Cost and Effectiveness of Community-Wide Integrated Pest Management for German Cockroach, Cockroach Allergen, and Insecticide Use Reduction in Low-Income Housing

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ABSTRACT Many low-income housing units in the United States continue to have chronic German cockroach, *Blattella germanica* (L.), infestations and high prevalence of cockroach allergens despite the availability of highly effective cockroach control products. Several studies have demonstrated the greater effectiveness of integrated pest management (IPM) compared with routine chemical interventions in apartment buildings and the benefit of cockroach allergen reduction using IPM. Yet, there has been little information on the cost and benefit of community-wide cockroach IPM, which is critical for voluntary adoption of IPM programs. We evaluated a community-wide IPM program in two low-income apartment complexes in Gary, IN. The program included education of staff and residents, monthly monitoring, and nonchemical (laying sticky traps) and chemical treatment based on monitoring results. One complex of 191 apartments was treated with cockroach gel bait, boric acid dust, and sticky traps by state licensed entomologists from Purdue University (E-IPM group). The other complex of 251 apartments was treated by pest management professionals (PMPs) from a contractor (C-IPM group) following the same protocol as the E-IPM group. Purdue University researchers trained Gary Housing Authority (GHA) staff on cockroach biology and management and cockroach allergen reduction techniques. GHA staff educated all residents in the two complexes on cockroach control and allergen reduction through printed materials, demonstrations, or both. Purdue University entomologists conducted the initial and monthly monitoring in both complexes (laying six sticky traps per apartment and retrieving them the next day) with the assistance from GHA to evaluate program effectiveness, guide insecticide applications, and identify apartments with poor sanitation conditions. Dust samples were collected from kitchen floors of 72 cockroach-infested apartments at the beginning, and again at 6 and 12 mo to evaluate changes in cockroach allergen Bla g 1 concentration. E-IPM resulted in significantly faster cockroach trap count reduction than C-IPM. At 12 mo, the number of cockroach-infested apartments decreased by 74% in both treatment groups. Geometric mean cockroach trap counts decreased from 99.7 at baseline to 0.4 (99.6% reduction) by E-IPM and from 76.0 at baseline to 1.3 (98.3% reduction) by C-IPM. From the first quarter to the fourth quarter, cockroach bait use decreased by 88.5 and 92.7% for E-IPM and C-IPM group, respectively. From month 0 to month 12, geometric mean Bla g 1 concentrations decreased from 27.8 to 2.2 U per gram of dust (U/g) in the E-IPM group and from 5.8 to 2.4 U/g in the C-IPM group. Assuming salary rates at \$60/h for PMPs and \$19/h for housing authority staff, the mean monthly cockroach management (material and labor expenses) cost was \$7.5 USD/apartment for both groups excluding education cost. The cost for subsequent years service is expected to be lower due to reduced cockroach infestations. The effectiveness of both IPM programs was affected by the lack of assistance from housing authority with periodic inspections of the apartments, lack of proper maintenance of the properties, and inadequate cooperation from residents.

KEY WORDS *Blattella germanica*, cockroach allergen, apartments, control

The German cockroach, *Blattella germanica* (L.), is one of the most common indoor pests, especially among multifamily housing units (Rivault and Cloarec 1997, Whyatt et al. 2002, Wang et al. 2008). Cockroaches present potential human health risks through food contamination (Brenner 1995) and allergen production in homes (Gelber et al. 1993, Rosenstreich et al. 1997, Leaderer et al. 2002). A recent report stated that 13% of U.S. kitchen floors had >2.0 units per gram of dust (U/g) cockroach allergen (Bla g 1) concentrations, and 10% had >8.0 U/g, a level associated with

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asthma morbidity (Cohn et al. 2006). Cockroach allergens play a significant role in urban asthma morbidity (Rosenstreich et al. 1997, Arruda et al. 2001, Huss et al. 2001, Rogers et al. 2002). The prevalence of cockroach allergens in homes and the link between cockroach allergen and asthma indicate that reducing cockroaches and allergens will have significant health benefits.

There are several studies examining the effectiveness of cockroach control and other strategies for cockroach allergen mitigation (for review, see Gore and Schal 2007). Effective control of cockroaches was found to be critical in significantly lowering cockroach allergen concentrations (Arbes et al. 2004, Sever et al. 2007). Thus, implementation of an effective cockroach management program may have additional benefits besides cockroach infestation reduction.

Since the late 1990s, highly effective gel bait has been the dominant formulation for managing cockroach infestations in inner cities in the United States (Appel 1992, Reierson 1995) and resulted in significant decline in both pesticide use and cockroach infestations (Greene and Breisch 2002). Unfortunately, chronic cockroach infestations continue to plague low-income housing in the United States. Many factors, including poor sanitation, lack of proper maintenance of the apartments, and budget constrains, contribute to the high levels of German cockroach infestation and cockroach allergen levels.

