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Case Study

Effectiveness of Building-Wide Integrated Pest Management Programs for German Cockroach and Bed Bug in a High-Rise Apartment Building

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Abstract

Bed bug, *Cimex lectularius* (L.) (Hemiptera: Cimicidae), and German cockroach, *Blattella germanica* (L.) (Blattodea: Ectobiidae), infestations are commonly found in low-income housing communities and result in negative health effects and economic burden. Integrated Pest Management (IPM) has been shown to be an effective approach for managing these pests, yet practice of IPM in housing communities is very limited. We evaluated the effectiveness of a contractor-led bed bug IPM program and researcher-led cockroach IPM program in a high-rise apartment building for 1 yr. A second apartment building that received conventional monthly pest control service was used as control. The bed bug infestation rate decreased from 9% at 0 mo to 3% at 12 mo (63% reduction), even though the contractor only partially followed the IPM protocol; the German cockroach infestation rate decreased from 49% at 0 mo to 12% at 12 mo (75% reduction). In the control building, no monitors were installed in the infested apartments and the apartments received cursory treatment services from an existing pest control contractor. The bed bug infestation rate increased from 6% at 0 mo to 12% at 12 mo (117% increase); the German cockroach infestation rate decreased from 47% at 0 mo to 29% at 12 mo (39% reduction). IPM is a much more effective approach for building-wide control of cockroaches and bed bugs than conventional pest control service. This study confirms the benefit of building-wide IPM on pest reduction and challenges existed for carrying out IPM programs in low-income communities.

Key words: *Cimex lectularius*, *Blattella germanica*, integrated pest management, monitoring, low-income housing

Bed bugs, *Cimex lectularius* (L.) (Hemiptera: Cimicidae), and German cockroaches, *Blattella germanica* (L.) (Blattodea: Ectobiidae), are urban pests of major public health and economic importance (Roth and Willis 1957, Arruda et al. 2001, Tachbele et al. 2006, Potter et al. 2010, Doggett et al. 2012). Bed bugs are obligate blood feeders and their bites cause itchiness, welts, and emotional distress (Potter et al. 2010, Doggett et al. 2012). For cockroaches, public health concerns include mechanical transmission of pathogens (Roth and Willis 1957, Tachbele et al. 2006, Menasria et al. 2014) and chronic health effects including asthma exacerbation and allergy trigger and exacerbation (Arruda et al. 2001, Huss et al. 2001, Matsui et al. 2003).

Low-income housing communities suffer from a disproportionately higher level of bed bug and cockroach infestations (Miller and Meek 2004, Wang et al. 2008, Wang et al. 2016). Chronic high pest infestations rates can be a tremendous economic burden to low-income communities. Control failures are often found in public housing, where low-bid contracts are common, and the quality of pest control is poor. For bed bugs, many companies rely solely upon pesticides to control bed bugs and use a standard protocol of 1–2 visits per infestation in spite of the fact that more than two visits are often necessary to eliminate well established infestations (Singh et al. 2013, Cooper et al. 2016b). For cockroaches, control methods often consist of cursory treatment of apartments when residents are home with no follow-up visits or monitoring of cockroach activity.

Even when utilizing effective insecticides properly, challenges with pesticide resistance can occur. Insecticide resistance has been documented in bed bugs to pyrethroids (Romero et al. 2007, Doggett and Russell 2008, Zhu et al. 2010, Dang et al. 2015), neonicotinoids (Romero and Anderson 2016), and pyrethroid and neonicotinoid mixture products (Gordon et al. 2014). Insecticide resistance to conventional sprays of organophosphates (Jang et al. 2017) and several pyrethroids (Valles 1998, Wei et al. 2001, Kristensen et al. 2005) has been documented in several German cockroach populations. Additionally, since bait applications became more common in the 1990s, bait aversion has

been observed in German cockroach populations (Wang et al. 2004, Liang et al. 2017). At present, widespread resistance to cockroach baits and control failure using baits has not been reported, but resistance to active ingredients in bait products including abamectin, indoxacarb, hydramethylnon, fipronil, and imidacloprid (Wang et al. 2004, Ko et al. 2016, Wu et al. 2017) has been documented.

Other factors contributing to chronic infestations may include poor sanitation, presence of clutter, and a lack of monitoring and evaluation. Sanitation has been indicated as a factor associated with presence of cockroaches and poor cockroach control results (Schal 1988, Wang et al. 2019). Presence of clutter significantly increases the difficulty in eliminating bed bug infestations and is a factor associated with control failures (Cooper et al. 2015). With cockroach control, sticky traps have been found to be an important tool for monitoring and aid in control (Kaakeh and Bennett 1997, Wang et al. 2019). Monitoring can aid in targeted bait applications so the location and amount of product applied can be decided upon based on trap counts. Monitoring with passive pitfall-style traps has been found to be an important tool to aid in bed bug detection and ensuring proper elimination, especially when bed bug numbers are low during introduction or near elimination (Cooper et al. 2016a).

