Accuracy of Trained Canines for Detecting Bed Bugs (Hemiptera: Cimicidae)

RICHARD COOPER, CHANGLU WANG,[1] AND NARINDERPAL SINGH

Department of Entomology, Rutgers University, 93 Lipman Drive, New Brunswick, NJ 08901

J. Econ. Entomol. 107(6): 2171–2181 (2014); DOI: http://dx.doi.org/10.1603/EC14195

ABSTRACT Detection of low-level bed bug, *Cimex lectularius* L. (Hemiptera: Cimicidae), infestations is essential for early intervention, confirming eradication of infestations, and reducing the spread of bed bugs. Despite the importance of detection, few effective tools and methods exist for detecting low numbers of bed bugs. Scent dogs were developed as a tool for detecting bed bugs in recent years. However, there are no data demonstrating the reliability of trained canines under natural field conditions. We evaluated the accuracy of 11 canine detection teams in naturally infested apartments. All handlers believed their dogs could detect infestations at a very high rate (≥95%). In three separate experiments, the mean (min, max) detection rate was 44 (10–100)% and mean false-positive rate was 15 (0–57)%. The false-positive rate was positively correlated with the detection rate. The probability of a bed bug infestation being detected by trained canines was not associated with the level of bed bug infestations. Four canine detection teams evaluated on multiple days were inconsistent in their ability to detect bed bugs and exhibited significant variance in accuracy of detection between inspections on different days. There was no significant relationship between the team's experience or certification status of teams and the detection rates. These data suggest that more research is needed to understand factors affecting the accuracy of canine teams for bed bug detection in naturally infested apartments.

KEY WORDS *Cimex lectularius*, canine scent detection, inspection, monitoring

Bed bugs have plagued mankind since the beginning of recorded history (Potter 2011, Davies et al. 2012). Although once prevalent in the United States and other developed countries, they were virtually eradicated in many parts of the world shortly after World War II through the widespread use of pesticides such as DDT and malathion (Pinto et al. 2008). After a nearly 50 yr absence, beginning in the late 1990s, bed bugs returned in an unexpected and dramatic fashion, sweeping across North America, the United Kingdom, and Australia (Doggett et al. 2011, Eddy and Jones 2011, Davies et al. 2012). The global resurgence of bed bugs has prompted research on a wide variety of topics including basic biology, behavior, physiology, chemical ecology, management practices, and methods of detection (Davies et al. 2012). Early detection of bed bugs is recognized as a key factor in reducing both the costs associated with bed bug management and the spread of bed bugs from infested dwellings to new locations (Pinto et al. 2008). Despite the importance of detection, effective tools and methods for identifying low-level populations remain limited (Wang et al. 2011, Wang and Cooper 2012, Lewis et al. 2013).

Current methods of detection include visual inspection, deployment of monitoring devices, and canine scent detection. Visual inspection, the most common detection method employed, is labor intensive and very intrusive, requiring beds and furniture to be flipped over for inspection. Moreover, because bed bugs are so secretive, visual inspections are not regarded as a reliable method of detection when only a few bugs or eggs are present (Cooper 2007, Pinto et al. 2008). Wang et al. (2011) compared the effectiveness of visual inspection, passive pitfall-style interceptors, and active (with lure) monitors in lightly infested apartments. In their study, when very few bugs were present, the greatest number of infestations was detected by passive pitfall-style monitors (70%) placed under the legs of beds and upholstered furniture for 7 d, compared with visual inspections (50%) and various active monitors (10–60%) placed next to beds and upholstered furniture for 1 d. Detection rates using interceptors can be increased to 90% or greater by increasing the trapping interval from 7 to 14 d (R. C., unpublished data). The limitation of using monitoring devices is that they do not provide immediate results, and a minimum of two visits are required.

Due to the limitations associated with visual inspection and monitoring devices, the use of trained dogs has gained popularity as an alternative method for identifying bed bug infestations (Cooper 2007, Pinto et al. 2008, Potter et al. 2011). This method could be efficient for large area inspections and provides immediate results, a combination not available with

[1] Corresponding author, e-mail: cwang@aesop.rutgers.edu.

other detection tools and methods. Canine scent detection is especially well suited for less traditional settings such as schools, office buildings, retail stores, and movie theaters, where other detection methods are not esthetically or economically practical (Pinto et al. 2008, Wang and Cooper 2011). However, their effectiveness in correctly identifying natural infestations has never been reported.

Numerous studies have demonstrated the effectiveness of trained dogs for the detection of biological and nonbiological odors (Johnston 1999, Browne et al. 2006), including a number of insect pests such as gypsy moths (Wallner and Ellis 1976), screwworm pupae and larvae (Welch 1990), termites (Lewis et al. 1997, Brooks et al. 2003), and more recently, fire ants (Lin et al. 2011) and bed bugs (Pfiester et al. 2008). Pfiester et al. (2008) found canine detection teams were 98% accurate at detecting as few as one bed bug and had no false indications using planted bugs in hotel rooms. Their study demonstrated the ability of bed bug scent dogs to detect low numbers of bed bugs with a high degree of accuracy under controlled conditions. The researchers also worked directly with a highly skilled canine scent detection trainer who provided both the bed bug detection dogs and conducted the inspections. As a result, the conclusions may not translate into real-world inspections conducted in naturally infested dwellings.

The accuracy of canine scent detection for bed bugs is especially important for two obvious reasons. First, the high cost of canine detection services dictates that a higher detection rate should be provided compared with other available detection methods. Second, any false-positive finding (indicating the presence of bed bugs when bed bugs are nonexistent) can result in unnecessary application of pesticides and control costs along with disturbance of work and daily life. The objective of this study was to evaluate the performance of trained canines for detecting bed bugs under natural field conditions. We hypothesized that—1) average detection rate is much lower than 95%; 2) average false-positive rate is >10%; and 3) detection and false-positive rates vary significantly between inspections and teams.

