

# Effects of Various Interventions, Including Mass Trapping with Passive Pitfall Traps, on Low-Level Bed Bug Populations in Apartments

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## Abstract

Two experiments were conducted to evaluate the effects of various interventions on low-level bed bug, *Cimex lectularius* L., populations in occupied apartments. The first experiment was conducted in occupied apartments under three intervention conditions: never treated (Group I), recently treated with no further treatment (Group II), and recently treated with continued treatment (Group III). Each apartment was monitored with pitfall-style traps (interceptors) installed at beds and upholstered furniture (sleeping and resting areas) along with ~18 additional interceptors throughout the apartment. The traps were inspected every 2 wk. After 22 wk, bed bugs had been eliminated (zero trap catch for eight consecutive weeks and none detected in visual inspections) in 96, 87, and 100% of the apartments in Groups I, II, and III, respectively. The second experiment investigated the impact of interceptors as a control measure in apartments with low-level infestations. In the treatment group, interceptors were continuously installed at and away from sleeping and resting areas and were inspected every 2 wk for 16 wk. In the control group, interceptors were placed in a similar fashion as the treatment group but were only placed during 6–8 and 14–16 wk to obtain bed bug counts. Bed bug counts were significantly lower at 8 wk in the treatment group than in the control group. At 16 wk, bed bugs were eliminated in 50% of the apartments in the treatment group. The implications of our results in the development of bed bug management strategies and monitoring protocols are discussed.

**Key words:** trap, interceptor, monitoring, pest management, population dynamics

The recent resurgence of bed bugs, *Cimex lectularius* L. and *Cimex hemipterus* (F.), has been global in nature (Davies et al. 2012, Doggett et al. 2012, Potter et al. 2013), creating economic (Doggett et al. 2012), social (Eddy and Jones 2011, Aultman 2012), and public health (Goddard and de Shazo 2009, Aultman 2012, Doggett et al. 2012, Susser et al. 2012) challenges, as bed bugs spread throughout communities. Failure to recognize or report the presence of bed bugs promotes the establishment of infestations that are more costly and difficult to eliminate (Wang et al. 2010, Singh et al. 2013, Stedfast and Miller 2014, Cooper et al. 2015a). In a field study conducted by Singh et al. (2013), infestations in apartments with initial bed bug counts below 30 were eliminated within 3.5 mo, while those with initial counts over 30 continued to persist beyond 5.5 mo, in spite of repeated treatments. Other field studies have demonstrated that bed bug populations can usually be reduced by more than 90%; however, it is not uncommon for small numbers of bed bugs to persist even after repeated treatments (Potter et al. 2006, 2008, 2012; Moore and Miller 2009; Wang et al. 2009, 2013). Reducing but not eliminating infestations can lead to chronic infestations. Installation of passive pitfall-style traps (interceptors) at, and away from, host

sleeping and resting areas, is effective for monitoring low-level bed bug activity (Cooper et al. 2014) and can prevent the premature termination of treatments in apartments where bed bugs are present in low numbers but are not detected at host sleeping and resting areas (Cooper et al. 2015a).

Bed bugs exist in small numbers when they are first introduced into a new environment and just prior to the eradication of an infestation (Booth et al. 2012). The success of bed bugs in becoming established following a new introduction or becoming re-established after having populations reduced to very low levels has not been examined. While it is generally agreed upon that light infestations are more easily controlled and less likely to spread (Pinto et al. 2007), the dynamics of low-level infestations are poorly understood. In this paper, two experiments were conducted to investigate the effect of various interventions in apartments with low-level bed bug populations. The first experiment evaluated the dynamics of low-level bed bug populations in apartments with or without treatments. The second experiment investigated the impact of interceptors as a control measure in apartments with low-level infestations.

## Materials and Methods

### Experiment I. Trap Catch in Untreated and Treated Apartments With Low-Level Infestations

The purpose of this experiment was to study the dynamics of low-level bed bug ( $\leq 10$  based on trap counts) populations (*C. lectularius*) in apartments with or without treatments. The apartments were divided into three groups—I: never treated, II: recently treated with no further treatment, III: recently treated with continued treatment. The experiment was conducted in one-bedroom apartments (47 m<sup>2</sup>) in an affordable housing community occupied by elderly (>62 yr old) and disabled residents located in Newark, NJ. This study protocol (number E11-766) received approval from Rutgers University Institutional Review Board (IRB).