Integrated pest management (IPM) has long been recognized as an effective means for managing cockroaches (for review, see Robinson and Zungoli 1995). More recently, several studies demonstrated the greater effectiveness of IPM strategies compared with chemical interventions in apartment buildings for managing cockroaches (Kramer et al. 2000, Miller and Meek 2004, Williams et al. 2005, Wang and Bennett 2006). There were several reports on effectiveness of IPM programs in low-income housing (Brenner et al. 2003; Wang and Bennett 2006; Peters et al. 2007; Environmental Health Watch 2003, unpublished report). These IPM programs resulted in 50 to 95% final cockroach reduction.

Only one published report analyzed the comparative cost of IPM and traditional control strategies (Miller and Meek 2004). The authors reported that the IPM program was much more expensive and significantly more effective than traditional crack-and-crevice spray treatments. However, the comparison was biased because the two treatment strategies used different chemical tools that varied significantly in their efficacy against German cockroaches. Brenner et al. (2003) reported the cost of IPM in apartments but did not provide the cost estimation methodology. They calculated the IPM cost as $46–49 per unit in the first year in an East Harlem apartment building in New York City.

Several community-wide IPM programs have been demonstrated in U.S. public housing in the past. Although these programs were reported to be successful, final pest infestation reduction was only modest or the data were unavailable. Safer Pest Control (1996, unpublished report) documented 82.5% reduction in cockroach gel bait use after 10 mo of IPM implementation in the Henry Horner Homes, Chicago, IL. Approximately 830 U were involved and 90% of the residents surveyed indicated the program was very successful. There was no quantitative measurement of the cockroach population changes that resulting from IPM implementation. The Asthma Regional Council of New England (2006, unpublished report) evaluated the cost and effectiveness of an IPM program in an 85-unit apartment complex. Over a 1-yr period, they reported a monthly cost per apartment of $20.80 and $23.60, respectively, for IPM and traditional pest control. Yet, the IPM program resulted in only 15% decrease in pest levels after 12 mo. The most recent study by Kass et al. (2009) reported a single IPM intervention (8–12 person-hours of labor) resulted in 43% cockroach trap count reduction at 3 mo and 14% trap count reduction at 6 mo in 280 public housing apartments.

Public housing authorities typically select the lowest priced bidder when setting up a pest control contract with commercial pest control service providers. For example, Miller and Meek (2004) reported that $1.7–$2 per unit per month was paid by a housing authority in Virginia. Gary Housing Authority (Gary, IN) paid a contractor approximately $2 per unit per month in 2005. This type of contract prevents pest management professionals (PMPs) from committing necessary time to serve each apartment. PMPs simply had to skip many apartments or conduct their service in each apartment in a very cursory manner (one or two minutes in each apartment). The very essential components of IPM: inspection, follow-up treatments, ongoing monitoring program, and community collaboration, were lacking.

It is clear that there is a need for effective and sustainable community-wide IPM programs in low-income housing. An operational IPM program must involve the active participation of property management staff and residents so that the IPM program can be properly executed (Robinson and Zungoli 1995). Pest control contracts need to focus on effectiveness of the program and long-term (per year) low cost rather than short-term (per month) cost. All apartments in a building need to be included because of the frequent movement of cockroaches between adjoining units (Owens and Bennett 1982), resident turnover, and new cockroach introductions. However, the IPM program must be cost-effective to be attractive to housing authorities. This information is critical for promoting voluntary adoption of IPM in low-income housing. The objectives of this study were to:1) determine the cost and effectiveness of a community-wide cockroach IPM program; 2) compare effectiveness of the IPM program delivered by PMPs and licensed entomologists; and 3) evaluate the effect of IPM on cockroach allergen levels and insecticide use reduction. We hypothesized that both PMPs and Entomologist-delivered IPM programs would provide effective cockroach control and significant reductions in insecticide use. Given the fact that cockroach num-

bers and cockroach allergen levels are directly correlated with each other, we also hypothesized that implementation of a community-wide IPM program also would significantly reduce cockroach allergen concentrations.

Materials and Methods

Study Site and Pest Infestation History. The study was conducted in two apartment complexes located in Gary, IN: Dorie Miller Homes (DM) (266 apartments) and Delaney Community (DL) (516 apartments). They were managed by Gary Housing Authority (GHA). The housing conditions, German cockroach infestation levels, and resident demographics were similar between these two apartment complexes. All residents had low to very low income. Each apartment had one to three bedrooms. All buildings were one or two stories; each included two to six apartments. Approximately 75% of the apartments were occupied during the study period. The apartment residents were a mixture of elderly and young people.

Approximately 50% of the occupied apartments had German cockroach infestations as estimated from surveys using sticky traps during summers 2002–2005. Each month, the apartment management office assembled a list of apartments with pest problems based on resident complaints and submitted this list to the pest control contractor. Approximately one fourth of the occupied apartments were treated each month for cockroaches, mice, ants, or spiders. The actual number of cockroach-infested apartments in any given month was always much larger than the complaint list because many cockroach infestations were not reported to the office. Some residents used boric acid dust, aerosol sprays, and insect foggers to control cockroaches. These residents were either not satisfied with the service provided by PMPs, or did not want to receive service from PMPs.

