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Research article

Bed Bugs: Prevalence in Low-Income Communities, Resident's Reactions, and Implementation of a Low-Cost Inspection Protocol

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Abstract

We examined bed bug prevalence in 2,372 low-income apartments within 43 buildings in four New Jersey cities using a combination of resident interviews, brief visual inspections, and monitoring with Climbup Insect Interceptors. Infestation rates ranged from 3.8 to 29.5% among the buildings, with an overall infestation rate of 12.3%. Within each apartment, the bed area trapped significantly more bed bugs per trap than the sofa (or upholstered chair) area. African American residents had a proportionally higher number of bed bug infestations than white residents. Women were more likely to report bed bug bite symptoms than men. Only 68% of the residents who experienced bed bug infestations reported symptoms after being bitten ($n = 475$). Among those with self-reported symptoms ($n = 319$), the frequency of the reported symptoms was: pain 90%, itchiness 20%, welts 13%, and insomnia 8%. Fifty-nine percent of the residents ($n = 539$) who experienced bed bug infestations applied insecticides to control bed bugs. Climbup interceptors detected 89 ± 1% and brief visual inspections detected 72 ± 3% of the infestations. Only two out of 291 infestations were not detected by brief visual inspection or interceptors. Assuming US$50 per hour labor rate, the average per apartment cost for the building-wide bed bug monitoring protocol was US$12 per apartment. Forty-nine percent of the infestations detected by the protocol were in apartments whose residents were unaware of the bed bug activity.

Key words: *Cimex lectularius*, urban pest control, monitoring, integrated pest management, low-income housing

Bed bugs, *Cimex lectularius* L. and *Cimex hemipterus* (F.) (Hemiptera: Cimicidae), were common pests prior to World War II. The advent of modern synthetic insecticides quickly decimated most bed bug infestations in the United States during the 1940s and 1950s (Potter 2011). A resurgence of bed bugs has occurred in the United States, Canada, Australia, Europe, and some Asian countries during the past 15 years (Hwang et al. 2005, Cooper 2006, Potter 2006, Doggett and Russell 2008, Kilpinen et al. 2008, Wang et al. 2013). In 1998, bed bug case reports started appearing in the United States (Potter 2006). The bed bug resurgence in the United Kingdom began around 2000 (Boase 2001) followed by Australia (Doggett and Russell 2008) and China (Wang et al. 2013) in 2001 and 2007, respectively. The exact cause of the bed bug resurgence remains unclear but is believed to be the result of a combination of factors including increased international travel, lack of awareness, lack of effective monitoring and management tools, and widespread insecticide resistance (Doggett et al. 2004, Romero et al. 2007).

Bed bugs are considered a public health problem because they are environmentally communicable, cause ill-health, and lack of well-being (Aultman 2013). Exposure symptoms include pain, itchiness, raised welts, loss of sleep, psychological distress, etc. to humans (Goddard 2009, Rieder et al. 2012). Reactions to bed bug bites vary among individuals, with some individuals not experiencing bite symptoms, while others suffer from systemic symptoms of lethargy, dysphagia, chest tightness, and difficulty breathing (Goddard 2009, Doggett et al., unpublished data). Individuals who suffer bed bug infestations sometimes are denied of health care service or public services by service providers for fear of bed bugs (Aultman 2013). Controlling bed bug infestations is also quite expensive (Wang et al. 2009, Potter et al. 2013). People often discard their furniture or other personal belongings trying to get rid of bed bug infestations.

A number of bed bug surveys were conducted in response to the recent resurgence. The first systematic survey of bed bug infestations revealed that bed bugs started appearing in Canadian homeless shelters in 2001 (Hwang et al. 2005). The study found most of bed bug complaints received by the Toronto Public Health were in apartments (63%), shelters (15%), and rooming houses (11%). In contrast, pest control operators in Toronto reported most of their bed bug treatments were single-family dwellings (70%), apartments (18%), and shelters (8%). This difference was suggested due to a tendency for persons experiencing bed bug infestations in single-family dwellings to rely on pest cooperators, whereas apartment

dwellers and homeless shelter staff may be more likely to contact public health authorities. Bed bug infestations were reported at 20 of 65 (31%) homeless shelters. At one affected shelter, 4% of residents reported having bed bug bites. In a door–door survey of residents living in rowhomes located in a Philadelphia low-income neighborhood, 11.1% of the 596 interviewed residents reported recent infestations and ~2.52% had existing infestations (Wu et al. 2014). In Virginia, 17 out of 26 housing authorities had bed bugs; 82% of them had less than a 5% infestation rate, with the highest infestation rate of 19.4% (Wong et al. 2013). While these surveys provide useful information on the extent of the current bed bug infestations and some distribution patterns, accuracy of self-reported infestations can be questionable. Surveys that rely upon resident interview alone include false reports of bed bugs and fail to account for unreported infestations. (Cooper et al. 2015a). Accurate data on the extent of the current bed bug prevalence are lacking.

