

# Evaluation of a model community-wide bed bug management program in affordable housing

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## Abstract

**BACKGROUND:** Low-income apartment communities in the United States are suffering from disproportionately high bed bug, *Cimex lectularius* L., infestations owing to lack of effective monitoring and treatment. Studies examining the effectiveness of integrated pest management (IPM) for the control of bed bugs in affordable housing have been limited to small subsets of bed-bug-infested apartments, rather than at the apartment community level. We developed, implemented and evaluated a complex-wide IPM program for bed bugs in an affordable housing community. Proactive inspections and biweekly treatments using a combination of non-chemical and chemical methods until bed bugs were not detected for three biweekly monitoring visits were key elements of the IPM program.

**RESULTS:** A total of 55 bed-bug-infested apartments were identified during the initial inspection. Property management was unaware of 71% of these infestations. Over the next 12 months, 14 additional infested apartments were identified. The IPM program resulted in a 98% reduction in bed bug counts among treated apartments and reduced infestation rates from 15 to 2.2% after 12 months.

**CONCLUSIONS:** Adopting a complex-wide bed bug IPM program, incorporating proactive monitoring, and biweekly treatments of infested apartments utilizing non-chemical and chemical methods can successfully reduce infestation rates to very low levels.

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**Keywords:** *Cimex lectularius*; multifamily housing; IPM; pest control

## 1 INTRODUCTION

The public in the United States is currently experiencing a resurgence of bed bug, *Cimex lectularius* L., infestations. The impacts associated with bed bug infestations can be physical, medical, mental and economic in nature,<sup>1–3</sup> all of which can be exacerbated in underserved communities.<sup>4–6</sup> In 2012, a survey of 16 New Jersey housing authorities revealed that up to 40% of the units were infested (Wang C, unpublished data). In another 2012 survey, 65% of 26 affordable housing communities in Virginia reported having bed bug activity; 6.4% of the apartments had been treated for bed bug infestations, with several communities suffering infestation rates between 8 and 19%.<sup>7</sup> Moreover, individuals living in homes with bed bug activity often become victims of social injustice, being refused access to health care and other public services.<sup>6</sup> In an effort to address bed bug infestations, residents often take matters into their own hands, which can result in the misuse of pesticides, with potentially harmful or dangerous consequences.<sup>8–10</sup> Improperly applied pesticides increase the risk of negative health effects among residents, especially vulnerable populations like children and the elderly. Pesticide misapplication also increases selection pressure on bed bugs, potentially promoting the development of resistance. Bed bugs are particularly difficult to eliminate in low-income communities,<sup>11</sup> where the necessary financial resources and knowledge to cope with the rapidly expanding bed bug infestations are often lacking.<sup>4,6,12</sup> Eradication

efforts often require numerous service visits from a pest management professional and involve the use of a variety of chemical and non-chemical control measures, along with the selective treatment or disposal of infested furniture and other personal belongings.<sup>11,13,14</sup> In spite of the challenging nature of bed bug management, affordable housing communities often hire pest management vendors on the basis of the lowest bid for service,<sup>15</sup> and only schedule treatment when residents complain. Unfortunately, residents often fail to report bed bug infestations for a variety of reasons: they are unaware of the infestation, they are ashamed or embarrassed, they do not want to be bothered with invasive pest control procedures or they fear negative repercussions by property management.<sup>4,5,12</sup> Failure to report infestations early on can result in established infestations that may spread to other apartments<sup>16,17</sup> and are more difficult and costly to control.<sup>18</sup>

Affordable housing communities for elderly and disabled residents are especially at risk for high infestation and reinfestation rates.<sup>7</sup> Ralph *et al.*<sup>18</sup> found the elderly to be the demographic least likely to self-report infestations. An extensive study examining dispersal of bed bugs in a high-rise housing community occupied by

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elderly and disabled residents found that 45% of the apartments were bed bug infested, and 53% of the apartments adjacent to infested apartments were also infested.<sup>12</sup> In spite of the high infestation rates observed in their study, over 50% of the residents with infestations were unaware they had bed bugs in their apartments. Thus, relying on a reactionary bed bug management approach in multifamily housing communities promotes the development of severe/chronic infestations that can spread to other apartments and increase the cumulative costs of control.

Integrated pest management (IPM) originated as an agricultural concept and has been defined as a pest management system that utilizes all sustainable techniques in a compatible manner to reduce pest populations and maintain them at levels below those causing economic injury (EIL).<sup>19</sup> Unlike agriculture, where the primary objectives of IPM are to reduce costs and maximize gains, the primary objective of IPM for pests of the urban environment is to reduce aesthetically displeasing pests that may also create public health hazards.<sup>20</sup> Often, acceptable pest thresholds are not based upon EIL but rather on what a client is willing to tolerate, and vary from one client to the next. This differs for pests such as cockroaches, rodents or bed bugs that have public health implications, and for which the acceptable threshold is often zero. Most commonly, IPM methods include education, monitoring and the implementation of non-chemical and chemical strategies. Wang and Cooper<sup>21</sup> suggested that an IPM approach is necessary at the apartment community level to achieve effective eradication of existing bed bug infestations. IPM methods could also reduce the spread of bed bugs and decrease the cost of control by identifying new bed bug introductions in the early stages.<sup>21</sup> In spite of the fact that IPM is widely recommended for the control of bed bugs in multifamily housing communities,<sup>7,11,22</sup> no studies examining the effectiveness of IPM at the apartment community level have been conducted. Instead, studies have focused on small subsets of apartments within infested communities.<sup>11,13–15</sup> These studies resulted in up to 97.6% reduction in bed bug populations, but never eliminated more than 67% of the treated infestations. Failure to eliminate bed bugs from infested apartments may result in chronic infestations that can endanger the financial stability of the property and the health of residents, and further serve as a source of new infestations.<sup>15</sup> Wong *et al.*<sup>7</sup> concluded that, because bed bug infestations have public health, financial and social justice implications, housing authorities must adopt more effective bed bug detection and control strategies.

Starting in 2012, we designed and implemented a model IPM program for the control of bed bugs in an affordable housing community for elderly and disabled residents in Jersey City, New Jersey. The program included education of property management staff and residents about bed bugs and their control. Inspections of apartments were conducted at the onset of the program to identify unreported infestations, as well as at 6 and 12 months to evaluate the effectiveness of the program and to identify other unreported infestations. Apartments with bed bugs were treated using an integrated management strategy that relied primarily on non-chemical measures with limited use of pesticides, applied in a targeted fashion. During the second half of the study we implemented a threshold-based approach in an effort to further reduce pesticide usage. Our primary objectives were (1) to reduce the apartment-complex-wide infestation rate by at least 70% within 12 months and (2) to reduce the amount of pesticide usage over the course of the study.