IPM Program Implementation. *Selecting a Pest Control Provider.* GHA originally planned to set up an IPM-based pest control contract with a pest control provider. Unfortunately, this was not done because of difficulties in financial arrangement with the sponsor of this study. Purdue University sent out a request for pest control service to local pest control companies and posted on Purdue University's web page. To discourage pest management companies from submitting low-cost, low-quality service bids, we listed three quality expectations: 1) >80% mean cockroach trap count reduction within 3 mo after starting the service; 2) >90% mean cockroach trap count reduction after 12 mo of service; and 3) >50% reduction in the number of cockroach infested apartments after 12 mo. These criteria were based on our previous study results at the same location (Wang and Bennett 2006). Three local pest control companies responded to the request. GHA invited them to the apartment complex to familiarize themselves with the housing conditions and cockroach infestation levels. A national chain company was selected based on the similarity of their service terms to our expectations and the reasonable cost. PMPs from this contractor provided the following services: monthly application of chemical and nonchemical tools (cockroach bait, boric acid dust, sticky traps, discarding infested items), reporting sanitation or maintenance problems, and reporting material use and time spent in each unit. The contractor was initially paid according to the number of serviced apartments during the first 2 mo due to the higher number of infested apartments at the beginning of the study compared with later time points. Afterward, the contactor was paid a fixed amount per month for convenience.

Initial Survey. GHA sent out a notice about the cockroach IPM program to all apartment residents in April–May 2006. The apartments with reported infestations and the neighboring apartments in the same building were included. Residents who were home during the visits were interviewed. The purpose of the interview was to obtain information on house sanitation, house repair needs, pest infestations, and pesticide use. Complete survey results were reported in Wang et al. (2008). Sanitary conditions of these apartments were rated on a scale from 1 to 4. A number 1 was given to apartments with minimum of trash, clutter, and food residue on the kitchen floor and counters. A number 4 was given to apartments with excessive trash, clutter, and food residues on the kitchen floor and counters. This information helped identify apartments with control difficulties and evaluate the relationships between housekeeping and pest management cost (time, material use). The survey questions used to interview residents were approved by the Purdue University Institutional Review Board.

In total, 361 occupied apartments (DM, 141; DL, 220) were selected initially. These apartments either had reported cockroach infestations or were in the same building as other infested apartments. During the course of the study, additional apartments with reported infestations, as well as apartments adjacent to infested units were subsequently included. Units that went from vacant to occupied in the same building as other enrolled apartments, also were included in the study. In total, 442 (DM,191; DL, 251) apartments were enrolled in the study.

Staff and Resident Education. Educating residents can significantly improve cockroach control and cockroach allergen reduction (McConnell et al. 2005). Before the field survey, the senior author trained the Community Program Service (CPS) staff on cockroach biology, cockroach allergens, IPM, cockroach allergen reduction techniques. Within 1 wk of the initial trapping visit, CPS staff delivered a cockroach prevention and control brochure designed by the authors of this article to each resident. They requested that residents whose apartments had poor housekeeping (sanitation rating >2) attend housekeeping classes offered by CPS. The CPS staff demonstrated housekeeping procedures to reduce clutter, remove trash and food residues, remove live and dead cockroaches, and clean the floors and cabinets. In total, 131 residents attended housekeeping training classes during the study period. Two vacuums were offered to res-

idents in each complex to remove dead and live cockroaches, debris, and food residues from their homes. Each resident was allowed to check out a vacuum for 2 h each time. These vacuums were not intended for daily use by all residents.

Chemical and Nonchemical Treatment. The apartments from DM and DL were treated separately by licensed entomologists from Purdue University (E-IPM) and PMPs from the contractor (C-IPM), respectively. We aimed to compare the cost and effectiveness of the Entomologist-delivered IPM and PMP-delivered IPM. Two PU entomologists and two PMPs treated the cockroach-infested apartments in each respective complex every month except that additional licensed entomologists and PMPs assisted in the treatment during the first 2 mo. The senior author (C. W.) of this article observed the PMPs's work at the beginning and middle of the study to record any aberrations from the treatment protocol.

A combination of boric acid dust (99% orthoboric acid; Waterbury Companies, Inc., Waterbury, CT) and cockroach gel baits were applied to cockroach-infested apartments. Boric acid dust was applied using a hand duster to cracks; holes; wall voids; along perimeter of the kitchen floors; and behind refrigerators, stoves, and furniture. Boric acid was not used inside furniture (such as cabinets) and moist areas (such as areas under refrigerators). Cockroach gel baits were applied to cockroach harborages using a bait gun. The boric acid dust was only used as supplement to the bait treatment. Therefore, the quantity per apartment was much smaller than previously reported (Ebeling et al. 1968). The location and number of bait placements were based on the trap catch numbers and visual inspection. The bait was applied either as 0.05–0.2-g dabs or as strips in harborages where numerous cockroaches were hiding. Each apartment received from a few grams to 131 g per treatment. Although no monitoring traps were placed in bedrooms, living rooms, and closets, these areas were inspected and treated if necessary during each visit. Maxforce FC Select (0.01% fipronil) and Maxforce (2.15% hydramethylnon) cockroach gel baits (Bayer Environmental Science, Research Triangle Park, NC) were used interchangeably during a 12-mo period. Heavily infested items such as clothes, boxes, toys were discarded with the approval of the residents during treatments. Up to five new sticky traps (brands varied) were placed in each apartment to help reduce cockroach numbers.