Recent studies revealed bed bugs spread through active dispersal, social interactions between residents, home visits, or exchange of infested furniture (Wang et al. 2010, Cooper et al. 2015b). Bed bugs are most prevalent in multiunit dwellings compared to single homes due to the proximity of units to each other within a building. Additionally, bed bug distributions in apartment buildings tend to be clustered, with one building having many infestations, and other nearby buildings bed bug-free (Doggett and Russell 2008, Wang et al. 2010). Prevalence of bed bug infestations is also associated with resident's socio-economic status. Previous surveys indicated low-income communities in the United States were more disproportionally burdened with bed bug problems than middle- and upper-income communities (Wang et al. 2010, Wong et al. 2013). Lack of financial resources to hire top-tier pest control service, ineffective pest management plans, and lack of resident cooperation in these communities contribute to chronic bed bug infestations (Wang et al. 2009, 2012, 2014, 2015; Cooper et al. 2015a).

Although bed bug resurgence has been recognized widely in the past 15 yr, there remain many questions about the current bed bug resurgence. How prevalent is the bed bug infestation in various communities? What are the main bed bug dispersal mechanisms within and among communities? How are sociological factors related to bed bug infestations? What materials and methods are used by residents to control bed bugs? Answering these types of questions is important for identifying challenges and opportunities for better bed bug management.

To combat the current bed bug resurgence in our society, it is logical that the effort should be concentrated where bed bug infestations are most prevalent. In this study, we selected low-income communities in four cities to investigate bed bug infestation patterns, impact of the bed bug infestations, and bed bug control methods used by residents. We used a combination of resident interview combined with community-wide inspection of apartments for bed bug activity to provide an accurate assessment of bed bug prevalence within low-income apartment housing communities. We also analyzed the cost and effectiveness of an economical community-wide bed bug inspection protocol. Our results will help gain an accurate picture of the current prevalence of bed bugs and provide valuable information for future bed bug management strategies.

Materials and Methods

Study Sites and Buildings

Four low-income communities with known history of bed bug infestations in northern New Jersey were selected for this study. They are located in the cities Bayonne, Hackensack, Irvington, and Paterson. We selected 43 buildings, which consisted of 2,730 apartments. We accessed 2,372 (87%) apartments using bed bug inspections and resident interviews. The other apartments were either vacant, without keys, or without resident consent for inspections. These buildings were managed by the respective public housing authorities in each city. In Bayonne and Irvington, only buildings occupied by seniors (≥62 yr old) were included. In Hackensack and Paterson, all buildings managed by the respective housing authorities were included. Family units represented 29 and 26% of the total units at Hackensack and Paterson, respectively. In each city, the distance between the two closest buildings ranged from 20 m to 3 km, except for two buildings that were connected through a hallway at Hackensack. Monthly bed bug control was provided by pest control contractors hired by the housing authorities in each city except Irvington where Rutgers University researchers treated ~45 apartments six months prior to this study.

Study Design

The study was a community-wide cross-sectional survey conducted between January and April of 2014. Three methods were used to detect bed bug infestations.

Visual Inspections

At least 1–3 d before the inspection, a notice was sent to inform all residents in each building about the upcoming bed bug inspections. Three experienced researchers (CW, NS, CZ) conducted visual inspections to determine whether live bed bugs or signs of bed bug infestation were present. The visual inspections were brief and cursory. For each bed, the corners of the bed sheets, bed frame, mattress, and box-spring were inspected. For each sofa or couch, seams located on the upper portion were inspected. Heavy furniture (bed and sofa) were not turned over during inspection. Apartments with dead bed bugs, shed skins, eggs, feces, blood smears from crushed bed bugs, and units of residents with complaints about bed bug bites but no live bugs observed during visual inspection were recorded as apartments with suspected bed bug activity. Climbup Insect Interceptors (Susan McKnight Inc., Memphis, TN), hereafter referred to as interceptors or traps, were installed, as described in the next section, as an additional detection measure.

Resident Interviews

The interviewers received Rutgers University IRB approval (protocol # E14-097). A consent form was presented to each resident prior to conducting the interviews. Only those residents who were at home during the visual inspection were interviewed. Interviews were conducted just prior to the visual inspection. They were first asked whether they experienced bed bug infestations or have current infestations. If they answered yes, then a questionnaire was read to the residents and answers were recorded (Table 1). A total of 539 questionnaires (23% of the accessed apartments) were completed. For Spanish speaking residents a translator conducted the interview.