#### Group I

Apartments that had not been treated for bed bugs within the previous two years were used. Climbug insect interceptors (Susan McKnight, Inc., Memphis, TN), hereafter referred to as interceptors or traps, were installed at 0 wk under the legs of beds and upholstered furniture or immediately adjacent to the furniture, if placement under legs was not feasible. Additional 17–18 interceptors were placed throughout each apartment. Figure 1 shows the typical location of traps in apartments. The mean (min, max) number of interceptors placed per apartment was 28 (21, 38). Interceptors were inspected for the presence of bed bugs 14 d later. Apartments with a total trap catch of 1–10 bed bugs were included. None of the residents were aware that they had existing bed bug activity. Residents' approval was obtained prior to the study. Residents were asked not to apply any insecticides in their apartments during the study. In total, 23 apartments were identified. No corrective actions (except

installation of traps) were taken to control the existing bed bugs. Each apartment was visited by two to three Rutgers researchers every 14 d until no bed bugs were captured in any of the interceptors for eight consecutive weeks at which time, a visual inspection of the bed and upholstered furniture was conducted. If bed bugs were detected during the visual inspection, the time was set back to 0 wk and the process was repeated until the elimination criterion was achieved. During each visit, interceptors were inspected for bed bugs, then cleaned and lubricated with talc or replaced with new traps, depending upon their conditions.

#### Groups II and III

Apartments that were recently treated by an independent professional pest control company for a bed bug infestation were included. The pest control company was blinded from the treatments and the objectives of the experiment. The initial treatment of these apartments by the pest control company included the following: 1) vacuuming visible bed bugs, 2) application of steam to furniture and baseboards, 3) encasing of mattresses and box springs with bed bug encasements (Allerzip Protect-A-Bed, Northbrook, IL), 4) installation of interceptors under the legs of beds and upholstered furniture, and 5) spot application of 0.03% lambda-cyhalothrin (Demand CS, Syngenta Crop Protection, LLC, Greensboro, NC) along baseboards throughout the apartment. Following the initial treatment, the apartments were inspected by the pest control vendor every 14 d, and additional treatments made as necessary, at the technicians' discretion, using one or more of the following methods: 1) vacuuming visible bed bugs, 2) application of steam to visible bed bugs, and 3) re-application of a pesticide using 0.05% chlorfenapyr (Phantom SC, BASF Corporation, Durham, NC) to baseboards of the apartments. Follow-up visits continued until no bed bugs were found