## 2 EXPERIMENTAL METHODS

### 2.1 Study site

The study was conducted at Jersey City Housing Authority (JCHA) located in New Jersey. The housing community consisted of four high-rise apartment buildings (A, B, C and D) and a total of 358 apartments, of which 288 were one-bedroom, 54 studio and 16 two-bedroom apartments. During the study period, 92–98% of the apartments were occupied. The residents were low-income elderly (>62 years old) or disabled people. Among them, approximately 75% were African Americans, 20% were Hispanics and 5% were of other ethnic groups. Based upon historical pest control records provided to us by property management, the first bed bug infestation in the community was reported in 2007. The number of known infested apartments rose from one apartment in 2007 to 32 reported apartments in 2008. Between 2008 and 2011, 118 apartments with bed bug infestations were treated, of which 46 apartments experienced repeat bed bug activity caused either by reintroduction of bed bugs or by control failure. The infestations were treated by an in-house staff member licensed in the application of pesticides by the New Jersey Department of Environmental Protection. The in-house pest control staff used a variety of measures to control bed bugs, including the use of mattress encasements, physical removal through vacuuming of bugs, application of steam and the application of several pesticides, including liquid residual, aerosol and dust formulations. There was no consistency in the materials or methods used to treat one infestation to the next. Likewise, there was no protocol for follow-up services or when to stop treating infested units; both were left to the discretion of the in-house pest control technician. Treatment efforts were typically terminated when residents indicated that they were pleased with the results of the treatment effort.

### 2.2 Education of the apartment community

#### 2.2.1 Educational seminar and resident survey

At the onset of the project, 11 management/staff members attended a bed bug training session. Five of them were management-level employees, and the other six were general staff with varying roles such as maintenance, electricians, plumbers, painters, etc. The educational program was conducted in a classroom setting in a community room at the apartment complex. Education consisted of a 1 h PowerPoint presentation projected onto a large (1.5 × 1.5 m) movie screen at the front of the room. Each of the attendees received a bed bug awareness poster, two bed bug fact sheets (each in English and Spanish) and a copy of the United States Department of Housing and Urban Development guidelines for multifamily housing (all items can be found at <http://njaes.rutgers.edu/bedbug/?building-managers>). In addition, a short (7 min) video on bed bug IPM (<http://njaes.rutgers.edu/bedbug/?videos#IPM>) was projected onto the movie screen. Refreshments (food and beverages) were provided to attendees.

Resident training was held immediately following the staff training and was carried out in community rooms located in buildings A and B, and a shared community room for residents of buildings C and D. Notices announcing the training topic and date of the training were distributed to all residents 1 week prior to the training. The notice also advised residents that refreshments (food and beverage) would be provided during the training session. Residents were shown a 30 min PowerPoint presentation designed specifically for residents in multifamily

housing (<http://njaes.rutgers.edu/bedbug/?residents>). Residents were also provided with two different bed bug fact sheets (in English and Spanish); however, the PowerPoint and video were only presented in English. Subjects discussed during both staff and resident training included the resurgence of bed bugs, basic biology, behavior, identification, prevention and control, as well as the roles and responsibilities for each audience. Key messages delivered during the educational session included: (1) bed bugs do not discriminate – anyone can get bed bugs regardless of cleanliness or social status; (2) if you suspect bed bugs, it is important to report the problem to property management immediately; (3) if you have or suspect bed bugs, it is not necessary to throw your bed away – most of the time beds can be saved; (4) do not apply pesticides on your own, this may spread the infestation and can be potentially harmful to your health – leave pesticide applications to professionals who know how to treat the problem correctly; (5) you can help eliminate bed bugs by frequently laundering bed linens and by eliminating clutter under, on and immediately adjacent to beds and upholstered furniture.

At the beginning of the meeting, residents filled out a brief survey. Questions included: (1) are you aware of bed bug activity in your apartment at the present time; (2) have you ever experienced bed bug activity in your apartment; (3) if you previously have had a bed bug infestation in your apartment, did you apply insecticides to control the bed bugs?

#### *2.2.2 Distribution of bed bug fact sheets and resident interviews during initial inspection and 12 month inspection of apartments*

Apartments were inspected for bed bugs at the beginning of the study (initial inspection) and at 6 and 12 months. Each of these inspections consisted of two visits 14 days apart. Residents were provided with bed bug fact sheets (three pages) (in English and Spanish) during the first visit of the initial, 6 month and 12 month inspections. A verbal interview was conducted with residents who were home during the second visit (14 days later) of the initial and 12 month inspections. At the completion of every interview, the resident's responses were discussed with the resident, to explain which answers were correct, incorrect or partially correct. This was done in an effort to further educate the residents. Interview questions that were evaluated during both the initial and the 12 month inspections included: (1) do you believe bed bug infestations are caused by people who do not clean well; (2) if a bed becomes infested with bed bugs, is it necessary to discard the bed or are there methods to save it? Questions that were evaluated during the 12 month interview only included: (1) have you ever experienced a bed bug infestation and, if so, how long ago; (2) if you have experienced an infestation, did you develop bite symptoms; (3) if your apartment became infested with bed bugs, would you be very concerned, somewhat concerned or not concerned; (4) if your apartment became infested with bed bugs, would you report the infestation to property management; (5) how do you believe bed bugs are introduced into apartments (neighboring apartments, visitors, public places, second-hand items, bed wetting, other)? 'Bed wetting' was included in the choices for question 5 because many residents mentioned bed wetting as a cause of infestation during our initial inspections.

### **2.3 Proactive procedure for new residents**

A resident 'move-in' procedure was implemented in an effort to discover new bed bug introductions in association with the arrival

of new residents. When signing a new lease, the new resident was provided bed bug education materials by property management. Within 1 month after move-in, the JCHA pest control technician visited the new resident's apartment and inspected beds and upholstered furniture for bed bugs. If no bed bugs were observed, interceptors were installed under the legs of beds and upholstered furniture and checked 14 days later.

### **2.4 Initial inspection of apartments**

At the onset of the study, apartments in all four apartment buildings A, B, C and D were visited, and residents who were home were asked if they were aware of bed bug activity in their apartment at the present time or within the past 12 months. Regardless of the resident's response to this question, an average of ten Climbug<sup>®</sup> interceptors (Susan McKnight, Inc., Memphis, TN), referred to hereafter as interceptors, were installed under the legs of beds and upholstered furniture in every unit in building A. Alternatively, in buildings B, C and D, interceptors were only installed in apartments of residents who indicated (1) that they were aware of or suspected bed activity, or (2) that their apartment had been treated for bed bugs by the housing authority within the past 12 months. In total, 53 of the 202 apartments in these three buildings were monitored. The rationale for this was to save cost, because of the very low infestation rates in these three buildings, based upon historical pest management records. In the previous 12 months, a total of 15 out of 202 units were treated in buildings B, C and D combined, compared with 32 infestations in building A (156 units). All apartments with interceptors were inspected 14 days later by 2–3 Rutgers University researchers, and a visual inspection of the beds and upholstered furniture was conducted if no bed bugs were observed in the interceptors.

### **2.5 Treatment of infestations**

All treatments were performed by the licensed in-house pest control technician employed by JCHA. Rutgers University researchers assisted in the treatment of the first three infested apartments to allow the in-house pest control technician to become familiar with the treatment protocol. A second housing authority staff member assisted in lifting heavy beds and furniture. Two months after the onset of the study, the second staff member was no longer available owing to a labor shortage. All treatment data were transferred to Rutgers researchers and analyzed for effectiveness of the IPM program. The protocols for the initial treatment and follow-up services were as follows.