Each apartment complex received a total of 12 treatment visits. During each visit, only those apartments showing cockroach infestation (based on monthly monitoring results) were treated. The visit intervals were 4–5 wk except that PU entomologists treated the infested apartments at 8-wk intervals between November 2006 and March 2007 due to lack of access to the apartments and time constraints.

Monitoring and Evaluation. Baseline cockroach population levels in both complexes were estimated using sticky traps (Trapper Monitor & Insect Trap; Bell Laboratories, Inc., Madison, WI) by PU entomologists with the aid of GHA staff. Six traps were placed in the following locations for 24 h: 1) cabinet under the kitchen sink, 2) cabinet above the kitchen sink, 3) stove, 4) refrigerator, 5) alongside furnace or under the shelves in the utility room, and 6) behind the toilet. Cockroach numbers in the traps were used to evaluate the effectiveness of the IPM program. After examinations, these traps were either left in each apartment (if the trap was clean and had no cockroaches) or replaced with new traps (if the trap was dirty or had cockroaches) to help detect the existence of cockroaches, to reduce cockroach numbers, or both.

Monthly monitoring after the initial treatment was performed by PU entomologists in collaboration with CPS staff. We originally designed the project so that CPS Staff would conduct the monthly monitoring in DL and transfer the monitoring data to PMPs, and CPS staff would receive feedback from PMPs to guide the resident education and compliance effort. The IPM program following this design might be more sustainable and cost-effective. Unfortunately, CPS staff reduction at the onset of this study and eventual complete shutdown of the CPS department forced PU entomologists to take over the monthly monitoring duty. We did not request PMPs to conduct the monthly monitoring because of cost and concerns for data quality.

If no cockroaches were found in an apartment (based on trapping and interviewing residents when available) for two consecutive months, the apartment was then monitored every three months. Those enrolled apartments without cockroaches at the beginning were monitored every six months.

Data Collection. Dust sample collection and analysis. We originally took samples from 52 infested apartments in each apartment complex. Those apartments were the first identified apartments with cockroaches based on trap counts. Subsequent resident turnover and vacancy reduced the total valid samples to 72 (DM, 32; DL, 40). The first batch of dust samples was collected during 16–17 April 2006 in DM and 8–10 May 2006 in DL after the cockroach infestation survey. Dust samples were collected from the same apartments again at 6 and 12 mo. The dust samples were collected using a ProTeam LineVacer vacuum cleaner (ProTeam Vacuum Company, Boise, ID) with a dust collector (Indoor Biotechnologies, Charlottesville, VA) placed on the distal end of the vacuum's extension wand. In each apartment, the kitchen floor perimeter (maximum 30 cm away from the baseboard) was vacuumed for 5 min. Dust from other rooms was not collected because the kitchen areas consistently had the highest number of cockroaches among the rooms in each apartment based on our trapping data. The dust samples were sent to Johns Hopkins University Dermatology, Allergy and Clinical Immunology Reference Laboratory. The Bla g 1 concentrations were determined by monoclonal antibody-based enzyme-linked immunosorbent assays (Indoor Biotechnologies). Details of the analysis methods were described in Wang et al. (2008). PU entomologists recorded the exact time spent for preparing and applying insecticides in each apartment. PMPs recorded

the service time per apartment by dividing the total service time by the number of serviced apartments after each visit to the apartment complex. They visually estimated the bait usage. PU entomologists calculated bait usage based on the number of bait tubes (30 g per tube) used and determined dust usage by weighing the materials before and after application.

The cost of materials and labor was estimated using the following rates: bait, \$0.14/g; boric acid dust, \$0.01/g; trap, \$0.25/trap; labor, \$60/h for PMPs; and \$19/h, for GHA staff.

Data Analysis. Those apartments with at least nine trapped cockroaches during the initial survey were used to evaluate the effectiveness of IPM on cockroach population reduction. The log-transformed trap count data were analyzed using a linear model with repeated measurement analysis to compare the effectiveness of the E-IPM and C-IPM program (Proc MIXED, SAS Institute 2003). Changes in sanitation ratings for apartments where dust samples were analyzed were evaluated using Student's *t*-test. The log-transformed Bla g 1 concentrations from months 0 to 12 within each apartment complex were analyzed using a mixed effect model to evaluate the significance of the changes. The difference in log-transformed Bla g 1 concentrations between apartment complexes at 12 mo was analyzed by a linear model with month 0 data as covariant (Proc GLM, SAS Institute 2003).

