication 15 November 1996; accepted 18 February 1997.

Journal of Integrated Pest Management
OPEN ACCESS
CASE STUDY

Advancement of Integrated Pest Management in University Housing

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J. Integ. Pest Mngmt. 2(3): 2011; DOI: http://dx.doi.org/10.1603/IPM10011

ABSTRACT. Research was conducted in collaboration with the University of Florida (UF), Department of Housing and Residence Education (DOHRE) to assess and advance the campus integrated pest management (IPM) program they initiated in 2003. Beginning in 2008, the UF, DOHRE advanced IPM program was based on resident education, periodic inspection, and a systematic decision-making process whereby apartments were monitored, pests identified, action thresholds determined, and safe and effective pest management options used. The continuously improved process began with pest management methods based on resident behavior, such as sanitation and pest exclusion accomplished by the residents, accompanied by physical controls, including barriers installed by maintenance personnel and pest control devices maintained by DOHRE IPM technicians. If pest problems persisted, low risk materials were used, for example, dishwashing detergent solutions, boric acid, diatomaceous earth, bait stations, and botanical or microbial insecticides. There was a significant improvement in pest prevention behavior of the residents after the 2008 DOHRE IPM education and inspection campaign; however, there was no change in the already low annual number of pest complaints. From 2003 through 2008, ants were the most common pest reported, followed in order by cockroaches, stored product pests, and termites. The amount of insecticide active ingredient used per year decreased by ≈92%, virtually eliminating the use of hydramethylnon, borate, desiccants, organophosphates, fipronil, and pyrethroids. Further advancements can be made in campus IPM by increasing resident education and DOHRE IPM technician training, and the level of pest preventative inspection and maintenance.

Key Words: urban IPM; insecticides; pest insects

As in agriculture, urban IPM is a systematic approach to managing pests based on long-term prevention or suppression by a variety of methods that are cost effective and minimize risks to human health and the environment (Lewis et al. 1997, USDA 2004). Urban pests can just be a nuisance or cause significant health problems, damage to buildings, and additional economic losses because of food contamination, diminished esthetics, and pest management costs. The use of insecticides to manage urban pests also can have negative consequences, such as environmental pollution and adverse health effects for humans and animals (Buckley 2000, Alarcon et al. 2005). By systematically practicing sustainable urban IPM, risks associated with pests and pesticides can be minimized (IPM Institute 2011).

Urban IPM, developed by incorporating many of the established concepts of agricultural IPM (Stern et al. 1959), integrated biotic and abiotic factors, including the appropriate use of pesticides. Concepts, such as scouting, accurate pest identification, action thresholds, and conservation of natural controls were adapted for use in structural and landscape pest management (Flint et al. 1991). As urban IPM advanced, education became a key factor in preventing pest infestations, improving sanitation, and increasing tolerance of nonrisk pests (Byrne et al. 1984, Robinson and Zungoli 1985, Greene and Breisch 2002). Today, the goal of urban IPM is to manage pests primarily by prevention and elimination of their access to food, water and harborages, along with changing human behavior. Low-risk insecticides are used only when necessary and rarely those with the signal words "warning" or "danger" indicated on their U.S. Environmental Protection Agency (EPA) labels. Insecticide use in urban housing and associated health risks (Buckley 2000, Alarcon et al. 2005) can be minimized by instituting IPM based on low-risk practices that maintain pests at very low levels (Williams et al. 2006).

Universities often have campus IPM programs at some stage of development but rarely obtain, analyze and publish data on their methods, materials, experiences, and successes. IPM studies have been conducted in public housing (Greene and Breisch 2002) but most were restricted to low income units primarily in inner-city neighborhoods (Rosenstreich et al. 1997, Campbell et al. 1999, Brenner et al. 2003, Williams et al. 2006, Peters et al. 2007). We are not aware of a published study on the effectiveness of an IPM program in university graduate student and family housing, even though ≈2.4 million students live in college and university housing nationwide (U.S. Census Bureau 2009). The purpose of this research was to document, assess and advance the University of Florida (UF) Department of Housing and Residence Education (DOHRE) IPM program after its first 5 years, 2003–2008. Specific objectives in maintaining UF, DOHRE properties with minimal exposure of residents to pests and pesticides were to (1) educate residents about pests and pest prevention, (2) assess pest problems systematically to determine the best IPM options, (3) base IPM actions on accurate identification of pests, knowledge of their biology, and reasonable thresholds, and (4) increase the effectiveness of the IPM program.

Materials and Methods

The DOHRE began using basic IPM practices for UF housing and residence halls in 2003, including routine apartment inspections, sanitation requirements, requests for maintenance to UF Facilities Management, and use of low-risk insecticides and baits. Low-risk products had the signal word "caution" on their EPA labels. To advance the initial UF, DOHRE IPM program, all bait stations for ants and cockroaches were removed from the apartments and prophylactic insecticide treatments were discontinued. In 2008, we instituted the following: a written IPM policy, a dedicated IPM specialist trained at UF, prescribed pest prevention practices, education of residents about insects, a pest monitoring system, accurate pest identification, an electronic pest complaint procedure, a rapid response and collaborative decision-making process, preferential use of nonchemical pest management methods, application of low-risk insecticides if necessary, continuous IPM program evaluation, and comprehensive record keeping. The advanced DOHRE IPM program has been documented in a training manual that describes how to institutionalize IPM, pre-

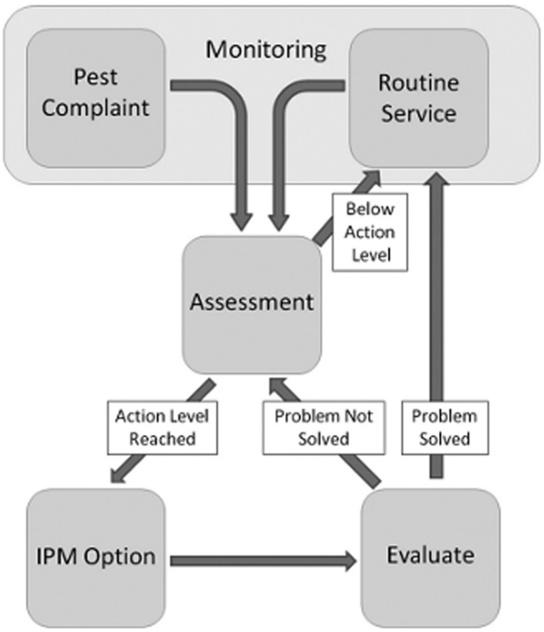

Fig. 1. The IPM decision-making process developed between initiation of the IPM program on 1 January 2003 and its advancement in 2008. The process begins with either a pest complaint by a resident or pest sighting during a routine service inspection. The potential infestation is assessed and appropriate action taken if a threshold is reached. The outcome is evaluated and additional action taken if warranted or monitoring is resumed.

vent pest problems, and select pest-specific IPM options (Juneau et al. 2009).

The systematic DOHRE IPM decision-making process is based on experience gained from 2003 to 2008 (Fig. 1). IPM actions begin with a pest complaint (pest management request) submitted by a resident or a pest sighting by a DOHRE IPM technician during routine service. In either case, the pest is identified and a thorough assessment made to determine if it has reached a level of abundance or caused damage that triggers an IPM action. General action thresholds for the pests encountered in UF housing and residence halls were indicated in the IPM training manual (Juneau et al. 2009). Continued monitoring, perhaps with an increased frequency of inspection, is the only requirement if the action level has not been reached. Above the action threshold, IPM options are selected by the DOHRE senior IPM technician in consultation with the residents based on their effectiveness, safety, and cost. Examples of safe options are modifications to the physical environment, changes in resident behavior, animal traps with finger guards, and the judicious use of reduced risk insecticides (EPA 2011) to mitigate pest infestations. A subsequent evaluation is made to determine if the pest problem has been solved; if not, the IPM actions are reassessed. This decision-making process has two feedback loops to monitoring: (1) monitoring—assessment—below action level—continued monitoring and (2) monitoring—assessment—above action level—IPM options—evaluation—problem not solved—reassessment. Eventually, if the pest is no longer apparent or causing damage, continued monitoring is the only required IPM action.

Study Location. In collaboration with DOHRE, an ≈50-year-old U.S. Department of Housing and Urban Development (HUD) apartment complex located on the UF main campus in Gainesville, FL, was selected to serve as the study site. The complex consisted of 28 residential buildings encompassing 220 apartments and one additional support building containing a common area for residents, an office, and a laundry room. Twenty-seven of the residential buildings each had two 1-bedroom and two 2-bedroom apartments downstairs and upstairs. Another building had four 1-bedroom apartments. The complex housed single graduate students and both married undergraduate and graduate students and their families. Most of the residents were international students with a wide range of living habits and attitudes about pests and pest management.

Resident Education. The DOHRE senior IPM technician provided a 1-hour verbal orientation for new residents of the apartment complex at the beginning of the spring semester in January 2008. During an evening, the new residents gathered as a group in the common area to learn about pest prevention and associated apartment inspection criteria (Table 1). They were encouraged to contact DOHRE for pest management services, rather than attempt to control pests with over-

Table 1. Improvement in inspection criteria between the first (Mar. 11–April 11, 2008) and second (Jan. 5–26, 2009) inspection ($n = 155$ apartments)

Inspection criteria	Number of deficiencies		% Improvement
	First inspection	Second inspection	
1. Outdoor pest harborage	18	7	−11 (61.1%)
2. Screen door open	39	40	1 (−2.6%)
3. Odor in apartment	36	26	−10 (27.8%)
4. Mold present	45	1	−44 (97.8%)
5. Carpet in poor condition	1	1	0
6. Garbage cans not covered	113	77	−36 (31.9%)
7. Garbage spilled around can	15	6	−9 (60.0%)
8. Food stored open on counter	75	44	−31 (41.3%)
9. Food stored in rooms not kitchen	15	12	−3 (20.0%)
10. Rotting food present	15	11	−4 (26.7%)
11. Kitchen sink dirty	16	9	−7 (43.8%)
12. Kitchen floor dirty	14	8	−6 (42.9%)
13. Kitchen counters dirty	14	12	−2 (14.3%)
14. Kitchen cabinets cluttered	13	4	−9 (69.2%)
15. Food spills in kitchen cabinets	44	23	−21 (47.7%)
16. Bathroom sink or tub dirty	9	2	−7 (77.8%)
17. Bathroom floor dirty	7	1	−6 (85.7%)
18. Carpet dirty	12	7	−5 (41.7%)
19. Clutter throughout apartment	16	15	−1 (06.3%)
20. Stove dirty	6	1	−5 (83.3%)
21. Under refrigerator dirty	23	14	−9 (39.1%)
22. Improper food containment	70	75	5 (07.1%)
23. Poor general organization	18	11	−7 (38.9%)
Net improvement in IPM	634	407	−227 (35.8%)

the-counter pesticides. As an alternative to insecticides, a 1-liter spray bottle was provided to each household with instructions on how to mix a 6% solution of dishwashing detergent. Household cleaners, including detergents, have been shown to kill insects on contact (Baldwin and Koehler 2007) and can be used to remove insects, pheromone trails, frass, and associated debris. The residents received additional IPM information and instruction during routine inspections and in response to pest complaints. They also were given educational brochures produced for the DOHRE IPM program: Bed Bug Prevention, Tips to Keep Pests Out of an Apartment, Extended Vacation Checklist, Campus Gardening, and Identification of Common Insect Pests in UF Housing (Juneau 2009). These documents were e-mailed to the residents, linked to their on-line newsletter, The Villager, placed in the apartment complex common areas, and made available on the IPM Florida Web site (http://ipm.ifas.ufl.edu).

Apartment Inspections. An initial inspection of apartments was conducted between March 11 and April 11, 2008, followed by another during January 5–26, 2009. Vacant apartments and those with new residents during the second inspection were not included in the study. The final 155 apartments were inspected for pest-conducive physical defects and deficiencies in resident behavior based on 23 criteria (Table 1). There were 11 types of maintenance problems, including cracks or holes in walls, window screens not secured, windows not sealed, inadequate door sweeps or seals, improper gutter drainage, walls with evidence of water leaks, improper escutcheon plate installation, condensation on plumbing, pipe leaks, inadequate ventilation, and cracks or holes in the ceiling. The number and types of resident behavioral deficiencies and physical defects were recorded during the initial and subsequent inspection for each apartment. Changes in inspection criteria were analyzed with a paired *t*-test using JMP 7.0 (SAS Institute 2007).

Pest Complaints. Pest complaints had been recorded for each of the 220 apartments since January 1, 2003. These and subsequent complaints during this study were grouped by the most abundant pest types or listed as unknown, including spiders, mites, booklice, bed bugs, mice, mosquitoes, and wasps. The data were totaled for each pest type by month and a time series analysis was used to determine possible seasonal patterns. The numbers of pest complaints also were compared before and after resident IPM education and apartment inspections were intensified in January 2008. Pest complaints were used as a proxy because there were no historical records of the exact numbers of specific kinds of pests present in the apartments. Because many pests were not reported, complaints served as a conservative estimate of the actual pest exposure for the residents. The pest complaint data were analyzed as a time series using JMP 7.0 (SAS Institute 2007).

Insecticide Applications. DOHRE insecticide use records included the apartment numbers, product names and amounts, and application dates. Monthly data from January 1, 2003 to December 3, 2008 were analyzed by comparing the weight (mass) of active ingredients in insecticide products across widely varying formulations. Records for each apartment were kept on the total weight of active ingredients for solid and gel formulations but only on the volume applied for liquids and aerosols. Because these liquid products are almost all water, the mass of each was estimated by first multiplying its specific gravity (SG) derived from the Material Safety Data Sheet (MSDS) by the density of water (1 g/ml) to determine the density of the product. The density of a product was then multiplied by its volume to determine its mass. The percentage of active ingredient in each solid, gel, liquid, and aerosol product is listed on the EPA label, so the percentage times the mass of the product yielded an estimate of the mass of active ingredient:

$$\text{Density}_{\text{product}} = \text{Specific Gravity}_{\text{product}} \times \text{Density}_{\text{water}}$$

$$\text{Mass}_{\text{product}} = \text{Volume}_{\text{product}} \times \text{Density}_{\text{product}}$$

$$\text{Mass}_{\text{active ingredient}} = \text{Mass}_{\text{product}} \times \%\ \text{Active Ingredient in the Product}$$

The insecticides were grouped according to class (Kegley et al. 2008) and the mass of active ingredients applied in each class was totaled monthly.

Results

Resident Education and Apartment Inspections. The UF, DOHRE IPM resident education and apartment inspection campaign improved pest prevention practices within the first year. Residents should have learned about proper food storage and sanitation from the orientation meeting and brochures provided in January 2008. However, the first inspections conducted in March through April 2008 revealed that they still had major shortcomings in their pest prevention behavior (Table 1). The apartment inspections reinforced the importance of sanitation and other pest prevention practices. During the second inspections in January 2009, the average number of deficiencies in inspection criteria per apartment decreased significantly from 4.14 ± 0.27 to 2.65 ± 0.22 (mean ± SD; $n = 155$; paired *t*-test, $t = 5.29$; $P < 0.0001$). The maintenance defects remained unchanged from 2.85 ± 0.14 to 2.86 ± 0.14. IPM cleaner solution spray bottles were present in all 155 apartments; however, the number of apartments with over-the-counter insecticides was reduced only from 57 to 52. DOHRE IPM technicians could conduct routine apartment inspections but did not have the authority to require residents to discard insecticides they had purchased.

The apartments were evaluated for all 23 inspection criteria during both the first and second inspection (Table 1). For the first inspection, 634 deficiencies were observed but the number declined to 407 for the second inspection, a 35.8% overall improvement. Decreases occurred in all but two of the inspection criteria, screen door open and improper food containment. There were 12 major deficiencies, those in >15% of the apartments, during the first inspection. These included outdoor pest harborage, screen door open, odor in apartment, mold present, garbage cans not covered, food stored open on counter, kitchen sink dirty, food spills in kitchen cabinets, clutter throughout apartment, under refrigerator dirty, improper food containment, and poor general organization. Of the entire set of 23 deficiencies, all except five were reduced by >25%, including screen door open, food stored in rooms not kitchen, kitchen counters dirty, clutter throughout apartment, and improper food containment. Nevertheless, the percentage of apartments with screen door open, garbage cans not covered, food stored open on counter, and improper food containment remained unacceptable.

Pest Complaints. There was no overall pattern in the annual number of pest complaints preadvancement (2003–2007) and postadvancement (2008) of the IPM program (Fig. 2). However, complaints about ants and cockroaches appeared to increase after 2005, as did complaints for all pest types in 2008, except stored product pests. The mean ± SD numbers of monthly pest complaints recorded for 72 months from 2003 to 2008 were ants (4.03 ± 0.53), cockroaches (1.38 ± 0.16), stored product pests (0.21 ± 0.05), termites (0.31 ± 0.09), and unknown (1.0 ± 0.13).

There were 290 complaints involving ants, the major pest being the dark rover ant, *Brachymyrmex patagonicus* Mayr (Hymenoptera: Formicidae), an adventive species from South America. Though not statistically significant ($P = 0.09$, autocorrelation = 0.314), ant complaints appeared to have a 12 month cycle with increases during the summer months and decreases during the winter (Juneau 2009). There was a peak in ant complaints during May 2008 probably resulting from ants being disrupted by the installation of high-speed Internet cables. Trenching around buildings redistributed the soil and created a barrier to foraging that forced ants indoors. In response to these complaints, the ants were treated almost exclusively with a borate and honey bait formulation. Inside apartments, the ants accumulated most often in kitchens. They were observed entering through air conditioning ducts and cracks in the drywall. Although we did not open walls to follow the trails, large colonies of *B. patagonicus* previously had

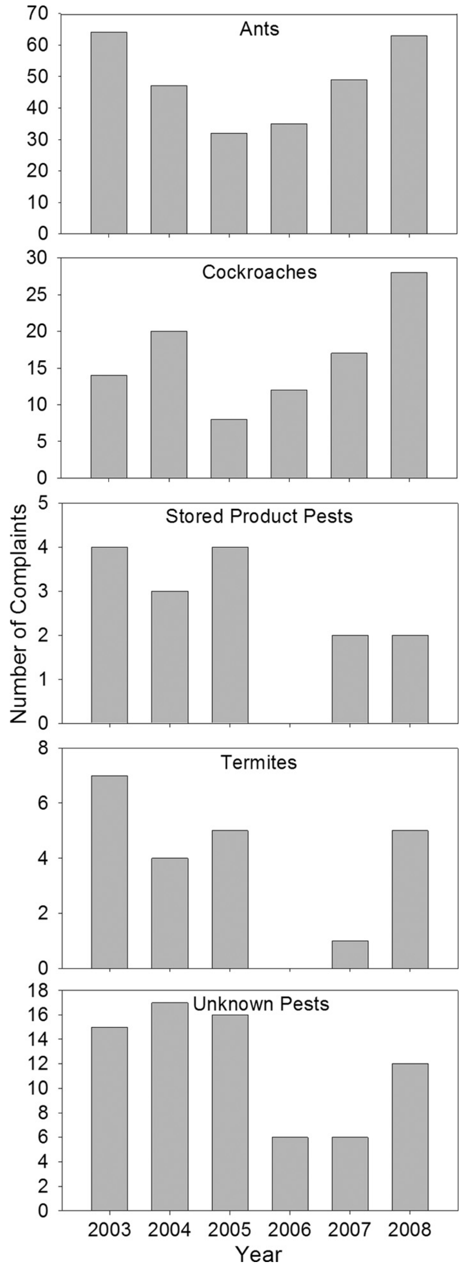

Fig. 2. The total number of pest complaints per year for each of the pest types from 220 apartments preadvancement (2003–2007) and postadvancement (2008) of the IPM program.

been discovered in bathroom and kitchen walls when apartments were renovated. These ants have been reported to nest inside walls (MacGown et al. 2007).