#### *2.5.1 Initial treatment*

Bed linens and any clothing on floors were bagged, and residents were provided with laundering instructions and tokens to offset the expense of laundering. Mattresses and box springs were encased (AllerZip<sup>®</sup>; Protect-A-Bed<sup>®</sup>, Northbrook, IL). An Omega Green Supreme IPM HEPA vacuum (Atrix International, Burnsville, MN) was used to remove visible bugs, and a Steamax steamer (AmeriVap<sup>®</sup> Systems, Dawsonville, GA) was used to apply hot steam to upholstered furniture, bed frames, headboards, footboards and furniture within 90 cm of beds. Pesticide applications during initial treatments were limited to two low-impact products, MotherEarth<sup>®</sup> D (100% diatomaceous earth; Whitmire Micro-Gen Research Laboratories, St Louis, MO) and a proinsecticide Phantom<sup>®</sup> aerosol (0.5% chlorfenapyr; BASF, Research Triangle Park, NC). MotherEarth D was applied using a bulb duster along baseboards and outlets and switch plates located behind

beds and upholstered furniture, and extending 90 cm to either side of sleeping and resting areas. The same dust was also applied inside upholstered furniture by poking the duster through the dust cover on the underside of the furniture. Phantom aerosol was applied around the perimeter on the underside of furniture, as well as around the legs and beneath the fabric skirt if one existed. Phantom aerosol was also used to treat other areas where bed bug activity was observed. Interceptors were installed under legs of bed frames and upholstered furniture. Additional interceptors were placed at the corners of the living room and bedroom, as well as one in each closet, the bathroom and kitchen.

At 6 months into the study, a 'threshold-based' treatment protocol was introduced for the initial treatment in apartments with newly identified bed bug activity. Control measures in apartments identified with five or fewer bed bugs, based on interceptors and visual inspections, were limited to non-chemical methods only, which included physical removal of bugs, encasement of the mattress and box spring and installation of interceptors as described above. If bed bug counts greater than five were observed during one of the follow-up service visits, other measures, including the use of pesticides, were made available. The threshold of five or fewer bugs is conservative, and was based upon the results of a previous study in which we eliminated bed bugs from 77% (30 of 39) of apartments with initial bed bug counts of ten or fewer bed bugs, using nothing more than encasements and installation of a similar number of interceptors as this study (Cooper RA, unpublished data).

### 2.5.2 Follow-up service visits

During each service visit, residents were asked if they were aware of any new activity (seeing bed bugs or being bitten). All interceptors were inspected and either maintained (cleaned and talc powder reapplied) or replaced, depending upon their condition. A visual inspection of bed and upholstered furniture was also conducted during each service visit. When the total number of bed bugs from interceptors and visual inspection combined was five or fewer, the visible bugs were physically removed. If more than five bugs were observed, live bugs were removed and the area of activity was treated using one or more of the following: (1) steam; (2) vacuum; (3) MotherEarth D; (4) Phantom aerosol; (5) Transport<sup>®</sup> GHP liquid residual spray (0.05% acetamiprid and 0.06% bifenthrin; FMC Corporation, Philadelphia, PA) applied with a 1 gal B&G sprayer (B&G Equipment Co., Jackson, GA). If bed bugs were still found after 5 months from initial treatment, more aggressive measures such as discarding infested items or heating of infested items in a portable heat chamber (Thermal Strike<sup>®</sup> Expedition Bed Bug Heat Treatment, Fort Collins, CO) were implemented at the technician's discretion.

Follow-up service visits continued on a biweekly basis until three criteria were met over three consecutive 14 day intervals: (1) no bed bugs captured in any of the interceptors; (2) no bed bug activity observed during visual inspection of beds and upholstered furniture; (3) no new reports of bed bug activity or bite symptoms by the resident. Once these criteria were met, follow-up service visits were terminated and the infestation considered resolved. The criterion of three consecutive visits of no observed activity was selected on the basis of previous unpublished results showing that the chance of finding bed bugs again was <10% (Cooper RA, unpublished data).

### 2.5.3 Pesticide use

The amount of pesticide used in each apartment was recorded by measuring the weight of the dust bulb and aerosol can immediately before and after each treatment using a Salter balance (model 1015; Salters Housewares, Oakbrook, IL). The amount of liquid residual applied was estimated by comparing the volume of the solution in the B&G sprayer before and after each application.

## 2.6 Evaluation of the effectiveness of the IPM program

Inspections of all 358 apartments in four buildings were conducted at 6 and 12 months. These inspections served two purposes: (1) to detect unreported bed bug infestations, and (2) to evaluate the program effectiveness. To detect unreported infestations, interceptors were installed under the legs of beds and upholstered furniture in all occupied apartments that were not currently being treated in all four buildings, and were checked 14 days later for bed bugs. A visual inspection was conducted if no bed bugs were found in the interceptors and any one of the following conditions was met: (1) the unit was treated for bed bugs during the 6 months prior; (2) the resident believed bed bugs were present in the unit; (3) the resident moved in after the initial inspection. Visual inspections were also conducted in units adjacent to apartments that had 50 or more bed bugs and were treated within the previous 6 months.

The effectiveness of the IPM program was measured at the conclusion of the 6 and 12 month inspections using the following parameters: (1) changes in the number of infested apartments; (2) changes in mean bed bug count; (3) changes in the amount of pesticides used.

## 2.7 Cost of the IPM program

The cost of the IPM implementation was measured by calculating the labor and material cost for inspections, treatments and pesticide usage. During inspections, the time spent in apartments as well as the time between units, waiting for residents, unlocking doors and other down time encountered were recorded. Labor cost was \$US 50 per hour based on JCHA estimate. Costs for equipment were not included in the cost calculation because the housing authority already owned all of the equipment necessary (duster, vacuum, steamer and compressed air sprayer), and these tools are typically owned by those providing bed bug management services. The costs of education were limited to those associated with the printing of materials and time for staff to attend training. Costs for the delivery of education were not included in the cost calculation because training is available free of charge through extension service or pest management vendors. Additionally, all of the educational materials used in this study are available to the public at <http://njaes.rutgers.edu/bedbug>. PowerPoint presentations are available with full narrative text, and are also available in a video format. The 7 min IPM video and the video of the resident PowerPoint are available in English and Spanish. The pesticide use was compared with that used in other published bed bug management studies in low-income communities.

## 2.8 Statistical analysis

Only responses from English-speaking residents were used for the analysis of questions asked during the educational seminar and the resident interviews during the initial and 12 month inspections. A chi-square test<sup>23</sup> was used to compare responses of residents to two questions asked during both the initial and the 12 month interviews. A chi-square test was also used for analyzing

whether level of concern about bed bugs was related to whether they had an infestation within the past 12 months. Regression analysis<sup>23</sup> was conducted to evaluate the relationship between the number of treatment visits required to eliminate a bed bug infestation and the logarithmic transformed initial bed bug count. The relationship between the total amount of pesticide usage and the logarithmic transformed initial bed bug count was also analyzed using regression analysis. One outlier with a very large initial bed bug count (1413 bed bugs) was excluded from the analysis. The numbers of service visits to eliminate infestations in the apartments identified during the initial inspection and those identified after the initial inspection were compared using analysis of variance.