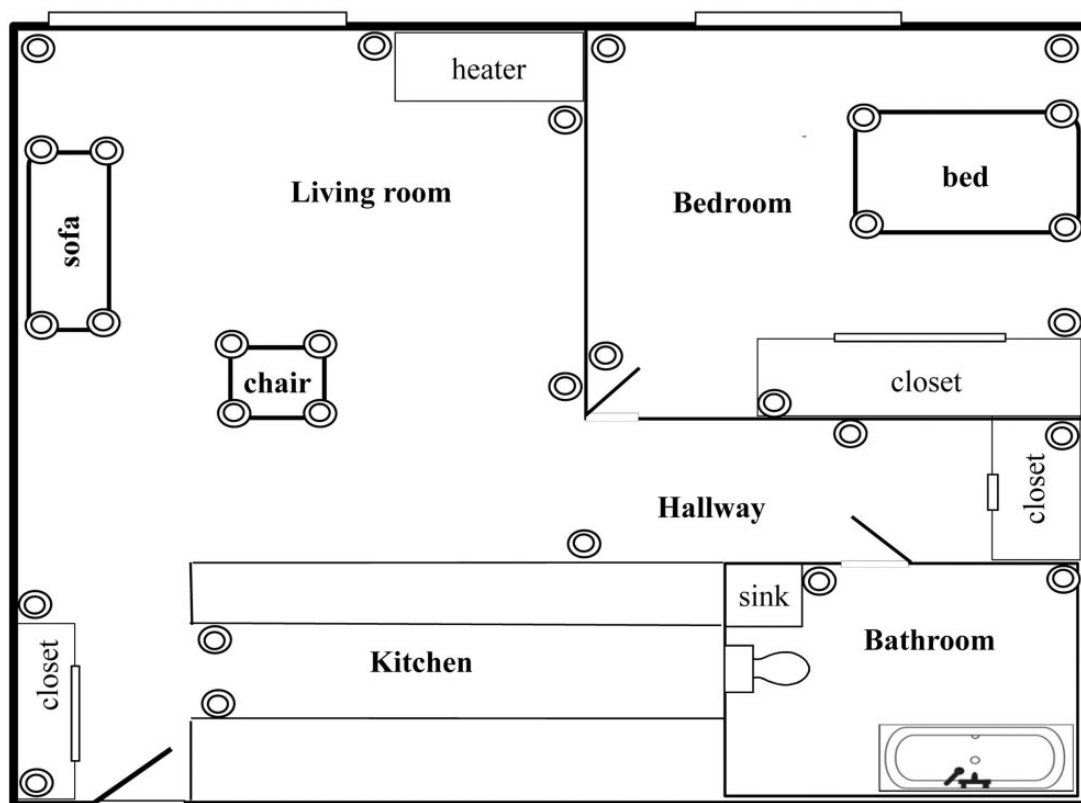


Fig. 1. Typical layout of interceptors in each apartment in Experiment I. Double circles are interceptors.

based upon all of the following: 1) visual inspection, 2) trap catch, and 3) the resident indicated that they had not seen any bed bug activity since the previous visit.

Within 1 wk of the termination of the treatment program, we installed interceptors throughout 67 apartments in the same manner described for Group I. None of the residents were aware that they still had existing bed bug activity. The mean (min, max) number of interceptors placed per apartment was 29 (22, 34). Interceptors were inspected for the presence of bed bugs 14 d later. With the exception of two apartments, whose residents requested their apartment to be in Group III, apartments with a trap catch of 1–10 bed bugs were randomly placed into one of the two groups: Group II—no further treatment (23 apartments) or Group III—continued treatment (21 apartments). Apartments in both the groups were inspected by Rutgers researchers every 14 d until bed bugs were eliminated based on the same evaluation methods as Group I. Apartments in Group III were visited every 2 wk by the professional pest control vendor using similar methods as their previous follow-up visits.

In all treatment groups, if the bed bug count increased to 20 or more bugs at any time, the apartment was discontinued from the experiment according to the IRB protocol, and property management was notified so the apartment could be scheduled for treatment. Apartments discontinued from the study were included in data analysis until the time they were discontinued. All of the apartments received a final inspection at 9–12 mo postelimination. The inspection included monitoring the apartment with interceptors for 14 d followed by a visual inspection of the sleeping and resting areas.

### Experiment II. Impact of Interceptors on Low-Level Bed Bug Infestations

Based upon the results of the previous experiment, we investigated if interceptors placed throughout the apartments were contributing to the decline of *C. lectularius* counts and eventual elimination of infestations in apartments with low bed bug counts. The experiment was conducted in an affordable housing community occupied by elderly (>62 yr old) and disabled residents in Irvington, NJ. Two 11-storey apartment buildings were inspected for bed bugs using a combination of visual inspection and placing interceptors. The visual inspection was brief (5–10 min with two people) and limited to beds and upholstered furniture. Interceptors were placed under the legs of beds and upholstered furniture and checked for bed bugs 14 d later. Apartments meeting the following conditions were included: 1) total count of 1–10 bed bugs based upon trap catch and visual inspection count, 2) residents indicated that they were not emotionally upset about the bed bug activity and they did not suffer bed bug bite symptoms and agreed to participate in the study, and 3) residents agreed not to apply any insecticides in their apartments during the study. This study protocol (number E11-766) received approval from Rutgers University IRB.

In total, 36 apartments were used (6 one bedroom and 30 studio apartments). They were randomly divided into two similar groups (18 apartments per group) based upon total bed bug counts and apartment type (one bedroom or studio). Residents were asked whether or not they were aware of the bed bug activity in their apartments. The treatment group had interceptors continuously present both at sleeping and resting areas and along room perimeters throughout the apartments. A mean (min, max) of 22 (13, 35) interceptors were installed in each apartment and then inspected every 2 wk for 16 wk. In the control group, interceptors were only present between 6–8 wk and between 4–16 wk in order to obtain bed bug

counts at the midpoint (8 wk) and endpoint (16 wk) of the study. A mean (min, max) of 23 (16, 33) interceptors were installed in each apartment. A thorough visual inspection of all furniture used for sleeping and resting was conducted in apartments from both groups at 8 and 16 wk. Bed bugs observed during visual inspection of apartments were left undisturbed. If total bed bug counts from interceptors, visual inspection, or both, exceeded 20, the apartment was discontinued from the experiment according to the IRB protocol, and property management was notified so the apartment could be scheduled for treatment. Apartments that were discontinued from the study were included in data analysis until the time they were discontinued.