There were 99 complaints about cockroaches from January 2003 to December 2008 with no distinction between the two combined species, the German cockroach, *Blattella germanica* L., and American cockroach, *Periplaneta americana* L. (Blattodea: Blattidae). The complaints were not cyclic because German and American cockroaches are domestic and peridomestic, respectively (Hagenbuch et al. 1988, Atkinson et al. 1990), and are only indirectly affected by outdoor weather. The relative abundance of the two cockroach species was not noted. Complaints about cockroach infestations increased in 2008 but remained infrequent regardless of deficiencies in apartment sanitation. The presence of food, water, and harborages supports cockroach infestations (Schal 1988), so increased sanitation possibly could reduce the number of complaints.

The remainder of the pest complaints involved stored product pests (15), subterranean termites (Isoptera: Rhinotermitidae) (9), drywood termites (Isoptera: Kalotermitidae) (13), and unknown (72). Complaints about stored product pests were intermittent and the unidentified insects were discarded with the contaminated food. Termite infestations were uncommon and various kinds of unknown pests were handled on a case by case basis.

Insecticide Applications. The classes of insecticides used at the apartment complex in 2003–2004 were primarily amidinohydrazone (hydramethylnon), borate (boric acid), desiccants (silica gel and diatomaceous earth), and an organophosphate used to exterminate drywood termites (Fig. 3). Borate and desiccant insecticides were used to control ants, cockroaches, and other crawling insects. After 2004, EPA registrations were discontinued for most organophosphates. During 2004–2005, formulation of cockroach baits changed from hydramethylnon to fipronil, a pyrazole. This decreased the weight of active ingredient necessary to treat for cockroaches in 2006 because the proportion of fipronil per product (0.05%) is less than hydramethylnon (2%). Mosquitoes that rested in stairwells were treated with pyrethroids beginning in 2004 but only minor amounts of hydramethylnon, silica gel and bifenthrin have been used at the apartment complex since 2006. Synergists and an insect growth regulator were used infrequently and therefore not included in the analysis. In 2007, trench and rod applications of an insecticide product containing fipronil were made around the apartment buildings to control subterranean termites. Pyrethroids continued to be the predominant insecticides applied because their formulations are effective, easy to use, repellant, and labeled for use on many insects.

The amount of insecticides used per year increased from 1952.45 g in 2003–4318.60 g in 2005, and then decreased to 155.61 g in 2008 as the advanced IPM program was implemented (Fig. 4). The switch from applying insecticides routinely to addressing only identified pest problems accounted for most of the subsequent low quantity and intermittent use of these chemicals. After spring 2008, borates and other desiccants were no longer routinely placed in wall voids, under cabinets, and throughout the kitchens, and all baits were removed from the apartments. There was a bed bug, *Cimex lectularius* L. (Hemiptera: Cimicidae), infestation in June 2008 that warranted the use of a desiccant and pyrethroid (Fig. 3). These insecticides were confined inside wall voids, behind baseboards, and in cracks and crevices. In conjunction with the insecticides, a heat treatment shown to kill bed bugs (Pereira et al. 2009), was used for sensitive items, such as a mattress and box springs, bedding, furniture, and clothing. From September to November 2008, a hydramethylnon product was used to eliminate potentially harmful red imported fire ants, *Solenopsis invicta* Buren (Hymenoptera: Formicidae). Also in 2008, there were many complaints about ants, requiring applications of a boric acid and honey bait.

Discussion

This research documented and advanced the IPM policies and practices instituted by UF, DOHRE for the buildings and grounds they manage. As a result, DOHRE IPM technicians are trained to assess pest problems systematically, determine the best IPM options in consultation with the residents, and base their actions on accurate identification of pests, knowledge of pest biology, and reasonable thresholds (Juneau et al. 2009). Thresholds are reached before appropriate IPM options are selected, ranging from nonchemical methods and, if necessary, the use of effective, low risk insecticides. Nonchemical methods include exclusion, sanitation, trapping, or perhaps tolerating the pest. If insecticides become necessary, they are applied after the residents are notified and during appropriate times to maximize their effectiveness and protect human health and the environment. Low-risk products are selected and placed in locations where human exposure is minimal. All insecticides are handled according to state and federal laws and there are no routine, periodic applications.

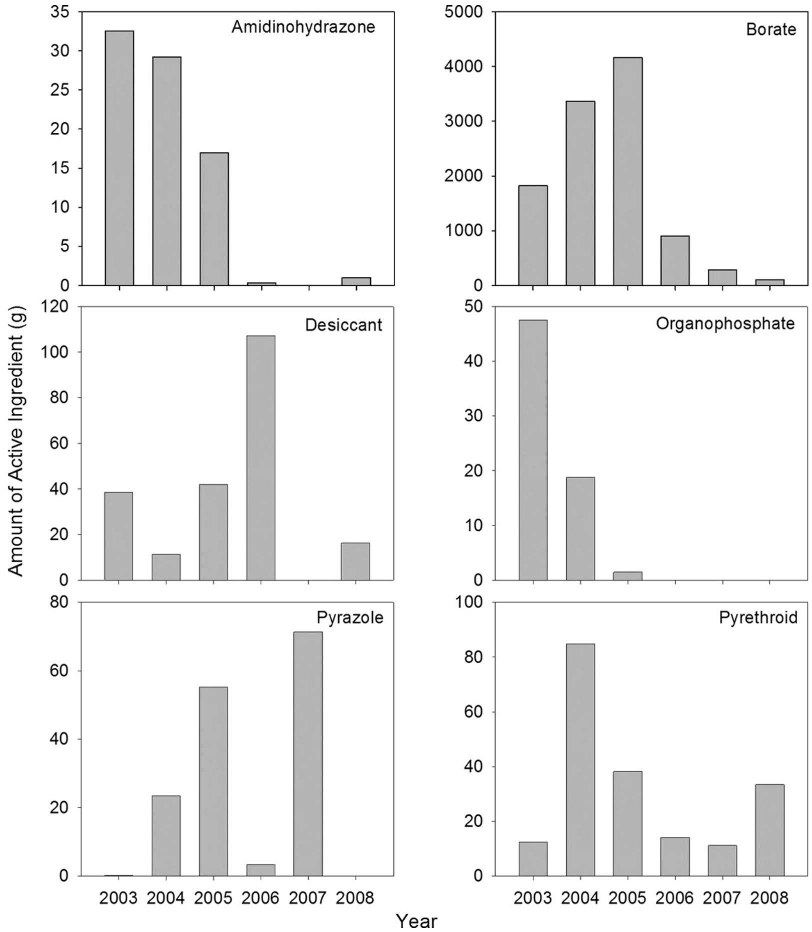

Fig. 3. The average amount (weight) of insecticide active ingredient in indicated classes used each year from 2003 to 2008.

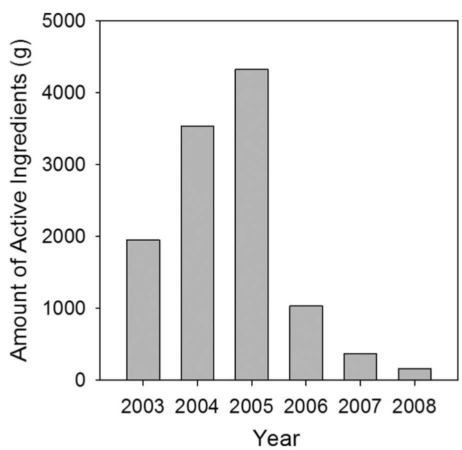

Fig. 4. The total amount (weight) of insecticide active ingredients used per year between 2003 and 2008.

The DOHRE IPM technicians and residents cooperate in determining that the IPM options they select are acceptable and effective in eliminating pest infestations.

The DOHRE IPM program for university housing achieved the goal of minimizing exposure of residents to pests and pesticides by altering the behavior of both residents and DOHRE IPM technicians. An IPM policy was instituted that emphasized education about pests and pest prevention. In a related pilot study, a brief educational session and booklet influenced residents to accept and comply with an IPM program (Campbell et al. 1999). In our study, residents improved their sanitation and food handling practices significantly after receiving verbal guidance, associated written IPM educational materials, and thorough apartment inspections. However, after nearly a year of the advanced DOHRE IPM program, many of the residents still provided insects access through open screen doors, continued to have unacceptable odors and clutter throughout their apartments, and did not store food properly. Several years may be required to reduce the number and kinds of pests infesting the apartments, as in previous studies of public buildings (Greene and Breisch 2002). Further reductions are possible, however, because residents will receive IPM instruction repeatedly during their 3- to 6-year educational programs. It has been shown that continuing education is essential for changing attitudes about the presence of arthropods and implementing an urban pest management program (Byrne et al. 1984).

The public wants a pest-free environment but prefers pest management practices that minimize the use of pesticides (Potter and Bessin 1998). The UF, DOHRE IPM program is designed to achieve this goal. It effectively maintained minimal pest levels, indicated by a continuous low number of pest complaints, while decreasing the amount of insecticide applied by 92%. From 2005–2008, cockroach and ant complaints averaged less than two and five per month, respectively, for 220 apartments. The number of pest complaints fluctuated widely as the IPM program advanced and additional reductions may not be achievable. Pest complaints involve attitudes about pests and pesticides, as well as the level of pest exposure (Byrne et al. 1984, Potter and Bessin 1998). The use of amidinohydrazone, borate, and desiccant insecticides was minimized and organophosphate and pyrazole insecticides were eliminated. Conversely, pyrethroids were used in relatively large quantities, although less frequently. Active ingredients should be rotated to reduce the probability that the pests develop insecticide resistance or avoidance. The IPM program recently achieved Green Shield certification (IPM Institute 2011) but can be improved further by increasing communication and cooperation between the residents, DOHRE IPM technicians, and Facilities Management.

Acknowledgments

We thank Norbert Dunkle, Terry McDonald, and other personnel of UF, DOHRE for their guidance and use of their facilities. The faculty, staff and students of the UF, Entomology and Nematology Department contributed technical assistance. Funding was provided by USDA, NIFA through IPM Florida and a Steinmetz Endowment to the UF, Entomology and Nematology Department. Expert reviews of the manuscript were contributed by Phil Koehler and Carrie Koplinka-Loehr. Dan Hahn assisted with presentation of the data.

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Received 20 July 2010; accepted 13 October 2011.

Comparison of Conventional and Integrated Pest Management Programs in Public Schools

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J. Econ. Entomol. 98(4): 1275–1283 (2005)

ABSTRACT This study compared an integrated pest management (IPM) program with conventional, calendar-based pest control in nine North Carolina elementary schools. Both programs primarily targeted the German cockroach, *Blattella germanica* (L.). The IPM program relied heavily on monitoring and baiting, whereas the conventional approach used baseboard and crack-and-crevice sprays of insecticides. Within the constraints of an existing pest management contract, we quantified service duration, materials used, cost, levels of cockroach infestation, and the pesticide residues generated by the two service types. IPM services were significantly more time-consuming than conventional services, resulting in a significantly higher cost associated with labor. Nevertheless, the two types of treatments incurred similar total costs, and the efficacy of both treatments was also similar. Most importantly, pest monitoring, a central element of the IPM program, revealed few cockroaches and indicated that most of the conventional treatments were unnecessary. Environmental residues of the organophosphate pesticides acephate, chlorpyrifos, and propetamphos were significantly higher in swab samples taken in the conventionally treated schools. This study demonstrates that an IPM program is an appropriate and preferable alternative to conventional methods of pest control in the school environment.

KEY WORDS school IPM, IPM, German cockroach, *Blattella germanica*

EXPOSURE OF CHILDREN TO PESTICIDES has been a major public concern for the past several decades, first brought to public attention by the National Research Council report *Pesticides in the Diets of Infants and Children* (National Research Council 1993) and further motivated by the observations that "pound for pound of body weight, children breathe more, eat more, and have more rapid metabolisms than adults, and they also play on the floor and lawn where pesticides are commonly applied" (USGAO 1999). Children therefore are at greater risk of pesticide exposure, and the health impact may be more profound than for the rest of the population. Recent interest has focused specifically on pesticide use in schools, in part in response to reports of the American Association of Poison Control Centers that there were 2,300 complaints of pesticide-related exposures in schools between 1993 and 1996 (USGAO 1999).

The school environment creates a unique problem for insect pest suppression because schools are expected to be pest-free, while still restricting occupants' exposure to pesticides. In an effort to understand who is conducting pest control in schools, the North Carolina Cooperative Extension Service conducted a survey of 120 public school systems in North Carolina (Anonymous 1999). The survey concluded that 1) fewer than one-half of the schools used any integrated pest management (IPM) techniques to control pests; 2) 15% of the schools used school employees who were unlicensed in pest control; 3) cost was the most important factor in choosing a pest control company for 19% of the schools; 4) only 51% of the schools kept any records of pesticide applications; and 5) baseboard applications of residual broad-spectrum pesticides was reported in 70% of the schools. These general findings are probably not unique to North Carolina.

In the school environment, IPM can serve to prevent pest problems while reducing the risk of pesticide exposure to children. Yet, as of 2005, fewer than one-half of the states in the United States have laws requiring the use of IPM techniques in their schools, and the School Environmental Protection Act (U.S. House of Representatives 2005), which was originally introduced in 1999 to require the use of IPM methods in all public schools, has yet to be adopted as federal legislation. Although most experts agree that IPM programs will benefit schools and children, there are also enduring concerns over such legislation (USGAO 1999), mainly related to the cost of IPM programs, which is thought to be higher than conventional pest control. Also, there is apprehension that national mandates would be too broad to address the specific pest

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control needs in different areas of the country. And finally, once IPM is mandated, there is uncertainty about implementation and enforcement of these laws to ensure that schools are in compliance.

A review of our current understanding of pest management in schools plainly reveals that scarcely any data exist on the types of pesticides used in schools, where they are applied, program costs, or the efficacy of such services. Therefore, deliberations for or against adoption of IPM approaches are largely based on conjecture and subjective judgment. We undertook an analysis of two distinct pest management programs in public schools in an effort to compare the costs and benefits of these approaches.

Materials and Methods

Schools. The study was conducted in Nash County, North Carolina. Public elementary schools were included in the study based on their pest populations, similarity of school age and design, and the cooperation of the pest control company, which was contracted to service all nine schools and associated administrative buildings. According to the contract agreement, the schools were to be serviced monthly, but the type of service and materials were not specified. The areas specified to be serviced each month were vending machine areas and lounges, cafeteria serving, preparation, dish washing, and dining areas, all restrooms, and custodial closets. Classrooms were treated only when a pest problem was reported. The pest management professional (PMP) made all decisions about the types and amounts of pesticides applied and areas treated.

Conventional and IPM Services. The study was conducted during a 12-mo period, from March to February. For the first 5 mo, all nine schools were under the conventional pest control service, and during this time baseline data were collected to describe this program. The conventional services were in place before this study began and served to represent a typical pest control service in North Carolina schools. Those services were simply observed, and no attempt was made to change the services in any way. In August, five of the schools were switched to an IPM program and monitored for 6 mo until February. The remaining four schools continued to be serviced with the conventional methods.

The conventional service consisted of monthly applications of residual pesticides to baseboards in key areas. Applications were made with a 3.785-liter pressurized spray tank with a pin-stream nozzle (Prime Line, B&G Equipment Co., Plumsteadville, PA). Treated areas included all bathrooms, cafeteria kitchen (including the serving, preparation, dish washing, and storage areas), cafeteria dining room, teachers' lounge, custodial closets, principal's office, and the secretarial office. Other areas were treated as requested by the school staff regardless of pest presence. Although insecticide baits were occasionally used by the PMP, they were often used after an area had been treated with a liquid insecticide. The following products were used in the conventional services: Orthene Crack and Crevice Pressurized Residual (Whitmire Micro-Gen, St. Louis, MO), Maxforce Roach Bait Stations and Maxforce FC Roach Killer Bait Gel (Maxforce Insect Control Systems, Oakland, CA), Invader Residual Insecticide with Baygon (Waterbury Companies, Inc., Independence, LA), and Gentrol IGR Concentrate and Catalyst Emulsified in Water Insecticide (Wellmark International, Bensenville, IL). The conventional service did not include any regular inspections for pest problems or follow-up inspections of problem areas.

In July, the PMP was trained in IPM principles, based upon guidelines established by the North Carolina State University School IPM Committee. The IPM program consisted of only the most fundamental components of IPM because it had to be implemented within the general time and financial constraints of the existing pest control contract. Generally, each IPM service consisted of visual inspections of all key areas described for the conventional service. Insect glue traps (Trapper Monitor & Insect Trap #TM2601, Bell Laboratories, Inc., Madison, WI) or rodent glue boards (Catchmaster # 72MB-PB, Atlantic Paste and Glue Co. Inc., Brooklyn, NY) were placed in areas with the greatest pest potential. Any pest sightings reported by the staff were followed-up with an intensive inspection. If no pests were found, then traps were deployed in the area and checked the following service (month). Pest problems were treated only on an as-needed basis with the least hazardous (not necessarily least toxic) formulations that would provide quick and lasting control. An action threshold of one live cockroach per room was used due to the length of time (1 mo) between successive visits, and the high reproductive potential of the German cockroach. The following products were used in the IPM services: Drax Ant Kill Gel and Drax Ant Kil-PF (Waterbury Companies, Inc.); Outsmart Sweet Ant Bait Gel (BioSmart Ideas, Inc., Royal Palm Beach, FL); Maxforce Ant Killer Bait Stations, Maxforce Fine Granule Insect Bait, Maxforce Roach Bait Stations, and Maxforce FC Roach Killer Bait Gel (Maxforce Insect Control Systems); and Advance Granular Ant Bait and Inspector Pressurized Contact Insecticide (Whitmire Micro-Gen).

Analyses of Pest Control Services. Each school was serviced monthly, and data were collected from 46 conventional services over 9 mo and 26 IPM services over 5 mo. Each service was timed starting when the PMP entered the school and ending when the PMP exited the school. Travel time to the schools was not recorded. The area of regularly serviced rooms in each treatment was calculated from blueprints to ensure that any difference in service durations was not due to differences in the size of the schools. There was no significant difference between the areas serviced in the conventional and IPM schools ($t = 0.33$; df = 7; $P = 0.75$).

The materials used during each service were recorded. The volume of pesticide applied with the pressurized sprayer was estimated by monitoring the level in the tank before and after each service. The amount of material applied during aerosol applications was extrapolated from the duration of each application and the amount dispensed into a graduated cylinder during a timed application. The amount of bait in the translucent container was measured before and after each service. Bait stations, monitors, and glue boards were counted as used.

The amount of active ingredient applied was calculated based upon the percentage of active ingredient as stated in each product label. For liquid products, volumetric units were converted into mass according to their specific gravity as listed on the material safety data sheet (MSDS). The mammalian LD_{50} values also were obtained from the MSDS when available or calculated from the LD_{50} values of the active ingredient.

Cost of each service was determined by combining the cost of labor and materials. An hourly labor rate of $8.75 was calculated from the annual salary of the PMP and a 40-h workweek. The labor cost of each visit was calculated from this hourly rate and the duration of the service. The cost of materials was determined from product prices obtained from a local pest control vendor. Thus, these cost estimates are for performance of the respective pest control services and do not represent the actual cost to the school.