Installing Interceptors

Interceptors were installed under bed and sofa legs in both suspected apartments and those apartments with previously identified bed bugs by our brief visual inspections. These interceptors were used in several previous studies and found highly effective in detecting low-level bed bug infestations (Wang et al. 2011; Cooper et al. 2014, 2015a). The reason for installing interceptors in apartments where visual inspection found live bed bugs was to obtain information on infestation levels and distribution patterns between the beds and sofas. The interceptors were inspected ~10–17 d after installation.

Table 1. Questionnaire to residents about bed bug infestation

1. How long have you lived in this building complex? _____
2. Have you experienced bed bug infestations in the past?
   a) Yes ____; How long ago? ____; How did you get bed bugs? _____
   b) No ____
3. Do you know if you currently have a bed bug infestation in your apartment?
   a) Yes ____; No ____; Not sure ___
4. If bed bugs are found in your apartment, what is your level of concern?
   a) No concern ____; Some concern ____; Very concerned ____
5. When you had bed bugs, what symptom have you experienced?
   a) I had no symptoms ____;
   b) I had some symptoms ____; Specify _____
   c) I do not know yet ____
6. What have you done to control bed bugs? (Check all that apply)
   a) Used pesticides ____; Product name(s) _____; Quantity/frequency _____
   b) Discarded furniture and belongings____; Quantity/frequency _____
   c) Laundering of bed linens_____; Frequency _____
   d) Other _____
7. Are you satisfied with the current pest control service provided by the building management office?
   a) Yes ____; No ____; No comment ____

Self-identified demographic information

Senior/non-senior ____ ; Gender ____ ; Ethnicity _____

The time in each building from entering the first apartment until the end of each work day, minus the lunch break, was recorded. One or two people inspected each apartment. The total man hours were divided by the number of apartments inspected to obtain mean inspection time per apartment. If two people inspected an apartment, the total inspection time was multiplied by two to obtain total time spent per apartment.

Data Analysis

To standardize the bed bug counts from interceptors, the total counts in each apartment were adjusted by dividing the counts by number of days of placement then multiplied by 14 to yield 14 d counts. Bed bug counts were logarithmic transformed to fit the assumption of normal distribution. Differences in the logarithmic transformed bed bug counts per interceptor among the interceptors under beds and sofas were analyzed using Student's *t*-test. Chi-square analysis was performed to test the relationship between race and bed bug infestation, between levels of concern to bed bugs and resident age or gender, between presence of bed bug bite symptoms and gender or age, between presence of bed bug infestation and satisfaction level to pest control service, between awareness of infestation and frequency of laundering. The association between percentage of apartments with existing bed bugs and the length of residency was analyzed using regression analysis. All statistical analyses were conducted using SAS software (version 9.3; SAS Institute 2010).

Results

Characteristics of the Bed Bug Infestations

All bed bug infestations were *C. lectularius*. The bed bug infestation rates in four cities ranged from 5.7 to 24.5% (Table 2). The overall infestation rate (the total number of infested apartments divided by the total number of accessed apartments) was 12.3%. Bed bug count data, based upon adjusted 14-d trap catch, were collected from 262 infested apartments. Distribution of the counts is shown in Fig. 1. The majority (54%) of the apartments trapped 1–10 bed bugs, 10% of the apartments had a zero trap count despite bed bugs being found by initial visual inspections. The maximum bed bug count in interceptors from one apartment was 780.

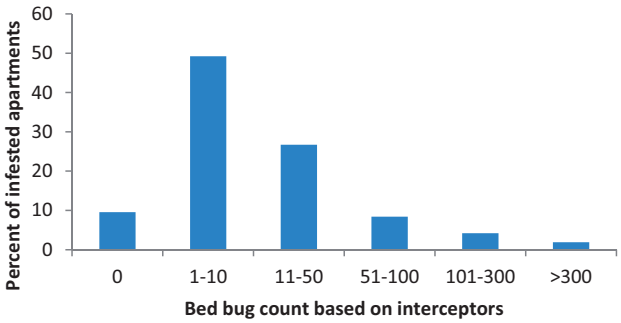

Fig. 1. Distribution of bed bug counts based on interceptors placed under furniture legs for 14 d in 262 bed bug-infested apartments. (Online figure in color.)

Within each city, bed bug infestation rates varied greatly among building complexes. A building complex is defined as a high-rise apartment building or a group of low-rise apartment buildings located close to each other. The ranges of infestation rates among building complexes in each city were: Bayonne 3.8 to 13.0%, Hackensack 4.1 to 8.2%, Irvington 23.6 to 25.2%, and Paterson 6.5 to 29.5%.