Integrated pest management (IPM) is a pest control approach that includes proper identification, pest monitoring, prevention, adopting treatment thresholds, using multiple control tactics, and monitoring treatment results (https://www.epa.gov/managing-pests-schools/introduction-integrated-pest-management#Principles). Utilizing IPM has been proven more effective than conventional bed bug and cockroach control (Miller and Meek 2004, Shahraki et al. 2011, Wang et al. 2012, Nalyanya et al. 2014, Wang et al. 2018). An IPM approach in schools to control cockroaches reduced cockroach allergens more than conventional pest control (Nalyanya et al. 2014) and reduced indoor pesticide residues (Williams et al. 2005). A 12-mo long IPM program carried out by licensed housing staff with assistance from researchers in a low-income apartment building reduced bed bug infestation rate from 15% to 2.2% (Cooper et al. 2015).

At present, adoption of effective IPM programs in low-income communities in the United States is very limited. There are few long-term studies documenting the effectiveness of building-wide IPM. In this study, we implemented a year-long IPM program in a senior, low-income, high-rise community. Another high-rise apartment building that received conventional pest management was used as the control. The objectives were to evaluate the effectiveness of a building-wide IPM program for cockroaches and bed bugs. We hypothesized the IPM program will: 1) achieve a high level (approximately 80%) reduction in the number of bed bug and cockroach infestations after 12 mo, and 2) result in significantly greater reduction in percentage of apartments with cockroaches and bed bugs compared with conventional pest control service. The first hypothesis was based on previous studies in similar communities (Wang and Bennett 2009, Cooper et al. 2015). This study is different from previous studies in that 1) sticky traps were placed for 2–4 wk in each apartment for monitoring the presence of cockroaches, 2) high-rise apartment buildings were used which favors dispersal of cockroaches among units both horizontally and vertically (Zha et al. 2019), and 3) the bed bug IPM program was implemented by a contracted pest control provider.

Methods and Approach

Study Sites

Two high-rise, low-income buildings for senior and disabled residents at the Paterson Housing Authority in Paterson, New Jersey were selected to compare IPM and conventional pest control programs. Both buildings had significant number of cockroach and bed bug infestations based on residents' complaints and staff reporting before the study. The first building is a 13-story building with 188 apartments (176 one-bedroom and 12 two-bedroom). An IPM program was implemented in this building over a 1-yr period from May 2016 to May 2017. Hence, this building is referred to hereafter as the IPM building.

Occupancy rates during the three building-wide inspection periods were 97% to 99%. There was an overall resident turnover rate of 10% throughout the duration of the study. The ethnic distribution in this community was approximately 52% Hispanic, 38% African American, 7% White, 2% Asian, and 1% other.

The second building is a 15-story building with 112 one-bedroom units. Conventional monthly pest control service was provided between April 2017 and June 2018. Hence, this building is referred to hereafter as the control building for comparing with the IPM building. The ethnic distribution in this community were approximately 53% Hispanic, 43% African American, 3% White, and 1% other. Although pest management was conducted 1 yr later than the IPM building, this building was considered as a control site because the two buildings were similar in structural design, resident demographics, and pest infestation history.

Before the current study, pest control service in the IPM building was provided by an outside contractor for general pest control services. The cost was approximately $0.96 USD per unit per month for all 992 units managed by the housing authority. Bed bug treatment was offered separately at $85 USD per room, per visit and treatment was only provided when residents reported bed bugs to the management office. Before our study, Demand CS (0.03% lambda-cyhalothrin, Syngenta Crop Protection, LLC, Greensboro, NC), Suspend SC (0.06% deltamethrin, Bayer Environmental Science, Research Triangle Park, NC), and Gentrol (0.07% hydroprene, Wellmark International Brand, Schaumburg, IL) sprays were used by the contractor to treat bed bug infestations. Maxforce FC Select (0.01% fipronil, Bayer Environmental Science, Research Triangle Park, NC) gel bait was used for cockroach control. All apartments were scheduled to be treated monthly rather than based upon presence of pest activity. The pest control staff visited all apartments once per month treating all apartments when residents were in the apartment. For cockroach control, based on our visual observations, less than 1 min was spent per unit and based upon treatment records < 0.5 g of bait was applied per unit to kitchen cabinet hinges and the bathroom.

Pest control service in the control building was offered by a different contractor at a similar price as that in the IPM building. Maxforce FC Select and Advion cockroach gel bait (0.6% indoxacarb, Syngenta Crop Protection, LLC, Greensboro, NC) were used for cockroach control. One to two tubes of gel bait (30–60 g) were applied per month in the building for cockroach treatments. Two sticky traps per apartment were placed to monitor cockroach activity. Bed bug infestations were treated with PT Phantom II (0.5% chlorfenapyr, Whitmire Micro-Gen Research Laboratories, INC., Saint Louis, MO), Bedlam (0.4% phenothrin and 1.6% MGK 264, MGK, Minneapolis, MN), Zenprox EC (16.2% etofenprox, 64.8% piperonyl butoxide, Central Garden & Pet Company, Schaumburg, IL), Gentrol sprays, and CimeXa dust (92.1% silicone dioxide, Rockwell Laboratories, Kansas City, MO). BlackOut Bed Bug Detectors (Bed Bug Central, Lawrenceville, NJ) were installed in the apartments after bed bug treatments to monitor bed bug activity. Follow-up visits were only conducted in bed bug–infested apartments when a resident complained about bed bug activity.