Square root-transformed total treatment time, bait use, and number of treatment visits to each infested apartment were analyzed for their relationship with the initial trap counts and sanitation ratings (Proc REG, SAS Institute 2003).

Many apartments were only serviced quarterly according to the treatment protocol. Some cockroach-infested apartments were not accessible due to locked screen doors or lack of assistance from housing authority. These apartments were treated during the following monthly visit. For these reasons, we did not attempt to compare the monthly treatment data; instead, quarterly (three consecutive treatment visits) use of materials and cost (converted to dollar values) were summarized to evaluate the changes over service periods.

Results

Initial German Cockroach Infestation Levels. The initial survey identified 74 German cockroach-infested apartments in DM and 118 German cockroach-infested apartments in DL. Among them, the median 24 h trap count was 56 in DM and 32 in DL; the mean ± SEM trap counts were 161 ± 52 in DM and 121 ± 27 in DL; the maximum trap counts were 3,657 in DM and 2,514 in DL. The mean trap counts for each apartment complex was not significantly different ($F = 0.41$; df = 1, 190; $P = 0.52$). Among all enrolled apartments, 95 DM and 155 DL apartments had German cockroach infestations based on trap counts during the study period. They represented 49.7 and 61.8% of the enrolled apartments in DM and DL, respectively.

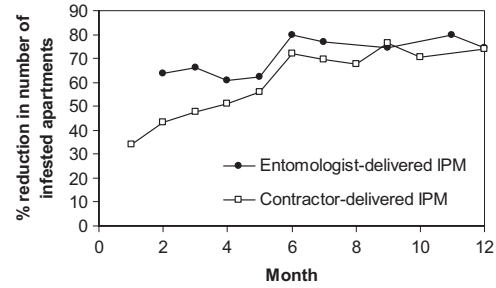

Fig. 1. Reduction of German cockroach infestations in apartments after implementation of IPM.

Effect of Community-Wide IPM on German Cockroach Infestation Levels. After 12 mo, the number of German cockroach-infested apartments decreased from 74 at baseline to 19 (74.3% reduction) for E-IPM and from 118 at baseline to 31 (73.7% reduction) for C-IPM (Fig. 1).

After 3 mo, E-IPM and C-IPM resulted in 95.5 ± 1.9% ($n = 49$) and 71.8 ± 6.8% ($n = 67$) trap count reduction (mean ± SEM), respectively (Fig. 2). E-IPM resulted in greater trap count reduction than C-IPM ($F = 3.3$; df = 7, 169; $P < 0.01$). This difference was at least partially due to 20 of the infested apartments in DL being left untreated during the first month because of PMPs' scheduling difficulties. At 6, 9, and 12 mo, there were no significant differences in mean trap count reductions between E-IPM and C-IPM. At 12 mo, mean trap reduction was 95.2 ± 2.2% for E-IPM ($n = 39$) and 94.2 ± 3.2% for C-IPM ($n = 61$). Geometric mean cockroach trap counts decreased after 12 mo from 99.7 at baseline to 0.4 (99.6% reduction) by E-IPM and from 76.0 at baseline to 1.3 (98.3% reduction) by C-IPM.

Effect of IPM on Cockroach Allergen Levels. Geometric mean cockroach trap counts per apartment surveyed before initial dust sampling was 33 and 27 in DM and DL, respectively. The geometric mean cockroach allergen Bla g 1 concentrations in the E-IPM and C-IPM group were 27.8 and 5.8 U/g, respectively. The latter was unusually low considering the similar cockroach population levels between the two groups and

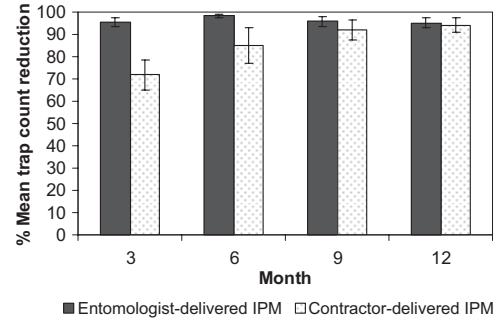

Fig. 2. German cockroach count reduction (mean ± SEM) in two apartment complexes after implementation of IPM.

Table 1. Cumulative treatment data (mean ± SEM) per infested apartment over 12 mo

Treatment group	*n*	No. treatments	Bait (g)	Dust (g)	Time (min)
Entomologist-delivered IPM	108	3.8 ± 0.3a	61 ± 7a	68 ± 7a	76 ± 7a
Contractor-delivered IPM	229	3.8 ± 0.2a	63 ± 4a	16 ± 2b	50 ± 3b

Means within the same column followed by different letters indicate significant differences ($P < 0.05$; ANOVA).

