Effectiveness of Bed Bug Monitors for Detecting and Trapping Bed Bugs in Apartments

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ABSTRACT Bed bugs, *Cimex lectularius* L., are now considered a serious urban pest in the United States. Because they are small and difficult to find, there has been strong interest in developing and using monitoring tools to detect bed bugs and evaluate the results of bed bug control efforts. Several bed bug monitoring devices were developed recently, but their effectiveness is unknown. We comparatively evaluated three active monitors that contain attractants: CDC3000, NightWatch, and a home-made dry ice trap. The Climbup Insect Interceptor, a passive monitor (without attractants), was used for estimating the bed bug numbers before and after placing active monitors. The results of the Interceptors also were compared with the results of the active monitors. In occupied apartments, the relative effectiveness of the active monitors was: dry ice trap > CDC3000 > NightWatch. In lightly infested apartments, the Interceptor (operated for 7 d) trapped similar number of bed bugs as the dry ice trap (operated for 1 d) and trapped more bed bugs than CDC3000 and NightWatch (operated for 1 d). The Interceptor was also more effective than visual inspections in detecting the presence of small numbers of bed bugs. CDC3000 and the dry ice trap operated for 1 d were equally as effective as the visual inspections for detecting very low level of infestations, whereas 1-d deployment of NightWatch detected significantly lower number of infestations compared with visual inspections. NightWatch was designed to be able to operate for several consecutive nights. When operated for four nights, NightWatch trapped similar number of bed bugs as the Interceptors operated for 10 d after deployment of NightWatch. We conclude these monitors are effective tools in detecting early bed bug infestations and evaluating the results of bed bug control programs.

KEY WORDS bed bug, *Cimex lectularius*, monitoring, traps, dry ice

Bed bug, *Cimex lectularius* L., infestations are increasing rapidly on a global scale, and bed bug resurgence will probably last for many years, in part, due to lack of effective detection and control techniques (Ter Poorten and Prose 2005, Harlan 2006, Kilpinen et al. 2008, Potter 2008). A recent study suggests infestations may spread rapidly through passive and active dispersal of bed bugs (Wang et al. 2010). Low-income communities are more likely to suffer chronic and increased bed bug infestations in the years to come due to a lack of financial resources available to provide effective community-wide eradication of infestations.

Individuals living in bed bug infested environments are not always aware that an infestation exists for a variety of reasons. Some people do not react to bed bug bites (Reinhardt et al. 2009). Others often confuse bed bug bites with poison ivy, mosquito bites, and other non–bed bug-related causes, allowing the bugs to continue to proliferate without being identified and eliminated.

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Even when bed bugs are suspected, they can be very difficult to find, particularly when just a few bugs are present (Wang et al. 2009a,b). They rest in very secretive hiding places or areas that may not be readily accessible for inspection. Visual inspections are labor intensive and are often unreliable (Pinto et al. 2008). Interviews with residents are not reliable either because many people do not recognize the presence of bed bug infestations or are unwilling to report the problem (Wang et al. 2010).

Using dogs trained to detect bed bugs has been a frequently used method by professionals for detecting low level infestations. It is a very efficient detection method. However, this method has several disadvantages: 1) it is not readily available in all parts of the United States; 2) the cost is high (≈$300/h of service); and 3) the accuracy can vary significantly from one dog–handler team to another (Pinto et al. 2008).

Lack of affordable and effective tools for detecting bed bugs leads to the failure to detect bed bugs in their early infestation stages. In turn, it leads to greater difficulty and increased costs associated with eradication efforts. In response to the need for affordable and effective bed bug monitoring tools, both passive (without attractants) and active (with attractants) monitors have been developed. In a recent study, the effectiveness of a passive pitfall trap was examined and proved to be more effective than visual inspections in detecting bed bugs (Wang et al. 2009a). Based on the same principles, a commercial product (Climbup Insect Interceptor, Susan McKnight, Inc., Memphis, TN), was subsequently developed and proved to be effective in detecting bed bugs (Wang et al. 2009b). However, Interceptors cannot be used under furniture where legs are too large or are missing and are not designed to monitor rooms that are vacant.