Materials and Methods

Apartments. High-rise affordable housing communities located in Newark and Jersey City in New Jersey with current bed bug activity were selected for Experiments I–III. The apartments were either studio, one or two bedrooms and were occupied by elderly residents. Presence or absence of bed bugs in experiments with preselected apartments (Experiments I and II) was determined by placing an average of 28 Climbup interceptors (Susan McKnight, Inc., Memphis, TN), hereafter referred to as interceptors, in each apartment for 14 d plus visual inspections of the apartment if no bed bugs were captured in the interceptors. Apartments were not preselected in Experiment III. For this experiment, monitoring with interceptors and visual inspection was performed postcanine inspection. The residents were informed of the inspections and given a preparation list before the canine inspection. In a few apartments where exposed insecticide dusts were present, the researchers vacuumed out the dusts before canine inspections. After canine inspection, monitoring with interceptors and visual inspections were conducted in all units where the canine scent detection results differed from the expected results based upon detailed records of the current and previous infestation history of all apartments in the building. Low-rise garden style apartments (studio, one or two bedrooms) located in New Jersey were used in Experiment IV. Apartment sizes in Experiment I ranged from 28 to 74 m^2, 48 m^2 for all apartments in Experiments II, and 59–74 m^2 for Experiment IV.

Canine Detection Teams. A total of 11 detection teams participated in three experiments. Teams selected were all within 322 km of the inspection sites. Five teams were from New York City, five from New Jersey, and one from Maryland. Among them, two teams were selected based upon the recommendation of a highly respected canine scent detection trainer. Four teams were selected based upon their prominence in the bed bug detection industry. Another four teams were selected based upon an Internet search and one team volunteered to participate in the study. All of the companies claimed or implied inspection accuracy of ≥95%. Before the start of the study, companies had been providing bed bug dog detection services for an average of 2.4 yr. The average length of time that dogs and handlers had been working together as a team was 1.1 yr. Additional background information for the teams is summarized in Table 1.

Determination of Accuracy of Dog Inspections. Accuracy of a dog and handler team was measured by two independent variables—1) detection rate and 2) false-positive rate. Each was equally important in determining the overall accuracy of a team's inspection. The higher the detection rate and lower the false-positive rate during a given inspection, the more accurate the team was. The "detection rate" was the number of apartments with confirmed bed bug activity in which the dog alerts, divided by the number of apartments with confirmed live bed bug activity. The "false-positive rate" was the number of apartments without confirmed bed bug activity in which the dog alerts, divided by the total number of apartments in which live bed bug activity could not be confirmed. Confirmation of bed bug activity was based upon 1) preinspection conducted by researchers within 2–4 d before the initial dog inspection, 2) postinspection in apartments with bed bug counts of ≤5 bugs during preinspection to reconfirm the presence of bed bugs, and 3) postinspection in apartments with alerts by dogs, in which bed bug activity was not previously known to exist.

Experiment I: Blind Evaluation in Preselected Apartments. Eight canine scent detection teams (Teams 1–8) belonging to seven companies were evaluated. The experiment was conducted in July 2011 in an apartment complex consisting of four separate buildings within two blocks of one another in a housing complex in Jersey City. Each firm was contacted by a representative of the housing authority to request a canine scent inspection of 24 apartments. The firms were unaware that they would

Table 1. Background information of the canine teams evaluated in this study

Team	Original training facility	Background of handler prior to bed bug detection	Team working together (mo)	Certification	Type of reward	On or off lead	Dog breed	Sex of dog	Age of dog (mo)
1	Michigan	Pest control	12	IAOCPI	Food	On lead	Lab–Collie mix	F	40
2	Michigan	Pest control and termite detection dog/handler	24	IAOCPI	Food	On lead	Beagle–Pug mix	M	36
3	Kansas	Hardware business	5	NESDCA	Food	On lead	Terrier–Pointer mix	M	30
4	Florida	Property manager	14	None	Food	On lead	Golden Retriever	F	24
5	Alabama	Pest control	24	WDDO	Food	On lead	Coon-hound–Pointer mix	M	42
6	Florida	Police officer	36	WDDO	Food	On lead	Beagle–Jack Russell mix	M	60
7	Florida	Pest control	6	NESDCA	Food	On lead	Beagle	M	11
8	New Jersey	Pest control	6	None	Food	On lead	Black Lab	F	30
9	Florida	Pest control	20	NESDCA	Food	On lead	Beagle	M	52
10	North Carolina	Equestrian care	8	None	Play and toy	Off lead	Black Lab	M	30
11	Company employed trainer	Military K9 bomb dog handler	2.5	None	Play	Off lead	Yellow Lab	M	12

IAOCPI, International Association of Canine Pest Inspectors; NESDCA, National Entomology Scent Detecting Canine Association; WDDO, World Detector Dog Organization.

Table 2. Background information of the apartments inspected by canine teams in Experiment I

Status of bed bug activity	No. of apartments	
	Group 1	Group2
Previously infested within last 2 yr	5	5
No history of bed bug activity	7	9
Low-level bed bug activity (<10 bed bugs)[a]	8	7
Moderate-level bed bug activity (11–50 bed bugs)	3	1
High-level bed bug activity (51–73 bed bugs)	1	2
Total no. of apartments	24	24

[a] Bed bug counts were based on interceptors placed for 14 d.

be evaluated by a team of researchers. The seven firms quoted an average US$757 (US$480–1,000) for inspecting 24 units. A total of 48 apartments were selected for inclusion in the experiment and divided into two groups of 24, each group with a similar number of infested and noninfested apartments. The number of studio, one bedroom, and two bedroom apartments inspected was similar in each group with 4, 19, and 1 in group 1 and 6, 19, and 2 in group 2. The infested apartments in each group were also similar in level of infestation (Table 2).