### Data Analysis

Bed bug count data were log transformed prior to analysis of variance to compare differences among treatments. Nonparametric analyses were conducted on bed bug count data that could not fit normal distribution after transformation. Kruskal–Wallis test was used to compare the bed bug counts among treatment groups at 12 wk for Experiment I and at 8 wk for Experiment II. Data after these observation periods were not analyzed because apartments with bed counts  $\geq 20$  were discontinued from the experiments. Kruskal–Wallis test was also used to compare bed bug counts between apartments whose residents were aware or who were unaware of the presence of bed bugs in their apartments at the time of the initial inspection. Wilcoxon signed rank test was used to compare the mean bed bug count per trap at and away from sleeping and resting areas. All analyses were performed using SAS software version 9.3 (SAS Institute 2011).

## Results

### Experiment I. Trap Catch in Untreated and Treated Apartments With Low-Level Infestations

The mean number of bed bugs based upon 14-d trap catch at 0 wk was similar in the three groups ( $\chi^2 = 0.82$ ;  $df = 2$ ;  $P = 0.66$ ; Table 1). Nymphs were trapped in 17–22% of the apartments. Adult females were present in at least 78% of the apartments and adult males in  $\leq 30\%$  of the apartments in each group. Bed bug counts per interceptor were similar in traps located at or away from host sleeping and resting areas in Group I ( $S = 54.5$ ;  $P = 0.10$ ), while more bed bugs were captured in traps located away from host sleeping and resting areas than those at sleeping and resting areas in Group II ( $S = -78.5$ ;  $P = 0.003$ ) and Group III ( $S = -73.5$ ;  $P = 0.01$ ; Table 2). There was also a much higher percentage of apartments with bed bugs trapped away from sleeping and resting areas in Groups II and III apartments compared with Group I (Table 2).

The bed bug counts at 12 wk declined to 0 in at least 71% of the apartments in all three groups. There were no significant differences in the mean bed bug counts among Groups I, II, and III ( $\chi^2 = 5.07$ ;  $df = 2$ ;  $P = 0.08$ ; Fig. 2). Bed bug counts increased to 20 or more bed bugs in two apartments; one from Group I (20 bed bugs at 12 wk) and one from Group II (26 bed bugs at 20 wk). These two apartments were not inspected after the bed bug count reached  $\geq 20$ , and they were considered still infested at 40 wk. At 22 wk, bed bugs had been eliminated in 96, 87, and 100% of the apartments in Groups I, II, and III, respectively (Fig. 3). At 40 wk, when the study was terminated, two apartments (Group II) still had bed bugs (counts were two and one, respectively).

Among all apartments, the mean number of visits to eliminate bed bugs and the mean number of visits that bed bugs were detected

**Table 1.** Summary of apartments used in Experiment I at 0 wk

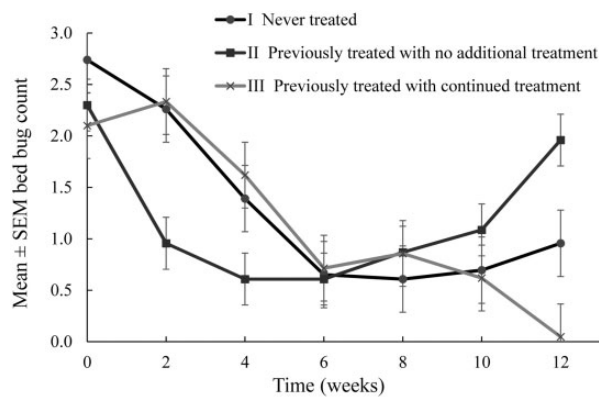
Treatment group	No. of apts.	Mean bed bug count $\pm$ SEM	No. of apts. with adult bed bugs trapped			No. (%) apts. with nymphs trapped
			Female only	Male only	Female and male	
I. Never treated	23	2.7 $\pm$ 0.5	12	1	6	4 (17)
II. Recently treated with no additional treatment	23	2.4 $\pm$ 0.4	15	1	4	5 (22)
III. Recently treated with continued treatment	21	2.2 $\pm$ 0.4	14	0	4	4 (19)