Anderson et al. (2009) evaluated a pitfall trap baited with CO_2 (CO_2 cylinder as source), chemical lures, and heat. They found the trap was able to catch large numbers of bed bugs in a vacant apartment. Wang et al. (2009c) demonstrated pitfall traps baited with CO_2 (dry ice as source) and chemical lure can detect the presence of bed bugs that are not detected by visual inspections. This was the first study showing that an inexpensive active monitor can be used in detecting bed bugs and assessing the effectiveness of bed bug control programs.

Two commercial monitors, CDC3000 (Cimex Science LLC, Portland, OR) and NightWatch (BioSensory Inc., Putnam, CT) became available in early 2009. Both use CO_2, heat, and a chemical lure to attract bed bugs. To date, there are no reported studies on the effectiveness of bed bug active monitors in field settings. Examining the effectiveness of bed bug monitors under field conditions is necessary to provide accurate information on the potential role of these monitoring tools in bed bug management. The objective of this study was to determine 1) the effectiveness of active bed bug monitors compared with visual inspection in detecting the presence of bed bugs and 2) the relative effectiveness of three active bed bug monitors. The three active monitors were CDC3000, NightWatch, and a home-made dry ice trap (baited with dry ice).

Materials and Methods

Study Sites. The study sites were two high-rise apartment buildings located in Bayonne, NJ. All units in each building were one-bedroom or studio apartments of $\approx$36–45 m^2. One or two elderly people resided in each apartment during the study. These apartments were treated with diatomaceous earth dust and pyrethroid sprays at least one month before the study as part of the regular pest management contract. Diatomaceous earth dust residues were visible on floors and furniture in all apartments included in this study.

Bed Bug Monitors. The CDC3000 monitors were provided by Cimex Science LLC. NightWatch bed bug monitors were purchased from the manufacturer. Both monitors use CO_2, heat, and synthetic lures to attract bed bugs. Exact chemical lure components and their concentrations were not disclosed by the manufacturers. The home-made dry ice baited trap (hereafter referred as dry ice trap) was made from an inverted cat feeder covered with white polyester fabric on exterior surface (Fig. 1; Wang et al. 2009c). The size of the cat feeder was 35.5 by 17.5 by 7 cm (length by width by height; Van Ness Plastics, Clifton, NJ).

Fig. 1. A dry ice trap consisted of an inverted cat feeder and an insulated jug.

The fabric size was same as the outer surfaces of the cat feeder. The edges of the fabric were secured to the cat feeder using 1.27-cm-wide masking tape. The interior surface of the inverted cat feeder was coated with a very thin layer of talcum powder to prevent bed bugs from escaping. A 1,127-ml insulated jug (Coleman Company, Inc., Wichita, KS) filled with dry ice pellets was placed on top of the cat feeder as CO_2 source. The lid of the jug was opened slightly allowing CO_2 to escape into the atmosphere. Unlike the CDC3000 and NightWatch device that uses CO_2, heat, and lure, the dry ice trap only uses CO_2 to attract bed bugs. The residents were asked not to tamper with the monitoring devices.

Each CDC3000 used a 166-g CO_2 cylinder containing 46 g of liquid CO_2. Once screwed onto the CDC3000 trap, the cylinder continuously released CO_2 at $\approx$42 ml/min for 10 h. Each NightWatch used a 567-g CO_2 cylinder. The NightWatch monitors were programmed by the manufacturer to release CO_2 for 8 h each day. The median CO_2 release rate (determined by measuring the average CO_2 cylinder weight loss per night based on measurement from 10 NightWatch monitors) was 161 ml/min. At this rate, each full cylinder could provide CO_2 for at least four nights. The dry ice trap released CO_2 at a rate of 731–801 ml/min for 12–15 h in a room maintained at 23–25°C. The dry ice trap CO_2 release rate was equivalent to 2–3 times the CO_2 emitted by an adult human (Leff and Schumacker 1993).