Several intensive inspections for cockroaches did not yield any useable data because of the generally low infestations in these schools. Also, reports of pest problems from faculty were determined to be insufficiently reliable (e.g., misidentification of pests) to be used in determining pest levels. Therefore, the number of cockroaches present was determined from trap catches. Traps were placed in the same areas that were regularly treated or inspected in all of the schools. An average of 13 ± 1.5 traps was always present in each school to monitor cockroach levels.

Sampling Insecticide Residues. Unfortunately, before we collected pesticide residue samples from the IPM-serviced schools at the conclusion of the study, the pest control contract was awarded to a different company, which promptly treated the five schools with baseboard applications of residual insecticides. Therefore, five different schools were recruited in Wake County, North Carolina, for this part of the study. These schools were serviced by trained in-house PMPs who implemented IPM approaches similar to ours.

Sample collection methods were modified from Wright et al. (1984). Samples were collected in each school from the bathroom, main office, dining room, cafeteria, and teachers' lounge. Other areas such as hallways and classrooms were randomly sampled as well. Samples were taken from baseboards where insecticides were generally applied, and from walls ≈90 cm above the baseboard, representing a nontarget area that a child may contact. A sterile cotton ball was soaked in isopropyl alcohol, excess alcohol was removed by squeezing with sterile forceps, and the cotton ball was then drawn repeatedly across a 100-cm^2 surface with a latex-gloved hand. The swabbing procedure was repeated with a second cotton ball, and both cotton balls were stored in 20-ml isopropyl alcohol in a glass vial with a Teflon-lined cap. Control samples were prepared by placing sterile cotton balls directly into collection vials. All samples were stored in the dark at −20°C.

Each sample was extracted by sonication in acetone (Branson #450, Branson Ultrasonics Corporation, Danbury, CT) for 2 min. The sample volume was reduced in a 40°C rotary evaporator to ≈5 ml, filtered through a 0.45-μm syringe filter, reduced to 1 ml under a stream of N_2, transferred into 2-ml autosampler vials, and stored in the dark at 7°C until analyzed.

Sample analysis was performed on a gas chromatograph (Star 3400X, Varian Inc., Palo Alto, CA) equipped with a nitrogen-phosphorous TSD detector. A DB-35 column (30 m by 0.53 mm ID by 1-μm film thickness; Agilent Technologies, Palo Alto, CA) was temperature programmed from 170°C (2 min) to 200°C at 2°C/min (hold 2 min) and then to 280°C at 25°C/min (hold for 2 min). Helium was the carrier gas at a flow rate of 6.05 ml/min and the makeup rate was 24.93 ml/min. The inlet (splitless mode) and detector temperatures were set at 175 and 300°C, respectively. Gasses to the detector were helium and air at 4.0 and 169.1 ml/min, respectively. Data were quantified using 5 μg/ml external standards autoinjected between every five or six samples during a run.

The identities of some peaks were confirmed by mass spectrometry. We used a Network Mass Selective Detector (model 5973, Agilent Technologies) equipped with a DB-5 column (30 m by 0.32 mm ID by 0.25-μm film thickness). Two microliter injections were made into a splitless inlet at 250°C. The oven temperature was programmed from 100°C (5 min) to 300°C (5 min) at 6°C/min. The carrier gas was helium at a constant flow of 1 ml/min.

Statistical Analyses. For direct statistical comparisons of IPM and conventional treatments, only contemporaneous services were compared. Therefore, the 26 IPM services in five schools were compared with 16 conventional services in four schools. All differences were examined in SAS with pooled *t*-tests (SAS Institute 1989). For all means, SEM was used as the measure of variation.

Results

Duration of Services. The duration of each service represented the time that the PMP took to service the school, including pesticide applications, time spent talking to school staff, completing paperwork, gaining access to locked areas, and time spent waiting for children or faculty to clear an area before applications were made. The average duration of each conventional service before the nine schools were split into two treatments was 43 ± 4.5 min (n = 30). Initially, each of these early services were lengthy (71 ± 13.3 min/service; n = 30), but their duration declined to 29 ± 2.5 min/service (n = 30) within 4 mo and re-

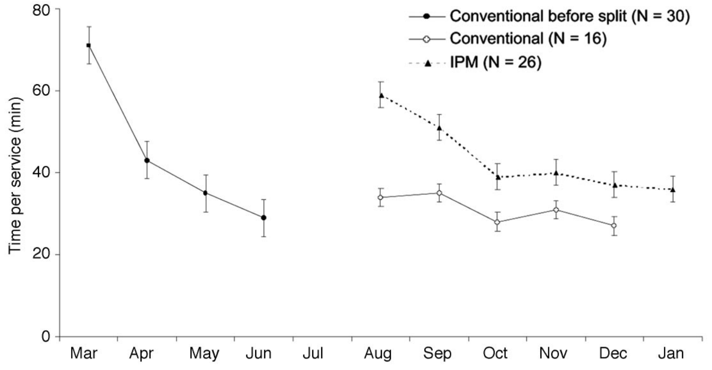

Fig. 1. Average monthly duration (mean ± SEM) of conventional and IPM services in elementary schools. Nine schools were split into two treatments (conventional and IPM) after being serviced from March to June with conventional treatments.

mained constant at ≈30 min in the four schools that remained under the conventional treatment (Fig. 1).

The average duration of each of the IPM services (45 ± 3.2 min; $n = 26$) was significantly longer than the contemporaneous conventional services ($t = 3.02$, df = 40, $P = 0.004$). Overall, conventional services were relatively invariable, whereas the IPM services varied greatly. But over time, the duration of the IPM services became shorter (Fig. 1). Under these low cockroach populations, these data suggest that in a stable program it would take only slightly longer to actively inspect and monitor a room than it takes to spray all the baseboards.

Materials Used. The amount of each active ingredient used per service in each of the two programs is listed in Table 1. Approximately 383 ± 92 ($n = 4$) linear meters of baseboard was treated during each conventional service with an average of 10.36 g of active ingredient. Propetamphos, an organophosphate insecticide, was used most often, usually in a tank mix with the insect growth regulator (IGR) hydroprene, at a rate of 9.53 ± 0.63 g active ingredient per service ($n = 16$) (Table 1).

Organophaspate pesticides were not used in the IPM services. Instead, fipronil (in a bait or gel formulation), and pyrethrins (combined with synergists in an aerosol formulation for flushing out insects during inspection) were used most often. All were used sparingly—only 11.22 mg of active ingredient was used in each IPM service—because the cockroach infestations were generally low (see below). Boric acid and hydramethylnon, both in bait formulations, also were used in the IPM services, but primarily against ants and therefore were not considered further in this study. Although not included in Table 1, traps were regularly installed in the IPM services (5.2 ± 1.1 traps/service; $n = 26$) and contributed to the overall cost of materials for the service.

Cost of Services. The cost of each service reflected the combined cost of labor and materials. Generally, labor costs figured most prominently into this calculation, and therefore the cost data (Fig. 2) closely mirror the service duration data (Fig. 1). Thus, the initial costs in both the conventional and IPM services were high, but both declined over time. The average monthly cost of the conventional services declined by 43.9% from $16.92 in March to $7.42 in June. During the following 6 mo (August to January) the average cost of this service in four schools remained relatively stable at ≈$7.50 per service. Likewise the IPM service

Table 1. Average amount of active ingredients (mean ± SEM) used in conventional and IPM services

Active ingredient (product, formulation)	Oral LD_{50} (mg/kg)[a]	Mean amt of active ingredient ± SEM (mg)		
		Conventional before split ($n = 30$)	Conventional ($n = 16$)	IPM ($n = 26$)
Abamectin (Advance-Gr)[b]	>5,000			0.01 ± 0.01
Acephate (Orthene-A)	5,190	2.46 ± 2.46		
Boric acid (Drax, Outsmart-Gel)[b]	3,160			25.0 ± 15.6
Fipronil (Maxforce-BS, Gel)	>5,000	0.34 ± 0.18		0.64 ± 0.20
Hydramethylnon (Maxforce-BS, Gr)[b]	>5,000	1.00 ± 1.00		1.35 ± 1.15
Hydroprene (Gentrol-EC)	>5,100	1,084 ± 106	832 ± 142	
Methylcarbamate (Invader-A)		96.8 ± 90.4		
n-Octyl bicycloheptene dicarboximide[c]				4.23 ± 1.19
Piperonyl butoxide[c]				4.23 ± 1.19
Pyrethrin (Inspector-A) [c]	4,730			2.12 ± 0.60
Propetamphos (Catalyst-EC)	451	10,503 ± 604	9528 ± 632	

A, aerosol; BS, bait station; EC, emulsified concentrate; G, gel; Gr, granular.
[a] LD_{50} values given are for the formulated product.
[b] These compounds were used for pests other than cockroaches.
[c] These compounds are all components of the same aerosol pesticide.

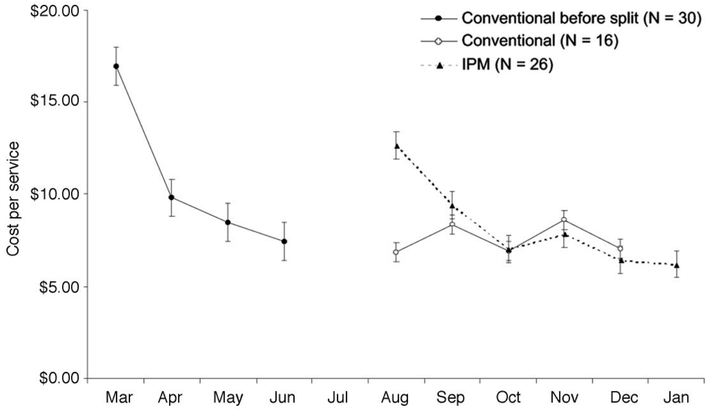

Fig. 2. Average monthly cost (mean ± SEM) of conventional and IPM services. Nine schools were split into two treatments (conventional and IPM) after being serviced from March to June with conventional treatments.

incurred a higher cost at its inception in August ($12.63), but declined by 49.1% to only $6.20 by the end of the study. At the conclusion of the study the cost of the IPM program was not significantly different from the cost of the conventional program.

The average cost of materials for each conventional service ($2.80 ± 0.29; $n = 16$) was higher than for each IPM service ($1.91 ± 0.34; $n = 26$), but the difference between the two treatments was only marginally significant ($t = 1.81$, df = 40, $P = 0.07$). However, because each IPM service was of longer duration, the average cost of labor for each ($6.66 ± 0.47; $n = 26$) was significantly higher ($t = 3.02$, df = 40, $P = 0.004$) than for each conventional service ($4.69 ± 0.34; $n = 16$). Overall, the total cost of each service (materials and labor) was approximately the same in the IPM and conventional treatments, $8.57 ± 0.73 and $7.49 ± 0.52 respectively ($t = 1.06$, df = 40, $P = 0.29$), suggesting that once established, the monthly costs of either a conventional or IPM service remain relatively constant, at least when implemented under the financial constraints of an existing contract.

Cockroach Infestation Levels. Generally, both sets of schools were not highly infested with cockroaches and live cockroaches were seen only sporadically. Only 23 of 354 traps that were deployed for 12-mo captured cockroaches. In total, only four cockroaches were trapped in the conventional schools on two occasions during 16 visits (0.25 ± 0.19 cockroaches per visit; $n = 16$), and 51 cockroaches were trapped in the IPM schools in nine unique locations during 26 visits (1.96 ± 0.78 cockroaches per visit; $n = 26$) ($t = 1.69$, df = 40, $P = 0.10$).

Pesticide Residues. In the four conventionally treated schools, 38 residue samples were swabbed from 13 areas (Table 2). As expected, more propetamphos was found in surface swabs than any other insecticide, and it was found in all areas where it was regularly applied, at an average of 38.89 ± 14.27 μg/100 cm^2 ($n = 21$). Surprisingly however, propetamphos residues also were routinely recovered from almost all nontarget areas that were sampled. On average, 1.11 ± 0.54 μg/100 cm^2 ($n = 17$) was found on walls ≈90 cm above the sites of insecticide appli-

Table 2. Pesticide residues (mean ± SEM) recovered in conventionally treated schools

Area sampled	No. samples	Mean amt (μg) of chemical per 100 cm^2 ± SEM			
		Acephate	Chlorpyrifos	Fipronil	Propetamphos
1 Office baseboard	3	3.33 ± 1.72	5.25 ± 5.08	0	96.04 ± 73.31
2 Office wall	4	0	0.08 ± 0.06	0	0.81 ± 0.72
3 Teachers' lounge baseboard	3	0	0	0	100.22 ± 50.74
4 Teachers' lounge non-target area	3	0	0.01 ± 0.01	0	0.42 ± 0.19
5 Student bathroom baseboard	4	0.28 ± 0.28	0.03 ± 0.03	0	5.22 ± 3.60
6 Student bathroom wall	4	0.003 ± 0.003	0.38 ± 0.35	0	0.19 ± 0.12
7 Cafeteria dining room baseboard	4	0	4.07 ± 2.21	0	43.64 ± 17.41
8 Cafeteria dining room wall	4	0.01 ± 0.01	0.30 ± 0.10	0	0.85 ± 0.52
9 Cafeteria kitchen baseboard	3	0	0.19 ± 0.08	0	3.07 ± 2.39
10 Cafeteria kitchen wall	2	0	0.80 ± 0.71	0	5.11 ± 4.05
11 Cafeteria food storage baseboard	1	0	0.34	0	0.89
12 Hallway baseboard	2	0	0.58 ± 0.46	0	6.34 ± 2.34
13 Classroom baseboard	1	0	0.09	0	9.64
Avg baseboards (1, 3, 5, 7, 9,11–13)	21	0.62 ± 0.33	1.63 ± 0.86	0	38.89 ± 14.27
Avg nontarget (2, 4, 6, 8, 10)	17	0.004 ± 0.003	0.27 ± 0.12	0	1.11 ± 0.54
Grand avg	38	0.29 ± 0.19	1.03 ± 0.48	0	21.99 ± 8.39

Table 3. Pesticide residues (mean ± SEM) recovered in IPM-serviced schools

Area sampled	No. samples	Mean amt (μg) of chemical per 100 cm^2 ± SEM			
		Acephate	Chlorpyrifos	Fipronil	Propetamphos
1 Office baseboard	5	0.01 ± 0.01	0.03 ± 0.02	0	0
2 Office wall	5	0	0.08 ± 0.05	0	0
3 Teachers' lounge baseboard	4	0	0.01 ± 0.01	0	0
4 Teachers' lounge non-target area	1	0	0.04	0	0
5 Student bathroom baseboard	5	0	0.04 ± 0.02	0	0
6 Student bathroom wall	5	0	0.01 ± 0.01	0	0
7 Cafeteria dining room baseboard	5	0	0.08 ± 0.04	0.03 ± 0.03	0
8 Cafeteria dining room wall	5	0	0.04 ± 0.02	0	0
9 Cafeteria kitchen baseboard	5	0	0.04 ± 0.02	0.17 ± 0.17	0
10 Cafeteria kitchen wall	5	0	0.06 ± 0.04	0	0
11 Cafeteria food storage baseboard	5	0	0.14 ± 0.11	0.01 ± 0.01	0
12 Hallway baseboard	1	0	0.01	0	0
13 Classroom baseboard	1	0	0	0	0
Avg baseboards (1, 3, 5, 7, 9,11–13)	31	0.001 ± 0.001	0.06 ± 0.02	0.03 ± 0.03	0
Avg nontarget (2, 4, 6, 8, 10)	21	0	0.05 ± 0.02	0	0
Grand avg	52	0.001 ± 0.001	0.05 ± 0.01	0.02 ± 0.02	0

cation. Paired comparisons of baseboard and wall samples ($n = 15$) indicated that 165.5 ± 50.6-fold more pesticide was recovered from the baseboard than from the respective wall ($t = 2.78$, df = 14, $P = 0.01$). Interestingly, in the cafeteria kitchen, 60.1% more propetamphos was found on the walls than on baseboards, probably because the kitchen floor was more frequently cleaned. We did not quantity hydroprene residues in these samples.

During the initial conventional services, crack-and-crevice applications of acephate, another organophosphate insecticide, were made infrequently, only 2.46 ± 2.46 mg per service ($n = 30$) (Table 1). Small amounts of acephate were recovered from only five of the 38 areas sampled and in 13.2% of the total samples (Table 2). Although we had no record of chlorpyrifos applications during any of the conventional pest control services, chlorpyrifos was recovered in 12 of the 13 areas sampled and in 71.1% of the 38 total samples. Small amounts of fipronil gel (0.34 ± 0.18 mg per service; $n = 30$) were occasionally applied in cracks and crevices for cockroach control in the conventional schools. However, no fipronil residues were recovered from any of the samples collected.

In contrast to conventionally-treated schools, little pesticide deposits were found in schools under an IPM-guided service. In total, 52 samples were taken from 13 areas in five IPM schools (Table 3). Because a new set of IPM schools was recruited for the residue study the types of pesticides applied in these schools are known only from records and not from direct observations. Propetamphos residues were never recovered, and only one sample contained a small amount (0.04 μg/100 cm^2) of acephate (Table 3), consistent with records indicating that these pesticides were not used in the IPM schools. We were surprised, however, to recover residues of chlorpyrifos from 75% of the samples in the IPM schools, with a fairly uniform distribution on baseboards and walls (Table 3). Nevertheless, the level of chlorpyrifos residues found in the IPM schools was significantly lower than chlorpyrifos residues found in the conventionally serviced schools ($t = 2.36$, df = 88, $P = 0.02$).

Discussion

This study consisted of a focal survey of PMP practices in two common pest control programs in North Carolina elementary schools. It demonstrates that in a school environment with relatively mild cockroach problems, even a basic IPM program can be implemented with essentially no negative trade-offs. The benefits of the IPM approach were clear: significantly less insecticide used with considerably lower mammalian toxicity, almost no insecticide residues were available for children to contact compared with applications of residual spray insecticides, and insecticide translocation was essentially undetectable compared with the extensive drift of residual insecticides. Although data on the comparative efficacy of the two approaches were limited, we can conclude that both methods controlled cockroaches equally. Therefore, overall, the IPM program is preferable to conventional methods of pest control for health, environmental, and economic reasons. A much more thorough IPM design, incorporating extensive pest exclusion, structural modification, and more intensive monthly services, would have undoubtedly been even more effective. However, our research was constrained by contractual arrangements between the schools and a pest control company and a more intensive IPM program would have had limited appeal to both under their respective contractual obligations.

A major impediment to the adoption of IPM practices, especially in schools, is the perception that they incur higher costs. Indeed, the start-up costs of the IPM service were higher than costs associated with an ongoing conventional program (Fig. 2). However, the conventional service also incurred higher initial costs, suggesting that the initial higher costs in both programs were related to the PMP spending more time becoming familiar with the elements of each program and becoming more comfortable being observed.

Nevertheless, there are several expected cost advantages to the IPM approach, not obvious from this study. Labor, and thus the duration of each service, is the major contributor to overall cost (also see Miller and Meek 2004). Whereas most IPM-related tasks (e.g., caulking, baiting) can be made during school hours, resulting in more flexible work hours, the conventional services (e.g., baseboard and crack-and-crevice spraying) require that all people vacate the rooms. In the conventionally serviced schools the PMP routinely waited for students to be dismissed before initiating a pesticide application. More importantly, pesticides, primarily baits, used in the IPM schools, have long residual activity and are generally placed in areas that are less likely to be exposed to routine cleaning. Therefore, in the long-term, it is expected that subsequent services would use less bait, resulting in cost savings in materials and further reducing pesticide exposure to occupants.