**Table 2.** Trap count distribution within apartment and bed bug detection rates at 0 wk

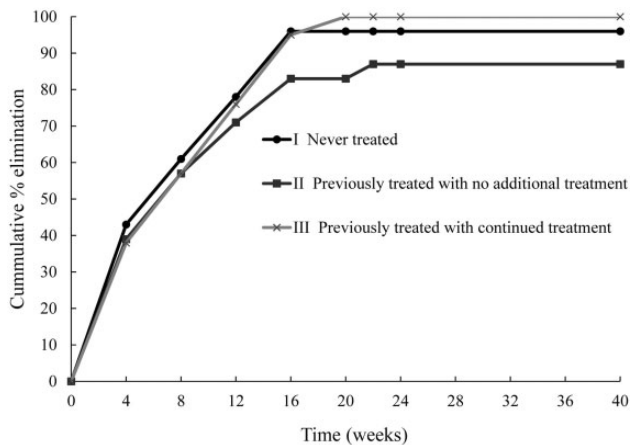
Treatment group	Average bed bug count by trap <sup>a</sup> (mean no. of traps per area) $\pm$ SEM		Average % of total trap catch		% of apts. with bed bugs trapped	
	At sleeping and resting areas <sup>b</sup>	Away from sleeping and resting areas	At sleeping and resting areas	Away from sleeping and resting areas	At sleeping and resting areas	Away from sleeping and resting areas
	I. Never treated	0.19 $\pm$ 0.04 (10.1 $\pm$ 0.8)	0.07 $\pm$ 0.01 (17.7 $\pm$ 0.2)	44	56	61
II. Recently treated with no additional treatment	0.06 $\pm$ 0.02 (11.8 $\pm$ 0.7)	0.11 $\pm$ 0.02 (17.5 $\pm$ 0.2)	17	83	39	100
III. Recently treated with continued treatment	0.05 $\pm$ 0.02 (10.1 $\pm$ 0.6)	0.10 $\pm$ 0.02 (17.5 $\pm$ 0.2)	17	83	33	90

<sup>a</sup> Average bed bug count is the total number of bed bugs captured divided by the number of traps present in the area.

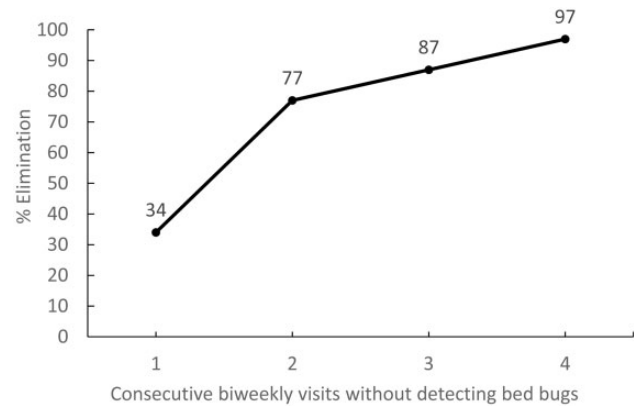
<sup>b</sup> Sleeping and resting areas refer to beds and upholstered furniture.



**Fig. 2.** Mean  $\pm$  SEM bed bug count based upon total trap catch in each apartment during the first 12 wk in Experiment I. Data between 12 and 40 wk were not shown because two apartments were removed from the study.



**Fig. 3.** Cumulative percent elimination of infestations over time. Elimination is based upon four consecutive 14-d interval visits with zero trap catch and no live bed bugs observed during visual inspection.



**Fig. 4.** Relationship between the number of consecutive visits with zero bed bug counts in interceptor traps and elimination rate. In total, 65 infested apartments were included at 0 wk.

was 4.1 and 2.5, respectively. There were only two out of 65 apartments where bed bugs were observed during visual inspection following four consecutive visits without interceptor trap catch. Thus, four consecutive visits without bed bug activity detected in interceptors were necessary to achieve 97% confidence of bed bug elimination in apartments (Fig. 4). Seven months after bed bugs had been eliminated new bed bug activity was reported by a resident in Group II. In total, eight bed bugs were detected on the sofa based on visual inspection and 14-d interceptor counts in this apartment. Two bed bugs were also detected in interceptors in one apartment from Group I, 12 mo after the infestation had been eliminated.

#### Experiment II. Impact of Interceptors on Low-Level Bed Bug Infestations

The initial number of bed bugs and their sex distribution based upon trap catch and visual inspections are summarized in Table 3.

**Table 3.** Summary of apartments used in Experiment II at 0 wk

Treatment group	No. of apts.	No. of residents aware of infestation <sup>a</sup>	Mean bed bug count $\pm$ SEM	No. of apts. with adult bed bugs trapped			No. (%) apts. with nymphs trapped
				Female only	Male only	Female and male	
Interceptors continuously present	18	12	2.8 $\pm$ 0.6	7	0	4	7 (39)
Interceptors present periodically <sup>b</sup>	18	11	2.4 $\pm$ 0.4	9	0	1	8 (44)

<sup>a</sup> Indicates the number of apartments in which the resident was aware of the infestation prior to being entered into the study.

<sup>b</sup> Interceptors were present between 6–8 wk and between 14–16 wk.