Climbup Insect Interceptors (hereafter referred to Interceptor) were installed before and after deploying the above-mentioned active monitors for the purposes of selecting test apartments, comparing it with active monitors, and confirming the presence–absence of bed bugs after deploying the active monitors. The Interceptors were provided by Susan McKnight, Inc.

Experiment I. Three heavily infested apartments located on three floors were identified to comparatively assess the performance of the three active monitors. Brief visual inspections found at least 426 bed bugs (adults and nymphs) in each apartment. Immediately after visual inspection, the three types of mon-

Table 1. Comparative effectiveness of bed bug monitors for detecting bed bug infestations in apartments

Initial count of bed bugs per apartment from Interceptors and visual inspections	No. apartments	Detection rate (% detected infestations)				
		Visual inspection	Interceptor	Dry ice trap	CDC3000	Night Watch
1–9	10	50	70	60	50	10
11–35	5	60	100	100	100	80

Note: The Interceptors were installed under furniture legs 7 d before visual inspections. Other monitors were deployed for 1 d.

itors were randomly assigned to the three apartments. The monitors were placed around the infested area (sofa, bed, or piles of clothing) in each apartment between 1 p.m. and 6 p.m. The monitors were examined the next day (≈24 h later). Each monitor was then placed in a different apartment on each of the next 2 d following a Latin square design. On each day, the monitors were examined and reset in the afternoon. Bed bug counts from two dry ice traps and one CDC3000 monitor were estimated nearest to the 10's due to time constraints. The NightWatch monitor was programmed to release CO_2 immediately after setting up on each day. Thus, all monitors released CO_2 immediately after setup on each day.

Experiment II. Fifteen lightly infested apartments located on eight floors were used to evaluate the effectiveness of monitors for detecting the presence of small numbers of bed bugs. To select the apartments, we first installed Interceptors under beds, sofas, or both where the residents stayed during the night time in 39 apartments with reported infestations. In most apartments, bridges (e.g., bed linens touching the floor) between the furniture and the floors or walls were not completely removed due to lack of resident cooperation or large footing of the bed frames. These conditions might have negatively affected the effectiveness of the Interceptors. After 7 d of deployment, the Interceptors were removed and examined for the number of bed bugs. We (C.W., R.C., J.W.) immediately conducted a visual inspection of the apartment. The mean inspection time was 13 min per apartment by three people (total, 39 min per apartment). The bed bugs found during inspections were not removed. Fifteen apartments with one to 35 bed bugs in total collected from Interceptors plus visual inspection were selected.

One day after visual inspections, five CDC3000, five NightWatch, and five dry ice traps were randomly assigned to the 15 selected apartments. The number of trapped bed bugs was recorded the next day. The experiment was continued for another 2 d. On each day, the three types of monitors were rotated among the apartments so that every apartment received each type of monitor during the 3-d period. NightWatch monitors were programmed to release CO_2 immediately after installation.

Experiment III. This experiment was to evaluate the daily trapping pattern of NightWatch in lightly infested apartments and determine the effectiveness of NightWatch monitor when it was operated for multiple days. Eight of the original 15 apartments in Experiment II were selected to conduct this experiment. The eight apartments were chosen by placing Interceptors in the 15 apartments for 10 d and selecting units that had four to 25 trapped bugs. The Interceptors were deployed for 10 d instead of 7 d as in experiment II because of scheduling difficulties. Immediately after examining and removing the Interceptors, a NightWatch was placed beside the infested furniture (bed or sofa) in each apartment. All NightWatch monitors used 567-g CO_2 cylinders that allowed the monitors to operate for four consecutive nights. The monitors were programmed to begin releasing CO_2 at 20:00 h each day as per manufacturer's instructions. The NightWatch monitors were examined daily for four consecutive days. The trapped bed bugs were counted and then removed. All CO_2 cylinders attached to the monitors still contained CO_2 at the end of the 4-d experiment. After removing the NightWatch monitors on the day 4, Interceptors were once again placed under the legs of infested furniture for 10 d to compare with the NightWatch monitor and confirm the presence–absence of bed bugs after deployment of NightWatch monitors.