### 3 RESULTS

#### 3.1 Education of the apartment community

##### 3.1.1 Survey during the seminar

Residents from 167 (47%) apartments attended the bed bug education meeting and filled out the survey. Fifty-two percent of the respondents ( $n=121$ ) indicated that they either had a current infestation (16) or previously had an infestation (47) in their apartment. Of the 63 residents who had experienced bed bugs in their apartment, 56% indicated that they applied pesticides on their own to treat the problem.

##### 3.1.2 Interviews during home inspections

Table 1 lists questions and answers during the initial and the 12 month interviews, or the 12 month interview only. The percentage of residents who believed bed bugs are caused by a lack of cleanliness remained similar at the initial and at the 12 month interview ( $\chi^2=0.01$ ;  $df=1$ ;  $P=0.91$ ). However, the number of residents who said infested beds must be discarded decreased significantly during the 12 month interview compared with the initial interview ( $\chi^2=13.9$ ;  $df=1$ ;  $P=0.0002$ ). Among residents who said they had experienced a bed bug infestation during their lifetime, 76% of the infestations had occurred within the last 10 years. There was no relationship between the level of concern expressed by residents about getting bed bugs and their previous infestation history within the past 10 years ( $n=133$ ) ( $\chi^2=3.69$ ;  $df=2$ ;  $P=0.16$ ). Additionally, infestation history had no impact upon whether residents would report the infestation to property management.

Regarding the source of infestations, residents were familiar with the following ways that bed bugs can be introduced: second-hand items such as used furniture (97%); visitors to the apartment (91%); neighboring apartments (80%); from public places (79%). Surprisingly, 38% of the residents believed bed wetting was one of the ways bed bug infestations occurred.

#### 3.2 Initial inspection results and treatment of apartments

##### 3.2.1 Initial inspection

A total of 209 out of 358 apartments were inspected. All of the apartments in building A (156) were inspected, along with 31 of 130, 14 of 36 and 8 of 36 in buildings B, C and D, respectively. Inspections were completed by two researchers over a 7 week period (27 June 2012–14 August 2012). A total of 2077 interceptors were installed under the legs of beds and furniture (a mean of ten interceptors per apartment). The mean time required for installation of interceptors was 4.5 min per apartment. During the 14 day follow-up inspection, interceptors were inspected in all 209

apartments, and visual inspections were conducted in 81 of the apartments. The mean time to inspect interceptors and to conduct visual inspections was 6.6 and 16 min per apartment, respectively (not including down time between apartment inspections).

Fifty-five apartments with bed bug activity were identified. JCHA was unaware of 71% of the infestations. Interceptors detected 95% of the infestations, and 5% were detected by visual inspections after interceptors failed to reveal the presence of bed bugs. The numbers of apartments identified with bed bug activity in buildings A, B, C and D were 39, 4, 8 and 4, respectively. Among the 55 apartments with bed bug activity, 25 had <10 bugs, 20 had 10–50 bugs, six had 51–100 bugs and four had >100 bugs based on the total counts in interceptors. The mean (min, max) bed bug count per apartment was 66.4 (1, 1,413) based upon a 14 day trapping period.

##### 3.2.2 Initial treatment of apartments with bed bug activity

The 55 apartments with bed bug activity were treated by the in-house pest control technician between 25 June 2012 and 21 August 2012. The mean time required to provide the initial treatment was 102 min per apartment. The mean amount of chemical applied per apartment was 12.1 g of MotherEarth D and 62.6 g of Phantom aerosol. Initially, each apartment was serviced by two people, the in-house pest management technician and a helper to assist with lifting and moving of heavy furniture, bagging of clothing, organizing equipment, etc. However, after just 2 weeks the helper was no longer available owing to a shortage in staff, leaving 23 apartments to be treated by the in-house technician without any assistance.

#### 3.3 Inspection results and evaluation of IPM program at the conclusion of 6 and 12 month inspections

##### 3.3.1 The 6 month inspection

A total of 304 out of 358 apartments were inspected. Among the 54 apartments not inspected, 30 were vacant, six were occupied by residents who either refused access (4) or had private locks (2) and 18 were being treated for bed bugs. The inspections took two researchers 7 weeks to complete (4 January 2013–21 February 2013). A total of 2912 interceptors were installed under the legs of beds and furniture (a mean of ten interceptors per apartment). The mean time required for installation of interceptors was 2.1 min per apartment. During the 14 day follow-up inspection, interceptors were inspected in all 304 apartments, and visual inspections were conducted in 54 of the apartments. The mean time to inspect interceptors and to conduct visual inspections was 3.7 and 15.6 min, respectively (not including down time between apartment inspections).

Seven apartments with bed bug activity were identified during the 6 month inspection. Six of the infestations identified were detected by interceptors, and one through visual inspection after interceptors failed to detect any bed bugs. Four of the apartments with activity were in building A, two in building B and one in building C. The mean (min, max) bed bug count among the seven apartments was 2.4 (1, 8). Two of the seven apartments with bed bug activity were not monitored during the initial inspection. None of the residents in the seven apartments was aware that bed bugs were present in their units.

##### 3.3.2 The 6 month evaluation of the IPM program

Prior to the 6 month inspection, two apartments with bed bug activity were reported by residents, one in building C and the other

**Table 1.** Resident interview questions and answers during home inspections<sup>a</sup>

Question	<i>n</i>	Percentage answered yes
Are bed bug infestations caused by lack of cleanliness?	59	Initial inspection – 56% 12 month inspection – 42%
Is it necessary to discard a bed that has become infested with bed bugs?	60	Initial inspection – 77% 12 month inspection – 42%
Do you have current bed bug infestation or have you previously had an infestation?	145	53%
Did you experience bite symptoms? Only those who had had bed bugs in the past 10 years were included.	59	40%
If your apartment became infested with bed bugs, how concerned would you be?	133	Very concerned – 68% Somewhat concerned – 15% No concern – 17%
Would you report the infestation to the management office if your apartment became infested?	142	Have bed bugs – 87% Do not have bed bugs – 87%

<sup>a</sup> The results for questions 3 to 6 are from the 12 month interview.

in D. Neither of these apartments had been inspected during the initial inspection at the onset of the study, and both had fewer than five bugs based upon interceptor trap catch and visual inspection.

By the conclusion of the 6 month inspection, a total of 64 apartments had been identified with activity (Table 2). Among them, 62 were treated. Bed bugs were eliminated from 52 apartments. Among the 10 treated apartments still with bed bugs, five were identified during the initial inspection and the other five were identified after the initial inspection. The mean bed bug count among treated apartments was reduced by 96% by the conclusion of the 6 month inspection. The infestation rate was reduced from 15 to 2.8%. Bed bugs were not detected in any of the apartments where infestations had already been eliminated, and thus at 6 months the recurring infestation rate was zero.