the close correlation between cockroach population level and Bla g 1 levels (Wang and Bennett 2008). The geometric mean Bla g 1 concentrations in dust samples decreased to 11.1 U/g at 6 mo and 2.2 U/g at 12 mo in the E-IPM group (92.2% reduction). Those in the C-IPM group increased from 5.8 U/g at 0 mo to 16.7 U/g at 6 mo, but decreased to 2.4 U/g at 12 mo (59.5% reduction). The sudden increase of Bla g 1 concentration from month 0 to month six coupled with decrease in cockroach trap counts further suggested the abnormally low initial measurement of Bla g 1 concentration in the C-IPM group. Both IPM programs resulted in significant reductions in Bla g 1 concentrations (E-IPM: $F = 53.9$, df = 1, 31, $P < 0.001$; C-IPM: $F = 8.4$, df = 1, 39, $P = 0.01$). After 12 mo, the Bla g 1 concentrations in both treatment groups were not significantly different ($F = 1.8$; df = 1, 69; $P = 0.19$). From month 0 to 12, total number of apartments with ≥8 U/g Bla g 1 (a level associated with asthma morbidity) decreased from 46 to 13 (71.7% reduction).

After 12 mo, 27 of the apartments sampled for kitchen dust still had cockroaches. Median trap counts at 0, 6, and 12 mo were 31, 0, and 0, respectively. Mean sanitation ratings of the apartments at 0, 6, and 12 mo were 2.2 ± 0.1, 2.4 ± 0.1, and 2.3 ± 0.1, respectively. There was no significant change in sanitation ratings from month 0 to month 6 (*t*-test: $t = -2.0$, df = 40, $P = 0.0503$) or from month 0 to month 12 (*t*-test: $t = -0.46$, df = 57, $P = 0.65$), indicating the education effort did not have a significant impact on house keeping. Several residents were evicted due to poor house keeping.

Insecticide Use. The German cockroach-infested apartments received an average of four treatments (Table 1). In both apartment complexes, the number of apartments that received chemical treatments was larger than the number of German cockroach-infested apartments. The differences were due to Oriental cockroach infestations, requests by residents, or unnecessary treatments by the contractor. PU entomologists applied significantly more dust and spent more time than PMPs treating each infested apartment ($P < 0.05$). PU entomologists and PMPs applied similar amounts of bait in each infested apartment.

Regression analysis showed that the sanitation ratings and initial cockroach population levels (sticky trap counts) were closely correlated with the number of insecticide applications ($F = 28.8$, df = 2, 115; $P < 0.01$), total treatment time ($F = 20.5$, df = 2, 115; $P < 0.01$), and amount of bait ($F = 9.6$, df = 2, 115; $P < 0.01$) applied for cockroach suppression.

The quarterly insecticide usage in both IPM groups decreased sharply as the number of treatments decreased during the 12-mo period (Table 2). From the first quarter to the fourth quarter, the numbers of treatments reduced from 164 to 60 in the E-IPM group and from 374 to 62 in the C-IPM group. Lack of access to some infested apartments (due to CPS staff shortage) in the C-IPM group contributed to the sharp decrease in the number of treatments from the second quarter to the fourth quarter in the C-IPM group.

From the first quarter to the fourth quarter, the total bait usage decreased from 3,377 to 388 g (88.5% reduction) for E-IPM and from 8,151 to 591 (92.7% reduction) for C-IPM. Total boric acid usage decreased from 19.3 to 14.9 g (23.0% reduction) for E-IPM and from 7.7 to 0.9 g (87.8% reduction) for C-IPM. PU entomologists significantly increased the use of boric acid dust per treatment in the fourth quarter, thus caused much lower reduction in boric acid use in the E-IPM group compared with that in the C-IPM group.

Program Cost. PU entomologists applied more dust and spent more time per treatment than PMPs during the first and the last quarter. The quarterly control cost (from the first to the fourth quarter) decreased from $4,324 to $1,432 (66.9% reduction) and from $6,292 to $886 (85.9% reduction) for E-IPM and C-IPM, respectively.

The mean estimated cost per apartment was calculated by dividing the total estimated service cost by the number of enrolled apartments (DM, 191; DL, 251). The cost per apartment in 12 mo was $61.4 for E-IPM and $57.2 for C-IPM. The cost per apartment per month was $5.1 and $4.8 for E-IPM and C-IPM, respectively. It does not include the monthly monitoring expenses. The monthly monitoring and evaluation typically required 1 d in DM and 1.5 d in DL for two people. In total, 3,012 and 4,645 traps were used for

Table 2. Quarterly changes in total material use, treatment time, and estimated treatment cost

Treatment period	Entomologist-delivered IPM						Contractor-delivered IPM					
	n[a]	Bait (g)	Dust (g)	Time (minutes)	No. traps	Cost ($)	*n*	Bait (g)	Dust (g)	Time (min)	No. traps	Cost ($)
First quarter	164	3,377	3,690	3,814	0	4,324	374	8151	1931	4,662	1,880	6,292
Second quarter	121	1,883	177	1,934	110	2,227	300	4180	882	3,612	1,345	4,542
Third quarter	60	927	663	1,146	9	1285	126	1507	709	2,332	305	2,626
Fourth quarter	60	388	2,841	1,294	223	1432	62	591	235	790	42	886