**Table 4.** Relationship between resident awareness of existing bed bugs and bed bug count based on interceptors and visual inspections

Treatment group	Mean initial bed bug count $\pm$ SEM		Mean 8-wk bed bug count $\pm$ SEM	
	Aware <sup>a</sup>	Unaware	Aware	Unaware
Interceptors continuously present	3.1 $\pm$ 0.8 ( <i>n</i> = 12)	2.2 $\pm$ 0.5 ( <i>n</i> = 6)	7.8 $\pm$ 4.4 ( <i>n</i> = 12)	0.2 $\pm$ 0.2 ( <i>n</i> = 6)
Interceptors present periodically	2.8 $\pm$ 0.6 ( <i>n</i> = 11)	1.7 $\pm$ 0.4 ( <i>n</i> = 7)	63.3 $\pm$ 32.9 ( <i>n</i> = 11)	1.9 $\pm$ 0.7 ( <i>n</i> = 7)

<sup>a</sup> The resident's awareness is based upon resident interview prior to our detection of bed bugs in their apartment and historical pest control records.

The bed bug counts were similar between the two groups ( $\chi^2 = 0.05$ ; *df* = 1; *P* = 0.83). Nymphs were trapped in 39 and 44% of the apartments in the treatment and control group, respectively. Adult females were captured in 56–71% of the apartments and adult males in no more than 22% of the apartments in each group (Table 3). At 8 wk, the bed bug count was significantly lower ( $\chi^2 = 9.11$ ; *df* = 1; *P* = 0.003) in the treatment group (5.2  $\pm$  3.0) than in the control group (39.4  $\pm$  21.0). The percentage of apartments with zero bed bugs at 8 wk was 61 and 11% in the treatment and control groups, respectively. We further analyzed the bed bug counts in apartments whose residents were aware and those who were unaware of the presence of bed bugs. At 0 wk, bed bug counts were similar in those who were initially aware and those who were unaware (treatment:  $\chi^2 = 0.04$ ; *df* = 1; *P* = 0.85; control:  $\chi^2 = 0.58$ ; *df* = 1; *P* = 0.45). At 8 wk, trap counts among apartments whose residents were aware were similar to those who were unaware in the treatment group ( $\chi^2 = 2.4$ ; *df* = 1; *P* = 0.12), but were significantly higher than those who were unaware in the control group ( $\chi^2 = 9.5$ ; *df* = 1; *P* = 0.002; Table 4). Bed bug counts increased to  $\geq 20$  in eight apartments; two from the treatment group (37 and 43 bed bugs) and six from the control group with a mean  $\pm$  SEM count of 108.2  $\pm$  55.5. The eight apartments with bed bug counts over 20 were not inspected again and were considered still infested at 16 wk.

At 16 wk, two more apartments had bed bug counts greater than 20 (both in the control group). All 10 apartments with bed bug counts that exceeded 20 bed bugs during the study period were in apartments whose residents were aware of the bed bug activity at the time we first detected them. Eleven (61%) apartments had zero bed bug counts in the treatment group. Among these, nine had zero counts from 8 wk through 16 wk, suggesting that bed bugs were eliminated in these apartments. In comparison, two (11%) apartments in the control group had zero counts. One of them also had zero bed bugs at 8 wk, suggesting that bed bugs may have been eliminated in at least one apartment.

## Discussion

This study provides important information regarding the effects of various interventions on low-level bed bug populations. We found

that many of the small populations of bed bugs were eliminated without any professional treatment and only a small percentage escalated in number over a period of 4–10 mo. The presence of the traps throughout the apartments represented a mass trapping approach and contributed to the decline of bed bugs in low-level infestations. These findings suggest that low-level infestations can be eliminated without insecticide applications and highlights the importance of early detection, and a threshold-based approach to bed bug management, by which the treatment protocol is based upon population size.

Previous studies have shown interceptors to be more effective than trained bed bug sniffing dogs (Cooper et al. 2014) or visual inspection (Wang et al. 2010, 2011; Cooper et al. 2014, 2015a) for detecting bed bugs present in low numbers. We used interceptors to identify 103 apartments (total number of apartments in Experiments I and II) with low-level bed bug activity. Of these, residents from 80 of the apartments were unaware that they had bed bugs. These results clearly demonstrate the effectiveness of pitfall traps as detection devices of bed bugs present in small numbers.