To compare the bed bug distribution between beds and sofas (or upholstered chairs), we only included one-bedroom apartments and studio apartments that had interceptors installed under the beds (usually in the bedroom) and sofas (usually in the living room). Apartments with more than one bedroom were excluded because more than one bed used in each apartment and therefore, many more interceptors were installed under the beds than under the sofas. We also excluded 11 apartments out of 184 because they had total bed bug counts per apartment >100. This threshold was used to avoid large variances when calculating the mean bed bug count per trap. The mean number of interceptors under the beds and sofas in the one-bedroom and studio apartments were 4.1 ± 0.1 and 4.9 ± 0.2, respectively. Significantly more bed bugs were found per interceptor under the beds than those under the sofas ($t = 6.6$; $df = 183$; $P < 0.0001$). The mean bed bug count per interceptor

Table 2. Prevalence of bed bug infestations in low-income apartments in four cities in New Jersey in 2014

City	No. of building complexes	No. of buildings	No. of accessed apartments	% access rate[a]	No. of infested apartments	% infestation rate[b]
Bayonne	4	6	669	83	57	8.5
Hackensack	6	13	489	98	28	5.7
Irvington	2	2	359	83	88	24.5
Paterson	7	22	855	86	118	13.8
Total	19	43	2,372	87	291	12.3

[a] Access rate is the number of accessed apartments divided by the total number of apartments in the buildings.
[b] Infestation rate is the number of infested apartments divided by the number of accessed apartments.

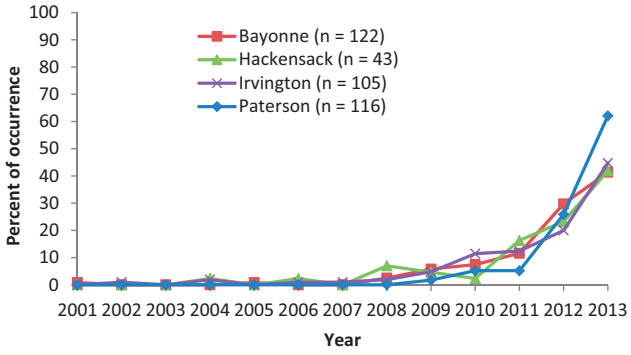

Fig. 2. Distribution of bed bug infestation history based on interviews with low-income residents in four cities in New Jersey. (Online figure in color.)

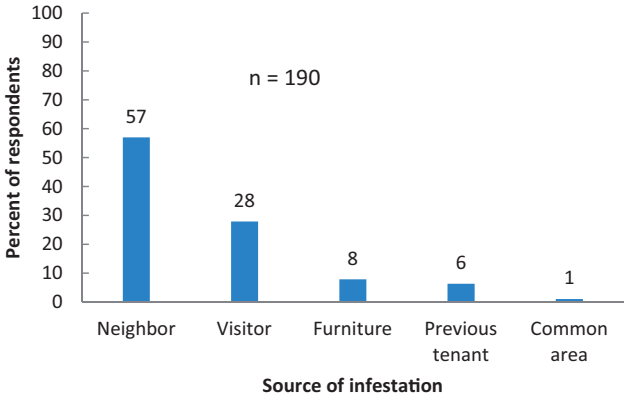

Fig. 3. Sources of bed bug infestations based on resident interviews. (Online figure in color.)

under the beds and sofas were 2.8 ± 0.3 and 1.2 ± 0.2, respectively. There were 27 (15%) apartments in which bed bugs were only detected under sofas and 51 (28%) apartments that bed bugs were only detected under beds. These numbers suggest that if interceptors were not installed under both sofas and beds, 15 to 28% of the infestations would have been missed.

Among the 1,840 residents who were at home when conducting inspections, 25.7% said they experienced bed bugs in recent years or their homes were currently infested. Residents who experienced bed bugs were asked when they first experienced bed bug infestations. Among the 386 interviewed residents who experienced bed bug infestations during the bed bug resurgence, the earliest infestation occurred in 2001 (Fig. 2). Since 2011, the number of new infestations started to increase rapidly. There was a significant negative correlation between the number of years of residence and the percentage of apartments with active infestations among the 197 residents who resided in their apartments for five years or less ($t = -9.65$; $P = 0.002$). Ninety-six percent of the infestations were found in homes whose tenants moved in within last 5 yr, compared to 37% of the tenants that had lived in their apartment for over 5 yr. Among the 88 residents who knew their apartments had active infestations at the time of survey, 57% had bed bugs for more than 6 months and 36% of them had bed bugs for more than a year, indicating the pest control services were ineffective in eradicating infestations quickly.