Initial Building-Wide Pest Inspection

A building-wide inspection was conducted by three to four Rutgers University researchers. Brief (2–4 min) visual inspections of beds and sofas, chairs, and their surrounding areas were conducted for bed bugs using flashlights. If live bed bugs were present or bed bug activity was suspected due to presence of signs (exuviae, eggs, fecal stains, and blood smears) or resident complaint, Climbup Insect Interceptors (Susan McKnight, Inc., Memphis, TN), referred to hereafter as 'interceptors' or 'traps', were placed under the legs of bed frames and upholstered furniture (Fig. 1A). Interceptors were placed next to furniture legs or immediately adjacent to the furniture in instances where beds and furniture did not allow for interceptors to be placed beneath the legs (e.g., oversized furniture legs, platform design or beds on the floor). The interceptors were examined after 2 wk.

For cockroach inspections, four Trapper monitor & insect traps (1/3 of the whole piece; Bell Laboratories Inc., Madison, WI) were placed in every accessed unit. Traps were placed in four locations: 1) inside the cabinet under the kitchen sink, 2) next to the stove, 3) next to the refrigerator, and 4) beside the toilet. Common areas including the boiler room, laundry room, compactor room, community kitchen, and community room were also monitored with 3–7 sticky traps depending upon the size of the room. Also, one trap was placed by the trash chute on each floor. The traps were examined and number of cockroaches on the traps were recorded after 2 wk (Fig. 1B).

IPM Implementation in the IPM Building

Education

A 2–4 min, one-on-one educational session was provided at 0 mo for 151 residents that were present during our initial inspection or during the 2-wk follow-up for their apartment. Spanish and English materials about cockroach and bed bug prevention and control were provided to all residents. In addition, a 45-min educational seminar on bed bugs and cockroaches was given at 16 wk in both Spanish and English. There were 51 resident attendees and the community manager. During the one-on-one visits and the seminar, for bed bug control, residents were told about the importance of clutter reduction and washing bed linens and infested items in hot water and drying with high heat. For cockroach control, we focused on improving sanitation, keeping dishes clean, food off the counter, and removing garbage nightly. All residents were instructed to notify management as soon as they suspected pest problems. Additionally, residents were advised not to apply their own pesticides, and let the researchers and contractors properly treat their apartments.

Bed Bug Control Measures (Contractor-Modified IPM)

The Paterson Housing Authority hired a licensed pest management professional contractor to carry out bed bug control measures. The contractor was instructed to follow our protocol for bed bug control (Table 1). We visited four bed bug–infested units with the contractor to advise on how to implement the protocol. Although we encouraged the contractor to adopt our IPM protocol, we did not have the authority to enforce the program. As a result, not all aspects of the protocol were implemented or followed on a consistent basis. Therefore, the bed bug IPM program in this building was not strictly IPM but represented what may happen in the real world when implemented by commercial pest control providers. For example, the contractor did not use our trap count data to make follow-up treatments. Initial treatment decisions were based mostly on visual inspection and occasionally on bed bug counts in the BlackOut Bed Bug Detectors. With 44 recorded visits, 12 records contained information regarding monitors. Additionally, there were no notes documenting the use of steam or heat treatment methods and only one mention of vacuuming. According to provided records, 17 units received treatment compared with the 26 units with documented activity over the year from our survey. The contractor used CimeXa dust in 16 documented treatments. The records provided only indicated the use of Phantom II spray for three treatments, and Bedlam and Zenprox/Gentrol combination for one treatment each. There is no indication in the records that the contractor followed up until elimination.

In spite of the treatment protocol requiring the encasement of all mattresses and box springs, only 56% of bed bug infested units had fully encased beds while 40% had partially encased beds. Partial encasement included having either a box spring or mattress encased but not both, or not having both beds encased in two-bedroom units. Only one unit had no encasements. Rutgers University researchers conducted monthly visits to apartments with bed bugs to obtain interceptor trap counts to aid in the monitoring process. During periods of live bed bug activity, Rutgers University researchers installed encasements in three units and provided enough encasements for management to keep in stock to ensure all units could have had encased beds at no cost to residents or management.

Fig. 1. (A) Four Climbup Insect Interceptors retrieved under the bed legs from one apartment after 14 d placement. All of them had bed bugs. (B) Four sticky traps retrieved from one cockroach infested apartment after 14 d placement. From left to the right, the traps were located inside the cabinet under the kitchen sink, next to the stove, next to the refrigerator, and beside the toilet, respectively.

Table 1. Suggested treatment protocol for bed bugs in apartments

1. During the first visit do the following:
   a. Encase all of the mattresses and box springs with zippered plastic covers or fabric covers. Ask resident to launder bed linens at least weekly.
   b. Vacuum and/or apply steam to infested mattress/box springs, sofas, chairs, and rugs. Discard heavily infested items when necessary*.
   c. Apply insecticide dust or spray if necessary. Recommended products include CimeXa dust, nonpyrethroid based aerosol, pyrethroid-neonicotinoid mixture spray according to manufacturer label directions. Dust insecticide should be applied thoroughly around or on furniture following label directions and avoid over application and inhalation of dust during application.
   d. Interceptors should be placed under the foot of each bed, couch, and chairs. If placement under furniture legs is not possible, place adjacent to furniture corners where they will not create a tripping hazard for tenant.
   e. In the case when large amounts of clutter are present that make treatment difficult, the contractor should report to the office for correction.
2. Follow-up at least two times at 14 to 28 d intervals until the infestation is eliminated. During each follow-up visit, all interceptors must be examined and bed bug numbers are recorded at each location (bed or sofa) in the units. All interceptors must either be replaced or re-dusted with talcum powder and put back in place until the final inspection. Visually inspect the furniture and surrounding areas for live bed bugs. If live bed bugs are found, apply additional treatment (steam, spray, or dust). For trap counts < 10, only nonchemical control measures are recommended.
3. Continue biweekly visits until no bed bugs are found in interceptors and by visual inspection for 6 wk.