However, our cost estimates of the IPM services did not include time spent on training the PMP because they had received earlier training in general pest control and only a brief refresher in IPM techniques was necessary. Because school personnel in many districts are responsible for pest control services and they are not familiar with IPM, much more extensive training would be required for proficiency in IPM tactics. Some have contended that training costs should be included in estimates of the total cost of IPM programs (Rambo 1998; Washington State Department of Ecology-Hazardous Waste and Toxics Reduction Program 1999). However, as certification requirements change and IPM becomes a common element of PMP training, training costs are expected to be no different than for conventional pest control, and no cost adjustment would be necessary. The shift to IPM will obviously accelerate if schools specify in their pest control contracts that only individuals trained in IPM may conduct services.

Our results also underestimate the actual cost of implementing pest control services because this study was conducted within an existing contract with specifications for conventional pest control services under a lowest bid arrangement. We considered actual costs, without consideration of the contract costs, that is, the cost to the school. Rambo (1998) suggested that in the northeastern United States, conventional pest control services cost schools about $65 per hour, whereas IPM programs sell for about $80 per hour. Although costs in North Carolina may be significantly lower, over time the differential between the two service types should disappear because of hidden costs associated with conventional services. Liability is lessened, and therefore insurance costs should be dramatically reduced with IPM services. Likewise, equipment costs are considerably lower than in conventional services. However, a more thorough IPM program, including pest exclusion, changes in sanitation, and education of students and staff could significantly increase the cost of IPM services. In the long term, however, a more complete IPM program also should prevent pest problems, thereby reducing both the frequency of visits to each school and labor costs.

The 29% difference that we observed in duration (=cost) between conventional and IPM services would be expected to be greater with more severe infestations. IPM services in heavily infested apartments, for example, took ≈80% longer than conventional services (Miller and Meek 2004). The duration of the conventional services was relatively invariable in our analysis because this service was conducted with little regard to the pest population; the same areas were sprayed every month whether pests were present or not. Conversely, the IPM service responded to cockroaches in traps with a thorough inspection, increased monitoring, targeted baiting, and several follow-up visits, all of which took longer than attending to pest problems in the conventional manner. However, because the IPM treatment is far more efficacious than the conventional methods in heavy infestations (Miller and Meek 2004), a decline in the cost of materials and labor would be expected over time in the IPM service and not under conventional treatments.

Detection and monitoring of cockroaches can be made as real-time visual inspections or by trapping cockroaches (Schal and Hamilton 1990; Owens 1995). The monitoring efforts of this research had two distinct objectives: 1) As part of the IPM program, monitoring was used to target pest control efforts to infested sites; and 2) as part of an independent assessment of the efficacy of both programs, monitoring was used to provide rough estimates of pest populations. Both objectives were addressed with visual inspections and traps. However, the low cockroach infestations precluded a quantitative analysis of visual counts, and hence all data on efficacy were derived from traps that were deployed for 1-mo intervals. Even so, few cockroaches were trapped in the schools throughout this study (only 23 of 354 traps that were deployed for 12-mo captured cockroaches), and the trapping data suggest only spotty and unpredictable infestations. Overall, both types of services resulted in similar efficacy. In a similar study in apartments, with larger cockroach infestations, the IPM treatment was far more efficacious than the conventional methods, and in fact the conventional services were almost completely ineffective against large infestations (Miller and Meek 2004). The same would be expected in schools.

The two pest control programs differed markedly in the types, formulations, amounts, and toxicity of the insecticides they used. Consequently, they also differed significantly in the amount and spatial distribution of insecticide residues that resulted from the applications. The conventional services were based on monthly applications of emulsifiable concentrate formulations of broad-spectrum pesticides to all baseboards, whereas the IPM program used primarily baits. Consequently, the mammalian toxicity of the formulated products used in IPM services was lower (Table 1), and 99.9% less active ingredient was used in IPM services (Tables 2 and 3), consistent with similar comparisons in apartments (Miller and Meek 2004). Obviously, the less pesticide that is applied, the less chance there is for children to be exposed to it.

Furthermore, the two types of services differed dramatically in bioavailability and translocation of the insecticides. Baseboard spraying of liquid pesticides requires mixing of concentrated insecticides in an air-pressurized tank, a procedure that can, and on occasion did, leave residues of highly concentrated pesticide on the floor. Pressurized sprayers also are prone to leakage when they are not well maintained, especially from the wand and nozzle, and this has been suggested to cause significant amounts of nontarget contamination (Stout et al. 1995). Because the application was directed with a pin-stream nozzle at the baseboard, it is highly available to both cockroaches and children. Moreover, this application uses large amounts of product in water over large areas. Even careful applications can result in splash-backs and aerosol formation either directly from the nozzle or from impact with the treated substrate. Tiny droplets of pesticide are thus generated that are prone to drift to nontarget areas (Jackson and Wright 1975; Leidy et al. 1987; Wright et al. 1984, 1989). Misapplications also are more likely and were readily observed on several occasions, as pesticide was applied where it was not intended because the PMP was momentarily distracted. The results of the environmental sampling, showing pesticide residues on both target and nontarget surfaces (Table 2), confirm the drift of baseboard sprays to adjacent areas that are highly accessible to children.

Propetamphos was the primary insecticide used in the conventionally treated schools. Broadcast applications of propetamphos have been shown to create airborne residues (12–17 ng/liter) in ventilated structures hours after application (Koehler and Moye 1995). Similarly, Leidy et al. (1987) found the highest concentration of pesticide residues on the baseboards of a restaurant kitchen after spot treatments with chlorpyrifos, and Wright et al. (1989) found the highest levels of acephate residues ($194.1 \pm 89.7\ \mu g/100\ cm^2$) immediately above a cafeteria baseboard after application with a pressurized sprayer.

Based on direct observations and written records, chlorpyrifos was never applied during any of the conventional pest control services. Yet, chlorpyrifos was recovered in 12 of the 13 areas sampled and in 71.1% of the 38 total samples. It is conceivable that the chlorpyrifos residues resulted from applications of propetamphos with the same pressurized sprayer that had previously been used to apply chlorpyrifos in another service account. The extensive distribution of chlorpyrifos in almost all samples, albeit at relatively low levels, lends support to this suggestion. However, the discrepancy between propetamphos and chlorpyrifos residues on some surfaces (e.g., the teachers' lounge baseboards) (Table 2) also implicates possible aerosol applications of chlorpyrifos by school staff.

Alternatively, chlorpyrifos residues could have drifted from other treated areas or from outside. Wright and Leidy (1980) demonstrated that airflow had the effect of increasing airborne concentrations of chlorpyrifos ($0.4–0.7\ \mu g/m^3$) 4 h after crack-and-crevice applications. Moreover, because perimeter applications of pesticides create residues on indoor surfaces (Leidy and Stout 1996; Stout and Leidy 2000), it is possible that chlorpyrifos was used on the school grounds for pest control and was translocated via spray drift into the school. Last, chlorpyrifos residues remain detectable for >6 months after application (Wright et al. 1984; Leidy et al. 1987), so the residues we recovered are not necessarily the result of the widespread use of chlorpyrifos, but possibly the accumulation of residues from previous applications.

The IPM approach relied on remedial treatments of identifiable pest problems. Because visual inspections and monitoring with traps revealed few cockroaches, it was deemed that most of the monthly pesticide applications under the contractual arrangement of the conventional program were unnecessary. It was, however, critical that pest problems be found promptly, and probing chemicals provide benefits over unaided visual counts when searching for German cockroaches (Reierson and Rust 1977, Reierson et al. 1979). Pyrethrin aerosol was used in the IPM program to flush out hidden cockroaches from areas that could not be visually inspected, such as hollow pipes and deep voids. However, it was used in small amounts only after all students and staff had vacated the premises, and because it is inactive in air and it oxidizes rapidly (Windholz and Budavari 1983), it posed little hazard.

Most of the pesticides used in the IPM services were formulated as ready-to-use bait stations or baits in syringes, requiring no mixing. They were generally placed into cracks-and-crevices in difficult-to-reach places. Insecticides in bait formulations tend to exhibit much less passive drift to nontarget areas than sprays, in part because they are in a gel or solid matrix, but also because they have a much lower surface area that interacts with the atmosphere. Nevertheless, fipronil residues were recovered from three of the IPM surface samples, albeit at low levels (Table 3). On occasion, we observed gel baits flowing out of the syringe even after the application was completed. This was normally evident and easily cleaned up but could result in accumulation of residues on nontarget surfaces. Feeding cockroaches may also translocate baits in feces (Kopanic and Schal 1999) and oral secretions (Buczkowski and Schal 2001), and large cockroach populations can move significant amounts of insecticide away from its intended placement. However, because most cockroaches live and die in various voids within the structure, it is unlikely that their residues would be available to children via this route.

It is important to emphasize that the absolute values of environmental pesticide residues should not be used for formulating risk assessments. Our research did not optimize the recovery of various insecticides from different surfaces, the extraction procedure and gas chromatographic analysis, and the elapsed time between pesticide application and sample collection was variable. It has been demonstrated that total chlorpyrifos residues persist longer than transferable residues (Krieger et al. 2001). In addition human skin removes substantially less chlorpyrifos residue from surfaces than swipe samples, and <1% of the pesticide applied on a surface is actually removed as a result of direct hand contact (Lu and Fenske 1999). Nevertheless, estimates suggest that total dermal and nondietary oral doses of chlorpyrifos can be as high as 356 μg/kg/d from exposure to residues on surfaces after broadcast applications in the home (Gurunathan et al. 1998), and similar results would be expected from routine pesticide applications in schools.

In summary, an elementary IPM program, based on monitoring and reduced risk pesticides, was as effective as a conventional pest control program based on monthly applications of residual pesticides. The IPM program, however, used significantly less pesticides, the pesticides had much lower mammalian toxicity, and they resulted in significantly less environmental and off-target residues. The IPM program thus created a safer environment for children than the conventionally serviced schools. The benefits of an IPM approach far outweigh the convenience of a conventional, calendar spray-based approach and should be adopted by school systems and PMPs.

Acknowledgments

We thank the Nash-Rocky Mount School System, the Wake County School System, and King's Pest Control for cooperation in this study. Funding was provided in part by grants from the North Carolina Department of Agriculture and Consumer Services Pesticide Environmental Trust Fund, EPA-PESP program, NIH-NIOSH-Southern Coastal Agromedicine Center, North Carolina Biotechnology Center, the Blanton J. Whitmire Endowment, and a scholarship from the North Carolina Pest Control Association.

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Received 18 December 2004; accepted 8 April 2005.

Effectiveness of Six Insecticide Treatment Strategies in the Reduction of German Cockroach (Orthoptera: Blattellidae) Populations in Infested Apartments

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J. Econ. Entomol. 77: 1092–1094 (1984)

ABSTRACT Six insecticide treatment strategies that included the use of chlorpyrifos and dichlorvos were evaluated in apartments infested with *Blattella germanica* (L.). Following treatments, populations were monitored monthly for 4 months with sticky traps. Strategies which used chlorpyrifos were the most effective in reducing cockroach populations. Inclusion of dichlorvos in spray mixtures did not increase the effectiveness of chlorpyrifos. Dichlorvos total-release aerosol bombs were effective only when used immediately following an application of chlorpyrifos. Populations increased in 37.5% of the apartments that were next to units treated with chlorpyrifos plus dichlorvos, while populations increased in 50% of the apartments adjacent to units treated with dichlorvos total-release bombs.

CHLORPYRIFOS (Dursban®) is registered for the control of German cockroaches, *Blattella germanica* (L.), at concentrations of 0.25 and 0.50% (AI). A 0.50% emulsion of chlorpyrifos has been reported to reduce German cockroach populations in homes by 85% (Burden et al. 1972, Gupta et al. 1973, Wright and Hillmann 1973). Because the vapor pressure of chlorpyrifos is low (1.6×10^{-2} Pa at 25°C), cockroach mortality is generally a result of direct contact with a treated surface (Smith 1966).

Another organophosphate insecticide, dichlorvos (Vapona®, Vaponite®), has been used to reduce cockroach populations, both alone and in combination with other insecticides. Because of high vapor pressure (1.6 Pa at 20°C, Martin and Worthing 1974), dichlorvos, formulated in resin strips and tapes, has provided a 75% reduction of German cockroach populations (Miles et al. 1962, Ogushi and Tokumitsu 1969, Wright 1971). Dispensing dichlorvos from total-release aerosol containers (bombs) has been successfully (≥90% reduction) used in homes, buses, and submarines (Fales et al. 1966, Mulrennan et al. 1971, Meichsner et al. 1974).

To increase the number of insects killed through increased activity of cockroach populations during treatment, both the Dursban 2E and 4E labels state that an aqueous spray mixture containing 0.25% (AI) chlorpyrifos and 0.25% (AI) of either dichlorvos or pyrethrins may be used. Laboratory and field evaluations have supported the combination of dichlorvos and chlorpyrifos (Hardy 1970a,b, Bennett and Runstrom 1981), but poor control resulted from the use of dichlorvos alone (Gold et al. 1984).

We evaluated the effectiveness of each of six chlorpyrifos and/or dichlorvos treatment strategies on German cockroach populations in infested multifamily apartment buildings.

Materials and Methods

The insecticides evaluated in this study were 0.50% (AI) water emulsion spray concentrations of chlorpyrifos (Durs) prepared from 1.82 kg (AI)/3.8 liter (4E) and 0.25% dichlorvos prepared from 0.9 kg (AI)/3.8 liter (2E). We also tested mixtures of chlorpyrifos and dichlorvos (1:1) at both 0.25% and 0.50% (AI) concentrations. The effectiveness of dichlorvos at a concentration of 6.50% (AI) applied by a total-release aerosol bomb (170 g) was evaluated both by itself and as a supplemental treatment following the application of a 0.50% aqueous emulsion of chlorpyrifos. All treatments were randomly assigned and replicated a minimum of 14 times.

The study was conducted in apartment buildings managed by the Omaha Housing Authority, Omaha, Neb. Each building contained five or six apartments with one to three bedrooms per apartment. In the two- and three-bedroom apartments (72 and 90 m^2, respectively), the living room, kitchen, and utility room were located on the ground level, and the bedrooms and bathroom on the upper floor. All buildings were at least 30 years old and of similar construction.

Before the application of insecticides, the German cockroach population of each apartment included in the study was evaluated with three unbaited sticky traps (Mr. Sticky®, Mitsuboshi Boeki,

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Table 1. Mean monthly percentage of reduction of German cockroach populations following use of one of six insecticide strategies

Treatment strategy[a]	Baseline[b]	Avg amt applied (ml)	Avg time (min)	n	Avg % reduction at indicated month after treatment			
					1	2	3	4
Durs	29.5	3,321	61.4	20	58.6ab	59.3a	70.1a	64.7a
Vap	20.1	3,234	58.7	15	23.7c	29.7a	25.7bc	25.8a
Bomb	58.5	2 Bombs	3.5	16	27.8c	8.5a	16.1bc	23.3a
Durs/Vap I	18.6	3,235	60.4	17	31.9c	29.7a	33.3bc	42.3a
Durs/Vap II	76.3	3,645	50.7	17	38.1bc	24.6a	4.9c	29.2a
Durs/bomb	72.8	3,562+ 2 bombs	46.5	14	65.3a	58.0a	48.5ab	47.8a

Means, within a column, followed by the same letter are not significantly different ($P \leq 0.05$; Duncan's [1951] multiple range test).

[a] Durs, 0.50% (AI) Dursban emulsion; Vap, 0.50% (AI) Vaponite emulsion; bomb, two total-release aerosol (170 g) containing 6.50% (AI) Vapona; Durs/Vap I, emulsion containing 0.25% (AI) Durs plus 0.25% (AI) Vap; Durs/Vap II, emulsion containing 0.50% (AI) Durs plus 0.50% (AI) Vap; and Durs/bomb, 0.50% (AI) Durs emulsion spray followed by two Vapona bombs.

[b] Mean number of cockroaches caught per trap on the night before treatments.

Inc., Osaka, Japan) per apartment. In each apartment, one trap was placed at the rear of the cabinet under the kitchen sink, one behind the stove, and one behind the toilet. Traps were left in each apartment for one night. The following day, traps were removed and cockroaches counted. The mean number of cockroaches caught per trap per night became the baseline for each apartment. The neighboring apartments to those scheduled to receive either the "bomb" or "Durs/bomb" treatment were also trapped so that insecticide-induced cockroach migration could be measured. All apartments were reevaluated posttreatment with sticky traps placed in the same locations for 1 night each month for 4 months.

Before insecticide applications, the residents were required to empty all cabinets and closets. To prevent possible explosion in those apartments to be treated with Vapona bombs, the natural gas, stove, furnace, and water heater pilot lights were shut off. Once the residents had left the premises, a thorough insecticide treatment was applied by a banding technique, with a B & G sprayer system operated at 138 kPa (20 psi) fitted with a fan spray nozzle. Bomb applications were applied by releasing dichlorvos from two total-release containers. One container was released on the upper floor at top of the stairs while the other was released in the middle of the kitchen floor. Bombs were always placed on a piece of wood to prevent staining of floor surfaces. All windows were closed and all cabinet and dresser drawers opened. Bombs were released simultaneously by a pair of researchers who wore respirators and entered and left the apartment together. Both front and rear doors of the apartment were placarded warning residents not to enter. In addition, both doors were locked and tape placed over the keyholes for emphasis. After 3 h, researchers wearing respirators entered the treated apartments and opened windows. The residents were permitted to enter by the fourth hour. Time spent and amount of insecticide used were recorded for all strategies. Data were analyzed through the use of analysis of variance (ANOVA); means were separated at the $P \leq 0.05$ level with Duncan's multiple range test (Duncan 1951).

Results and Discussion

All six strategies provided less than satisfactory ($\leq$70 percent) reduction in German cockroach populations throughout the 4 months of this study (Table 1). There was no significant difference in control between Durs or Durs/bomb treatment strategies for the 4 months of this study. The use of dichlorvos alone or within any treatment strategy did not provide significantly more control of German cockroach populations and usually resulted in less control than did chlorpyrifos alone (Table 1). Although the level of dichlorvos in the air of apartments treated with the bomb strategy was not determined, Smittle and Burden (1965) reported that the use of dichlorvos as a vapor toxin would not be very practical if used at the safe tolerance limit of 1.0 μg/liter of air for 8 h exposure. We observed that, in apartments treated with dichlorvos, large numbers of adult female German cockroaches had released their ootheca. A similar response was reported by Kardatzke et al. (1982), who observed that fogging with pyrethrins caused premature dropping of egg capsules and a resulting increase in newly hatched nymphs.

Previous research with 0.50% (AI) applications of chlorpyrifos indicated difficulty in controlling German cockroaches in buildings managed by the Omaha Housing Authority (Ballard and Gold 1982). Vance (1983) reported that male German cockroaches captured from the same apartments as used in this study were 10-fold more resistant to chlorpyrifos than laboratory-reared Orlando Normal German cockroaches. Clearly, the failure of chlorpyrifos to control cockroaches well was due in part to resistance in the cockroach population.