Using simulation models, Pereira et al. (2013) predicted rapid population growth starting with a single male and female bed bug. Under their worst scenario, when food was only made available once per week for 5 min at a time, populations increase up to 300 individuals in 15 wk, with more rapid population growth rates predicted with increasing availability of food, as would be expected in an occupied residence. Our results suggest small populations rarely achieve their population growth potential under field conditions and that the introduction of a small number of bed bugs into previously uninfested apartments often fail to develop into high numbers, even when left untreated. Evidence of this can be seen in our first experiment among apartments in Group I. This group consisted of apartments that had no prior history of bed bug activity during the previous two years and whose residents were unaware of the bed bugs in their apartments prior to our detection. As we initially trapped 10 or fewer bed bugs in each of these apartments, it is reasonable to assume that these populations likely represented recent introductions. Bed bugs were eliminated (based upon trap catch and visual inspection) in 22 out of 23 of these apartments within 22 wk without any treatment intervention. In our second experiment, bed bug counts remained below 20 in a majority of the apartments with

newly identified infestations, regardless of whether or not interceptors were continuously present. These results support the assertion that residential infestations detected early, can be eliminated with relative ease (Pinto et al. 2007, Wang and Cooper 2011, Vaidyanathan and Feldlaufer 2013).

The use of monitoring traps as a control method for urban pests has been limited to stored-product pests, where pheromone traps have been used in mass trapping and mate disruption programs (Cox 2002, Phillips and Throne 2010). Schal and Hamilton (1990) pointed out that mass trapping does not appear to be a viable option for the control of cockroaches and that the lack of efficient trapping methods for cockroaches is probably the most significant single factor contributing to a heavy reliance on scheduled applications of insecticides. Wang et al. (2009) was the first to suggest that interceptors under the legs of beds and furniture may contribute to the reduction of bed bugs in infested apartments. The results of our first experiment demonstrate that most low-level populations of bed bugs are eventually eliminated even without treatment. One possibility is that interceptors placed throughout apartment remove bed bugs faster than they reproduce, contributing to the elimination of bed bugs present in small numbers. This was confirmed in our second experiment. Significant differences were observed in the dynamics of bed bug populations in apartments in the treatment group, which had interceptors continuously present for 16 wk, compared with those in the control group, which only had interceptors present periodically to obtain counts at 8 and 16 wk. The initial number of bed bugs present in apartments in Experiment II is likely to have been higher than in the first experiment due to differences in the number of interceptors placed per apartment for the initial detection of bed bugs, which may explain the lower elimination rates observed in the second experiment. In Experiment I, interceptors were placed at and away from sleeping and resting areas, while in Experiment II, they were only placed at sleeping and resting areas. Cooper et al. (2014, 2015b) demonstrated that bed bugs are often trapped in interceptors away from sleeping and resting areas, even in apartments with low bed bug counts. Thus, because apartments in Experiment II did not have any traps away from sleeping and resting areas, the actual number of bed bugs at the start may be underestimated.

An Allee effect is a feature that exists in low-density populations that limits population growth, such as failure to locate a mate when population size is small (Boukal and Berec 2009, Fauvergue 2012, Fauvergue et al. 2012). It is possible that such an effect also contributed to the low population growth observed in this study. The host-finding range of bed bugs is typically not more than 3 m (Marx 1955, Anderson et al. 2009, Singh et al. 2012). It has been suggested by Cooper et al. (2015b) that bed bugs that are more than a few meters from their host may become “lost” due to their inability to locate hosts. This could explain why bed bugs are commonly trapped in interceptors away from host-feeding sites, which may result in a decreased likelihood to locate a mate. At the onset of our first experiment, 56% of bed bugs in apartments that had never been treated were captured away from host sleeping and resting areas and up to 83% in apartments with infestations that had been treated. The differences in distribution between previously treated and untreated apartments could also be due to mortality of bed bugs at beds and furniture from treatment, as well as movement of bed bugs away due to application of insecticides. Romero et al. (2009) suggested that use of pyrethroids may present a potential problem for the spread of bed bugs. It is possible that pyrethroids used in the treatment of apartments in Groups II and III, along with other control practices, may have facilitated the increased capture of bed bugs in interceptors away from the sleeping and resting areas and

contributed to the persistence of bed bugs in Group II compared with Group I. Whether movement away from the host affects host and mate finding warrants further investigation.