*Disposal of furniture should be considered only after reasonable attempts to eliminate the bed bugs have been made and failed.

Table 2. Information on cockroach baits used in apartments during 12 mo in the IPM building

Period of use	Product name	Amount used (g)	Active ingredient	Insecticide class	Manufacturer
0–15 wk	Advion Cockroach Gel Bait	1,841	0.6% Indoxacarb	Oxadiazine	Syngenta Crop Protection LLC., Greensboro, NC
17–22 wk	Alpine Cockroach Gel Bait	286	0.5% Dinotefuran	Neonicotinoids	Whitmire Micro-Gen Research Laboratories, Inc., Saint Louis, MO
24–28 wk	Maxforce FC Select Gel Bait	352	0.01% Fipronil	Phenylpyrazoles	Bayer Environmental Science, Research Triangle Park, NC
32–38 wk	Avert Dry Flowable Cockroach Bait	133	0.05% Abamectin	Avermectins	Whitmire Micro-Gen Research Laboratories, Inc., Saint Louis, MO

Cockroach Control Measures (Researcher-Led IPM)

Rutgers University researchers carried out the cockroach control program. For initial treatments, Rutgers researchers applied Advion bait in 87 infested apartments. The amount of bait applied per apartment was based on trap counts and their distribution. An average of 16 ± 1 g (mean ± SE) of gel bait was applied per treated apartment, with a total of 1,404 g applied. Borid boric acid dust (99% orthoboric acid, Waterbury Companies Inc., Waterbury, CT) also was applied in 32 units that had >20 cockroaches in traps over a 14-day trapping period. Dust was applied behind the refrigerator and under the stove with an average of 6 ± 0.5 g per treated unit using a hand duster.

In all infested units, four sticky traps were placed continuously, until elimination, in order to evaluate the effectiveness of the program. Following the initial treatment, apartments were visited approximately every 2 wk from 0 to 6 mo and then monthly from 7 to 12 mo to inspect traps for cockroach activity. Traps were replaced during each visit if they were missing, dirty, or pest activity was present. In this study, we used 14-day trap count for cockroaches, which is different from other studies that have used a 1- to 3-day trap count for cockroaches (Miller and Meek 2004, Wang and Bennett 2006, Nalyanya et al. 2014). This was to increase sensitivity for detection; longer trap periods improve the detection of low-level infestations (Zha et al. 2018). Scheduling was easier as treatments were scheduled every 2 wk or longer.

Cockroaches were declared eliminated in an apartment if no cockroaches were found in traps for 1 mo and the resident (if present) indicated they had not seen cockroaches. Additional bait was applied when ≥5 cockroaches were present during follow-up visits. Those units with <5 cockroaches did not receive new bait if bait was present. Common areas were initially monitored at 5 wk and treated based on trap counts at 7 wk.

In an effort to address pesticide resistance (both physiological and behavioral), a variety of products with different chemistry were used (Table 2). Boric acid dust also was applied at 17, 22, 24, and 28 wk. The amount of boric acid dispensed was measured using a Fast Weight MS-600 digital pocket scale (Fast Weight, China).

Treatment for common areas varied based upon the environment. The boiler room was treated with 78 g Advion at 7 wk and 17 g boric acid dust at 17 wk. The compactor room was treated with 5 g Advion at 7 wk, 25 g Alpine at 15 wk, 0.3 liter Transport GHP Insecticide (0.11% A.I. acetamiprid and bifenthrin, FMC, Philadelphia, PA) at 24 wk, and 40 g boric acid at 17 and 28 wk. The laundry room was treated with total of 25 g Advion at 7, 9, and 15 wk and 3 g Alpine at 19 wk. The community kitchen was treated with 10 g Advion at 7 wk.

Total bait used quarterly for first to fourth quarter of the year-long study was 1788, 428, 360, and 37 g, respectively. To evaluate the amount of time spent per unit, total minutes working was recorded and divided by the number of units visited. Total minutes was then divided by the number of people to estimate the time spent per person. The number of researchers servicing each apartment during each visit ranged from one to three. The range of time spent per unit was 1.9 to 5.5 min per researcher, with an average of 3.8 ± 0.3 min, based on follow-up visits from 3 to 36 wk.

Pest Control Measures in the Control Building

Education of Residents

In April 2017, approximately 60 residents attended a 1-hr seminar offered by Rutgers University researchers about bed bug and cockroach prevention and control. Spanish and English materials about cockroach and bed bug prevention and control were provided to attendees. No further training was offered between April 2017 and June 2018.

Pest Control Measures

All apartments were visited once per month by a contractor if the apartment was accessible. However, the monthly pest control visits were brief, with each apartment being serviced for less than 1 min for cockroach infestations based on the total time spent in the building and the number of apartments visited. The contractor used gel bait in each apartment controlling for cockroaches during monthly visits. The insecticides for cockroach infestations included Maxforce FC Select, Maxforce FC Magnum (0.05% fipronil, Bayer Environmental Science, Research Triangle Park, NC), and Vendetta Plus cockroach gel (0.05% abamectin + 0.5% pyriproxyfen, McLaughlin Gormley King Company, Minneapolis, MN). Treatment of bed bug units was only scheduled if the management office notified the contractor. If residents did not prepare following the company's preparation sheet, then bed bug treatment was not conducted.