Data Analysis. Analysis of variance (ANOVA) was conducted to compare the effectiveness of the monitors using Proc Mixed (for bed bug counts) or Proc Genmod (for bed bug infestation detection rate) in SAS software (SAS Institute 2003). The bed bug counts in experiment I were logarithmic transformed before ANOVA. The bed bug counts from experiment II were square root transformed before ANOVA. Means were separated using the Student's least significant difference separation test.

Results

Experiment I. In heavily infested apartments, an average of 850 ± 390, 207 ± 99, and 58 ± 28 bed bugs was trapped overnight by dry ice trap, CDC3000, and NightWatch, respectively. Relative effectiveness of the three monitors was as follows: dry ice trap > CDC3000 > NightWatch ($F = 269.3$, df = 2, 2; $P = 0.0037$). The maximum number of bed bugs trapped by dry ice trap, CDC3000, and NightWatch per day was 1,365, 329, and 95, respectively.

Experiment II. The effectiveness of bed bug monitors is shown in Table 1. The 15 lightly infested apartments were divided into two groups: very low level infestations (<10 bed bugs per apartment) and low level infestations (11–35 bugs per apartment). NightWatch was significantly less effective than the other monitors in detecting very low level infestations ($\chi^2 = 16.3$, df = 4, $P = 0.003$). In apartments with low level

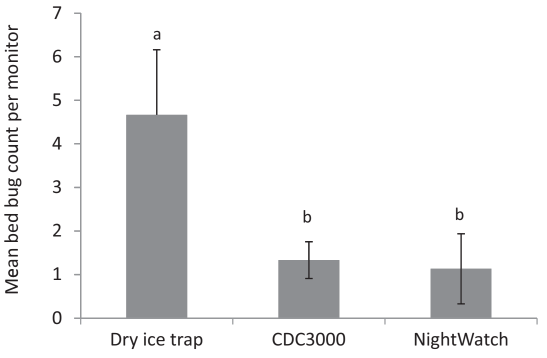

Fig. 2. Bed bug counts (mean ± SEM) from three monitors (1-d deployment). Different letters above the bars indicate significant differences ($P < 0.05$; ANOVA).

infestations, all monitors were able to detect ≥80% of the infestations.

Among the 15 lightly infested apartments, an average of 4.7 ± 1.5, 1.3 ± 0.4, and 1.1 ± 0.8 bed bugs was trapped overnight by dry ice trap, CDC3000, and NightWatch, respectively (Fig. 2). The mean numbers of bed bugs trapped by the three active monitors were significantly different ($F = 8.00$; df = 2, 26; $P = 0.002$). The dry ice trap caught significantly more bed bugs than CDC3000 and NightWatch. The mean counts per apartment from Interceptors (7-d deployment) before and after deployment of monitors were 7.3 ± 2.5 and 5.2 ± 1.5, respectively. The mean count from visual inspections was 2.5 ± 1.4. The Interceptors operated for 7 d trapped similar number of bed bugs as the dry ice trap and trapped more bed bugs than CDC3000 and NightWatch operated for 1 d. Based on daily counts from Interceptors (total counts divided by the number of deployment days), the Interceptors were as effective as visual inspection, CDC3000, and NightWatch and were less effective than dry ice trap ($F = 2.6$; df = 5, 70; $P = 0.04$).

Experiment III. The mean counts per apartment from Interceptors before and after deployment of NightWatch were 12.5 ± 2.3 and 5.3 ± 2.1, respectively. NightWatch trapped bed bugs in six apartments on the first day and an additional apartment on the second day. It failed to trap bed bugs from one apartment after 4-d deployment. The average daily bed bug counts per apartment from NightWatch was 1.5 ± 0.6, 1.3 ± 0.8, 1.1 ± 0.6, and 0.8 ± 0.4 from day 1 to day 4, respectively. The cumulative bed bug count in 4 d was 4.6 ± 2.1 per apartment. It was not significantly different from the Interceptor counts (original counts adjusted by a factor of 4/10 to reflect the differences in trapping period) ($F = 1.47$; df = 2, 19; $P = 0.26$).