The relative size of the cockroach population in any of the apartments adjacent to apartments treated with either Durs/bomb or Vapona bomb did not change significantly regardless of whether or not the plumbing was in common. There also was no significant reduction in the cockroach pop-

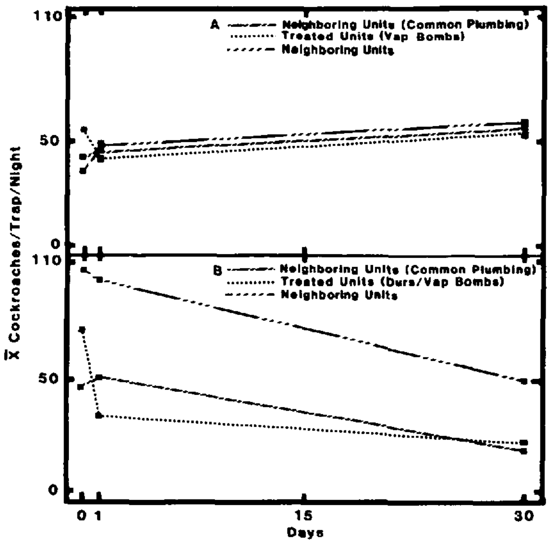

Fig. 1. A and B. Dispersal of German cockroach populations (roaches per trap per night) in treated and adjacent apartments following implementation of either a Vapona bomb or a Dursban/Vapona bomb treatment strategy.

ulation in apartments treated with the bomb strategy; however, a significant ($P \leq 0.05$) reduction in cockroach population was recorded at both 1 day and 1 month following treatment with Durs/bomb (Fig. 1). Although significant cockroach movement from treated to neighboring apartments was not found, 50% (based on 22 observations) of the apartments adjacent to bomb-treated apartments had increased catches of cockroaches the night following the treatment compared to only 37.5% (based on 16 observations) for apartments adjacent to the Durs/bomb-treated apartments (Fig. 1). The increase in cockroach population movement in apartments adjacent to units treated with a "flushing agent" insecticide such as dichlorvos agrees with the findings of Owens and Bennett (1982), who reported increased migration of cockroach populations treated with pyrethrin.

Based on these experiments, we concluded that the use of dichlorvos either as an emulsion spray or in total-release aerosol bombs was ineffective in reducing populations of the German cockroach. Dichlorvos was effective as a flushing agent, but was effective as an insecticide only when applied following an initial treatment with chlorpyrifos.

Acknowledgment

Published as Paper No. 7447, Journal Series, Agric. Exp. Stn. Investigations were supported by the Univ. of Nebraska Agric. Exp. Stn. Project No. 17-038.

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Received for publication 5 March 1984; accepted 29 May 1984.

Comparative Study of Integrated Pest Management and Baiting for German Cockroach Management in Public Housing

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J. Econ. Entomol. 99(3): 879–885 (2006)

ABSTRACT This study assessed the cost and effectiveness of a building-wide cockroach integrated pest management (IPM) program compared with bait alone treatment in public housing. In total, 12 buildings (66 apartments) were treated and monitored for cockroach infestations over 7 mo. The buildings were divided into two groups: bait treatment and IPM. Apartments in the bait alone group were treated with Maxforce FC Select (0.01% fipronil) during the first 12 wk and Maxforce Roach Killer Bait Gel (2.15% hydramethylnon) from 16 wk when necessary. For the IPM group, cockroaches were flushed and vacuumed at the beginning of the study; sticky traps were placed in all apartments to monitor and reduce cockroach numbers; educational materials were delivered to the residents; and Maxforce FC Select and Maxforce Roach Killer Bait Gel were applied to kill cockroaches. Two seminars were presented to the manger, and Community Service Program staff of the Gary Housing Authority to help gain tenant cooperation in the program. Effects of the treatments were monitored using sticky traps (six per apartment) at 2, 4, 8, 12, 16, and 29 wk after treatment. More treatments were applied during each monitoring visit when necessary. Those apartments with high levels of infestations (≥12 cockroaches in six traps) before treatment were used to compare the IPM and bait only treatments. IPM resulted in significantly greater trap catch reduction than the bait treatment. The IPM (n = 12) and bait only treatment (n = 11) resulted in 100.0 and 94.6%, respectively, reduction in trap catch after 16 wk. At 29 wk, only one apartment in the IPM group had a high level (>12 cockroaches) of cockroach infestation. In contrast, five apartments in the bait treatment group had high level infestations at 29 wk based on overnight trapping counts; thus, IPM is a more sustainable method of population reduction. Sanitation levels in the IPM group significantly improved at 29 wk (n = 11) compared with that at the beginning of the study. The sanitation levels in the bait treatment group remained similar throughout the experiment (n = 9). The cumulative cost of IPM was significantly higher than that of the bait treatment. The median costs per apartment during 29 wk were $64.8 and $35.0 for the IPM and bait treatment, respectively. The median amount of bait used per apartment in the IPM and bait treatment was 45.0 and 50.0 g, respectively. The cost of the IPM group for the 29 wk service was similar to that of the bait treatment group. We expect that IPM will provide better control at similar cost compared with bait treatment beyond 29 wk.

KEY WORDS *Blattella germanica*, integrated pest management, public housing

The German cockroach, *Blattella germanica* (L.), is a common indoor pest in low-income housing. Cockroaches not only spoil food but also transfer pathogens and cause allergic reactions and psychological distress (Brenner 1995). According to U.S. Department of Housing and Urban Development, cockroach allergens are excessive in 30–50% of the inner city housing (Federal Register Volume 69, No. 94). These allergens are most important in childhood asthma causes (http://www.nih.gov/news/pr/mar2005/niehs-08.htm).

Insecticides are the major tool used by professionals and residents for German cockroach control (Koehler et al. 1995). The advent of highly effective bait products in the early 1990s significantly reduced the overall cockroach infestations in the United States (Greene 1996, Gooch 1999, Hedges 1999). In a study conducted by the U.S. General Services Administration, use of cockroach bait products dramatically reduced liquid insecticide use from 1988 to 1999 (Greene and Breisch 2002). Cockroach complains in 1999 were only 6.9% of the number of cockroach complains 11 yr earlier due to the bait based management program. Through many years of pesticide use, the German cockroach has developed resistance to nearly every class of insecticide (Roslavtseva 2002). Recently, cockroach aversion to gel baits was reported (Harbison et al. 2003, Morrison et al. 2004, Wang et al. 2004, Liang 2005, Miller and McCoy 2005). Some gel bait-resistant cockroaches were highly resistant to a variety of current gel baits in the market (except the new baits and modified bait formulations). These lead to increased bait usage and excessive bait residues, which were evident in many public housing areas based on our observations. More importantly, gel bait resistance is inherited and fairly stable even after six generations (Wang et al. 2006). Rotation of gel baits may not overcome the resistant cockroaches because they exhibited adverse behavior to gel baits from different manufacturers with various active ingredients. Given the history of insecticide resistance in the German cockroach, it is inappropriate to rely solely on the use of chemicals for resolving German cockroach problems.

Effective nonchemical techniques include sanitation, trapping, vacuuming, and sealing of harborages (Kardatzke et al. 1981, Frishman 1995, Robinson and Zungoli 1995, Kaakeh and Bennett 1997). Low levels of sanitation and clutter provide more food, water, and harborages to cockroaches. These conditions favor the growth and survival of cockroach populations. Sanitation condition is correlated with cockroach populations (Wright 1979, Schal 1988). Among water, food, and harborages, water was the most important factor influencing the German cockroach populations (Bertholf 1983). Sanitation also is closely correlated to the control result because cockroaches can avoid contacting insecticide dust or spray or feeding on insecticide bait (Gupta et al. 1973, Schal 1988, Lee and Lee 2000). Placing sticky traps in cockroach-infested areas has been a standard method for monitoring the cockroach population level, spatial distribution, and effectiveness of the German cockroach management programs (Owens and Bennett 1983, Kaakeh and Bennett 1997). It supplements the visual inspection method and provides an additional tool for monitoring and reducing cockroach numbers (Bennett et al. 2003). Vacuuming (after using a flushing agent) has the potential to remove significant number of cockroaches (Kaakeh and Bennett 1997). This technique is especially useful for initial clean-out treatment of serious cockroach infestations. Sealing harborages and holes prevents cockroach movement between adjacent buildings and reduces the number of hiding sites, thereby assisting the long-term management of cockroaches.

Because residents' activities have a great impact on the pest abundance and control result, education of the residents should be an important component of an integrated pest management (IPM) program. Educational programs had positive impact on residents' attitude (Robinson and Zungoli 1985). Unfortunately, this is often not a part of the contract set by the management of the public housing properties. Pest management professionals often feel frustrated by the lack of cooperation from the residents. Lack of proper maintenance of the residence, e.g., poor sanitation and presence of unwashed dishes and clutter, in many public housing units contributes to the cockroach infestation and control failure.

Biology- and behavior-based German cockroach IPM programs have been discussed previously (Gupta et al. 1973, Slater et al. 1979, Wood 1980, Hedges 1994, Bennett et al. 2003). The strategy includes an array of independent components: repeated monitoring, integration of multiple control strategies, client education, and use of pesticides only when other practices are not practicable (Greene and Breisch 2002, Brenner et al. 2003). Safer Pest Control (http://www.spcpweb.org) and Environmental Health Watch (http://www.ehw.org/Asthma/ASTH_Cockroach_Control.htm) conducted studies on IPM for controlling indoor cockroaches (pests). Their efforts proved the effectiveness of IPM approach for reducing cockroach infestations and reducing insecticide use. Despite its greater chance of sustainable success for German cockroach management, IPM has never been widely accepted by the pest control industry or by housing authorities. The higher cost of IPM program compared with simple chemical control is a major factor that has hindered the implementation of IPM (Schal and Hamilton 1990, Miller and Meek 2004).

Table 1. Cockroach infestation in public housing units, Gary, IN

Cockroach no.	% apartments		
	2002 (n = 138)	2003 (n = 210)	2004 (n = 211)
≥12 in six traps	33	31	31
<12 in six traps	26	16	14
0	41	53	55

Counts (separated by year) were based on six Trapper glue board traps (8.0- by 15.0-cm glue area) placed in each apartment for ≈24 h.

Most public housing projects in the United States have multiple apartments per building. Shared common plumbing and low levels of sanitation contribute to the severity of cockroach infestations (Gold 1995). Cockroaches remain the single most important indoor pest in public housing units in Gary, IN (Table 1). Inter-apartment movement of up to 30% per week was found where construction design permitted (Owens and Bennett 1982). Plumbing connections between adjacent apartments were main corridors for cockroach movement (Runstrom and Bennett 1984). These factors, together with incomplete coverage by control programs, support the need for area or building-wide cockroach management programs in multifamily housing units. A study supported by the Environmental Protection Agency's Partners for Environmental Stewardship Program (PESP) showed that partial treatment of a building did not eliminate cockroaches in a majority of the test apartments (Kramer et al. 2000). From our experience, partial treatment of a building seldom eliminates the cockroach populations. Many residents and housing authorities have realized the need for an area- or building-wide cockroach management. Yet, there is a lack of practical IPM programs in place for area or building-wide cockroach management in public housing.

In response to the risk of indoor pesticide use and need to promote a safe and healthy environment, we aim to comparatively assess the cost and effectiveness of area or building-wide IPM program compared with bait treatment alone to manage German cockroaches.

An area- or building-wide management plan will prevent the formation of "reservoirs" of cockroaches that lead to repeated infestations after partial elimination. We hypothesize this approach will lead to reduced pesticide use and improved long-term cockroach control. The result will help pest management professionals, public housing authorities, and residents in selecting for optimum strategies in managing indoor cockroach infestations.

Materials and Methods

Survey and Selection of Apartments. The study was conducted in a multifamily apartment complex (Dorie Miller Homes) managed by the Gary Housing Authority, Gary, IN. There were a total of 50 buildings, each with four to six apartments. Each apartment had a family room, kitchen, utility room, bathroom, and one to three bedrooms. Approximately 180 occupied apartments were surveyed using glue board traps (Trapper Monitor & Insect Trap, Bell Laboratories, Inc., Madison, WI). Six glue board traps (each with 8.0- by 15-cm glue area) were placed in the kitchen, utility room, and bathroom of each apartment. Standard trapping locations were 1) in the cabinetry under the kitchen sink, 2) in the cabinetry above the kitchen sink, 3) beside the stove, 4) beside the refrigerator, 5) beside the shelf or water heater in the utility room, and 6) behind the toilet in the bathroom. The traps were placed such that one edge was touching a wall or a vertical component of the cabinetry. The traps were retrieved after ≈24 h. The numbers of trapped cockroaches were counted. Those buildings with at least 50% of the apartments having ≥12 cockroaches were selected. In total, 12 buildings was selected for the experiment. The buildings were randomly assigned to two treatment groups: IPM and bait treatment. The survey was conducted 10–13 May 2004.

Interventions. In the bait alone treatment group, Maxforce FC Select gel bait (0.01% fipronil, Bayer Environmental Science, Raleigh, NC) was applied to cockroach harborages in all apartments during 0–12 wk. Maxforce Roach Killer Bait Gel (2.15% hydramethylnon) was applied at 16 and 29 wk when necessary. For the IPM group, flushing and vacuuming, trapping, and baiting were applied to those apartments with ≥12 cockroaches. Trapping and baiting were applied to those apartments with <12 cockroaches. Tenants from the IPM group apartments received educational materials on cockroach IPM.

The initial interventions were carried out 25 and 26 May 2004. All apartments with cockroach infestations were treated. The bait was applied to all infested areas in each apartment with the aid of a flashlight. The number of placements, location, and amount of bait applied in each apartment were determined based trap counts and distributions. The mass of a typical bait placement was 0.2–0.4 g. Larger placements were applied to harborages with large number of cockroaches. More bait was applied around the refrigerator and under the sink because these locations often had most cockroach numbers.

Those apartments with ≥12 cockroaches in the IPM treatment group were flushed with CB-38 Extra (0.3% pyrethrin and 2.4% piperonyl butoxide, Waterbury Companies, Inc., Waterbury, CT). The flushing agent was used sparingly and limited to hard-to-reach areas to minimize use and possible contamination of the cockroach bait (Appel 2004). This was immediately followed by vacuuming using a HEPA-filter equipped LineVacer vacuum machine (ProTeam, Inc., Boise, ID) to remove running and dead cockroaches. After vacuuming, 10–30 small Trapper glue boards (6.2- by 7.6-cm glue area) or Victor-M327 glue boards (5.0- by 8.5-cm glue area, Woodstream, Lititz, PA) were deployed in each apartment. Glue boards were placed on the kitchen counter, in cabinets, beside the refrigerator, beside the stove, in closets, in the bathroom, in the utility room, on shelves, and any other infested areas with one side of the trap touching a vertical surface. Maxforce FC Select gel bait was then applied into cockroach harborages to kill the remaining cockroaches. During subsequent visits, the old traps were replaced if they became dirty or had cockroaches. More bait was applied to new harborages if cockroaches were still present as determined by monitoring trap counts. Those apartments with <12 cockroaches were treated by baiting and trapping only. In both treatment groups, Maxforce Roach Kill Bait Gel was used when baiting was necessary from 16 wk to avoid resistance development.

During each visit, the number of small traps, amount of bait and flushing agent used, and time spent on treatment were recorded. Numbers of cockroaches on the small traps and those removed by vacuuming were counted or estimated. Costs of materials and labor were calculated using the following rates: bait, \$0.18/g; trap, \$0.09/small trap; labor, \$60/h; flushing agent, \$0.025/g; and vacuum machine, \$1.00 per apartment per service. These rates were determined based on the market price of these materials or service.

Tenant and Staff Education. After the initial survey, all residents of the apartments in the IPM treatment group and the management personnel received cockroach IPM education materials. This includes information on cockroach biology, behavior, chemical, and nonchemical control techniques, and IPM principles. During each visit, the residents were asked to cooperate through proper housekeeping, sanitation, and reduction of cockroach harborages. A resident from each building was asked to ensure that all residents in each building would cooperate with the IPM study. These individuals served as mentors to communicate with residents in the same building on issues related to cockroach management. A letter was left with the residents in the IPM group during each monitoring visit to update cockroach control results and recommendations.

We presented two seminars to the residence managers, and the Community Program Service staff (total ≈20) of the Gary Housing Authority on 21 June and 20 July 2004. The seminars provided information on biology, importance, and methods to control cockroaches. Sanitation conditions of the kitchen, living

Table 2. Scales used to rate the degree of sanitation (modified from Schal 1988)

Rating	General condition	Amt of clutter	Amt of trash on floor	Amt of food on floor and kitchen counter
1	Clean	Few	None	None
2	Clean	Many	None	Some
3	Dirty	Few	Some	Some
4	Dirty	Many	Some	Some
5	Severely dirty	Many	Many	Many

Table 3. Initial cockroach population density in the two treatment groups

Treatment	No. apartments	Cockroach no.			
		Mean	Median	Min.	Max
IPM	12	130.1	113.5	13	354
Bait	11	117.1	146.0	14	312

Those apartments with ≥12 cockroaches after overnight trapping were included.

room, utility room, and the bathroom in the test apartments were rated (1–5) during each visit and reported to the office (Table 2). Those apartments with a consistently poor sanitation rating (≥4) were referred to the Community Program Service department by the management office. The referred residents were required to attend at least 4 h of housekeeping classes.

Treatment efficacy was monitored using the previously described cockroach sampling method at 2, 4, 8, 12, 16, and 29 wk after treatment. We also conducted visual inspections (using a flashlight) and talked to residents whenever possible to determine the presence of cockroaches at 29 wk. During each visit, more bait was applied to new harborages if cockroaches were still present. Those apartments with <12 cockroaches during initial survey were serviced every 4 or 8 wk.

Data Analysis. Trap catch data were compared with initial survey data to obtain percentage reduction in trap catch. Those apartments with low numbers (1–11) of cockroaches were only compared for cost. They were not used for comparing the treatment efficacy because the trap catch reduction data had very large variances. Data were evaluated using both nonparametric and parametric statistical methods. The Wilcoxon–Mann–Whitney test was used to compare the effect of the two treatments on trap catch reduction. For the parametric method, the numbers of live cockroaches (n) were transformed by $\log(n + 1) - \log(n_0 + 1)$, where n_0 was the initial number of cockroaches before treatment. The transformed data were analyzed using a mixed effects model repeated measures approach (PROC MIXED, SAS Institute 2001). The fitted slopes of the weeks were compared with to determine the overall differences between treatments. Means at each period were assessed to determine differences between treatments for each period. The amount of bait (log transformed) and cost of the two treatments were compared using analysis of variance (ANOVA) (PROC GLM, SAS Institute 2001). Changes in sanitation ratings of the test apartments at the beginning and the end of the experiments were compared using a Student's *t*-test to evaluate the effect of the intervention programs.

Results

Initial Infestation Level. In total, 12 buildings (66 apartments) were selected for this study and randomly divided into two groups (IPM and baiting). Among them, 41 and 44% of the apartments had German cockroach infestations based on overnight trap counts, respectively. Among the infested apartments, 23 had ≥12 cockroaches (Table 3). These 23 apartments had similar mean trap counts between the two assigned groups ($F = 0.18$; df = 1, 22; $P = 0.68$). Specimens of the oriental cockroach, *Blatta orientalis* L., were found only in one apartment.