Based on treatment records left by the contractor, insecticide sprays and steam treatments were applied for controlling reported bed bug infestations. The insecticides included D-Force (0.06% deltamethrin, FMC, Philadelphia, PA), Gentrol, Sterifab (0.22% phenothrin, 60.39% isopropyl alcohol, 0.114% didecyl dimenthyl ammonium chloride, 0.076% dimenthyl benxyl ammonium chloride, Noble Pine Products, Inc. Yonkers, NY), and Suspend SC. The contractor did not place any monitors for cockroaches or bed bugs. Each bed bug infested and reported apartment was treated once or twice. Unreported apartments did not receive treatments.

Program Evaluation

Building-wide inspections were repeated at 6 and 12–14 mo to evaluate the effectiveness of the pest management programs in both buildings. Approximately 3–15% of the units were not accessed. The inaccessible apartments had either private locks, were vacant, the resident refused entry, or residents were uncooperative and disposed of our traps. Each apartment in the two buildings was accessed at least once during the three building-wide inspections. Monthly average temperature data of the study area were obtained from https://www.wunderground.com/weather/us/nj/paterson/07501.

Statistical Analysis

Trap catches were based upon the sum from interceptors for bed bugs or sticky traps for cockroaches per apartment. For instances where categorical infestation levels are represented in the analysis, infestation level was recorded as low, medium, or high for cockroach counts of 1–10, 11–50, or >50, respectively. Among the apartments that had all four traps present during the 0-mo inspection, the distribution of cockroaches (total 3,375) from location 1 to 4 (under sink, beside stove, beside refrigerator, beside toilet) was 17, 35, 36, and 12%, respectively. These percentages were used for adjusting the total trap catches in apartments with missing traps throughout the duration of the study. In order to compare the trap counts, all cockroach trap catches were adjusted to 2 wk (14 d) from 0 to 6 mo and 4 wk (28 d) after 6 mo. This is because traps were placed for approximately 2 wk during 0–6 mo and 4 wk after the 6-mo inspection.

Regression analysis was used to analyze the association between cockroach population size and amount of bait used in the unit. Both cockroach count and bait usage were logarithmically transformed to meet normal distribution. In addition, apartments with ≤2 or >100 cockroaches were excluded from data analysis in order to satisfy normal distribution. Chi-square analysis was performed to analyze association between cockroach infestation level and number of treatments (categorized as I: one treatment, II: 2 to 3 treatments, and III: >3 treatments). Chi-square analysis was also performed to test the proportion of apartments with increased cockroach counts. Analysis of variance was used to compare the monthly temperatures between seasons. All statistical analyses were conducted using SAS software (SAS Institute 2011).

Results

Bed Bug Program Evaluation (Contractor-Modified IPM)

Initial Inspection

Bed bugs were detected in 16 apartments. Visual inspections detected four units and interceptors detected 15 units. The mean bed bug count per apartment based on interceptors was 20 ± 8.

Treatment Results

By 6 mo, infestations were eliminated in 50% of the units identified during the initial inspection. At 6 mo, eight units were infested, among which three were newly detected infestations and five were ongoing. One unit that had bed bugs caught fire soon after the 0-mo inspection, all contents were removed, and bed bugs were not present during the 6- and 12-mo inspections.

The number of infested units was reduced by 63% from 0 to 12 mo. At 12 mo, six units were infested, among which four were newly identified infestations. One of the infested units that was previously treated did not have activity during the 12-mo inspection but was found with bed bugs during the previous inspection and thus was not included among those considered eliminated. Throughout the duration of the study, bed bugs were found in 24 units (21% of the total units) in the building.

Overall, the bed bug infestation rate decreased from 9% to 4% and 3% at 6 and 12 mo, respectively (Fig. 2). Based upon 14 d adjusted total interceptor count per infested apartment, the average count during 0, 6, and 12 mo was 20 ± 8, 4 ± 1, and 2 ± 1, respectively.

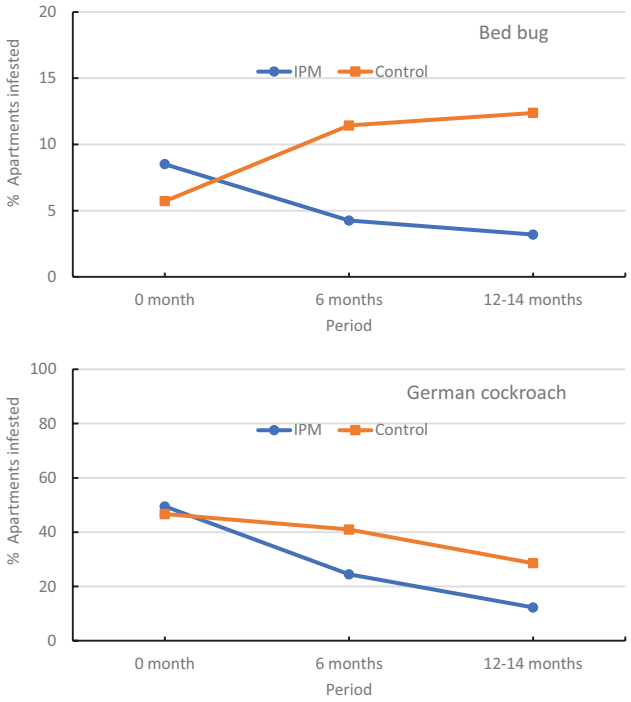

Fig. 2. Comparative effectiveness of building-wide IPM and conventional treatment on the percentage of apartments with German cockroach and bed bug in two apartment buildings.