[a] Total number of treatments. A "treatment" refers to applying either one or combination of the following tools: bait, dust, sticky trap.

monthly monitoring in DM and DL, respectively. Assuming that GHA were to conduct the monthly monitoring at $19/h, the average monitoring cost per apartment per month would be $2.4 and $2.7 in DL and DM complexes, respectively. The total estimated cockroach management cost per apartment per month would be $7.5 for both E-IPM and C-IPM group

Discussion

This study demonstrated multiple benefits from implementation of a community-wide IPM program in low-income housing. The prescribed IPM program was highly effective compared with results reported by Sever et al. (2007) (98 versus 81% trap count reduction in kitchen), Miller and Meek (2004) (94 versus 60% trap count reduction), Brenner et al. (2003) (74% versus 52% reduction in number of infested apartments), and Asthma Regional Council of New England (unpublished data; 74% versus 15% reduction in number of infested apartments) in similar settings. Moreover, the cost and chemical usage of the IPM program decreased substantially as the number of infestations decreased, indicating long-term savings in pest management costs and environmental benefits (lower pesticide residues).

Program Cost. In 2005 (1 yr before this study), GHA paid a pest control contractor $2.2 and $1.75 per apartment per month for pest control service (based on the total service charge and the number of apartments in each complex) in DM and DL, respectively. The majority of the service was for cockroach control. In this study, we paid the pest control contractor $4.9 per apartment per month. This number was very close to the calculated costs for monthly treatment ($5.1 for E-IPM and $4.8 for C-IPM). On top of that, the monthly monitoring costs were $2.4 and $2.7 per apartment in DM and DL, respectively. The total estimated program cost was $7.5 per apartment per month for the first year (assuming $60/h labor cost for PMPs and $19/h labor cost for GHA staff). In 2006, Indianapolis Housing Agency paid PMPs $6.3 per apartment per month for pest control service (with cockroaches being the dominant pest). The IPM program cost in this study was not substantially higher than that paid by Indianapolis Housing Authority.

The cost for conducting IPM training, resident education, and apartment maintenance was not added because: 1) there are free IPM training sources (videos, printed materials) available from various government or not-for-profit organizations; 2) resident education can be efficiently done together with the monthly monitoring visits by the same staff; and 3) building maintenance should not be listed solely as pest prevention cost. The Asthma Regional Council of New England demonstrated a similar community-wide IPM program in 85 apartments in Boston, MA during 2003–2004. Their estimated IPM program cost was $20.8 per apartment per month. They included cost of housing authority administration, IPM training, and installation of door sweeps, which were not included in our study.

The apartments enrolled in this study represented very challenging conditions for cockroach management. In apartment complexes with lower cockroach infestations and better housing conditions, the cockroach management costs would not be as high as calculated in this study. The cost for subsequent year's cockroach management is expected to be lower because cockroach populations were suppressed to very low levels after 12 mo. Regional differences in the prevalent PMPs' labor cost can increase the estimated cost because technician time is the single greatest expense for an IPM program (Table 1, also see Miller and Meek 2004).

Cockroach Allergen Reduction. The geometric mean cockroach allergen (Bla g 1) concentrations decreased to very low levels after 12 mo of IPM implementation. Thus, an effective IPM program also will be extremely effective in keeping cockroach allergen levels low. These results support previous findings showing cockroach allergens can be significantly reduced by addressing cockroach infestations (Arbes et al. 2004, Sever et al. 2007). The cost of IPM is lower than that associated with hiring a professional cleaning service to reduce cockroach allergen levels. Among the apartments sampled for allergens, 38% still had German cockroaches at 12 mo, suggesting that there was potential for further allergen reductions. As pointed out earlier in the results, the baseline allergen concentration in DL apartments was unusually low considering the high levels of cockroach populations in the sampled apartments. The samples were analyzed twice with similar results. The discrepancy might have related with sampling or handling procedures even though the same protocols were followed. The DL samples were taken without the senior author's direct participation. All apartments were treated soon after dust sampling without the opportunity for resampling the units. We did not attempt to maintain untreated control apartments for comparing the cockroach population and cockroach allergen levels between treated and untreated apartments because 1) there is close relationship between cockroach population level and cockroach allergen level (r = 0.73; see Wang et al. 2008); 2) residents did not like their homes being visited without receiving treatment; and 3) final dust sampling was conducted in the same season as the baseline sampling.

Components of the IPM Program. Greene and Breisch (2002) summarized four essential components of structural IPM programs: repeated population monitoring; integration of multiple control strategies; client education at all levels; and the use of pesticides only when other practices are not practical. The IPM program in this study included all the above components, but as in many other previous studies, they (except the first component) were not fully implemented. For example, vacuuming is an effective nonchemical strategy to remove live and dead cockroaches and reduce pesticide use (Kaakeh and Bennett 1997). In this study, we provided vacuum machines to each apartment complex, but only a few residents used them. PMPs were reluctant to use vac-

uum machines in this study because of time constraints. The E-IPM group did not use vacuum machines to avoid inconsistency in treatment protocols between the two groups.