Treatment Efficacy. The IPM treatment resulted in a significantly greater trap catch reduction than the bait treatment (ANOVA: $F = 5.9$; df = 11, 95; $P < 0.001$). Weekly comparisons also showed that the IPM treatment had greater trap reductions at 4 wk ($t = -2.5$, df = 95, $P = 0.013$) and 16 wk ($t = -2.0$, df = 95, $P = 0.049$) after treatment than the bait treatment (Table 4). The IPM and bait treatments resulted in 100.0 ± 0.0 and 94.6 ± 2.8% trap catch reduction, respectively, at 16 wk after initial intervention. Although all of the apartments in the IPM group did not have cockroaches based on trap catches at 16 wk, cockroaches were still found in some of the apartments based on visual inspection. Nonparametric analysis results were similar to that from ANOVA, except that the trap catch reduction in the IPM group was only marginally greater than the bait treatment at 4 wk ($\chi^2 = 2.9$, df = 1, $P = 0.091$).

At 29 wk, 16% of the IPM group ($n = 34$) had cockroaches. One apartment had high cockroach numbers. In contrast, 28% of the apartments in the bait

Table 4. Effect of IPM and bait treatments on field German cockroach populations

Treatment	% trap catch reduction (mean ± SE)[a]					
	2 wk	4 wk	8 wk	12 wk	16 wk	29 wk (7-mo)
IPM	65.3 ± 10.2a (12)	76.4 ± 11.1a (11)	90.2 ± 7.2a (12)	81.0 ± 14.0a (10)	100.0 ± 0.0a (11)	98.3 ± 0.0a (11)
Bait	48.2 ± 14.1a (11)	18.3 ± 23.5b (11)[b]	96.2 ± 2.0a (11)	94.0 ± 4.7a (9)	94.6 ± 2.8b (10)	85.8 ± 0.1a (11)

Those apartments with ≥12 cockroaches before treatments were included.

[a] Values in parentheses are numbers of apartments. Means within each column followed by different letters were significantly different ($P \leq 0.05$; ANOVA).

[b] Two apartments had large negative values.

Table 5. Total treatment cost per apartment over 29-wk period

Treatment group	No. apartments	Median (min.-max)			
		Time (min)	Bait (g)	No. traps	Cost/apartment ($)
IPM	12	49 (10–185)	45 (10–215)	40 (35–131)	65 (17–234)
Bait	11	22 (8–63)	50 (15–165)	0	35 (11–81)

Only those apartments with ≥12 cockroaches during initial survey were included.

treatment group (n = 32) had cockroaches. Five apartments had ≥12 cockroaches.

Effect of Education on Sanitation. The average sanitation rating in the IPM group changed from 3.8 to 2.4. The change from the beginning of the experiment to 29 wk was significant (t = 3.5, df = 10, P = 0.006). The sanitation level in the bait treatment group also improved (from 4.0 to 3.2), but the change was not statistically significant (t = 0.94, df = 8, P = 0.37). There was not a significant difference in the sanitation rating between IPM and bait treatments at 29 wk (F = 2.34; df = 1, 18; P = 0.14).

Effect of Nonchemical Tools on Reduction of Cockroach Numbers. Among the 12 heavily infested apartments, the median (minimum-maximum) number of cockroaches removed by trapping during the test period was 439 (15–5,783). Nine apartments received vacuuming which removed 300 (10–3,300) cockroaches. Among them, one apartment received two services, one apartment received three services, and the others received one service. For those apartments with ≥113 cockroaches in traps during the initial survey, at least 300 live cockroaches were removed by vacuuming. The effect of flushing and vacuuming was not obvious among those apartments with <113 cockroaches in traps. Less than 30 live cockroaches were removed by vacuuming from each of these apartments. The percentage of reduction by flushing and vacuuming was not clear because the total numbers of cockroaches in each apartment were unknown.

Besides cockroaches, the following animals also were found in the monitoring traps: mice, ants, small flies, spiders, millipedes, and beetles. During a visit on 14 December 2004, tenants from eight test apartments complained of mouse infestations. We placed six Trapper monitoring traps in each apartment. Mice were trapped in five of the mouse infested apartments after 24 h. Tenants were generally pleased to see both traps and baits were used to reduce cockroaches and other pests, especially mice.

Effect of IPM on Reduction of Insecticide Use. Similar amount of bait (log-transformed) materials were used in the two treatment groups during 7 mo (Table 5) (F = 0.1; df = 1, 21; P = 0.75). Most of the use occurred in the first month. For the 29 wk service, the IPM and bait treatment groups used 2.0 ± 1.1 and 6.5 ± 2.5 g per apartment, respectively. The difference was not significant (F = 1.5; df = 1, 20; P = 0.23).

Cost of Treatments. Because a good control program for cockroaches usually requires more than one visit, we used the cumulative cost during a 7-mo experimental period to compare the two treatment strategies. Education effort, necessary repairs, and sanitation effort were not factored into the cost because they were easily incorporated into the existing community service program offered by the housing authority. The median costs of the IPM and bait treatments were $64.8 (17.0–233.5) and $35.0 (10.7–81.0) per apartment, respectively (Table 5). The cost of IPM was significantly greater than that of the bait only treatment (F = 5.5; df = 1, 21; P = 0.03). This greater cost of IPM was mainly due to the additional time needed to perform flushing and vacuuming. Because flushing and vacuuming were only used 1–3 times at the early stage, the cost of IPM decreased significantly from 16 wk. The costs of IPM and bait treatments were $39.5 ± 7.8 and $15.6 ± 1.5 per apartment for the initial treatment, respectively. The costs reduced to $2.8 ± 1.3 and $5.7 ± 2.3 per apartment for the 29-wk service, respectively. The cost for the 29-wk service in the IPM group was similar to that in the bait treatment group.

Those apartments with one to 11 cockroaches during the initial survey were treated by trapping and baiting or baiting only. There were no significant differences in the costs between the two treatments (F = 0.06; df = 1, 13; P = 0.81). The mean cost per apartment during 7 mo was $13.4 ± 3.0 ($n$ = 7) and $14.4 ± 3.2 ($n$ = 8) for IPM and bait treatments, respectively. Those apartments did not have cockroach infestations or became vacant were excluded.

Discussion

The overall trap catch data during the 7-mo period demonstrated that IPM significantly improved the control of cockroach infestations than the bait alone treatment. The difference, however, was small. This was partly due to the high level of control by the Maxforce FC Select gel bait. The difference may persist beyond 29 wk due to the use of monitoring traps. Using monitoring traps not only assisted in removing the remaining cockroaches that were not killed by bait but also helped determine location and population levels of the remaining cockroaches. IPM may require significantly less bait beyond 29 wk because of the more precise placement of bait as a result of the use of monitoring traps.

It was not surprising to find that the cost of IPM was much greater than the bait treatment for the 7-mo period. The higher cost was largely due to the vacuuming procedure at the beginning of the experiment. The costs of IPM and bait only treatment for just the 29-wk service became similar. Despite the fact that IPM used more tools, its cost might continue to be similar to the bait treatment beyond 29 wk due to greater control and the need for less frequent treatments.

One of the objectives of IPM is to reduce the insecticide use. Although no significant differences in bait use were found between IPM and baiting in this study, we did see reduced amount of bait applied and fewer applications in the IPM group at the end (29 wk). More importantly, IPM achieved better control than baiting after 7 mo. The lower cockroach populations in the IPM group will make it less dependent on insecticides beyond 7 mo.

Miller and Meek (2004) found IPM was more effective and much more expensive than crack and crevice spray in controlling German cockroach infestations in public housing. The prescribed IPM treatment (baiting and vacuuming) resulted in 84% trap catch reduction after 5 mo. The IPM program in our study achieved 100% trap catch reduction after 4 mo. The main differences between the two IPM programs were that in this study, an improved bait (Maxforce FC Select) and traps were placed in the infested apartments to reduce cockroach numbers. The traps assisted in the placement of the bait. The greater efficacy of this IPM program indicates that sticky traps should be an integral part of a successful IPM program.

Vacuuming not only removes cockroaches but also has the potential to reduce cockroach allergens because vacuuming can remove large amount of cockroach products (e.g., dead cockroaches, cockroach feces, cast skins, egg cases). This benefit needs to be quantified and may be used to promote the adoption of IPM. Our laboratory studies indicated that white bread and beer baited sticky traps could increase the trap catches by 34-fold (unpublished data). Sticky traps are safe, nontoxic, and easy to use. The emergence of cockroach bait aversion and concerns about indoor pesticide overuse may prompt greater use of traps in future cockroach IPM programs.

Treatment with Maxforce FC Select gel bait alone resulted in a 96% population reduction at 8 wk, even with generally poor sanitation conditions. The bait treatment alone reduced cockroach population by an average of 95% during weeks 8–16. This demonstrates that when carefully applied and monitored, this gel bait was able to effectively reduce the cockroach infestations. However, 16 and 28% of the apartments in the IPM and bait treatment groups, respectively, still had cockroaches after 7 mo. Residents in public housing had various levels of knowledge and attitudes toward cockroach infestations. Some residents had fairly high levels of tolerance to cockroaches. They did not take action themselves to prevent or reduce cockroach infestations. Clutter and inaccessibility in some apartments were the main obstacles to cockroach elimination. For example, one apartment had a >30-cm deep pile of unwashed clothes in the utility room for ≈3 mo. Large numbers of cockroaches were found among the clothes. Flushing and vacuuming were conducted three times. In total, 215 g of bait and 185 min were required to properly treat this apartment. The cockroach counts reduced from 224 to 0 at 16 wk. However, a few cockroaches were still found by visual inspection.

Currently, the apartments managed by Gary Housing Authority receive treatment only when residents report cockroach infestations to the office. Persistent cockroach infestations in the apartments indicate the claim-based cockroach control practice does not effectively relieve the problem. Some residents did not report their cockroach infestations to the management office. The effectiveness of the insecticide applications were not documented or monitored. It is obvious that the current pest control contract terms need to be revised. Actions are needed to design, promote, and monitor self-sustaining IPM programs to effectively reduce cockroach population, reduce pesticide use, and lower cockroach allergen levels in multifamily housing. The goal of the pest management contract needs to be redefined with human health, especially children's health, in mind. Effectiveness of the program should have priority over the cost. Active monitoring and enforcement seem to be the key to the success of cockroach reduction. This requires coordination between the housing authority, pest management professionals, and tenants to set standards, goals, and commitments.

From our conversations with the tenants, there were misconceptions about the benefits and risks of various insecticides. Some residents only believed in "insecticide bombs" or baits in controlling cockroaches. Some preferred using sprays or dusts. Lack of proper use was evident based on the improper placement of insecticide baits or dusts. The tenants in the IPM group apartments were offered both education materials and person-to-person consulting during each visit whenever possible. They were willing to use simple education materials that help them understand the options available to prevent and control cockroach infestations. Continuous effort in delivering IPM information to the residents will help the adoption of community-wide IPM program.

There are a variety of effective cockroach management tools in the market. Our experience with Gary Housing Authority indicates that the management staff is fully aware of their chronic cockroach problems. However, they lack the proper funding, motivation, and coordination to implement more effective, and more expensive, IPM programs. This study provided new evidence on the severity of cockroach infestations, and on cost and effectiveness of IPM versus baiting for cockroach management. The findings stressed the need for building- and areawide IPM programs to protect the residents' health and the environment.

Acknowledgments

We are grateful to Donald Baumgartner for constructive suggestions and continuous support. We thank Gary Housing Authority for proving the study sites and assisting with the treatments; Bayer Environmental Science for providing bait materials; Brian Judt and student workers for assistance with the field research; and Arthur Appel and Jonathan Neal for critical reviews of the manuscript. The study was funded by the United States Environmental Protection Agency grant X8–96519501-0. This is journal article no. 2005-17653 of the

Agricultural Research Program of Purdue University, West Lafayette, IN.

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Received 13 May 2005; accepted 18 January 2006.

Cost and Efficacy Comparison of Integrated Pest Management Strategies with Monthly Spray Insecticide Applications for German Cockroach (Dictyoptera: Blattellidae) Control in Public Housing

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J. Econ. Entomol. 97(2): 559–569 (2004)

ABSTRACT The long-term costs and efficacy of two treatment methodologies for German cockroach, *Blattella germanica* (L.), control were compared in the public housing environment. The "traditional" treatment for German cockroaches consisted of monthly baseboard and crack and crevice treatment (TBCC) by using spray and dust formulation insecticides. The integrated pest management treatment (IPM) involved initial vacuuming of apartments followed by monthly or quarterly applications of baits and insect growth regulator (IGR) devices. Cockroach populations in the IPM treatment were also monitored with sticky traps. Technician time and the amount of product applied were used to measure cost in both treatments. Twenty-four hour sticky trap catch was used as an indicator of treatment efficacy. The cost of the IPM treatment was found to be significantly greater than the traditional treatment, particularly at the initiation of the test. In the first month (clean-out), the average cost per apartment unit was $14.60, whereas the average cost of a TBCC unit was $2.75. In the second month of treatment, the average cost of IPM was still significantly greater than the TBCC cost. However, after month 4 the cost of the two treatments was no longer significantly different because many of the IPM apartments were moved to a quarterly treatment schedule. To evaluate the long-term costs of the two treatments over the entire year, technician time and product quantities were averaged over all units treated within the 12-mo test period (total 600 U per treatment). The average per unit cost of the IPM treatment was ($4.06). The average IPM cost was significantly greater than that of the TBCC treatment at $1.50 per unit. Although the TBCC was significantly less expensive than the IPM treatment, it was also less effective. Trap catch data indicated that the TBCC treatment had little, if any, effect on the cockroach populations over the course of the year. Cockroach populations in the TBCC treatment remained steady for the first 5 mo of the test and then had a threefold increase during the summer. Cockroach populations in the IPM treatment were significantly reduced from an average of 24.7 cockroaches per unit before treatment to an average 3.9 cockroaches per unit in month 4. The suppressed cockroach populations (<5 per unit) in the IPM treatment remained constant for the remaining 8 mo of the test.

KEY WORDS *Blattella germanica*, IPM, public housing

GERMAN COCKROACH, *Blattella germanica* (L.), is the predominant pest of low-income housing. Before the widespread use of cockroach baits, Koehler et al. (1987) reported that populations of 20,000 cockroaches in a single apartment unit were not uncommon. Although cockroach numbers have no doubt declined because baiting has become the preferred control method, cockroach numbers have not been reassessed and large populations in low-income housing are still prevalent. These populations have several negative effects on their immediate environment and human health. First, cockroaches are an esthetic nuisance frequently crawling on cooking utensils, food, and people. German cockroaches are also known to carry a number of pathogenic organisms (Roth and Willis 1957, Roth and Willis 1960) and can transfer these organisms to food and surfaces that they contaminate with their cast skins and fecal material (Brenner et al. 1990, Kang 1990). However, the most significant health risk associated with German cockroach infestation is the production of allergens (Brenner et al. 1990). These allergens accumulate in apartment units, become airborne, and are inhaled by the residents (Kang and Chang 1985).

The inhabitants of public housing are often the elderly or children. Both are sensitive to bronchial contaminates (Pope et al. 1993). Yet, these individuals frequently live with very large populations of cockroaches. During the winter, residents close up their apartments and turn on the heat. It is during these periods that the cockroach frass dries out and the

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allergens become airborne. Thus, the indoor air quality is greatly compromised. Inhalation of cockroach allergens has been identified as a major cause of asthma in inner city children (Rosenstreich et al. 1997).

When you combine these preconditions of sensitive occupants, poor sanitation, and cockroach allergens, it makes little sense to apply spray formulation pesticides in this environment (Landrigan et al. 1999). However, spray applications of residual insecticide, either as a preventative or a remedial treatment, have been the primary method of German cockroach control in public housing for the past 50 yr (Byrne and Carpenter 1986). The continued use of insecticide spray is even more perplexing when you consider the widespread documentation of German cockroach resistance to pyrethroids, organophosphates, and carbamates (Cornwell 1976; Robinson and Zungoli 1985; Cochran 1990, 1991). However, the main reason for the persistence of monthly insecticide sprays is that spraying is inexpensive both in cost and labor (Bennett and Owens 1986). The insecticide spray may cost as little as 2¢ per apartment unit per month, and it may take <2 min for the applicator to apply.

Outside of the public housing environment, there is considerable concern about cockroach resistance and the health risks associated with pesticide use (Cooper 1999, Greene and Breisch 2002). These concerns have stimulated the use of new pest management strategies that can be integrated to reduce cockroach resistance and the pesticide load in human living space. These integrated strategies are collectively referred to as integrated pest management (IPM). IPM for German cockroach control relies primarily on three tactics: prevention, monitoring, and the use of reduced toxicity control products. Prevention consists of increased sanitation, specifically, the removal of cockroach food, water, and harborage resources. Monitoring involves of the use of sticky traps and/or careful visual inspections to determine whether cockroaches are present and whether chemical control methods need to be applied. Reduced toxicity control products are those that have low mammalian toxicity and can be placed in precise locations (precision targeting) where they are available to cockroaches but inaccessible to residents (e.g., baits or bait stations and insect growth regulator [IGR] devices).

Compared with the calendar-based application of spray insecticides, IPM programs can reduce the amount of pesticide applied in the environment, eliminate unnecessary pesticide applications, and the target pesticide products more precisely. Yet, it has always been assumed that IPM would be prohibitively expensive (Snell and Robinson 1991, Hedges 2000, Greene and Breisch 2002) in the public housing environment, and that the lack of resident cooperation to clean their apartments would nullify control efforts. There exists considerable evidence to support the opinion that a lack of sanitation reduces the efficacy of IPM products (Burden and Smittle 1975, Bennett and Lund 1978, Farmer and Robinson 1982, Bertholf 1983). However, proponents of IPM argue that the program as a whole would provide superior control even in conditions of poor sanitation (Kramer et al. 2000). Subsequently, improved control would reduce the need for additional pesticide applications, making IPM more cost-effective over the long term. To date, there have been no field evaluations of the long-term costs and efficacy of an IPM program that did not first require residents to clean their apartments. Is it possible to control cockroach populations in conditions of poor sanitation by using IPM techniques? If so, how much more would it cost than the traditional method of monthly spray applications?

Our purpose was to examine the long-term cost and efficacy of an IPM program for German cockroach control in public housing. Specifically, we compared the amount of pesticide applied, the treatment costs, and the efficacy of two German cockroach control programs: IPM, and traditional, calendar-based, applications of spray formulation insecticide.

Materials and Methods

Field Site Conditions. Evaluations of cockroach treatment regimens were conducted from January to December 2002 in a public housing facility located in Portsmouth, VA. The facility consisted of duplex, fourplex, and eight-plex brick buildings that were either single or two-story, built on slab foundations. The public housing complex was built in 1953 and has been under numerous pest control contracts since that time. The complex was treated with spray formulations of chlorpyrifos (Dow AgroSciences, Indianapolis, IN) between 1992 and 1997. After 1997, the complex was treated with a variety of cockroach bait products. In addition, vacated units were fogged with Whitmire ULD BP 100 (1% pyrethrins, 2% piperonyl butoxide [PBO], Whitmire Micro-Gen, St. Louis, MO) between occupants.

The current pest management contractor had been applying alternate formulations of cockroach gel bait every 3 mo (imidacloprid, fipronil, and hydramethylnon) to prevent cockroach resistance. The contractor charges the Public Housing Authority $1.70–2.00 per unit per month for this service. Special services (due to resident complaints) are charged at $45.00 each. In January 2002, the pest management contractor was scheduled to begin a spray campaign for German cockroach control in the nontest buildings. The spray campaign had been implemented in response to a high number of cockroach complaints from residents. The spray treatment required residents to empty their cupboards and closets to allow for applications of Archer (1.3% pyriproxyfen, Syngenta Professional Products, Greensboro, NC) combined with Kicker (6% pyrethrins plus PBO, Aventis Crop Science, Research Triangle Park, NC) and Cy-Kick (0.1% cyfluthrin; Whitmire Micro-Gen). After the one-time spray treatment the contractor was to resume the monthly bait applications in all nontest units.