Among the infestations identified at 0 mo, 11 of them (73%) were eliminated by 6 mo, and 13 (87%) by 12 mo.

Resident Awareness of Bed Bug Infestations

At 0 mo, 14 residents who were interviewed had bed bugs in their homes. Among them, eight (57%) were unaware of bed bug activity. Among all other residents surveyed, three residents reported bed bugs, but no bed bugs were found with visual inspection or interceptors; during the 6- and 12-mo inspections, no bed bugs were found in these units either. Therefore, these units were not considered to have an existing bed bug infestation.

Cockroach Program Evaluation (Researcher-Led IPM)

Initial Inspection

Only one cockroach species, the German cockroach, was found in the traps throughout the study. There were 93 apartments (49%) with cockroaches. Eighty-nine of them had trap count data. The average count per apartment was 54 ± 11 with a median (range) of 11 (1–484). Among the trapped cockroaches, 87% were nymphs and 13% were adults.

Common areas including the boiler room, compactor room, laundry room, community kitchen, and trash chutes were monitored at 5 wk. The average trap count per trap was 11 ± 1, 10 ± 0, 15 ± 4, 1 ± 0, and 0, respectively.

Treatment Results

The total number of cockroach infested units decreased by 51% at 6 mo. Mean cockroach counts per apartment among the infested units was 19 ± 6. The median (range) for the trap counts was 2 (1–187). Fifteen units had newly identified infestations.

At 12 mo, there were 23 infestations. The total number of infested units decreased by 75% compared with that at 0 mo. Mean cockroach counts per apartment among the infested units was 9 ± 3. The median (range) of cockroaches per apartment was 3 (1–52). Nine new units were identified, one unit was ongoing from 0 mo, three units were ongoing from 6 mo, and the remaining units were previously declared eliminated.

Overall, the building-wide infestation rate decreased from 49% to 24% and 12%, at the 6- and 12-mo inspections, respectively (Fig. 2). Among those infested and treated at 0 mo, 72% and 89% of them no longer had cockroaches based on traps at the 6- and 12-mo inspections, respectively (Fig. 3). Throughout the duration of the study, cockroaches were found in 118 units (63% of the total units) in the building. In the common areas, only the boiler room and community room still had cockroaches at 12 mo. The mean trap count was 2 ± 0 per trap in both rooms.

Among the 107 infested units identified at 0 and 6 mo, an average 24 ± 2 g bait was applied per unit before elimination; an average 3.3 ± 0.3 treatments were conducted per unit before elimination. Higher cockroach infestation levels had higher bait usage and number of treatments (Table 3). The amount of bait used per unit before elimination was significantly associated with the initial infestation level ($F = 52.3$; df = 1, 74; $P < 0.0001$; $R^2 = 0.41$). The number of treatments (categorized as I: one treatment, II: 2 to 3 treatments, and III: > 3 treatments) required is also significantly related to the initial infestation level ($\chi^2 = 27.6$, df = 4, $P < 0.0001$).

Resident Awareness of Cockroach Infestations

We did not collect the resident awareness data at 0 mo. At 6 mo, cockroaches were found in traps in 35 apartments. Among these infested apartments, 19 residents (54%) were unaware of the presence of cockroaches. There were 27 residents that indicated they were seeing cockroaches but only 16 of them (59%) had cockroaches based on sticky traps. Of the 11 apartments (41%) without cockroaches detected at 6 mo, none of them had cockroaches detected at 12 mo, suggesting these residents most likely misidentified cockroaches rather than traps failed to detect cockroaches.

At 12 mo, 17 of the surveyed apartments had cockroaches based on trap catch. Among these infested apartments, 15 residents (88%) were unaware of presence of cockroaches. Nine residents said they were seeing cockroaches but only two of them had cockroaches based on sticky traps.

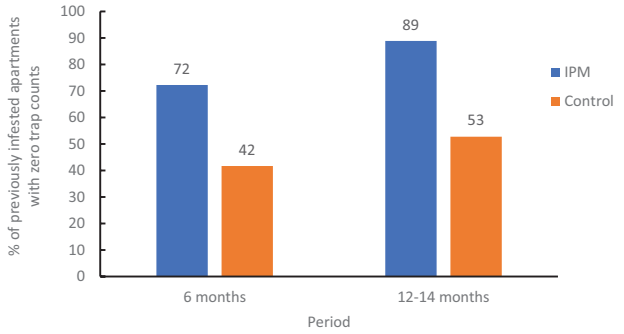

Fig. 3. Effect of IPM and conventional cockroach management programs on cockroach elimination.

Table 3. Treatment information for German cockroach infested apartments that were identified from 0 to 6 mo ($n = 107$)

Infestation level based on initial trap count	*n*	Average bait usage per apartment before elimination (g)	Mean number of treatments before elimination
L: 1–10	54	12 ± 2	2 ± 0
M: 11–50	26	20 ± 2	3 ± 1
H: > 50	27	53 ± 6	6 ± 1

Pest Infestation in the Control Building

At 0 mo, the bed bug infestation rate in the building was 6% (Fig. 2). The bed bug infestation rate increased from 6% at 0 mo to 11% and 12% at 6 and 14 mo, respectively. From 0 to 14 mo, the number of bed bug infested apartments increased by 117%.