Inspections began within 3 d after the apartments were selected. Two days before the inspections, the apartments were prepared following the requirements listed in Table 3. The apartments were inspected over four consecutive days. The mean daily high outdoor temperature over the 4 d of inspections was 33.4°C and ranged from 30.6 to 35.0°C (http://www.ncdc.noaa.gov/). The temperature within each of the inspected apartments was not recorded. However, the apartment buildings were very hot inside because hallways were not air conditioned and few residents used air conditioning. For those residents that did use air conditioning, all teams required the air conditioning and fans to be turned off during the dog inspections (Table 3).

Postinspections were conducted in apartments in which bed bugs were not detected before the canine detection, but alerts were recorded during the canine inspection. Inspections were also conducted in apartments with precounts of ≤5 bugs to verify that bed bugs were still present. Postinspections consisted of visual inspection of the entire apartment with emphasis in areas where alerts were recorded. If no bed bugs were found, interceptors were installed throughout the apartment for 14 d. Units where dogs alerted, but bed bugs were not found during both pre- and postinspections were classified as false positives. Approximately 12 mo after the canine scent inspection, all apartments with false-positive findings were inspected by placing interceptors under the legs of beds and upholstered furniture for 14 d, followed by a thorough visual inspection of beds and furniture if no bed bugs were observed in the interceptors.

Experiment II: Informed Inspection of Preselected Apartments. Subsequent to Experiment I, a similar experiment was conducted in August 2011 in Newark, NJ. This experiment was to obtain data on additional canine teams and to evaluate consistency in perfor-

Table 3. Required preparations prior to dog inspections in Experiment I

Team	Pesticides	Cleaning	Fans and air conditioning	Tobacco smoke	Pets	Items to remove
1 and 2	Na	Vacuum under beds, furniture & floor	Off during inspection	Na	Dogs out, cats in crate or locked in bathroom, remove pet toys, food bowls and litter boxes	Na
3	Na	Na	Off 20 min prior to inspection	Na	Dogs out, Cats crate or locked in bathroom	Potpourri, air deodorizers
4	Na	Na	Off during inspection	Na	Na	Na
5	Na	Vacuum apt. thoroughly	Off during inspection	Na	Na	Na
6	Na	Na	Off during inspection	Na	Na	Na
7	No essential oils within 30 d of inspection; no visible dust residues; provide list of any pesticides used in last 30 d	Na	Off during inspection	No smoking within 2 h of inspection	Dogs out, cats crate or locked in bathroom, remove pet toys, food bowls and litter boxes	Na
8	Na	Na	Off during inspection	Na	Dogs out, cats in crate or locked in bathroom	Na

Na, no requirement.

mance. Four scent detection firms were evaluated. Two of them (Team 1 and 4) were from the first study with the intention of examining their consistency. They were selected based on their high detection rate or low false-positive rate. Two new firms (Team 9 and 10) were selected based upon their strong reputation within the bed bug scent detection industry.

The apartment complex consisted of two five-story buildings (A and B) separated by a 60-m corridor. Twenty apartments were selected from the buildings using a combination of historical pest control records and premonitoring as in Experiment I. Among them, a mean bed bug count of 33 (range: 2–122) was obtained based upon interceptor trap catch in 11 of the 12 infested apartments. Inspections were conducted over 2 d. The maximum temperatures during the two days of inspections were 35.6 and 33.3°C, respectively. The inspection time spent in each apartment, the number and location of alerts in each apartment were recorded by the researchers. Within 24 h after the last canine scent team's inspection, postinspections were conducted in a similar manner as in Experiment I. The only difference was that precounts in Experiment I were based on a 14-d monitoring interval with interceptors, while in this experiment interceptors were inspected after 7 d. If no bed bugs were found, then the interceptors were inspected again at 14 d and a visual inspection was followed if no bugs were found in interceptors. Approximately 12 mo after the canine scent inspection, all apartments with false-positive findings were inspected again by placing interceptors under the legs of beds and upholstered furniture for 14 d, followed by a thorough visual inspection of beds and furniture if no activity was observed in interceptors.

Experiment III: Informed Building-Wide Inspection. The purpose of this experiment was to examine the performance of two canine teams when conducting a large scale building-wide inspection. The previous two experiments included small number of units and high proportions of infested units, which may not reflect real-world situations that are typically encountered by canine scent firms. In addition, the apartments inspected in Experiments I and II were spread out over five or more floors and two or more buildings. In this experiment, detection teams inspected a large number of apartments in a continuous block. This allowed the detection team to move from one apartment to the next in a continuous fashion, eliminating the disjointed nature of the previous two experiments. The experiment was conducted in the same apartment complex used in Experiment II; however, apartments were not premonitored. Team 9 from Experiment II inspected 102 apartments in Building A and a new team (Team 11) inspected 106 apartments in Building B.