A total of 12 262 g of finished product (Phantom aerosol 8849 g, Transport GHP 2528 g and MotherEarth D 885 g) was used to treat 62 infested apartments through to the end of the 6 month inspection. A mean of 198 g of pesticide per apartment was used in the treatment of 62 apartments.

### 3.3.3 The 12 month inspection

A total of 325 out of 358 apartments were inspected. Among the 33 apartments not inspected, 27 were vacant, three were occupied by residents who had private locks and could not be accessed and three were still being treated for bed bugs. The inspections took two researchers 6 weeks to complete (1 July 2013–10 August 2013). A total of 3346 interceptors were installed under the legs of beds and furniture (a mean of ten interceptors per apartment). The mean time required for installation of interceptors was 2.1 min per apartment. During the 14 day follow-up inspection, interceptors were inspected in all 325 apartments, and visual inspections were conducted in 51 of the apartments. The mean time to inspect interceptors and to conduct visual inspections was 2.9 and 16.3 min per apartment, respectively (not including down time between apartment inspections).

Five apartments with bed bug activity were identified during the 12 month inspection. Three of them were new infestations, and two were apartments with recurring bed bug activity that had been treated during the first 6 weeks of the study. All five infestations were detected by interceptors. Three of the apartments were in building A, and the other two apartments were in building C. Four apartments had counts between one and three bed bugs; however, one unit had approximately 500 bed bugs in interceptors and 4000 bed bugs based on visual inspection. No bed bugs

had been detected in this unit during the previous inspection at 6 months; however, during the 12 month inspection, bugs were visually observed crawling all over bed sheets. Residents in all five of the apartments, including the heavily infested one, indicated that they were not aware of the bed bug activity.

### 3.3.4 The 12 month evaluation of the IPM program

Prior to the 12 month inspection, two new apartments with bed bug activity were reported by homemakers providing in-home care to the resident. Both of these apartments were in building A. One of the apartments had a bed bug count of seven bugs, and the other had 14 based upon interceptor trap catch and visual inspection.

Over the course of the study, there were 69 unique apartments infested with bed bugs (55 at the onset, two between the initial and the 6 month inspections, seven during the 6 month inspection, two between the 6 and 12 month inspections and three during the 12 month inspection). Among these 69 apartments, 71% were identified through proactive inspections. Ninety-four percent of the infestations identified during proactive inspections were detected by interceptors. Four units were identified by residents or home-health aides, and 16 units were already known to the housing authority. During the study, 15 new residents moved into the housing community. No bed bug activity was identified during the inspection of these 15 apartments by the in-house pest control technician, as part of the 'new move-in' protocol. Recurring bed bug activity was detected during the 12 month inspection in two apartments treated during the first 6 weeks of the study, bringing the total number of bed bug occurrences to 71. Of the 71 occurrences, 66 were treated and five were scheduled to be treated after the conclusion of the study.

The infestation rate at the conclusion of the initial, the 6 month and the 12 month inspections was 15, 2.8 and 2.2%, respectively. Overall, bed bugs were eliminated in 92% of the treated apartments (Table 2), and the mean bed bug count was reduced by 98%. Among the five treated apartments still with activity, two were identified just prior to the 12 month inspection, one was identified during the initial inspection and had received 22 service visits but still had nine bed bugs at 12 months, and the other two were apartments with recurring activity, each with only one bed bug found.

The mean number of service visits required to eliminate infestations identified during the initial inspection was significantly greater (8.2 visits) compared with those identified after the initial inspection (2.7 visits) ( $F = 8.8$ ;  $df = 1$ ;  $P < 0.004$ ) (Fig. 1). There was

**Table 2.** Summary of inspection and treatment results

Inspection	Number of newly identified apartments with bed bug activity	Number of apartments treated	Number of infestations eliminated	Number of apartments with recurring infestations	Number of apartments remaining with bed bug activity
Initial	55	NA <sup>a</sup>	NA	NA	NA
End of initial inspection – end of 6 month inspection	9 <sup>b</sup>	62	52	0	10 <sup>c</sup>
End of 6 month inspection – end of 12 month inspection	5 <sup>d</sup>	4	9	2	8 <sup>e</sup>
Overall	69	66	61	2	8

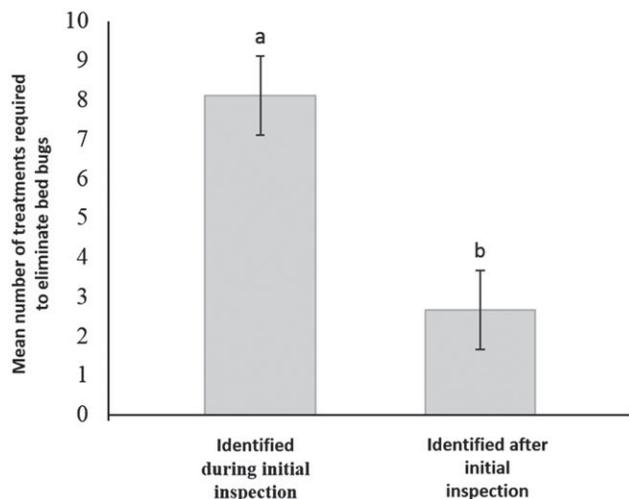
<sup>a</sup> Not applicable.

<sup>b</sup> Two of these apartments were reported between the end of the initial inspection and the start of the 6 month inspection.

<sup>c</sup> Five of these apartments were from the initial 55 apartments treated and five were from apartments identified between the initial inspection and the conclusion of the 6 month inspection.

<sup>d</sup> Two of these apartments were reported between the end of the 6 month inspection and the start of the 12 month inspection.

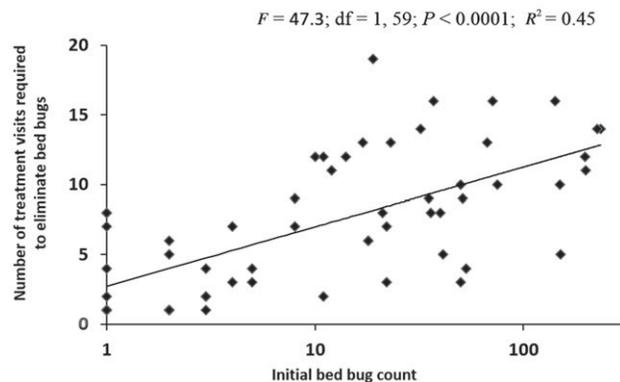
<sup>e</sup> Three of these apartments were from the initial 55 apartments (one was never eliminated and two were recurring), two apartments were identified between the end of the 6 month inspection and the conclusion of the 12 month inspection, and three apartments were identified during the 12 month inspection. The three new infestations and two recurring infestations were not treated until after the study was concluded.