At 0 mo, the cockroach infestation rate in the building was 47% (Fig. 2). The average number of cockroaches trapped in 2 wk per apartment was 37 ± 9. The cockroach infestation rate decreased from 47% at 0 mo to 41% and 29% at 6 and 14 mo, respectively. From 0 to 14 mo, the number of cockroach infested apartments decreased by 39%. Among those infested and treated at 0 mo, 42% and 53% of them no longer had cockroaches based on traps at the 6- and 14-mo inspections, respectively (Fig. 3). Throughout the duration of the study, cockroaches were found in 72 units (64% of the total units) in the building.

From 0 to 6 mo (April to October in 2017), 26% of the 47 cockroach-infested apartments had increased trap counts. From 6 to 14 mo (November 2017 to June 2018), 25% of the 32 cockroach-infested apartments had increased trap counts. These two percentages were not significantly different (χ^2 test: $\chi^2 = 0.003$, df = 1; $P = 0.96$). The average monthly outdoor air temperature during these two sampling periods were 19.0 ± 1.5 and 7.2 ± 3.1°C, respectively (Fig. 4). They were significantly different (ANOVA: $F = 12.2$; df = 1, 13; $P = 0.004$). Therefore, the warmer summer temperatures

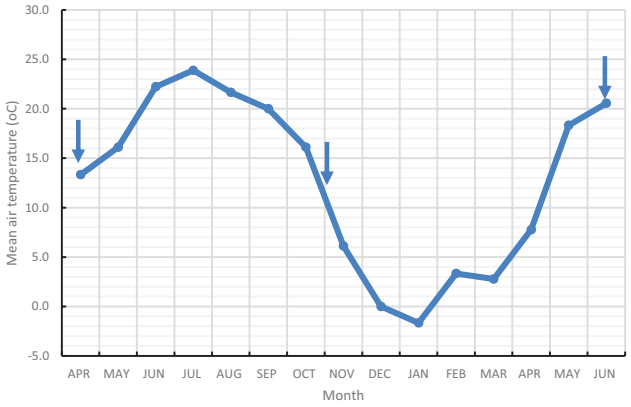

Fig. 4. Average monthly outdoor temperature of the study site from April 2017 to June 2018 (https://www.wunderground.com/weather/us/nj/paterson/07501). The three arrows represent the building-wide pest survey dates in the control building.

did not cause significant cockroach population increase compared with the winter season. The average trap count per apartment at 6 and 14 mo was 36 ± 12 and 42 ± 14, respectively.

Discussion

We showed that IPM programs were much more effective compared with the conventional pest control service in reducing pest infestations. The researcher-led cockroach IPM caused 75% reduction in the number of cockroach infested units after 12 mo. It is very similar to the results of a previous cockroach IPM study in garden style apartment buildings (74% reduction; Wang and Bennett 2009). The only unit with continuous trap counts had unique challenges including poor sanitation, high clutter level, and food and water was left out regularly in multiple locations for religious purposes. The cockroach infestations present at 12 mo were primarily due to new infestations (6 units) and reinfestations (10 units). The new infestations and reinfestation of previously declared eliminated units could be from new introductions from outside of the building or a result of cockroach dispersal within the building. It could also be that the infestations were not truly eliminated, and the numbers were just reduced to very low levels that went undetected. Even if this were the case our results demonstrate the number of infestations that may have been falsely declared eliminated is very low. Therefore, it is necessary to continue the implementation of IPM in large buildings on an ongoing basis to address newly introduced infestations and recurring infestations.

The contractor-led bed bug IPM program achieved a 63% reduction in the total number of infestations after 12 mo, compared with 85% reduction in another bed bug IPM program that was carried out by in-house licensed staff (Cooper et al. 2016b). Both studies were conducted in similar communities (i.e., low-income senior residents and one bedroom). The lower rate of reduction in this study was mostly due to the contractor not abiding to the IPM protocol. The contactor often relied upon visual inspection rather than our trap count to make treatment decisions, resulting in premature termination of treatment of apartments that still had bed bug activity. For example, there were units with consistent low-level activity based on interceptor counts; however, contractor's treatment records indicated no live activity found through visual inspection and treatment was not provided. Proper monitoring is a critical element to the protocol and should be used at all times, as interceptors have been found to be more reliable than visual inspections (Wang et al. 2010, Cooper et al. 2016b, Wang et al. 2016). Another challenge was the lack of encasement installment. Encasements were provided to management staff but not installed. Poor record keeping was an obstacle in evaluating contractor control efforts. Although records were provided throughout and after the study, it is unclear if we have the complete treatment records. On several occasions, records indicated follow-up treatments were scheduled; however, no further records were provided. Throughout the study, only four liquid residual treatments were documented in the records provided. The lack of treatment documentation makes it difficult to draw further conclusions regarding contractor's treatments. Additionally, on several occasions, contractor records indicated that the resident was not notified about the treatments and they had to reschedule. This lack of adherence to true IPM protocols is frequently seen in practice in the pest management industry.