Although efforts were made to enlist resident cooperation (flyers, classes, demonstrations, discussions during monitoring visits), most homes had some food residue and garbage on floors and kitchen counters. The sanitary conditions did not improve after the educational efforts. Some residents refused pest control service. Correlation between sanitation ratings with the number of insecticide applications, treatment time, and amount of bait use revealed from this study suggests the effectiveness and environmental benefit (reduction of pesticide use) of IPM could be improved with better resident collaborations. Innovative and more effective approaches are needed to change resident behavior in low-income housing.

The IPM program was further limited by the generally poor structural conditions such as water leaks, holes in walls and broken doors. Among the occupied apartments, 44% needed repair (for broken doors, windows, or screens), 36% had leaky pipes or faucets before this study (Wang et al. 2008). The conditions did not improve during the course of this study. The housing authority was not able to keep up with the maintenance needs or to conduct necessary repairs to reduce conditions that are conducive for cockroach survival and spread. In addition, shortage of staff from the apartment complexes caused delays in accessing cockroach-infested apartments.

Importance of Frequent Monitoring. A survey using sticky traps in May 2006 revealed 118 unreported German cockroach-infested apartments from Delaney Community. Only 36 U (31% of the infestations) were reported to the management office 2 mo before the survey. Without monitoring and treatment, the unreported infestations would serve as reservoirs, which might spread into adjoining apartments through utility penetrations and holes in the walls (Owens and Bennett 1982). Each infested apartment received an average of four treatments (Table 1). The monthly monitoring served multiple purposes such as evaluating the quality of the pest control contractor's service, providing guidance on treatments, enforcing resident compliance, and identifying the need for general structural repairs.

Because of GHA's inability to commit staff to the monthly monitoring program, PU entomologists took over the monthly monitoring task. Thus, the C-IPM was a hybrid of PMPs and PU entomologists' effort. Without participation from the researchers, the C-IPM group might not be as effective as that reported here.

Insecticide Applications. PU entomologists and PMPs differed in the time and amount of bait use for each treatment in an apartment (Table 2). The contractor did not allocate enough time in the first month to treat all infested apartments. The contractor had many clients and usually arranged a fixed amount of time each month for each client. This operational model was not always able to accommodate the specific needs of each client. Twenty infested apartments were omitted during the initial treatment visit due to time shortage. Removing refrigerators, cleaning out the garbage behind and under the refrigerators, and applying insecticides behind refrigerators are very important procedures to effectively control cockroaches. During the initial treatment, PMPs did not check areas behind refrigerators in an unknown numbers of the apartments. These factors contributed to the slower cockroach trap count reduction during the first 3 mo (Fig. 1). The large decrease in the number of treatments from the third quarter to the fourth quarter was partly due to lack of access to some infested apartments (Table 2). There were no significant differences between E-IPM and C-IPM in trap count reduction at 6 mo because all infested apartments were treated at least twice by that time, and the treatments were apparently highly effective.

It is not surprising that the PMP-delivered IPM program was highly effective in reducing cockroach trap counts (98.3% reduction in geometric mean trap count) and reducing the number of infestations after 12 mo (73.7% reduction). The chemical and nonchemical cockroach control techniques used in this study were not new. The PMPs devoted much more time during the first two months and spent more time when serving an apartment than they did for the other contracted service in apartments based on our conversations with the PMPs. Longer time allowed PMPs to apply bait more carefully. Although the initial cost was much higher than subsequent monthly costs, the reduction in the number of infested apartments kept the monthly treatment list small and long-term cost reasonable. We attribute the success of the C-IPM program to two key factors: 1) clearly defined program goals for PMPs; and 2) each infested apartment was treated monthly until the infestation became undetectable.

Boric acid was applied only as a supplement to gel baits. PU entomologists applied much more boric acid dust in the fourth quarter than the first quarter in an attempt to overcome the control difficulties from bait applications in the remaining infested apartments. More thorough applications as described by Ebeling et al. (1968) may help achieve greater effectiveness and reduce or even eliminate the need for gel baits. Applying boric acid dust alone (346 g/apartment) in apartments resulted in 80% reduction in German cockroach trap counts after 1 mo (our unpublished data).

Future Considerations. Considering the multiple benefits of community-wide IPM programs and the reasonable cost demonstrated in this study, promoting IPM programs as described here in low-income housing is justified. Even with many of the IPM elements missing, the IPM programs were very effective in controlling cockroaches, reducing cockroach allergen levels and insecticide use. However, ultimate adoption and sustainability of any cockroach IPM program is hinged upon motivated staff and residents. Many free IPM educational resources are becoming available as government and private organizations are increasingly aware of the needs

for reducing pest infestations in underserved populations (http://www.healthyhomestraining.org/IPM/). Through these and additional research and education efforts, greater acceptance of IPM in low-income housing can be achieved.

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