**Figure 1.** Mean number of treatments to eliminate infestations identified during initial inspection ( $n=52$ ) compared with apartments identified after the initial inspection ( $n=9$ ). Bars with different letters are significantly different ( $P < 0.05$ ; ANOVA).

a significant correlation between the initial bed bug counts and the number of treatment visits required to eliminate an infestation ( $F = 47.3$ ;  $df = 1, 59$ ;  $P < 0.0001$ ;  $R^2 = 0.45$ ) (Fig. 2). Among the treated apartments, 60% of the residents told the in-house pest control technician that they experienced no bite symptoms, and 62% were not aware that they had an infestation in their apartment. Prior to bugs being eliminated from their apartment, 76% of the residents indicated to the in-house pest control technician that they believed their apartment was no longer infested, even though bed bugs were still detected during biweekly inspections.

A total of 13 248 g of finished product (Phantom aerosol 9537 g, Transport GHP 2809 g and MotherEarth D 902 g) was applied over 12 months to treat 66 infested apartments (Table 3). A mean quantity of 201 g of finished product was used per apartment. Four of the six infested apartments identified during the 6 month inspection with fewer than five bed bugs were serviced using the threshold-based treatment protocol, the other two apartments



**Figure 2.** Correlation between bed bug counts and number of treatment visits required for eliminating an infestation.

being accidentally treated with chemical during the initial service. Bed bugs were eliminated from all six of these apartments in a single service visit. Regression analysis revealed a significant positive correlation between the amount of pesticide usage and the initial bed bug count ( $F = 35.6$ ;  $df = 1, 64$ ;  $P < 0.0001$ ;  $R^2 = 0.36$ ) (Fig. 3). The quarterly pesticide usage is shown in Fig. 4. As the number of active infestations decreased from the first quarter to the fourth quarter, pesticide usage decreased by 94%.

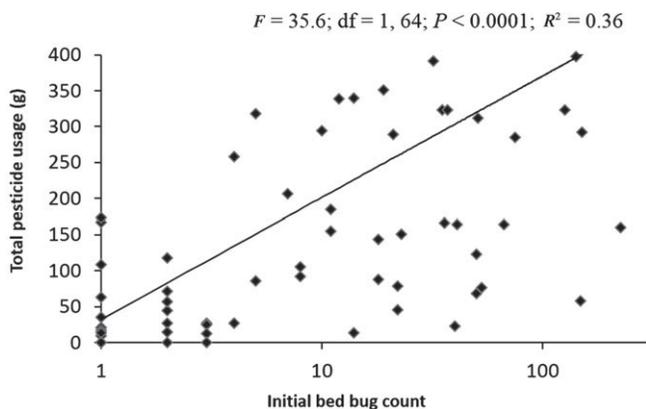
### 3.4 Cost of the IPM program

Costs for the IPM program are summarized in Table 4. Interceptors were purchased directly from the manufacturer at a cost of \$US 2.00 per interceptor. A total of 9897 interceptors were installed during inspections and treatment of apartments. The mean number of interceptors per apartment for inspections was 10, with an additional 11 added in apartments being treated for bed bugs, as part of the treatment protocol. A total of 350 man-hours were invested for the community-wide inspections. The labor spent for 0, 6 and 12 month inspections was 129, 112 and 109 h, respectively. Non-productive 'down time' between apartment inspections accounted for 61% of the labor (213 h). A labor rate of \$US 50 was used, based upon the salary, including benefits, for the

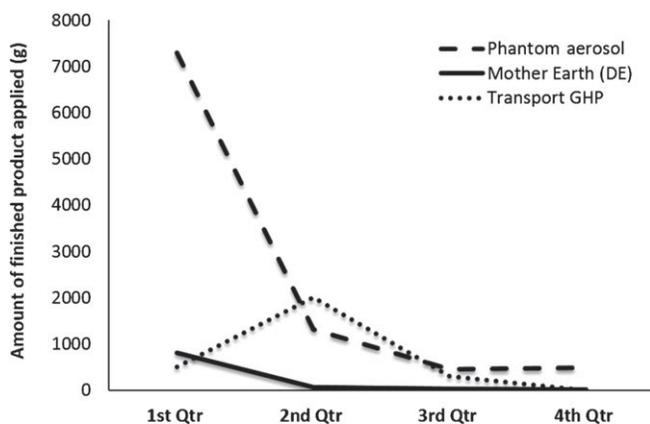
**Table 3.** Total pesticide used for treating 66 apartments

Time period	Finished pesticide product applied <sup>a</sup>			
	Phantom (g)	Transport GHP (g)	MotherEarth D (g)	Total applied (g)
Start – end of 6 month inspection	8849	2528	885	12 262
End of 6 month inspection – end of 12 month inspection	688	281	17	986
12 month total	9537	2809	902	13 248

<sup>a</sup> The respective formulation types for Phantom, Transport GHP and Mother Earth are aerosol, liquid and dust, respectively.



**Figure 3.** Correlation between bed bug counts and amount of pesticides used per apartment.



**Figure 4.** Quarterly insecticide usage for treating 66 apartments with bed bug activity.

in-house technician. The total costs for community-wide education, inspection and treatment were \$US 868, \$US 34 600 and \$US 30 068 respectively. The average cost for treatment of 66 apartments (labor and materials) was \$US 456 per apartment.

#### 4 DISCUSSION AND CONCLUSIONS

Our study is the first documented success of complex-wide IPM in an affordable housing community. The purpose of the study was not to evaluate specific treatment methods but rather to examine the effectiveness of an overall approach for the complex-wide management of bed bugs. The high level of control achieved is largely attributed to several practices: (1) a baseline inspection to identify unreported infestations; (2) a protocol for when to

stop follow-up inspections and treatments; (3) periodic inspections for the continued early detection of unreported infestations; (4) using a combination of non-chemical methods (installing encasements, applying steam, etc.) and chemical methods to treat existing infestations. The use of interceptors, rather than relying on visual inspections, also contributed greatly to the results achieved.

Education of staff and residents regarding biology, behavior and what actions to take is an important component of any IPM effort in multifamily housing. However, in our study the educational effort produced mixed results. Between the initial and 12 month interviews, education had little impact on residents' perception that bed bugs are caused by a lack of cleanliness. However, education was effective in changing the opinion of residents regarding what to do with beds that are infested with bed bugs. This was at least partially due to the fact that the housing staff installed mattress encasements in all infested apartments and therefore eliminated the need to discard the infested beds.

Over the course of the study, we noticed that a significant number of people believed bed bug infestations were caused by bed wetting behavior. It is possible that this belief is limited to the demographic present in this study, as all of the residents explained that they learned this as small children from their parents. Consideration should be given to include this topic in future educational material to dispel this misconception.

Bed bug management strategies are often reactionary in nature, with treatment of infestations occurring as they are reported to property management.<sup>11,15</sup> This approach is problematic because residents often fail to recognize and report infestations, which promotes the spread of bed bugs, can result in high infestation rates in multioccupancy and provides property management with a false understanding of the number of infestations that actually exist. At the onset of our study, management was unaware of 71% of the infestations. Through verbal interviews during service visits, we learned that residents in 62% of the apartments with bed bugs were unaware that bed bugs were present. Most of these residents (60%) were not experiencing bite symptoms, a phenomenon common among elderly individuals.<sup>24</sup> These results are similar to those reported by Wang *et al.*,<sup>12</sup> where only 50% of the elderly residents interviewed in an affordable housing community were aware of bed bug activity in their apartments. Our results clearly illustrate that relying on the reporting of bed bug infestation by residents is unreliable, promotes increased infestation size and furthers the spread of bed bugs to other apartments.