The inspections were conducted during September and October 2011. Unlike all other teams, the dog handler of team 11 used visual inspection after each dog alert in an effort to confirm the alert and therefore spent much longer time than team 9. The maximum outdoor temperature on the day building A was inspected was 23.3°C. The maximum daily high temperature outdoors over the three days of inspections for building B was between 19.4

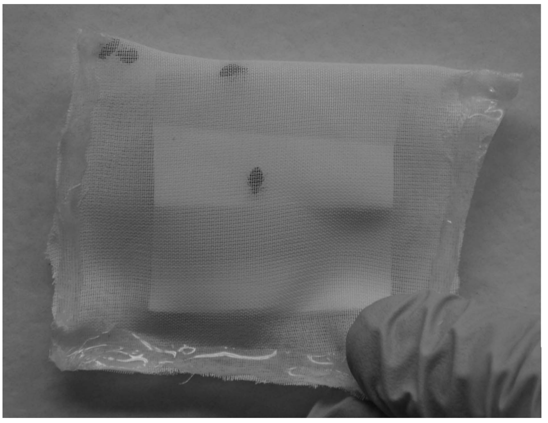

Fig. 1. A sealed sachet with five adult male bed bugs used for evaluating bed bug scent dogs in Experiment IV.

and 30.0°C. Postinspections were conducted in: 1) apartments with an alert, and 2) apartments without alerts but had previous history of bed bug activity within the past 24 mo, based upon historical records. These inspections were carried out in a similar manner to those in the Experiment II.

Experiment IV: Detecting Planted Hides in Apartments. To determine if a higher detection performance could be achieved under controlled conditions, team 10 from Experiments I and II was selected for this experiment. This team was selected because they had a very low detection rate (15%) in Experiment II and was willing to participate in this experiment. The experiment was conducted in four one- or two-bedroom apartments. No previous bed bug activity had ever been reported in the buildings where the apartments were located. Three of the apartments were fully furnished. Two of these three apartments were occupied and one was a model apartment used for showing to potential renters. The fourth apartment was recently vacated with some furnishings left behind including two mattresses, two box springs, a china closet, and six dining room chairs. Bed bug hides in fabric sachets were prepared in the laboratory the day before the experiment. Nitrile gloves were worn while handling the materials used to make the hides. The fabric sachets were ≈6.5 cm^2 and were made by folding a fine mesh nylon fabric (Party Time White Chiffon Fabric, Walmart, Princeton, NJ) in half and sealing the sides with hot glue to create a one square inch envelope open on one end. A paper harborage was inserted inside each sachet. For control hides, the end of the sachet was then sealed with hot glue. For live hides, five live adult male bed bugs were placed in each sachet before the sachet was sealed (Fig. 1). All control hides were stored in a plastic container and sealed before live bugs were handled. The live hides were stored in a separate plastic container. All sachets were stored overnight in the laboratory at room temperature and then transported to the study site. Each apartment received three control and three live hides. The hides were placed ≈1 h before the inspections. Latex gloves were worn to handle and place hides. One researcher placed the control hides and another researcher placed the live hides to avoid any cross contamination. Live hides were examined to ensure that all of the bugs were still alive at the time of placement in apartments. The hides were placed in a variety of areas including the upholstered furniture, beds, night tables, dressers, and closets. The control hides and live hides were placed in separate rooms to control for confusion over positive and false-positive alerts. The exact locations of all alerts were recorded. The scent dogs tested had no prior exposure to placement of hides by either researcher before this experiment.

In all four experiments, each team was instructed to inspect the entire apartment including the living room, bedroom, hallways, closets, bathroom, and kitchen. Teams were reminded of this again during their inspection if it was observed that their search pattern did not include all areas within the apartment.

Data Analysis. The bed bug count data were ranked and then the association between the rank and the team's detection result (yes or no) was analyzed. Four teams (team 1, 4, 9, and 11) which performed inspections in 21–25 infested apartments were examined by Wilcoxon rank sum test (PROC NPAR1WAY in SAS software, SAS Institute 2011). The relationship between a team's detection rate and the false-positive rate was analyzed by regression analysis (PROC REG in SAS software). The relationship between detection rate and a team's experience (number of years the dog and handler worked together) and certification status (yes or no) was also analyzed by regression analysis. For the four teams that performed multiple inspections (different days or locations), results were combined for regression analysis.

Results

Experiment I: Blind Evaluation in Preselected Apartments. Results for Experiment I are summarized in Table 4. The mean (min, max) time for detection teams to inspect an apartment was 3.2 (1.2, 6.0) min. One team's dog was too tired from the heat to inspect the last apartment. Another team was unable to inspect an apartment because the resident died the night before the inspection. Neither of these units had bed bugs. Bed bugs were detected in four units that were not known to have bed bugs before the canine inspection; however, each was detected by only one of the three or four dogs that inspected each of these apartments. The eight teams had mean (min, max) detection rate of 47 (10, 88)% and false-positive rate of 19 (0, 50)%.

Only four out of the 22 infestations were detected by all of the teams that inspected them. Bed bug counts from traps and visual inspection in the four apartments detected by all firms were 25, 31, 68, and 73. Another four apartments with 1, 25, 38, and 62 bed bug counts were missed by all teams that examined those units, indicating the level of infestation is not a predictable factor of probability of being detected by canines. Residents in two infested apartments owned

Table 4. Canine inspection results in Experiment I

Team	Group	No. apts. inspected	Avg. time per unit (min)	Time on break (min)	No. of infestations[a]	No. of infestations detected	No. of apts. with false-positive findings	Detection rate (%)	False-positive rate (%)
1	1	14	3.5	5	8	7	1	88	17
2	1	10	5.4	3	4	3	3	75	50
3	1	24	2.7	24	12	6	2	50	17
4	1	24	4.0	0	12	6	0	50	0
5	1	24	2.5	0	10	5	4	50	29
6	2	23	2.7	0	10	3	2	30	15
7	2	23	6.0	41	12	3	2	25	18
8	2	24	1.2	7	10	1	1	10	7

[a] The number of infestations is based upon a combination of interceptor trap catch and visual inspection.

pets: one owned a dog, another a cat. The apartments with the dog and cat had bed bug counts of 38 and 62, respectively, but no alerts were recorded by any of the three teams that inspected these two apartments. Among the apartments with ($n = 10$) or without ($n = 14$) previous bed bug history, false-positive alerts occurred in 50 and 56% of them, respectively, indicating false-positive alerts are not positively correlated with previous bed bug infestation history. Over the course of the next 12 mo, no bed bug activity was reported or detected in any of the apartments where false-positive findings were recorded.