Discussion

The study revealed that dry ice trap, CDC3000, NightWatch, and the Climbup Interceptor are effective monitors in detecting the presence of small numbers of bed bugs. When operated for just 1 d, dry ice traps and CDC3000 were equally effective as visual inspections for detecting very low level infestations. Placing and examining monitors require less skill and experience as visual inspections. In apartment buildings or hotels where multiple apartments or rooms are suspected having bed bug infestations, deployment of these bed bug monitors can be an efficient method for aiding in the detection of bed bug infestations.

The effectiveness of the monitors varied significantly. On a daily basis, NightWatch was the least effective monitor among the active monitors, but its effectiveness can be enhanced by running the device for several consecutive nights as designed by the manufacturer. Perhaps the most significant discovery is that the simple and inexpensive home-made dry ice trap is more effective than the two expensive commercial active monitors (≈$450 for NightWatch and $1,000 for CDC3000). The higher effectiveness and affordability make dry ice traps very appealing to those on a limited budget. The major disadvantage of using dry ice trap is the potential risk of injury from accidental ingestion or exposure to dry ice. When properly secured and operated, dry ice traps can be a very valuable monitoring tool in bed bug management.

Wang et al. (2009c) showed CO_2 was the most effective attractant to bed bugs compared with heat and chemical lure. All of the three active monitors tested use CO_2. However, their CO_2 release rates varied greatly. Dry ice trap released CO_2 at ≈4 times as that by NightWatch and nearly 20 times of that by CDC3000. Unlike CDC3000 and NightWatch, dry ice trap only employs CO_2 as attractant. Thus, the differential CO_2 rates may have at least partially accounted for the higher effectiveness of dry ice trap compared with CDC3000 and NightWatch.

Bed bugs take a bloodmeal every week or more frequently (Usinger 1966, Reinhardt et al. 2010). Thus, we may assume that only a small proportion of bed bugs in an occupied room searches for hosts each night. In addition, bed bug eggs are likely present from established infestations. Therefore, one should never assume zero catch implies the room being monitored is bed bug free. The multiple-night trapping with NightWatch verified that multiple night deployment provides better estimation of bed bug infestations than one night deployment.

This study was conducted in apartments where human hosts were present before and during the deployment of active monitors. The presence of human host might have competed with the active monitors and negatively affected the bed bug counts from the monitors. Our preliminary data show that hungry bed bugs are much more responsive to active monitors than recently fed bed bugs. In apartments that are left unoccupied for a few days or longer, effectiveness of the active monitors might be higher than that reported here.

This study further confirms that the passive Interceptors are an effective monitoring tool for detecting very low number of bed bugs (Wang et al. 2009a,b). The effectiveness of Interceptors is not surprising: the presence of human host in the bed turns the passive

Interceptor into an active monitor. When placed for 7 d, Interceptors can be equally effective as 1-d deployment of dry ice traps and are a safe and cost effective method for detecting low numbers of bed bugs. It should be noted that the effectiveness of Interceptors was compromised in most apartments due to bridges formed between the beds and the walls or floors (e.g., bed linens touching the floor). In addition, Interceptors were not installed under all upholstered furniture in each apartment.

Failure to detect bed bugs in their early stage infestation is recognized as a major challenge by pest management professionals. With the recent development of both active and passive monitors, greater control effectiveness may be achieved through more efficient early detections. Monitors may have the potential to reduce the need for pesticide applications because they can remove the few bugs that survive treatments. Additional studies on the effect of trap designs and environmental conditions (i.e., occupied and unoccupied) on the monitor effectiveness and the effect of trapping on bed bug populations will be extremely beneficial to future bed bug monitoring and control programs.

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