Building Selection. During our initial inspection of the housing complex (October 2001), we observed that sanitation levels varied among the individual units within each building. However, all buildings inspected had active German cockroach infestations and conditions conducive to cockroach survival.

To determine baseline cockroach infestation levels, whole buildings were monitored using sticky traps (Orkin Report Card, Woodstream Co., Lititz, PA) in November 2001. Three traps were placed in each apartment unit, one above the kitchen sink, one below the kitchen sink, and one behind the toilet. A total of 150 apartment units were monitored for 24 h. After the monitoring period, traps were removed and trap catch recorded. Those buildings with the highest levels of infestation were selected for participation in the test. Buildings were randomly divided between two treatment regimens, so 50 apartment units were in each test group. Buildings were then classified as either IPM (IPM; 10 buildings) or Traditional Baseboard, Crack and Crevice (TBCC; 12 buildings).

Treatment Regimens. Individual treatments, either IPM or TBCC, were applied only to the kitchens and bathrooms in each apartment unit. All treatments were applied by trained, certified pest management personnel (PMPs), from the Orkin Pest Control Company. The specific products (spray, dust, bait, and IGRs) used for both the TBCC treatment and the IPM treatment were selected by us and the Orkin PMPs as the most appropriate for the applications and most effective against German cockroaches. Treatment regimens were implemented in January 2002 and applied for one calendar year. The first application or "clean-out" was intended for PMPs to remove or kill as many cockroaches as possible on the first visit. Both the clean-out and monthly maintenance treatments allowed PMPs to use as much time and product as they felt necessary to impact the cockroach population. IPM and TBCC treatments were applied to each apartment "as is." In other words, housing residents were not required to empty their cupboards or clean their units at any time during the test.

TBCC Treatment. Clean-out for the TBCC buildings involved the PMPs making thorough applications of spray and dust formulation insecticide to bathrooms and kitchen areas. The products used were Tempo SC Ultra (aqueous solution of 0.025% beta-cyfluthrin; Bayer Crop Science, Kansas City, MO.) formulated in a B&G sprayer (1-gal Prime Line 2000, B&G Equipment Co. Jackson, GA) for baseboard application, and Borid Turbo dust (aerosol formulation of 20% orthoboric acid, Waterbury Companies Inc., Waterbury, CT) for crack and crevice application. After the initial treatment, PMPs continued to make monthly applications of spray and/or dust as they saw fit. All TBCC units were monitored monthly with sticky traps (Roach Motel, Clorox Co., Oakland, CA) for 24 h to measure treatment efficacy.

IPM Treatment. Sanitation was used as one of the initial clean-out strategies in the IPM treatment. PMPs used the Lil' Hummer backpack style vacuum (Pro-Team Inc., Boise, ID) to remove cockroaches and other debris from kitchen and bathroom areas. Vacuuming was used only twice during the test, at the initial clean-out and again 6 mo later. Sticky traps (Roach Motel, Clorox Co.) were also used as part of the IPM program to monitor cockroach populations. After initial clean-out, IPM buildings were monitored monthly (24 h) with sticky traps. If monitoring indicated a decline in German cockroach populations after 3 mo of treatment, treatment would be applied on a quarterly basis. Specifically, if a unit had two cockroaches or less in all three traps it would be placed on a quarterly treatment schedule. If a unit had >2 cockroaches in the three traps, the unit would continue to be treated on a monthly basis. If monitoring indicated that the cockroach population had increased in a unit after the quarterly service, that unit resumed treatment on a monthly schedule. The reduced toxicity control products used in the IPM tests were Maxforce Bait Gel (2.15% hydramethylnon, Clorox Co.), and the Gentrol Point Source (90.6% hydroprene, Wellmark International, Schaumburg, IL). Bait was applied only as needed and the IGR delivery devices were replaced every 3 mo according to the label. All units in the IPM test were monitored monthly with sticky traps for 24 h to measure treatment efficacy.

Table 1. Respective costs of the technician time and treatment products used in the TBCC treatment and the IPM program

Treatment	Expenses	Price/Quantity
TBCC	Technician time	1.00/min*
	Tempo SC Ultra	0.0002/g**
	Borid Turbo	0.01/g**
IPM	Technician time	1.00/min*
	MaxForce Gel Bait (hydramethylnon)	0.10/g**
	Gentrol point source	0.95/device**
	Sticky trap monitors	0.135/monitor**

* The Virginia Pest Management Association estimates the break-even cost of operation for a pest management company to be between $55.00 and 60.00/h ($1.00 min).

** Cost of products based on industry averages in 2002. Costs to individual pest management companies may vary based on company size, quantity ordered, and company relationship with manufacturer or distributor.

Data Collection: Quantification of Labor and Pesticide Costs. *Technician Time.* Upon arrival at the test site, the technican's time was recorded with a stopwatch. Technician time included the time the PMP spent preparing equipment, formulating insecticide, and treating each apartment unit. Total technician time was calculated for both the IPM and TBCC treatments and then divided by the number of apartment units (50) to get an average time spent per unit.

Labor Cost. Technician time was valued at $60.00/h ($1.00/min, industry standard) to calculate labor (plus overhead) costs. The technician time used to apply treatment was compared to determine the average labor cost per apartment unit for both the IPM and TBCC treatments (Table 1).

Amount of Formulation Applied. Treatment products were weighed in the application equipment before and after application to calculate the number of grams of product applied in each apartment unit. Total product applied was calculated for both the IPM and TBCC treatments then divided by the number of

Table 2. Mean technician time spent in each unit on the application (preparation, application, and clean-up) of the TBCC and IPM treatments

Treatment period	Mean technician time + SE (s) (min/s)			
	n	TBCC	*n*	IPM
Initial treatment	49	169.8 ± 3.4c (2 min 50 s)	49	715.7 ± 52.6a (11 min 55 s)
Month 2	49	146.8 ± 3.2c (2 min 27 s)	49	269.3 ± 14.6b (4 min 28 s)
Month 4	50	74.6 ± 1.6ef (1 min 14 s)	48	161.3 ± 27.3c (2 min 41 s)
Month 6	50	80.7 ± 2.3cf (1 min 21 s)	50	65.3 ± 18.9ef (1 min 5 s)
Month 9	50	90.2 ± 1.9def (1 min 30 s)	50	38.6 ± 11.9f (39 s)
Month 12	50	103.1 ± 2.9 cde (1 min 43 s)	49	43.8 ± 12.3f (44 s)

Two-tailed ANOVA. Means ± SE followed by the same letter are not significantly different ($P < 0.001$; Fisher's least significant difference test) (SAS Institute 1999).

apartment units (50) to get the average number of grams applied per unit.

Product Cost. The number of grams applied in each unit was converted into a dollar value to compare the average product cost per apartment unit for both the IPM and TBCC treatments (Table 1).

Treatment Efficacy. *Comparison of Trap Catch.* A total of three sticky traps (Roach Motel, Clorox Co.) were placed (one above the kitchen sink, one below the kitchen sink, and one behind the toilet) in each apartment unit every month and retrieved after 24 h. Average monthly trap catch per apartment unit was compared by treatment to determine treatment efficacy over the 1-yr test period. All units in each treatment were trapped every month to collect efficacy data. However, the time and cost data associated with monitoring IPM units on the quarterly treatment schedule were not recorded each month, but recorded quarterly only.

Statistical Analysis. Data were collected monthly for 1 yr to compare the long-term costs and efficacy of the two treatments. Monthly comparisons of technician time, amount of product applied, and treatment costs were analyzed using analysis of variance (ANOVA). Means were separated using Fisher's least significant difference test (SAS Institute 1999). The cumulative (12 mo) average per unit cost of each treatment was compared using Student's *t*-test (SAS Institute 1999).

Efficacy data (trap catch) were analyzed using Proc GLM (SAS Institute 1999) for nested repeated measures. The infested buildings were the experimental units and the apartment units within each building were the nested populations. The interest of this analysis was to test the interaction between the time and treatment. The expectation was that there would be no difference in the cockroach populations at the beginning of the test but that the effect of the treatments would be reflected in changes within the cockroach populations over time. Mean differences in the cockroach populations were compared at particular months to determine differences between the IPM and TBCC treatments. An additional feature of this analysis was the inclusion of the baseline population measurements as a covariate. Because the apartments differed in the initial levels of infestation before treatment, the initial untreated population means were adjusted and transformed using the square-root transformation to improve the homogeneity of the variances and the normality of the data. For all tests, values of $P \leq 0.05$ were used to indicate significance (SAS Institute 1999).

Results

Levels of cockroach infestation were assessed in all buildings selected for participation in the test before any treatment was applied. Twenty-four hour trap catch in buildings that were randomly assigned to the TBCC treatment averaged 13.1 ± 3.9 (range, 0–158) cockroaches per unit, with only 6 U out of 50 having no cockroaches trapped in 24 h. Buildings assigned the IPM treatment had an average of 24.7 ± 5.86 cockroaches per unit (range, 0–181), with only three units having no trap catch in 24 h. Although more cockroaches were caught in buildings assigned the IPM treatment, levels of cockroach infestation between the two groups of buildings was not significantly different ($P = 0.10$).

Quantification of Labor and Pesticide Costs. The initial clean-out of test apartment units took place in January 2002. Mean technician time to clean-out a single unit in the TBCC treatment was 2 min and 50 s. This time was significantly less ($F = 95.3$, df = 11, $P < 0.0001$; Table 2) than that taken to clean-out an IPM unit (11 min and 55 s).

Although the time spent treating the IPM units was significantly greater than in the TBCC units, the amount of product applied was significantly less ($F = 417.8$, df = 11, $P < 0.001$; Table 3). In the TCBB units, an average of 138.1 g of the spray and dust formulations were applied compared with only 5.7 g of bait and IGRs applied in the IPM treatment.

The reduced amount of product applied in the IPM units did not translate into a reduction in cost because the cost of the IPM products were much more expensive than the TBCC products (Table 1). Even though 24 times more formulated product was applied on average in the TBCC units, the cost was 19 times less ($0.13) than the product cost (not including the monitors) in the IPM units ($2.47).

Table 4 lists the monthly cost comparisons of technician time and products applied, including IPM monitors, in the TBCC and IPM treatments. The average clean-out cost of the IPM treatment was significantly

Table 3. Monthly comparison of the mean amount of formulated insecticide applied per apartment unit for TBCC treatment and IPM treatment

Treatment period	n	Product	TBCC (g) Mean ± SE	n	Product	IPM (g) Mean ± SE
Clean-out	49	Tempo SC Ultra	128.5 ± 0.0	50	Maxforce Gel	5.50 ± 0.4
		Borid Turbo	10.1 ± 0.5		Gentrol point source	0.26 ± 0.0
		Total	139.1 ± 0.5b		Total	5.70 ± 0.4f
Month 2	49	Tempo SC Ultra	98.5 ± 4.9	46	Maxforce Gel	3.40 ± 0.3
		Borid Turbo	11.0 ± 0.5		Gentrol point source	0.01 ± 0.1
		Total	109.5 ± 4.8c		Total	3.43 ± 0.3f
Month 4	50	Tempo SC Ultra	294.1 ± 13.1	45	Maxforce Gel	1.64 ± 0.4
		Borid Turbo	0.0 ± 0.0		Gentrol point source	0.00 ± 0.0
		Total	294.1 ± 13.1a		Total	1.64 ± 0.4f
Month 6	50	Tempo SC Ultra	42.8 ± 1.1	45	Maxforce Gel	2.20 ± 0.7
		Borid Turbo	0.0 ± 0.0		Gentrol point source	0.0 ± 0.0
		Total	42.8 ± 1.1e		Total	2.24 ± 0.7f
Month 9	50	Tempo SC Ultra	143.8 ± 5.0	47	Maxforce Gel	0.7 ± 0.3
		Borid Turbo	1.9 ± 0.2		Gentrol point source	0.0 ± 0.0
		Total	145.7 ± 5.0b		Total	0.7 ± 0.3f
Month 12	50	Tempo SC Ultra	96.0 ± 2.1	49	Maxforce Gel	1.1 ± 0.4
		Borid Turbo	0.0 ± 0.0		Gentrol point source	0.0 ± 0.0
		Total	96.0 ± 2.1d		Total	1.1 ± 0.4f

Two-tailed ANOVA. Means ± SE followed by the same letter are not significantly different ($P < 0.001$; Fisher's least significant difference test) (SAS Institute 1999).

greater than that of the TBCC treatment ($F = 131.5$, df = 11, $P < 0.0001$) with most of the cost being attributed to technician time ($11.74).

After the initial clean-out, both treatments entered the maintenance phase of the test. Technician time for the IPM treatment in month 2 was significantly less than it had been in month 1 (Table 2; $F = 95.34$, df = 11, $P < 0.0001$). This reduction in technician time was due to the elimination of the vacuuming portion of the initial treatment. Also, IGR devices had a 3-mo residual so the technician had only to apply cockroach bait and put out monitors to complete the IPM treatment. The technician time in the second month (2 min 27 s) of the TBCC treatment was not significantly different from that of month 1 (2 min 50 s; $F = 95.34$, df = 11, $P < 0.001$). However, the time it took to apply the TBCC treatment in month 2 was still significantly less than the time to apply the IPM treatment for the same month (4 min 28 s; $F = 95.34$, df = 11, $P < 0.0001$). Although the TBCC treatment data indicated no difference in technician time between months 1 and 2, technician time did decrease over the course of the next 10 mo (Table 2; $F = 95.3$, df = 11, $P < 0.0001$). The reason for this decrease was attributed to the technician becoming more efficient at applying the baseboard spray in these units and choosing not to apply the residual dust every month.

The amount of product applied in month 2 of the TBCC treatment was significantly less than that applied during the initial clean-out (Table 3; $F = 417.8$, df = 11, $P < 0.0001$). Although the quantity of product applied in the TBCC units was reduced in month 2, the amount was still significantly greater than that applied in the IPM units in month 2 (Table 3). The average amount of product applied in the IPM units during month 2 was not significantly different that the amount applied in month 1.

The reduction in technician time and amount of product applied in month 2 of the IPM treatment significantly reduced the average treatment cost from month 1 (Table 4; $P < 0.0001$). The cost of the TBCC treatment in month 2 did not differ from that of month 1 in either the products or technician time. Although the amount of product applied in the TBCC treatments was significantly less in month 2 than month 1, the cost of the products was the same due to the relative proportions of the products used. Overall, the costs of the IPM ($5.16 per unit) and TBCC ($2.41 per unit) treatments were more comparable in month 2

Table 4. Monthly contrast comparisons of mean treatment costs (technician time plus products) per apartment unit for TBCC applications and the IPM program

Treatment period	n	TBCC (mean $)			n	IPM (mean $)		
		Time	Product	Total ± SE		Time	Product	Total ± SE
Clean-out	49	2.62	0.13	2.75 + 0.06c	50	11.74	2.86	14.60 + 0.90a
Month 2	49	2.28	0.13	2.41 + 0.05c	46	4.28	0.87	5.16 + 0.26b
Month 4	50	1.12	0.06	1.18 + 0.03d	45	2.54	0.43	2.97 + 0.50c
Month 6	50	1.20	0.01	1.21 + 0.04d	45	1.04	0.31	1.35 + 0.39d
Month 9	50	1.31	0.05	1.36 + 0.03d	47	0.61	0.14	0.75 + 0.23d
Month 12	49	1.50	0.02	1.52 + 0.05d	49	0.69	0.18	0.87 + 0.24d

Two-tailed ANOVA. Mean costs ± SE followed by the same letter are not significantly different ($P < 0.001$; Fisher's least significant difference test) (SAS Institute 1999).

than they had been after the initial clean out, but IPM was still significantly more expensive ($P < 0.0001$).

After 3 mo of treating the IPM units, monitoring (trap catch) was used to determine which apartments could be put on a quarterly treatment schedule. In month 4, 28 of the IPM units had fewer than three cockroaches in all three monitors and were put on the quarterly treatment schedule. In month 5, an additional 11 units were put on quarterly treatment. By month 6, 50 apartment units were under the IPM regimen but only 10 units required actual treatment. This savings of technician time and product significantly reduced the average IPM cost to only $1.35 per unit in month 6 (Table 4). A comparison of IPM and TBCC treatment costs in month 6 indicated that the difference between the two treatments was not significant (Table 4). The difference in cost between the two treatments in months 9 and 12 was also not significant.

To minimize redundancy, a comparison of all monthly treatment costs is not presented here. However, it is important to include the cost analysis of the quarterly treatment months, when all units in the IPM program were treated: month 7 and month 10. In month 7, the average cost of treatment for IPM units was $8.02. This was significantly greater than the cost of the TBCC treatment, which averaged $1.81 per unit ($P < 0.001$). Likewise, in month 10 the average cost of treating an IPM unit was $5.29, which was significantly more expensive than treating a TBCC unit at $0.71 ($P < 0.001$).

However, the costs of the IPM and TBCC treatments cannot be adequately compared on a month-to-month basis. The low cost of the IPM treatment in month 9 is offset by the high cost of IPM in month 7. Therefore, the method for evaluating the true costs of both treatments requires a comparison of average per unit cost over the entire year. Figure 1A compares the cost of technician time averaged over all of the units treated in 2002. In month 1, it took the technician an average of 11 min and 55 s to treat each of the 50 units by using the IPM methodology at a cost of $11.74. In the TBCC treatment, the technician took an average of 2 min and 40 s to treat a unit at a cost of $2.62. By month 2, the technicians had treated a total of 100 units (the same 50 units treated twice). Therefore, to determine the true long-term cost of treating those 100 units, the technician time costs were summed over the 2-mo period and divided by 100. Thus, the average time taken by the technician to service each of the 100 IPM units was 8 min and 30 s ($8.50). If the cost of technician time is averaged across the entire year, the average time it took a technician to service each of the 600 IPM apartment units was 3 min and 5 s or $3.08 per unit. By using the same method to determine the long-term cost of the TBCC program, it was found that the average cost of technician time was $1.45 per unit. The long-term costs of technician time in the IPM treatment was significantly greater than the cost of the technician time in the TBCC treatment ($t = 9.7$, df = 1161, $P < 0.0001$).

Using the method described above, the average product costs were also evaluated over the entire year (Fig. 1B). After treating 600 units, the average product cost for the IPM treatment was $0.98 per unit compared with $0.05 for the traditional treatment. These product costs were significantly different ($t = 19.8$, df = 1161, $P < 0.0001$).

Finally, the amount of technician time was combined with the product costs to determine the total, per unit service cost over the entire year. Figure 1C illustrates that as more units were treated the difference in costs between the TBCC treatment and the IPM treatment were greatly reduced. However, at the end of 1 yr (600 units), the average per unit cost of the IPM treatment ($4.06) was still ≈3 times greater than that of the TBCC treatment ($1.50; $t = 12.6$, df = 1161, $P < 0.0001$).

Treatment Efficacy. Although the cost of a pest control treatment is an important consideration, a low cost is meaningless if the treatment does not work. The TBCC treatment used in this study was far more economical to apply than the IPM treatment, but it did not control cockroaches. The actual monthly trap catch data for each of the two treatments is reported in Fig. 2.