Experiment II: Informed Inspection of Preselected Apartments. Results for Experiment II are summarized in Table 5. The mean (min, max) time for detection teams to inspect an apartment was 5.3 (1.9, 8.0) min. One of the four canine teams (Team 1) identified an additional infestation not known to have bed bugs before the inspection. A single bed bug was detected based upon interceptor trap catch during postinspection and monitoring of the apartment, bringing the total number of apartments with bed bug activity to 13. The four teams had an average detection rate of 50 (15–77)% and false-positive rate of 32 (14–57)%.

Only one infested apartment with a precount of 68 bed bugs was detected by four teams. Two infested apartments with precounts of 6 and 20 bugs were missed by all four teams. Overall, 57% (4 of 7) of the apartments without bed bugs were alerted in by one or more teams. During postinspections, visual evidence of previous bed bug activity was observed in all but one of the apartments where false-positive alerts were recorded. The team with highest detection rate (77%) also had the highest false-positive rate (57%). Conversely, the team with lowest detection rate (15%) also had the lowest false-positive rate (14%). Over the course of the next 12 mo, no bed bug activity was reported or detected in any of the apartments where false-positive findings were recorded.

Experiment III: Informed Building-Wide Inspection. The results of Experiment III are summarized in Table 6. Team 9 completed the inspection of 102 units in a single day. The mean (min, max) working time to inspect each apartment, excluding all down time was 1.2 (0.5–2.0) min. The team took one 45-min break during the inspection. The mean time required for inspecting each apartment including the break and time between units was 2.7 min. The team only detected two of nine infested apartments, which had 2 and 14 bed bugs, respectively. The mean (min, max) number of bugs in the seven missed apartments was 12 (1, 52). Thirty-four of the 93 noninfested apartments had previous infestation history. Seventy-one percent (5 out of 7) of the false-positive findings were in apartments with prior history of bed bug activity. Approximately 3 mo after the canine inspection, four bed bugs were detected in one of the seven units previously recorded as a false positive; thus, the possibility that bed bug activity was present at the time of the dog inspection cannot be ruled out, making the ranking of this apartment as a false positive questionable.

Team 11 completed the inspection of 106 units in 3 d. The mean (min, max) working time to inspect each apartment, excluding all down time was 4.0 (1.0, 9.5) min. The team required 11 breaks totaling 7 h, to finish the inspections. The mean time required for inspecting each apartment including the break and time between units was 10.6 min. The team detected 8 of 21 known infestations and detected bed bugs in another two apartments where bed bugs were not known to exist before the team's inspection, bringing the total number of apartments with bed bug activity

Table 5. Canine inspection results in Experiment II

Team	Day and time of inspection	No. apts. inspected	Avg. time per unit (min)	Time on break (min)	No. of infestations[a]	No. of infestations detected	No. of false-positive findings	Detection rate (%)	False-positive rate (%)
1	day 1 PM	20	5.0	35	13	10	4	77	57
4	day 2 AM	20	5.0	40	13	9	3	69	43
9	day 2 PM	20	1.9	0	13	5	1	38	14
10	day 1 AM	20	8.0	20	13	2	1	15	14

[a] The number of infestations is based upon a combination of interceptor trap catch and visual inspection.

Table 6. Canine inspection results in Experiment III

Team	No. days to complete inspection	No. apts. inspected	Mean time (min) to inspect per apt.[a]	No. of infestations[b]	No. of infestations detected	No. of false-positive findings	Detection rate (%)	False-positive rate (%)
9	1	102	2.7	9	2	7	22	8
11	3	106	10.6	23	10	4	43	5

[a] Including down time (breaks and travel between apartments).
[b] The number of infestations is based upon a combination of interceptor trap catch and visual inspection.

to 23 and the number of these apartments detected by the team to 10. The mean (min, max) bed bug count in the 10 apartments detected was 5.0 (1, 15). The mean (min, max) bed bug count in the 13 missed apartments was 6.1 (1, 18). Seventeen of the 83 non-infested apartments had previous infestation history. Of the four false-positive alerts, two occurred in apartments with previous activity. Over the course of the next 12 mo, no bed bug activity was reported or detected in any of the apartments where false-positive findings were recorded.

From Experiments I–III, there were a total of 16 inspections (Team 11 was considered having performed three inspections). To calculate the overall accuracy of the inspections, we omitted two of the inspections (Teams 2 and second day inspection by team 11) because the total number of infested units was only 4 in each. The mean detection rate and false-positive rate for the 14 remaining inspections were 44 (10–100)% and 15 (0–57)%, respectively. False-positive alerts occurred nearly equally in apartments with bed bug history (49%) as in units with no infestation history (51%). Of the 67 apartments with bed bug activity, 93% (62 out of 67) were detected by placing interceptors for 7 or 14 d.