Dispersal of bed bugs from infested apartments to neighboring apartments has been implicated as a contributing factor in the spread of bed bugs within housing communities (Doggett and Russell 2008, Wang et al. 2010, Booth et al. 2012, Cooper et al. 2015a). Using mark–release–recapture, Cooper et al. (2015b) demonstrated active dispersal from five of six infested apartments to 42% of their neighboring apartments within 30 d. Moreover, the majority of actively dispersing adults captured in neighboring apartments were females. We also found females to be the more prevalent adult stage during our initial detection of bed bugs in the 103 apartments with low-level activity, regardless of whether the infestation was new or approaching elimination. It has been suggested that adult females are the primary dispersal stage in bed bugs (Pfiester et al. 2009, How and Lee 2010, Cooper et al. 2015b). This could explain why females are the dominant adult stage present in low-level bed bug populations. Dispersal of adult females would enable them to expand the infestation to other sleeping areas within the same living unit or neighboring units, as well as escaping control efforts targeted at host sleeping areas. However, the prevalence of adult females in our study could also be the result of trap bias for adult females compared with nymphs (both young and old) and adult males (Cooper et al. 2015b). For this reason, we are unable to conclude that adult female bed bugs are the primary disperser. Booth et al. (2012) and Saenz et al. (2013) suggested that low genetic diversity among bed bug populations within the same apartment building indicates that most populations are founded by genetically related individuals and suggesting that a single female could give rise to an infestation. Based upon our results, it seems likely that an introduction of a single female, or even a few bed bugs, may not readily become established. Instead, repeated introductions may be required.

We found bed bugs were more likely to remain low in number in apartments where residents were unaware of the presence of bed bugs compared with those who were aware of the presence of bed bugs. Of the 25 residents who knew about the bed bugs in their apartments, 23 indicated they were self-treating their apartments, prior to the experiment, with one or more over-the-counter products, while none of the residents that were unaware were self-treating. In spite of the self-treatment of apartments in the “aware” group, these apartments had significantly higher bed bug counts than the “unaware” group at 8 wk in the control group. We speculate that infestations in apartments whose residents were initially unaware of the activity are likely to be new introductions that have not yet become established, while those in apartments that had received treatments and whose residents were aware may be established infestations with persistent low-level activity.

Bed bugs can be more difficult to detect toward the terminal end of a treatment effort than when first introduced. The likelihood of detecting bed bugs in traps placed at sleeping and resting areas versus away from sleeping and resting areas was similar in apartments that had not been treated (Group I). However, among the 44 apartments that were treated (Groups II and III), 95% were detected in interceptors away from sleeping and resting areas and only 36% were detected in interceptors located at sleeping and resting areas. These results are similar to another study, where 47 of 67 apartments with bed bug activity were detected in interceptors located in areas such as kitchens, bathrooms, hallways, and hall closets but not through visual inspection or interceptors at beds or upholstered furniture (Cooper et al. 2014). As most of the bed bugs are found in less predictable areas away from sleeping and resting areas following

treatment, placement of traps away from beds and upholstered furniture significantly increases the likelihood of detecting bed bugs in treated apartments.

A single service visit without detecting live bed bugs is commonly used by the pest control industry as an indication that bed bugs are no longer present. Once bed bugs are no longer found the treatment program is typically terminated. However, even with interceptors placed throughout the apartment, bed bugs were not detected in all apartments during every visit. Premature termination of treatment can result in chronic infestations and lead to the continued spread of bed bugs within communities (Wang and Cooper 2011). Based upon our results, four consecutive 14-d interval visits without activity provides at least 97% confidence that bed bugs have been eliminated. Bed bugs were only detected in two apartments, one at 7 mo postelimination and the other at 12 mo postelimination, demonstrating the robust nature of our elimination protocol.

The results of our study have important implications that should be considered in the development of bed bug management programs in multiunit housing communities, particularly those at risk for high infestation rates. These include: 1) installing pitfall-style traps both at and away from host sleeping and resting areas significantly improves detection following treatments; 2) mass trapping can effectively suppress low-level infestations; and 3) more than one service visit without detection of bed bugs should be used as a criterion for determining bed bug elimination.

In conclusion, new infestations that are small in number often fail to become established in occupied apartments, while small populations remaining from previously established infestations are more persistent and likely to escalate in number. Low-level populations are easily eradicated through placement of a large number of traps throughout apartments, reinforcing the importance of early detection. There are drawbacks of using mass trapping as the sole method of control because it takes more visits to eliminate infestations than if combined with other methods (i.e., encasement, steam, vacuum, or pesticide). Also, mass trapping alone may not be acceptable if occupants are being negatively affected by bed bugs (experiencing bite symptoms). In spite of these drawbacks, our results demonstrate that mass trapping has a significant impact on low-level bed bug populations. We recommend incorporating mass trapping into bed bug management programs to reduce the need for pesticide applications as well as to confirm elimination.

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