The 39% reduction in cockroach infested units and 117% increase in bed bug infested units in the control site indicate that conventional pest control service had limited effect on reducing pest infestations in apartments. Key factors contributing to the poor results include, but are not limited to: 1) less frequent service than the IPM program during the first 6 mo; 2) no traps used to monitor cockroach populations; 3) very small amount of bait (<1 g) applied per cockroach-infested apartment and service time allocated to each infested apartment was very short; 4) bed bug treatment service was based on complaints and no treatments were conducted if residents did not prepare; and 5) bed bug treatment was limited to insecticide application. In contrast, the IPM program used traps to guide the treatment and the amount of bait used was adjusted based on cockroach population level. High rates of residents unaware of the presence of cockroaches and bed bugs proved that placing traps was necessary for detecting bed bugs and cockroaches. Biweekly visits during the first 6 mo allowed for faster elimination of cockroach infestations. Resident education during home visits may also have helped in the elimination of cockroaches and bed bugs in the IPM building.

Wang and Bennett (2009) estimated monthly IPM program cost for cockroach management was $7.5 USD/apartment per month. Detailed cost of the researcher-led cockroach IPM program in the current study was not calculated, but it is estimated to be more than $7.5 USD/apartment due to higher labor cost compared with that reported by Wang and Bennett (2009). Although the IPM program is very effective in reducing the cockroach infestation rate in the building, it is more expensive than the traditional monthly pest control services. Most pest control companies place less than four traps per apartment for monitoring cockroaches. They use insufficient amounts of bait materials, spend very short time in treating known infestations, and visit each building once a month. For bed bug management, installing interceptors and bed bug proof encasements would also increase the pest control cost. Even though the pest control cost after the first year will be lower due to the significant reduction in the number of infestations, the IPM program will still be much more expensive compared with what the housing authority was paying ($0.96 USD/apartment per month for general pests) before the program because of the requirement for laying monitors, documenting the trap counts, building-wide inspections, and detailed treatment protocol for each infested apartments; however, traditional pest control practices are ineffective in controlling cockroaches (Zha et al. 2018). Without raising the standard for pest control services, implementation of IPM in low-income communities will continue to be difficult.

Over the course of the study in the IPM building, 71 units never had cockroaches detected. If these 71 units would be treated

monthly, resources (insecticides and labor) would be wasted. Conducting treatments based upon trap count data would save time, achieve better results, and not waste resources; housing authorities would benefit by having these protocols in their contract, so they get results from the services they pay for; residents would have healthier homes, less stress from dealing with infestations, and reduced pesticide exposures.

Common areas of multi-unit dwellings also must be treated appropriately to ensure the success of a building-wide pest management program. Several common areas had a large number of cockroaches at beginning of the study. Without monitoring and treatment, they could serve as a reservoir and spread to apartments through common walls and plumbing (Runstrom and Bennett 1984). The connection between pests in common areas in high-rise buildings and those in apartments should be further evaluated.

Because of the lack of effectiveness of cockroach control service in the control building during the 14-mo study period, it is possible to examine the seasonal effect on German cockroach populations. In a survey of low-income apartments in north-central Florida, cockroaches were sampled using sticky traps. One building complex without monthly pest control service had higher cockroach count in warmer months of the year (Koehler et al. 1987). But in another apartment complex with pest control service, there were no seasonal differences in cockroach counts. Mollet et al. (1997) reported that cockroach trap count peaked in June based on six apartments in Roanoke, VA. The first 6-mo period in this study had much higher temperatures than the later 8-mo period. If cockroaches were more abundant in the warmer season, then we would expect the cockroach population to increase faster in warmer season than in colder season. However, the percentage of apartments with trap counts increased during the two periods were very similar (26% vs 25%). All apartments in the building were kept around 21°C in winter and most of the apartments had air conditioner in use in summer. Relatively stable indoor temperatures during the year in the apartment building may be an important factor for the lack of seasonal fluctuations in cockroach populations. The presence of monthly pest control service in the building may also have helped keep cockroach populations stable throughout the year. In future studies, tracking the indoor temperature and cockroach population through different seasons would be necessary to assess the effect of temperature on cockroach populations.

Recommendations

Although pest management in low-income housing communities is challenging, pest infestation rates can be reduced to very low levels if IPM principles are closely followed. Follow-up monitoring and evaluation are critical to ensure quality of the pest control program. Application of pesticides should be based on visual inspection and trap counts. All infested apartments should be visited every 2–4 wk until pest elimination is confirmed using monitors and visual inspection. There is no need to visit or treat all apartments in a building every month. Building-wide pest inspection once or twice a year is important to detect new and/or recurring infestations. From a pest management perspective, property management and procurement staff need to set up pest control contracts with the IPM components included explicitly. The management office should encourage residents to report infestations. When lack of resident cooperation occurs or residents are unable to perform the required preparations, it may be necessary for property management to assist the residents, rather than leaving those apartments untreated. The goal of the pest management program is to ensure all detected infestations are promptly treated and eliminated to minimize dispersal of pests. It would be beneficial to have in-house staff actively participate in the implementation of the pest management program. The staff should arrange for all infested units to be visited every 2–4 wk until elimination. Close supervision of the quality of the pest control service is necessary to ensure the IPM program is properly executed. Initial cost of the IPM program will be higher than the existing pest management program due to the need to knockdown large numbers of infestations existing in many of the low-income communities. Methods to improve the adoption of effective IPM programs in apartment buildings require further research.

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