We analyzed the relationship between the detection rate and false-positive rate. Teams 1, 4, 9, and 11were evaluated on multiple days. The combined detection rate and false-positive rate were used for these teams. Team 2 was excluded due to its small number of inspections. A team's detection rate was positively correlated to its false-positive rate ($F = 7.6$; df = 1, 8; $P = 0.02$; $R^2 = 0.49$; Fig. 2). There was no significant relationship between the detection rate and the length of time the team had been working together ($F = 0.36$; df = 1, 9; $P = 0.56$) and

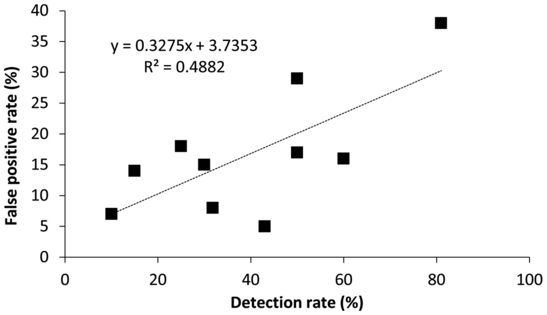

Fig. 2. Relationship between a dog team's detection rate and false-positive rate based upon 10 teams.

whether the team was certified ($F = 1.4$; df = 1, 9; $P = 0.26$; Table 7).

Teams 1, 4, 9, and 11 inspected >15 infested apartments and were used to analyze the relationship between bed bug population level and the probability of being detected by dogs. For each of these four teams, there was no significant relationship between the detection result (yes or no) and the rank of the bed bug count (team 1: $\chi^2 = 12.8$, df = 14, $P = 0.80$; team 4: $\chi^2 = 16.3$, df = 17, $P = 0.68$; team 9: $\chi^2 = 17.8$, df = 16, $P = 0.29$; team 11: $\chi^2 = 12.5$, df = 12, $P = 0.45$). Teams 1, 4, and 9 were evaluated twice. The accuracy of these teams varied greatly between inspections (Table 8). Team 11 spent 3 d to finish inspecting 106 apartments in Experiment III, inspecting 31, 39, and 36 apartments, respectively. We considered these inspections separate events for the purpose of evaluating consistency of inspections conducted by the same team on different days. The detection rate changed greatly during the three inspections (Table 8).

Experiment IV: Detecting Planted Hides in Apartments. Team 10 detected two of three live hides and did not alert on any of the controls in the first apartment. In the second apartment, all three of the live hides were detected with no false-positive findings. In the third apartment, two of three live hides were detected and one control was falsely alerted upon. In the fourth apartment, detection rate and false-positive rates were both 100%. Overall the team detected 83% (10 of 12) live hides and falsely alerted on 25% (4 of 12) of the control hides. The same team in Experiment II had 15% detection rate and 14% false-positive rate.

Discussion

This study is the first evaluating the accuracy of commercially available bed bug canine detection teams under field conditions. We found the detection rates and false-positive rates varied greatly among canine detection teams and within teams evaluated on different days. A team's detection rate is positively correlated with its false-positive rate. There was no significant relationship between bed bug infestation level, the team's experience, or certification status of teams and the detection rates. A detection rate of ≥90% and a false-positive rate of ≤10% occurred in only 1 out of 16 inspections (Team 11), and this team spent a much longer time than the other teams to inspect each apartment. It should also be noted that this team's perfect performance on the first day is negated by its disappointing low level performance the following 2 d. Overall, the team only detected 43% of the infestations in the building during its 3 d of inspec-

Table 7. Relationship between team profile and performance of the inspections

Team	No. of years in bed bug scent detection business	Team working together (mo)	Certification	Detection rate (%)	False-positive rate (%)
1[a]	2	12	IAOCPI	81	38
2	2	24	IAOCPI	75	50
3	1.5	5	NESDCA	50	17
5	3	24	WDDO	50	29
11[a]	0.8	2.5	None	43	5
4[a]	1.2	14	None	60	16
9[a]	4	20	NESDCA	32	8
6	3	36	WDDO	30	15
7	3	6	NESDCA	25	18
8	5	6	None	10	7
10	0.75	8	None	15	14

IAOCPI, International Association of Canine Pest Inspectors; NESDCA, National Entomology Scent Detecting Canine Association; WDDO, World Detector Dog Organization.
[a] Total detection and false-positive rates from multiple inspections.

tion. The accuracy of the 11 canine detection teams evaluated was much lower than that reported in controlled environments (Pfiester et al. 2008). The mean detection and false-positive rate in our study was 44 and 15%, respectively, compared with 98 and 0% using controlled hides conducted in hotel rooms. Consistent with this, we observed a marked difference between performance of a team evaluated in naturally infested apartments and in apartments with controlled hides.

Brooks et al. (2003) suggested, for detection of termites, that it is "not unreasonable to expect a properly trained dog to meet a minimum standard with a positive indication rate of ≥90% and a false-positive rate of ≤10%". The only other study investigating the accuracy of trained dogs for termites reported a mean detection rate of 81% and false-positive rate of 28% in a laboratory setting (Lewis et al. 1997). Our observed mean detection rate of 44% and false-positive rate of 15% is more in line with that reported by Lewis et al. (1997). Furthermore, mean detection and false-positive rates in our study were similar regardless of whether or not detection firms were aware they were being observed. When judged based on 90% detection rate, only one out of 16 inspections meet the proposed standard by Brooks et al. (2003). When judged by 10% false-positive rate, only 5 out of 16 inspections meet the expected standard by Brooks et al. (2003). When both standards are used to judge the canine teams' performance, all but one of the 16 inspections fall short of expectations. Comparing with the 93% detection rate from installing interception devices for 7–14 d, the results of the canine inspections were much less effective at detecting infestations. Moreover, use of monitoring devices eliminates false-positive findings, unless the inspector is not properly trained to distinguish bed bugs from other arthropods.