The results of the nested, repeated measures analysis where whole building populations served as the experimental units are listed in Table 5. The trap catch data indicates that the traditional treatment did not provide an acceptable level of German cockroach control. Although there was a slight decline in cockroach numbers after the initial TBCC clean-out, the cockroach populations rebounded a month later and quadrupled over the next 6 mo. The TBCC cockroaches finally began to decline after October (month 10) with the onset of cool weather, but this decline only returned populations to the pretreatment level.

The IPM treatment was significantly more effective at reducing cockroach populations. Cockroach populations were effectively suppressed in all but 10 units, reducing the number of cockroaches per unit per building from a pretreatment average of 23 cockroaches to an average of 7.9 cockroaches per unit per building by month 7 (Table 5). After month 7, cockroach populations in the IPM treatment remained suppressed for the duration of the test.

It is important to note that the actual monthly per unit trap catch (Fig. 2) is lower for both treatments than the adjusted trap catch reported in Table 5. This difference between the actual and the adjusted trap catch is due to our adjusting the initial cockroach population means to compensate for differences between the two cockroach population levels before treatment. Also, the adjusted means for each population within a building were averaged to determine the monthly treatment means.

Discussion

Treatment Costs. *Technician Time.* The results of this study confirm the assumption that the cost of IPM for German cockroach control is significantly more

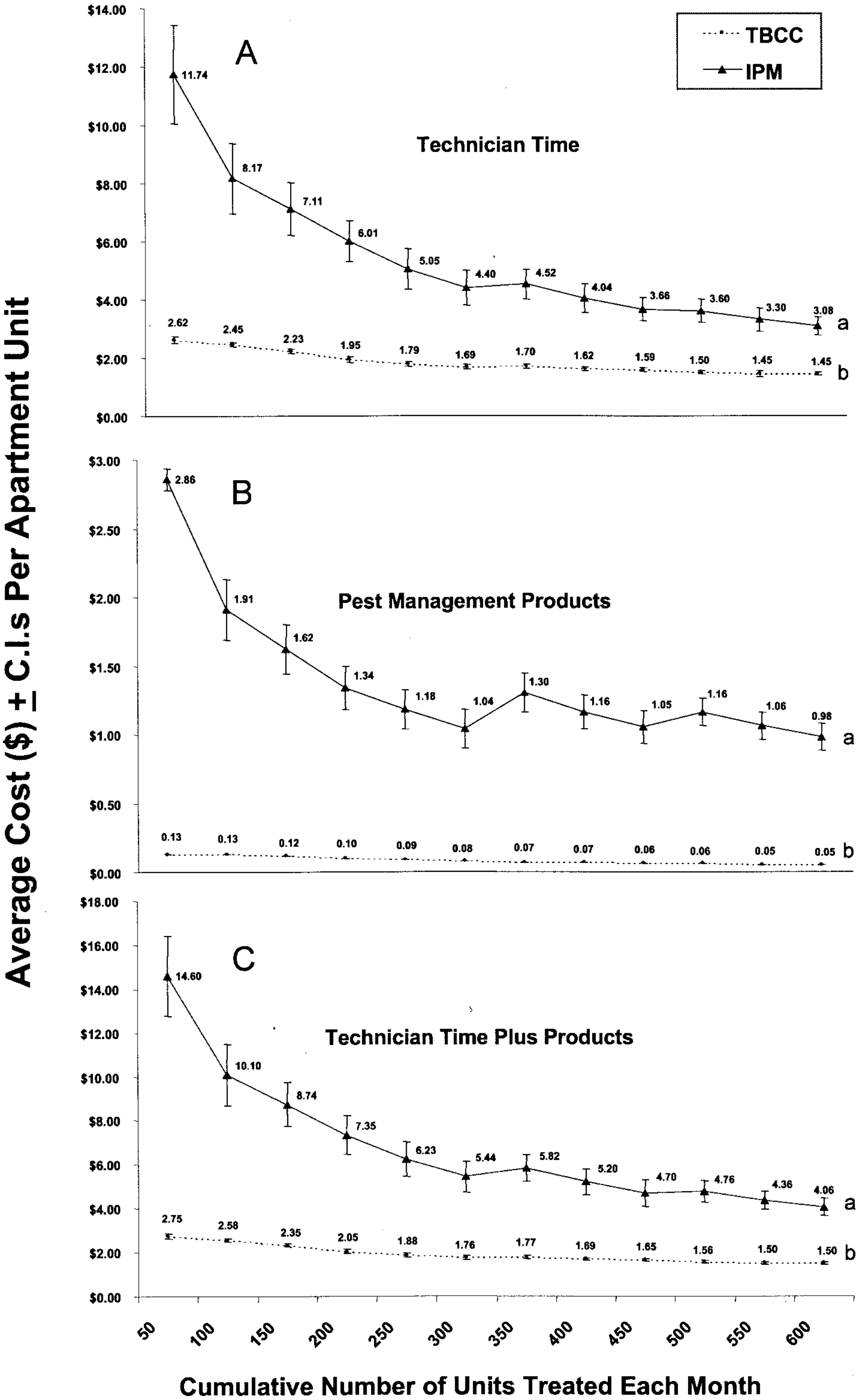

Fig. 1. Long-term cost analysis of the IPM treatment methodology compared with a TBCC treatment. The cumulative average per unit cost ± SE, for technician time, product cost, and total treatment cost, are presented as a function of the number of units treated. The average costs for treating 600 units that are followed by different letters are significantly different (Student's *t*-test, $P < 0.05$).

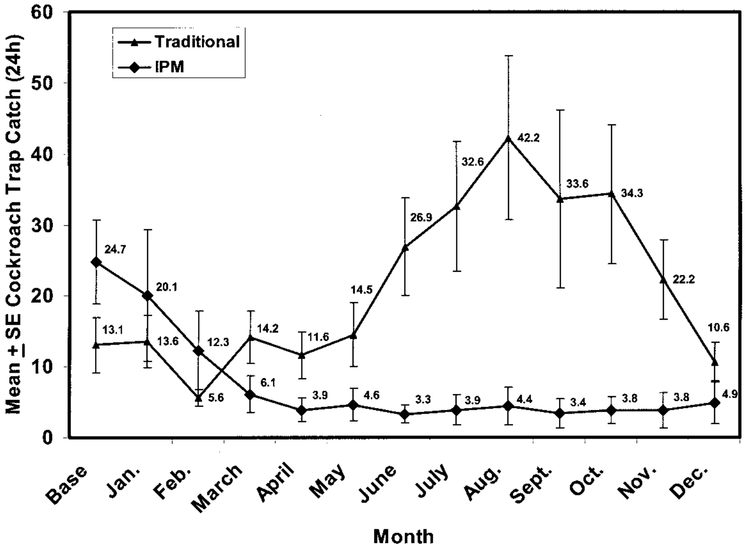

Fig. 2. Monthly German cockroach trap catch (mean ± SE) for units in IPM treatment and the TBCC treatment.

expensive than that of more traditional treatment. The cost difference was particularly apparent at the initiation of the program when technicians took a lengthy amount of time to clean out (vacuum) the IPM units. The cost of technician time during the clean-out had a significant impact on the average IPM treatment cost for the entire year. In fact, technician time was the single greatest expense for the IPM program.

Table 5. Monthly comparisons of adjusted trap catch using nested, repeated measures analysis

Month	Treatment	Trap catch ± SE	*F* Statistic	*P* Value
Baseline*	TBCC	18.1 ± 9.4		
	IPM	23.1 ± 4.2		
Month 1**	TBCC	17.9 ± 5.5a	1.35	0.260
	IPM	24.2 ± 11.4a		
Month 2	TBCC	6.6 ± 2.0a	0.29	0.590
	IPM	20.9 ± 12.0a		
Month 3	TBCC	20.5 ± 6.5a	6.74	0.018
	IPM	8.9 ± 4.9b		
Month 4	TBCC	17.2 ± 5.5a	7.18	0.015
	IPM	5.9 ± 3.2b		
Month 5	TBCC	17.3 ± 5.1a	11.31	0.003
	IPM	6.1 ± 2.8b		
Month 6	TBCC	30.4 ± 11.1a	8.24	0.010
	IPM	4.3 ± 1.9b		
Month 7	TBCC	34.8 ± 12.7a	7.14	0.015
	IPM	7.9 ± 4.7b		
Month 8	TBCC	36.1 ± 11.0a	15.60	0.0009
	IPM	9.3 ± 6.6b		
Month 9	TBCC	32.2 ± 10.4a	8.69	0.008
	IPM	6.6 ± 4.5b		
Month 10	TBCC	42.2 ± 14.2a	15.12	0.001
	IPM	7.4 ± 4.4b		
Month 11	TBCC	30.2 ± 9.0a	12.07	0.003
	IPM	7.6 ± 5.8b		
Month 12	TBCC	15.3 ± 5.5a	5.12	0.036
	IPM	9.2 ± 6.4b		

Cockroach population means were adjusted to account for differences in infestation levels before treatment. Adjusted trap catch was averaged by building to determine treatment means (df = 1.19).

* Pretreatment

** First treatment applied month 1, trap catch recorded 24 h after treatment.

Proc GLM repeated analysis contrast test (SAS Institute 1999). Mean trap catch within a single month followed by different letters are significantly different $P \leq 0.05$.

Less pesticide was applied in the IPM units than in the TBCC treatment, yet technicians had to spend more time applying the products. Applying baits and IGRs was more time-consuming because technicians had to seek out cockroach harborages and resources to place them effectively (precision targeting). These target locations varied from one apartment to another, requiring technicians to inspect each kitchen and bathroom before applying the baits or IGRs. By comparison, pesticide applications in the TBCC treatment were more standardized. Technicians had only to spray exposed baseboards and concentrate their dust applications in consistent locations such as behind the refrigerator, behind the toilet, and around pipe chases.

Product Costs. The products used in the IPM program were significantly more expensive per gram that those of the TBCC program. The amount of formulated product applied during the initial clean-out in the IPM treatment was <6 g per unit but the cost was \$2.86. This product cost was ≈20 times that of the TBCC treatment (0.13¢) even though the average amount of pesticide applied in the TBCC units was ≈140 g. This 20-fold difference in product cost between the treatments remained constant throughout the year, even after the majority of IPM units had been moved to the quarterly schedule.

One reason that product cost did not decrease after a large number of IPM units were moved to the quarterly treatment was that the new schedule changed the way that the technicians treated the remaining units. When relieved of the burden of treating all 50 IPM units, the technicians applied more bait in the remaining units than before. For example, during the initial clean-out when cockroach numbers were the worst, the average amount of bait applied was 5.5 g per unit. However, when the technicians had to treat only 10 units in months 5 and 6, they applied an average of 10.1 and 13.1 g, respectively, to each of those units. The twofold increase in the amount of bait applied in the "problem units" contributed to the relatively high monthly cost of the IPM program, even when the majority of units were not being treated at all.

Another cost associated with the IPM treatment that was not given consideration in our study was that of the Lil' Hummer vacuum. Although a number of the larger pest management companies are starting to use vacuums as part of their pest control service, many companies do not yet carry vacuums as part of their standard equipment. If a company had bid on the 50 IPM units in this study as a new IPM account, the purchase of the Lil' Hummer vacuum would have contributed to the cost by >$330.00 or >$6.60 per apartment unit.

Cost Evaluation. We have established that the cost of IPM was initially very high, yet as predicted by the proponents of IPM, the cost of the program declined over time. The cost of IPM was substantially reduced after the initial clean-out when we entered the maintenance phase of the program in month 2. By month 3, there was enough cockroach control to begin moving units to the quarterly treatment, reducing costs further (Table 4). As more and more units were added to the quarterly treatment schedule, the cost of IPM continued to decline to a minimum cost of $4.06 by month 12. This decline represented a 72% per unit cost reduction from the initial clean-out cost of month 1. We were able to determine from these results that the longer a group of buildings was under an IPM treatment regimen the more economical IPM would become. Thus, it would be reasonable to suggest that if this test were to continue for a second year, the cost of the IPM program would continue to decrease. However, it is doubtful that the cost of IPM would ever be equivalent to that of the TBCC treatment even under conditions of total cockroach control.

The cost of the TBCC treatment was also found to decrease over time. From an initial cost of $2.64 per unit to treat 50 units, the average cost declined to $1.43 per unit after treating 600 units. This was a 46% reduction in per unit cost. However, this cost reduction was not due to any evidence of cockroach control but rather the increased speed at which the technician had learned to apply the treatment.

Treatment Efficacy. The results of this study confirmed that Kramer et al. (2000) were correct in their assertion that IPM could reduce cockroach infestations in spite of poor sanitary conditions. These results were very promising because many studies have evaluated the effect of sanitation on German cockroach control programs. All have concluded that poor sanitation inhibited control efforts and increased cockroach potential for survival (Gupta et al. 1973, Sherron et al. 1982, Bennett et al. 1984, Farmer and Robinson 1984, Milio et al. 1986, Appel 1990). Therefore, we also would have predicted that with no cooperation from the residents to improve sanitation, the cockroach populations in the two treatments would have been the same at the completion of the test. However, we did observe a significant decrease in the German cockroach populations within the IPM units.

From the very first IPM treatment, we observed a population decrease between the baseline and January trap catch (Fig. 2). This initial decrease could not be attributed to the efficacy of the baits or the IGRs because neither work fast enough to affect a population within 24 h. Therefore, we credit the use of the vacuum with removing or at least disrupting the cockroach population enough to have caused this decrease in trap catch. So, although our efforts at sanitation may have been very cursory, they did seem to have an initial impact on the population.

As the IPM test progressed, we observed a steady population decrease (Fig. 2) that could be attributed to the efficacy of the bait and IGRs. After 6 mo of treatment, 40 of the IPM units had so few cockroaches that we could take them off the monthly treatment schedule. This left 10 units that required monthly bait applications. Yet, even these last 10 units had marked decreases in their respective cockroach populations. The average trap catch for all the IPM units stabilized at approximately five cockroaches per unit by month 4 and did not exhibit the normal population increase during the summer that we observed in the TBCC treatment units.

The seasonal timing of our test had an important effect on the efficacy observed in the IPM-treated apartments. We began our treatment in January when the cockroach populations were at the lowest level for the year. We were able to affect the cockroaches early enough to eliminate a large portion of the breeding population thus preventing the natural summer population increase. Had we started the treatment in June, the population would have been increasing every month, making it difficult to observe the effects of the treatment. Likewise, if we started the IPM program during the fall when the cockroach populations were in a natural decline, it would have been impossible to quantify what proportion of the decrease could be attributed to the treatment.

When the efficacy of the IPM treatment was compared with that of the TBCC treatment, there was a dramatic difference. Cockroach populations in the TBCC treatment seemed to be relatively unaffected by the applications of the Tempo SC Ultra and the Borid Turbo dust. Because the Tempo SC Ultra was a contact insecticide, we had expected to see some treatment effect within 24 h of the initial clean-out. However, trap catch in month 1 was not reduced from the baseline trap catch recorded before treatment. We did observe a population decrease in month 2. However, by the third treatment the population had rebounded and remained stable until month 5 when the population experienced the natural summer increase described by Koehler et al. (1987) and Ross et al. (1984).

A possible explanation for the failure of the TBCC treatment to reduce cockroach populations was cyfluthrin resistance. The population decrease observed in month 2 and subsequent rebound in month 3 suggested that we had eliminated the susceptible portion of the population at the beginning of the test. However, the Borid Turbo did not have a significant impact on the cockroach population either. Because there is no literature to suggest German cockroach resistance to disodium-octoborate-tetrahydrate, we had to conclude that there were possibly multiple factors contributing to the failure (moisture clumping the dust, grease binding the active ingredients, and resistance) of the TBCC treatment.

Summary. The TBCC treatment, although considerably less expensive to apply than IPM, was not effective in reducing cockroach numbers to an acceptable level. IPM was more expensive than the TBCC treatment, yet significantly less pesticide was applied in the IPM units. IPM also controlled German cockroach infestations, even under conditions of poor sanitation. The possible health benefits associated with reduced pesticide use and the elimination of cockroaches may off-set some of the monetary costs of IPM. A cost-benefit analysis of IPM in public housing will be presented in a subsequent study.

Practical IPM. The data presented here represent a controlled test where the IPM methodology was identified as a superior means of reducing cockroach populations and pesticide use in public housing units. However, considering the higher cost of IPM, the question then becomes, how can a PMP make IPM practical to apply in the field? We suggest that any PMP interested in offering IPM as part of his or her service have a very good grasp of operating costs for both the clean-out and maintenance portions of the contract and a willingness to set prices accordingly. It would also be advantageous for the PMP to investigate the treatment history of the facility to determine whether there might be cockroach resistance to certain active ingredients or chemical classes. Because monitoring is an essential component of IPM, a pest control operator would need to develop a workable monitoring program. In this study, we had the luxury of being able to pick up monitoring traps 24 h after treatment. This would be an impractical expense for a pest control company. One alternative would be to use very sturdy traps and put them in consistent, hidden locations each month. When the technician returned the following month, he or she could visually inspect the traps. A predetermined threshold level of $\approx$30 cockroaches (three cockroaches per day) or less in all three traps, would determine whether an apartment unit was ready to be moved to a quarterly treatment schedule.

Arguably, the most important requirement for making IPM a practical method of pest control would be a policy change on the part of public housing. Currently, pest control contracts are most often awarded to the lowest bidder. The responsibility of cockroach control then becomes the purview of the pest management company. If residents complain about cockroaches in their apartments, the pubic housing authority is able to point to the pest control contract as evidence of their effort to take care of the problem. However, as this study demonstrated, neither public housing nor the pest management company can expect to control cockroach infestations at a monthly price of $1.00–2.00 per unit. Furthermore, the public housing authority needs to be made aware that such low-cost contracts are completely inadequate. Thus, the practicality of IPM depends on two fundamental changes: first, public housing must be willing to pay a higher price for pest control if they expect to control cockroach infestations; and second, pest management companies must be aware of their costs and willing to charge what it would take to do the job.

Acknowledgments

We thank Danny Cruce, Hal Short, and Dewayne Alfred of the Portsmouth Redevelopment and Public Housing Authority for interest in this research and for contributing the use of facilities and personnel. We particularly thank Michael Gordon, John Myrtle, Curtis Shannon, Calvin (Big Daddy) Jennings, and Cameron Gordon of the Portsmouth Redevelopment and Housing Authority for devoted on-site assistance. We are also extremely grateful for the cooperation and invaluable technical assistance provided by Rae Martin, Michael Cable, and Travina Moore of Orkin Exterminating Inc., VA Beach, VA; and Mary Zinn of Orkin Exterminating Inc., Commercial Division, Norfolk, VA. A special thanks goes to the graduate students of the Virginia Tech Urban Pest Management Program, Rachael Perrott, Lois Swoboda, and Marc Fisher, for patient labor on this project. We thank Eric Smith, VA Tech Department of Statistics, for help with the data analysis. We are grateful to the following manufacturers who donated pest control materials: B&W Sales, Lithonia, GA; Bayer Environmental Science, Kansas City, KS; Waterbury, Waterbury, CT; WellMark Zoecon, Chicago, IL; Oldham Chemical, Memphis, TN; and Woodstream, Lititz, PA. We also thank Philip Koehler of the University of Florida for contributing a stash of Roach Motels. Finally, we express our deepest appreciation to Orkin Exterminating Inc., Atlanta, GA, for generous support of this research project.

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Received for publication 29 May 2003; accepted 12 October 2003.