When asked how bed bugs were introduced, 72% of the interviewed residents ($n = 504$) could not tell the source of infestation. Among those who thought they knew the source of infestations ($n = 190$), most believed the bed bugs came from their neighbors (57%), followed by visitors (28%) to their apartment (Fig. 3).

African American, white, and Hispanic ethnic groups represented 96% of the occupants in the surveyed communities (Fig. 4). Hispanic people accounted for 16% of the population and the same percentage of Hispanic people had existing bed bug infestations. Between African American and White residents, African American residents had proportionally higher number of bed bug infestations than white residents ($\chi^2 = 7.1$; df = 1; $P = 0.01$; $n = 420$).

Residents' Reactions to Bed Bug Bites and Infestations

The three most common ethnic groups: African American, white, and Hispanic were further analyzed for association between ethnic background, gender, age group, and reactions to bed bugs. Among the 476 residents, the distribution of age group (senior vs. nonsenior) and gender (male vs. female) across the three ethnic groups had no significant difference (Age: $\chi^2 = 4.3$; df = 2; $P = 0.86$. Gender: $\chi^2 = 1.3$; df = 2; $P = 0.51$). Overall, 67, 27, and 6% of the interviewed residents were very concerned, somewhat concerned, or not concerned, respectively. All these residents had previous experience with bed bug infestations. Seniors and nonseniors had similar levels of concerns with bed bug infestations ($\chi^2 = 0.09$; df = 2; $P = 0.96$). Among women, 73, 22, and 5% of them were very concerned, somewhat concerned, or not concerned, respectively. Among men, 60, 33, and 7% of them were very concerned, somewhat concerned, or not concerned, respectively. Women had higher levels of concerns about bed bugs than men ($\chi^2 = 9.1$; df = 2; $P = 0.01$). Hispanic residents were more likely to express "no concern" than white and African American residents ($\chi^2 = 13.9$; df = 4; $P = 0.01$; Table 3).

Overall, 68% of the residents reported symptoms and 32% did not report symptoms after being bitten ($n = 475$). Among those with self-reported symptoms ($n = 319$), the symptoms and their frequency were: pain 90%, itchiness 20%, welts 13%, and insomnia 8%. Women (72%) were more likely to report bed bug bite symptoms than men (63%) ($\chi^2 = 4.7$; df = 1; $P = 0.04$). There was no

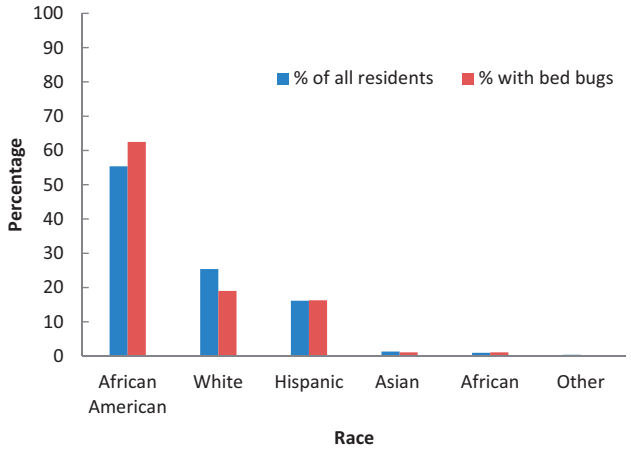

Fig. 4. Resident demographics and prevalence of bed bug infestations within each demographic group. (Online figure in color.)

Table 3. Relationship between ethnicity and levels of concern to bed bug infestations ($n = 476$)

Ethnicity	Percent		
	No concern	Some concern	Very concerned
African American	4	27	70
White	4	26	70
Hispanic	14	31	55

significant difference between seniors and nonseniors in the presence of self-reported symptoms from bed bug bites ($\chi^2 = 0.02$; df = 1; $P = 0.88$).

Among the residents who had existing bed bug infestations ($n = 64$) and those who did not ($n = 203$), 78 and 93% of them, respectively, were satisfied with the pest control service provided by management. Presence of bed bugs in their homes was associated with lower satisfaction rates ($\chi^2 = 11.6$; df = 1; $P = 0.001$) toward the pest control service provider. The Irvington site was excluded in this analysis because Rutgers University researchers treated many of the infested apartments before the surveys. Among those who had bed bug history ($n = 523$), 44% discarded furniture or personal items. The two most frequently discarded types of furniture were beds (27%) and sofas or chairs (23%).

Among 440 interviewed residents who had bed bug history, 70% laundered bed linens at least once a week, 30% laundered no more frequently than every other week. For those with active bed bug infestations ($n = 146$), there was no significant relationship between awareness of the presence of bed bugs in the apartment and frequency of laundering ($\chi^2 = 1.6$; df = 1, $P = 0.21$).