**Table 4.** Cost of the IPM program (\$US)

	Labor	Materials			Total	
		Interceptors	Encasements	Pesticide		Other
Education	600 <sup>a</sup>				268 <sup>b</sup>	868
Inspection	17 500	17 100	0	0	0	34 600
Treatment	21 010	2 694	5411	319	634 <sup>c</sup>	30 068
Subtotal	38 510	19 794	5411	320	1608	
Grand total						65 536

<sup>a</sup> Wages paid to staff to attend educational training session.  
<sup>b</sup> Includes costs for refreshments, paper, toner and copier maintenance to print educational materials and meeting announcements.  
<sup>c</sup> Includes cost of laundry tokens and heavy-duty 30 gal plastic bags.

Periodic inspections at 6 and 12 months were important for detecting unreported infestations. Following the initial inspection, a total of 16 apartments with bed bug activity were identified. Only 25% of these were reported to management by residents or home-health aides; the rest were the result of proactive inspections at 6 and 12 months. Moreover, periodic inspections facilitated early detection of infestations. Saenz *et al.*<sup>17</sup> concluded that early detection and mitigation of bed bug infestations are critical because infestations are generally started by only a few individuals. Our results support this conclusion, and demonstrate that early detection allows for early treatment, requires fewer service visits and less pesticide to eliminate an infestation and reduces spread of bugs compared with higher-level infestations that are well established. Surprisingly, during the 12 month inspection, an apartment with over 4000 bed bugs was identified. This apartment had no prior bed bug history and no activity detected during the initial or 6 month inspections. The apartment was more cluttered during the 12 month inspection than during the 6 month inspection. Piles of papers, magazines and clothing were strewn about on the sofa and throughout the apartment. Further investigation revealed that the bugs in this heavily infested apartment were apparently introduced in heavily infested packages received from a relative less than 2 months before the 12 month inspection. It was also clear that the residents in the apartment had no intention of reporting the bed bug infestation to property management. Fortunately, as a result of the periodic inspections, the problem was detected shortly after the bugs were introduced, subverting potential negative impacts on other apartments.

We demonstrated that a high level of bed bug population reduction is possible with an in-house pest management program in affordable housing where multiple obstacles to control exist. More importantly, we not only reduced bed bug numbers but also achieved a high elimination rate. Previous studies have achieved population reduction of >90%, but had low elimination rates.<sup>11–15,25,26</sup> By the end of the 12 month study, we achieved 92% elimination among the treated infestations, reducing the community-wide infestation rate from 15 to 2.2%. Wang *et al.*<sup>12</sup> suggested that a concentrated effort and greater financial input are very important in buildings with widespread infestations. Our results support this assertion. The high level of success achieved in our study was not realized without a great deal of persistence and vigilance. A mean number of seven service visits were required in the 61 apartments where bugs were eliminated. Similar numbers of visits have been reported in studies by Potter *et al.*,<sup>26,27</sup> Wang *et al.*<sup>11,13,14</sup> and Singh *et al.*,<sup>15</sup> where up to 66% of the apartments continued to experience bed bug activity even after treatment for

12 weeks or more. However, in our study a much higher elimination rate was achieved. Wang *et al.*<sup>14</sup> pointed out that the time to eliminate an infestation can amount to a few months or more, depending on infestation level, complexity of the environment, cooperation from the building occupants and thoroughness of the treatment procedures.

A variety of challenges contributed to the high number of service visits required to eliminate some of the infestations. During the first few months of the study, the in-house pest control technician was adjusting to the new treatment protocol and did not adhere to the biweekly follow-up service schedule. The lack of a second staff member to assist in some of the initial treatments and most of the follow-up service visits also compromised the quality and speed of the services. Finally, some residents did not follow the technician's instructions to reduce clutter and/or launder regularly, to assist the treatments. These factors contributed to the weak correlation between the initial bed bug count and (1) the number of service visits to eliminate the infestation and (2) the quantity of pesticides applied. For example, three of the initial 55 apartments treated had relatively low initial bed bug counts of 17, 19 and 33, but required 13, 19 and >22 service visits, respectively, to eliminate infestations. The mean quantity of pesticide applied (658 g) in these three apartments was above the mean quantity (201 g) for the 66 apartments treated. All three of these apartments were very cluttered, with bed bugs dispersed among items away from beds and upholstered furniture. Two of the apartments also had very heavy furniture that was difficult for the technician to move without a helper.

Lack of resident cooperation is commonly cited as a cause for control failure, even after months of repeated treatments.<sup>11,13–15,26,27</sup> To overcome inherent problems among low-income seniors, residents in our study were not asked to carry out any preparations prior to treatment. Instead, we took a more proactive stance. During each service visit, the staff bagged linens along with other infested items that could be laundered (i.e. stuffed animals, pillows, clothing, etc.), and residents who were not laundering their linen on a weekly basis were provided with tokens to encourage cooperation and offset the costs of laundering. Residents were also provided with heavy-duty garbage bags to offset the expenses associated with decluttering. Occasionally it was necessary for the technician to assist residents, particularly those with disabilities, with the decluttering process, and in a few cases a portable containerized heating chamber was employed to address items that could not be laundered or placed in a dryer. Over the course of the study, resident cooperation improved. A possible explanation for this is that residents had observed a

new level of commitment from property management in bed bug control since this IPM program was implemented.

Perhaps the most significant aspect of our IPM program was the implementation of an 'elimination' protocol. Seventy-six percent of the residents in our study mistakenly believed their units to be free of bed bugs while bed bugs were still present. This finding supports the idea that bed bugs often go undetected when their numbers are low, and that the decision when to stop bed bug treatment should not be based solely on resident satisfaction. Wang *et al.*<sup>11</sup> reported similar results in another study where, following treatment of 16 apartments, none of the residents complained about bed bug bites in spite of the fact that bed bugs were still detected by the authors in 50% of the apartments. In our study we defined bed bug elimination as the absence of bed bugs based upon a combination of interceptor catch, visual inspection and resident feedback for three consecutive visits. Moreover, interceptors were not only installed under legs of beds and furniture but also placed throughout the apartment, based upon the findings of Wang *et al.*<sup>12</sup> and Wang and Cooper,<sup>28</sup> decreasing the likelihood of premature termination of the eradication effort. The protocol proved to be very effective and prevented premature termination of follow-up service visits. Of the 63 apartments where bed bug counts were reduced to zero, bed bugs reappeared in 26 of them after one or two more inspections. Thus, the criterion of three consecutive visits without activity is important to prevent premature termination of the treatment. Following this criterion, only two out of the 63 apartments that were declared bed bug free experienced bed bug activity following termination of service. Only one bed bug was detected in each of these two apartments, and each had been removed from treatment for at least 6 months, suggesting a reintroduction rather than control failure in the two units. The very low reoccurrence rate demonstrates the robust nature of the elimination criterion and treatment program implemented in this study.