We attempted using an alternate method to measure a team's effectiveness: the "total correctness" (TC). TC is the total of correct positive alerts plus correct "nonalerts" divided by the total number of units inspected. Using TC can be very misleading. This is illustrated by team 9 who inspected 102 apartments in Experiment III. The team detected only two of nine infestations (22% detection rate) and falsely alerted in seven apartments. The TC was 86%; however, the very low detection rate and seven falsely identified infestations are diluted due to the large sample size of the apartments inspected (n = 102). We do not believe TC should be used as a measure of accuracy due to its misleading nature. Instead, we believe it is necessary to consider both detection rate and false-positive rate to evaluate a team's effectiveness.

The question remains, why the scent detection teams that we evaluated performed so poorly? An obvious difference between performance of a canine team under controlled and field conditions is that errors by dogs and handlers are identifiable and correctable in a controlled setting, while the natural field setting is very complex with odors from many different sources where errors can easily occur, go unidentified and thus remain uncorrected, reinforcing the incorrect behavior. This creates challenges in the ongoing training and evaluation of a team's performance. In a study with wild brown tree snakes, Savidge et al. (2011) suggested dogs were using scent cues from containers and humans who placed hides to help detect the target scent. To overcome this problem, they fed snakes dead mice with radio transmitters inside

Table 8. Consistency of canine detections in detecting bed bug infestations

Team	No. of apartments inspected/no. of infested apartments			Detection rate/false-positive rate (%)		
	Insp. no. 1	Insp. no. 2	Insp. no. 3	Insp. no. 1	Insp. no. 2	Insp. no. 3
1	14/8	20/13	–	88/17	77/57	–
4	24/12	20/13	–	50/0	69/43	–
9	20/13	102/9	–	38/14	22/8	–
11	31/7	39/4	36/12	100/0	25/11	17/0

and allowed the snake to hide on their own. In our controlled hide study, the dog exhibited a learning behavior over the course of four inspections in apartments with controlled hides. The dog was able to pinpoint the exact location of the live hides and recorded no false-positive findings in the first two apartments. By the third apartment the dog alerted on one control hide and by the fourth apartment, it alerted to all of the live hides and all control hides. There were no false-positive findings in areas where there were no hides. By the fourth apartment, it appears the dog may have changed the target scent profile from live bugs, to that of the sachet, the latex gloves worn when placing out the hides, or both. Subtle, but significant, changes such as this can be identified and corrected under controlled conditions. However, the same is not always true under field conditions. All of the firms evaluated had dedicated ongoing maintenance training varying in degree of complexity; however, none used field sites with naturally existing infestations to train their teams. Although only one team was evaluated under both controlled and field conditions, when asked about their in-house training programs, all of the teams evaluated indicated that they have >95% accuracy in their in-house maintenance training exercises, which was not reflected in the field results observed in our study. We suggest that self-evaluating the dogs in naturally infested apartment complexes, offices, hotels, etc. could help improve the accuracy of the inspection teams.

Other factors such as handler bias and unintentional handler cues (Waggoner et al. 1998, Gazit et al. 2005), confusing combinations of scents (Lit and Crawford 2006), insufficient training for all situations (Gazit et al. 2005, Lit and Crawford 2006, Lit et al. 2011), environmental conditions (Smith et al. 2003), level of maintenance training (Cablik and Heaton 2006), and enhanced distractions inherent in applied settings (Lit and Crawford 2006) can influence the team's performance. Smith et al. (2003) suggested the heat may have affected the accuracy of dogs to detect San Joaquin kit foxes in their study. To cool the body, dogs pant; however, while panting they are unable to sniff. Gazit et al. (2003) demonstrated an inverse relationship between increased panting and the efficiency of dogs to detect explosives. In our study, Experiments I and II were conducted when the average daily high temperature was 33.4–34.5°C. The hallways and most apartments were not air conditioned, creating hot conditions. During these inspections some of the dogs showed fatigue and increased panting, while others showed little to no visible affect from the hot weather. In Experiment I, the dog from team 3 became so fatigued that it was only able to inspect 23 of the 24 apartments. The team performed poorly with a 25% detection rate and 18% false-positive rate. The handler for team 1 stopped the inspection after the fifth apartment so he could remove his dog from the building to rest in his air conditioned vehicle. Interestingly, of the eight teams evaluated in Experiment I, team 1 had the highest detection rate (88%) with a false-positive rate of 17% despite the hot conditions. Gazit et al. (2003) and Garner et al. (2001) showed that dogs can be trained to adjust to working under severe physiological conditions. Companies offering canine scent detection for bed bugs must understand the limitations of their dogs and incorporate appropriate conditioning exercises for the various types of environments and conditions they are likely to encounter. Alternatively, they should refuse inspections when environmental conditions are not conducive for a quality inspection.

A context shift effect (Gazit et al. 2005) can also occur between maintenance training and real-world field inspections. For example, if routine training exercises never exceed 30 min during which time the dog is accustomed to being rewarded at least once, the dog may exhibit decreased attention once 30 min have elapsed without reward during a field inspection (Oxley and Waggoner 2009). A context shift, such as this, could be particularly problematic during a large scale inspection where only a few infestations exist. Conversely, a context shift effect could also occur when inspecting a facility with a much higher infestation rate than that in training exercises. Experiments I and II were done with high infestation rates (42–65%). After learning the results of their inspections, 4 of 10 handlers expressed concerns that the high infestation rate was greater than what they normally use in training exercises and may have negatively affected their results. While infestation rates should have no bearing on the accuracy of an inspection, from a context shift perspective, confusion can result when target scent is present at much greater frequencies than what the dog and handler are accustomed to. Based upon our observations during inspections in our study, it was not uncommon for handlers to begin second guessing the dog after it had alerted in what the handler believed to be too many units, creating handler bias which undermines the inspection. Thus, maintenance training should not only be done within the context of the environment that is to be inspected but should vary in duration from short to very long, and include scenarios in which target scent is 1) not present (no reward), 2) present at a typical frequency, and 3) present at high frequencies.