Insecticide Use by Residents

Fifty-nine percent of the residents who experienced bed bug infestations ($n = 539$) applied insecticides to control bed bugs. The insecticides belonged to three formulations: spray, dust, and fogger. Among those residents who used insecticides and provided responses, 95, 7, and 5% used spray, dust, and fogger, respectively ($n = 307$); 92% used one formulation and 8% used two formulations ($n = 306$). Based on the chemical structure of the active ingredients, we classified the products into five groups: pyrethroids, non-pyrethroid synthetic materials, essential oils, inorganic compounds, and household products (detergents, alcohol, mothballs, dryer sheets, etc.). Based on answers obtained from 245 residents, the frequency of products used was: pyrethroids 72%, household products 22%, essential oils 12%, inorganic materials 7%, and non-pyrethroid synthetic spray 1%. The top three ($n = 262$) most frequently purchased brands were: Hotshot 27% (Spectrum Group, St. Louis, MO), J T Eaton 13% (J T Eaton Co., Twinsburg, OH), and Raid 11% (S C Johnson & Son Inc., Racine, WI). In addition to insecticides, many residents also used household products to control bed bugs.

Cost and Accuracy of the Bed Bug Inspection Protocol

Inspection time was recorded during inspections in 1,794 apartments at Bayonne, Hackensack, and Paterson. Approximately 90% of them were one-bedroom or studio apartments, 10% were two- to four-bedroom apartments. Interceptors were installed in 20% of the apartments. Each completed questionnaire took an average of 3.8 ± 0.6 min. The mean time for resident interview, visual inspection, laying interceptors, walking between apartments, and waiting for opening the doors was 7.1 ± 1.0 min per apartment. For those apartments where interceptors were installed, the mean time to pick up and examine interceptors per apartment was 13.3 ± 2.6 min. This included the time for collecting live specimens in 194 apartments for later identification. For all 1,794 accessed apartments with accurate records, the average inspection time spent per apartment (including inspection of interceptors if they were installed) was 10.2 ± 1.4 min. In addition to the time cost, 4,180 interceptors (or 1.76 interceptors per accessed unit) were used. Assuming US$50 per hour labor rate and US$2 per interceptor, the average inspection cost per apartment is US$12 (labor US$8.5, material US$3.5). It should be noted that we installed interceptors in apartments where visual inspections already detected bed bugs. This was to obtain bed bug counts and distribution information. If only for bed bug detection purpose, we would only need to install interceptors in 8% instead of 20% of the apartments.

The majority of the 291 infestations identified in this study were unknown to the housing authority in Hackensack, Irvington, and Paterson (Table 4). Only Bayonne Housing Authority had accurate information about the status of their bed bug infestations. The four housing authorities were aware of less than 33% of the infestations. In all four cities, using interceptors was more accurate than relying on brief visual inspections. Overall, interceptors detected $89 \pm 1\%$ (257 of 291 apartments) and visual inspections detected $72 \pm 3\%$ (215 of 291 apartments) of the infestations.

Only two infestations, not detected by both visual inspection and interceptors, were found by residents. Among the 193 residents who had existing bed bugs in their homes and were available for interview, 47% were aware of the presence of bed bugs, 49% were unaware of the presence of bed bugs, and 4% were not sure.

Discussion

Community-wide inspections revealed a number of interesting bed bug infestation patterns. They confirmed that low-income communities experienced a resurgence of bed bug infestations and had high bed bug infestation rates. The trajectory of the bed bug infestation history in four cities suggests that bed bugs started to show up in residential buildings in the early 2000s, confirming earlier reports about the recent bed bug resurgence (Potter 2006, Doggett and Russell 2008). Earlier literature indicates bed bug resurgence was initially reported in middle-income apartments (Cooper 2006). This study shows that the rapid increase of infestations in low-income

Table 4. Bed bug detection rates by two inspection methods

City	No. of infestations	No. of infestations known by housing staff[a]	% infestations detected by interceptors	% infestations detected by visual inspections
Bayonne	57	63	88	70
Hackensack	28	9	89	64
Irvington	88	<20	91	80
Paterson	118	26	86	74

[a] These were estimated number of infestations to the best knowledge of the management office.

communities occurred approximately in 2011. Newer tenants were more likely to have bed bugs, indicating that resident turnover may be a factor in bed bug resurgence in apartment buildings. The high percentage of infestations that were unknown by residents and housing management highlights the importance of bed bug monitoring. Bed bug prevalence was associated with race in the studied communities; people's level of concern about bed bugs was associated with gender. The bed bug management contracts in the four low-income communities were not effective in bed bug elimination. Overall, results suggest an urgent need to suppress bed bug infestations in these communities and reduce further bed bug dispersal among communities. Specifically, the following steps will be critical: 1) adopt a proactive building-wide bed bug monitoring policy; 2) eliminate existing bed bug infestations in vacated units before allowing new tenants to move in; 3) monitor bed bug infestation soon after new tenants move in; 4) revise current bed bug control practices in at risk communities and resident groups; 5) educate residents in abandoning ineffective control methods and adopting effective and safer bed bug management practices.