The use of interceptors proved to be invaluable for identification of infestations, guiding treatments, evaluation of the treatment program and ultimately the success of the IPM program.<sup>11,12</sup> Ninety-four percent of the apartments identified through proactive inspections were detected by interceptors placed under the legs of beds and upholstered furniture. Among the 286 visual inspections conducted in units where no bugs were detected by interceptors, only four additional infestations were found. Thus, using interceptors is a reliable method for complex-wide bed bug detection. Moreover, it requires less expertise than conducting visual inspections. Efficiencies were gained in the complex-wide monitoring as we became more familiar with the residents and their apartments, and infestation rates dropped. The time required to install and inspect interceptors decreased by over a half during the 6 month inspection compared with the initial inspection. The average time to install and inspect interceptors during the 12 month inspection was 2.1 and 2.9 min, respectively, compared with 4.5 and 6.6 min during the initial inspection. In spite of their simplicity and effectiveness, the value of interceptors for the detection, monitoring and control of bed bugs is largely unrealized by pest management professionals and property managers of multifamily housing communities. In a survey of 251 pest management professionals, Potter *et al.*<sup>29</sup> reported that 99% conduct visual inspections to identify bed bugs, while only 50% use interceptors in their detection programs. The results of our study demonstrate the effectiveness of interceptors for detecting bed bug activity and suggest that using interceptors is cost effective for large-scale inspections.

Placing interceptors away from the furniture played an important role in the control effort. It was not uncommon for bed bugs to be captured in interceptors away from sleeping and resting areas, even though no bugs were observed at beds and upholstered furniture. This helped to prevent premature termination of the follow-up program and provided information that influenced treatment decisions during follow-up service visits. For example, in several apartments, bed bugs captured in over 50% of the interceptors away from beds and furniture prompted treatment of all baseboards with Transport GHP, resulting in a rapid decrease in the widespread activity. In other apartments, the location of trapped bugs led to increased additional inspection of closets, resulting in the location of bugs that may otherwise have been missed. It has also been suggested that interceptors may contribute to the control of bed bugs by removing trapped bed bugs.<sup>12,14,15</sup>

Reducing pesticide use and exposure are key goals of an IPM program. However, the majority of the pest management industry continues to use pesticides as the primary tool for the control of bed bugs. In a survey of pest management professionals, 94% not only relied on pesticides but also typically treated beds with them.<sup>29</sup> Early detection through periodic inspections coupled with a low-impact treatment protocol contributed to the very low pesticide usage. Our control strategy relied mostly on non-chemical measures, and at no time was pesticide applied to beds. Instead, mattresses and box springs were encased, and visible bed bugs were removed or destroyed using a vacuum, commercial steamer or hand removal with forceps. When pesticides were used, applications were targeted mostly to areas where bed bug activity was observed. Additionally, control measures were limited to physical removal of visible bugs during follow-up service visits when bed bug counts were reduced to below five. Generalized treatment of baseboards throughout the apartment with liquid residuals was limited to just three of 66 apartments where bed bug activity was widespread based upon interceptor trap catch. An average of 201 g of finished product was applied to treat 66 apartments, which was  $\geq 90\%$  less compared with other reported field studies.<sup>25–27</sup> Also contributing to the reduction in pesticides applied was the threshold-based non-chemical protocol implemented at 6 months for newly identified apartments with an initial count of five or fewer bugs. Bed bugs were eliminated from all four of the apartments where the non-chemical only protocol was applied, suggesting that, for very low-level populations, elimination is possible without the use of pesticides. These results also provide evidence in support of the assertion made by Wang *et al.*<sup>12</sup> that the use of interceptors is even more pronounced when bed bug numbers are low because they catch the few bed bugs present, reduce the risk of population build-up and reduce the need for pesticides.

The success of an IPM program is of little value if it is not economically viable and sustainable. The average annual cost for bed bug management at Berry Gardens during the 2 years prior to this study was approximately \$US 57 215 per year and failed to manage the bed bug problem effectively. In comparison, the total cost to implement our IPM program was \$US 65 536 and yielded a dramatic reduction in the bed bug infestation rate. Proactive inspections accounted for 54% of the total costs but were integral to the success of our program. Potter *et al.*<sup>29</sup> questioned whether property managers could be convinced to pay for proactive inspections. Based upon our results, not implementing a proactive inspection is more costly in the long run in communities with high infestation rates. Following the initial year, the cost of the periodic inspections is reduced by approximately 33% because

the initial inspection is no longer necessary. In addition, inspection costs can be further reduced by eliminating visual inspections and relying on interceptor trap catch for detection of bed bugs. Visual inspections accounted for approximately 11% (\$US 3800) of the inspection costs and only resulted in identification of four out of 71 infestations. Although not yet tested, we also believe the community-wide inspection cost can be further reduced by at least another 25% through restricting one of the two annual inspections to apartments with activity in the previous 6 months. Treatment of 66 apartments accounted for 46% of the costs. The mean cost of treatment per infested unit in our study was \$US 456. This is similar to the estimated treatment cost of \$US 463–482 and \$US 445 per apartment reported by Wang *et al.*<sup>11</sup> and Wong *et al.*,<sup>7</sup> respectively. While the cost of treatment is similar to other reported costs, a major difference is that bed populations were eliminated and not just reduced in the apartments treated in our study. Assuming an annual new infestation rate of 3–4%, total costs to maintain the IPM program in all four buildings are projected to be between \$US 21 045 and \$US 22 456 per year (an average of \$US 59–63 per apartment per year) and are likely to be much less because high-level infestations should be rare, requiring less time and material to eliminate. For example, bed bug activity in six of nine apartments identified between the 6 and 12 month inspections was eliminated in a single service visit. Four of these infestations were eliminated without any pesticide application. It is also expected that the number of infestations will continue to decrease. We also believe that, after 2 years of maintaining very low infestation rates ( $\leq 3\%$ ), the two community-wide inspections per year can be reduced to one community-wide inspection and a second inspection limited to apartments with bed bug activity during the previous 12 months. A modified approach such as this would easily reduce inspection costs by two-thirds, bringing the annual cost to maintain the community-wide bed bug IPM program down to \$US 15 521–16 785. Further field evaluation would need to be done to confirm whether this modified inspection protocol is sufficient to maintain low infestation rates.

In conclusion, our bed bug IPM program provided a model that is both effective and economically practical for implementation in affordable housing communities suffering from chronic bed bug infestations. We also demonstrated that the reporting of infestations by residents is unreliable. The protocol would not have been effective without the dedication of the in-house technician who implemented it. This point should not be overlooked, as many pest control contracts are based upon low bid and may lack the dedication and attention to detail necessary for a high level of success. Obstacles from lack of resident cooperation can be reduced through education of residents and increased assistance from the housing staff. Ongoing education and commitment of the housing staff will play an important role in the complete eradication of bed bugs.

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