Once introduced, bed bugs can rapidly spread to neighboring units and cause high infestation rates in multiunit dwellings (Doggett and Russell 2008, Wang et al. 2010). However, we found that the infestation rates can vary greatly among the buildings within a city. For instance, the lowest and highest infestation rate in Paterson was 7 and 30%, respectively. Both buildings had the first infestation four years ago and had similar resident demographic makeup. They were serviced by the same pest control provider. The top five most heavily infested apartments in the building with 30% infestation rate had 65–336 bed bug counts based on interceptors. Whereas, the two most heavily infested units in the building with 7% infestation rate had bed bug counts of 63 and 84. Recent studies show bed bugs can actively disperse into neighboring units within a building (Cooper et al. 2015b). The difference in the number of heavily infested apartments present in a building is likely to be a factor contributing to the different infestation rates in these two buildings. Other factors such resident turnover, resident social activities, house-keeping behavior, and resident level of cooperation with bed bug control may also contribute to the variations in the speed of bed bug dispersal within a building. Further investigations of these factors will be helpful for designing appropriate methods to minimize the dispersal of bed bugs in these communities.

Naturally, those residents who have bed bugs should be concerned and take steps to eliminate bed bugs. We therefore hypothesized that those who had bed bugs and were aware of their presence would launder their bed linens more frequently; however, a correlation was not detected, indicating that residents were not increasingly diligent or aware of the importance of hot laundering for controlling bed bugs. We found a negative association between satisfaction to pest control service and presence of bed bugs. However, a relatively high percentage (78%) of residents who had existing bed bug infestations were still happy with the pest control service. These results suggest the high tolerance of bed bugs among residents living in low-income communities, or lack of bite symptoms from the presence of low-level bed bug populations, or the survey distributor was thought being related with pest control service.

We demonstrated an economical and effective large-scale bed bug inspection protocol. It consisted of a combination of resident/staff interviews, brief visual inspections, and installation of interceptors under bed and sofa legs immediately after visual inspections in suspected apartments. The suspected apartments are those where no live bed bugs were found by brief visual inspection but had signs of bed bugs or residents believed bed bugs were present. A brief visual inspection of all units in a building is an important step in building-wide bed bug surveys. The rational for this was: 1) a detailed visual inspection of every apartment is too labor intensive for community-wide inspections and will require two staff members; 2) while live bed bugs are more difficult to find, bed bug signs can be easily detected by a quick visual inspection; 3) a brief visual inspection is much more economical and faster than installing and picking up interceptors in all apartments; 4) it provides information on the exact bed bug hiding sites and distribution; and 5) it can be easily adopted by housing staff or residents who wish to conduct self-inspections and do not have a helper to assist in lifting heavy furniture. The average time required to inspect an apartment may be less than 7.1 min (including time spent between apartments). A thorough visual inspection of similar apartments took an average of 16.3 min (Cooper et al. 2015a) and required two people to turn over the furniture. As shown in this study, the brief visual inspections were quite effective in detecting the majority of the infestations, eliminating the need to install interceptors in most of the apartments and saved material and labor costs. Because visual inspections often miss some infestations, installing interceptors only in apartments with uncertainty from visual inspections provides an additional detection method that ensures accuracy of the building-wide inspection protocol. The four housing authorities that were included in this study represented those with significant bed bug problems. Only three of the 26 surveyed housing authorities in Virginia had > 5% bed bug infestation rate (Wong et al. 2013), and the percentage of apartments within an apartment community that need interceptors should be below 8% based on our study.

Resident report of bed bug sightings was least reliable because of the high percentage of people (49%) who were unaware of bed bugs, even when their homes were infested. Similarly, a survey of 20 residents whose homes were infested found 70% of them were unaware of the presence of bed bugs (Wang et al. 2015). When both beds and sofas are present in an apartment, both of them should be inspected using visual inspection or interceptors to ensure accuracy. The cost savings of installing interceptors only under the beds does not justify the loss of accuracy. The protocol used in this study certainly will not detect all infestations; if cost is not a concern, installing more interceptors per apartment or inspecting the interceptors three times, at biweekly intervals, will increase the likelihood of detecting very low-level populations (Cooper et al. 2015c). Nevertheless, >67% of the infestations detected were not previously known by property management. Moreover, 53% of the infestations existed in apartments belonging to residents who were either unaware or unsure their apartment was infested.

Canine detection has been used for building-wide inspections recently (Cooper et al. 2014). The inspection protocol used in this

study is much more effective in detecting infestations than using trained canines. Furthermore, our protocol does not produce false alerts compared to canine inspections. The protocol needs an average of 10.2 min per apartment for visual inspection, interviewing residents, and installation and removal of interceptors in 20% of the apartments. Cooper et al. (2014) reported US$10–21 per apartment (average US$15.8) charged by canine inspection companies (Cooper et al. 2014). The labor cost of 10.2 min plus material cost of 1.76 interceptors per surveyed apartment (not just the apartments with interceptors installed) based on this protocol is lower than that by canine inspections (assuming highest labor cost of US$120/h). This cost could be even lower when monitoring buildings with very low infestation rates since the majority of the apartments will not require installation of interceptors. In addition, interceptors installed in bed bug-infested apartments are useful for monitoring treatment results. They are recommended in integrated pest management programs (Cooper et al. 2015a).

Cooper et al. (2015a) installed interceptors in all apartments and conducted detailed visual inspections when bed bugs were not detected by interceptors for building-wide bed bug surveys. The mean time to install interceptors, inspect interceptors, and conduct detailed visual inspection per one-bedroom or studio unit was 2.1, 2.9, and 16.3 min, respectively. Our protocol saved at least 80% material costs (installing interceptors in 20% versus 100% apartments) by performing visual inspection first and only placing monitors in apartments with known or suspected activity. The time saving of our protocol also is significant. Cooper et al. (2015a) spent 16.3 min/apartment (excluding time between apartments) for visual inspection in 81 of the 209 accessed apartments. This translates into 6.2 min per accessed apartment. Our protocol required 7.1 min/apartment including time for filling out a questionnaire in 23% of the accessed apartments, laying interceptors in 20% of the accessed apartments, and the down time between apartments. If excluding the time for questionnaire (3.8 min per apartments in 23% of the units), the time spent per apartment would have been 6.2 min, which is the same as that by Cooper et al. (2015a). If we further exclude the down time between apartments from our recorded time, our protocol would require a much shorter time than that reported by Cooper et al. (2015a). The saving is more distinct when inspecting multiunit buildings with very low infestation rates. For instance, in a 49-unit building in Hackensack where only two apartments had bed bugs, interceptors were only installed in three apartments after visual inspections. The labor cost was 348 min for visual inspections and 27 min for picking up interceptors (total 375 min). If we installed interceptors in all 49 apartments, the labor cost alone for installation and inspection of interceptors would be 544 min based on Cooper et al. (2015a). Our protocol saves 36% labor and 94% material costs compared to relying on interceptors alone. When compared to relying on detailed visual inspections alone, our protocol saves 70% labor. Although our protocol requires two trips for some apartments (to install and inspect interceptors) and material costs, it will still be more economical than relying on detailed visual inspections alone.

The majority of the residents (59%) who experienced bed bugs applied insecticides themselves in spite of the availability of professional pest control service contracted by the housing authorities. The vast majority of the residents who applied insecticides used pyrethroids, household products, and essential oils. These products are largely ineffective for controlling bed bugs due to bed bug resistance to pyrethroids and inherent lack of efficacy of most nonpyrethroid products used by residents (Romero et al. 2007, Singh et al. 2014). More concerning is that applying pyrethroid sprays on or around beds and sofas for bed bug control poses high risk of insecticide exposure by occupants. Hot laundering is an effective nonchemical bed bug control method (Naylor and Boase 2010). We found people who had an existing bed bug infestation and were aware of bed bug presence did not launder more frequently than those who did not have existing bed bugs. Although 70% of the interviewed residents said they laundered their bed linens at least weekly, this number might be inflated, as some residents might report shorter laundry intervals to disguise embarrassment. Educating residents and housing staff on the use of effective and safer nonchemical control methods is a logical step to achieve better control results and to reduce potential health risks from insecticide applications.

As the survey indicated, residents believed infested neighbors and visitors were primary sources of new bed bug introductions. Resident turnover is related to new bed bug introductions. High infestation rates and the presence of heavily infested apartments in the surveyed communities render them as reservoirs for new infestations. Low-income communities are more susceptible to the burden of bed bug infestations due to financial constraints. Successful bed bug elimination campaigns will hinge upon the implementation of more effective bed bug management programs in these communities.

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