Lit et al. (2011) illustrated that preconceived beliefs of handlers can influence the outcome of an inspection, leading to inaccurate results. False-positive alerts occurred in some of the apartments where old evidence of fecal spotting, carcasses, and exuvia were readily visible and recognized by handlers during the inspection. This may have led to unintentional cues to the dog by the handler. Some of the handlers we worked with also demonstrated a preconceived belief regarding where bed bugs were likely, or not likely, to be found. In our study, all teams paid close attention to bedrooms and living rooms but seven of the 11 teams did not plan on including kitchens, bathrooms, and all closets in their inspection, indicating to us that bed bugs were not likely to be found in these areas. Five of the seven teams included these areas in their inspection after we requested them to do so; still they paid less attention to areas away from beds and upholstered furniture. Two (teams 3 and 5) of the seven teams ignored our requests to inspect all rooms, halls, and closets because they were confident bed bugs would not be found in these areas. It is possible that some of the missed detections were the result of biased search patterns in which areas where the handler did not believe bed bugs were likely to be present were ignored. In 20 of 67 apartments, bed bugs were not detected in interceptors or through visual inspection at beds or upholstered furniture during pre- and postinspections but instead were only captured in interceptors located in less predictable locations such as kitchens, bathrooms, hallways, and hall closets. During the blind study (Experiment I), after requesting one handler to inspect the entire apartment thoroughly, the handler informed us that if bugs are present they will be in bedroom or living room. This team missed all the three units where bed bugs were only observed or captured in interceptors located in areas outside of the bedroom and living room (kitchen, bathroom, hall, or closets) but detected 67% (6 of 9) of the apartments where bed bug activity was observed in the bedroom and living room.

The term "team" is used because the accuracy of the inspection is dependent upon the ability of the dog to detect the target scent and the handler's ability to manage the inspection and interpret or "read" the dog's behavior. The alertness of the team, responsiveness of the dog to the handler, and the handler's ability to interpret the dog's behavior can affect the inspection (Furton et al. 2010). This was illustrated during the 3-d inspection by Team 11. The first day inspection by this team was perfect, with the dog detecting all seven apartments with activity and no false alerts, illustrating the ability of a team to operate with a high degree of accuracy under natural field conditions. On the second day, the dog alerted in the exact location where bed bugs were present in all four of the apartments with bed bug activity; however, three of the four alerts were dismissed by the handler who interpreted that the dog was "playing" him and was just looking for a reward. Thus, on the second day, the dog continued to work with a high degree of accuracy, however, the handler did not. By the third day, the dog alerted in only 17% (2 out of 12) apartments with bed bug activity, a marked difference from the previous two days. Based upon our observations, both the dog and the handler seemed disinterested during these inspections. Gazit et al. (2005) suggested that disinterest on the part of the handler could be unwittingly transmitted to the dog resulting in a decreased motivation by the dog to search.

False-positive alerts can result in significant direct and indirect costs. A total of 28 false-positive findings were recorded by one or more teams in this study. Over the course of the next 12 mo, the presence of bed bugs was confirmed in only one apartment. Had all of these units been treated based upon the results of the dog inspection, the direct treatment costs are likely to have exceeded US$13,000 based upon the typical treatment cost of US$463–482 per apartment reported by Wang et al. (2009). In addition to the direct financial impact, other potential costs include unnecessary exposure to pesticides, property loss from items discarded, and damage to reputation. Based upon the high false-positive rates observed among the teams studied, confirmation of existing bed bug activity in areas of alerts seems reasonable and appropriate. Duggan et al. (2011) suggested that following an alert by detection dogs for cryptic species, employing a second step to confirm the presence of the target can increase the effectiveness and decrease costs associated with large scale inspections. Alerts that cannot be confirmed should not be considered positive for bed bug activity. Instead, they should be considered suspect and worthy of additional inspection or monitoring to determine if bed bugs are in fact present.

There is also a great disparity in the degree of formal training received between handlers of bed bug scent dogs compared with that received by handlers in law enforcement and the military who go through extensive training under the instruction of a qualified instructor. A minimum of 40 h of classroom training and 200 h of practical application are recommended for these military and law enforcement canine handlers (Furton et al. 2010). Only two of the handlers in our study had previous experience handling scent dogs, the rest received fewer than 40 h of combined classroom and hands on training with scent dogs, conducted at the training facility where their dog was purchased. Due to the small number of handlers with previous experience and extensive training, we were unable to analyze the relationship between the degree of training and the quality of an inspection. This is an area where further research is required.

Furton and Myers (2001) suggested despite the fact that dogs are the most efficient, reliable and cost effective real time method for explosive device detection, operational complexities of dog handler teams coupled with limited scientific information on how the dogs function, as well as handler and dog training and operational deployment, makes the implementation of highly reliable and efficient detection teams less straightforward than analytical equipment. The low accuracy of trained dogs for bed bug detection suggests that the capability of dogs to determine presence or absence of bed bugs in natural conditions may be more limited than under controlled conditions. However, canine scent detection offers the only practical method for large scale inspections in nonresidential settings such as schools, office buildings, retail stores, theaters, or mass transit, where thousands of square meters may require inspection and where bed bugs are less predictable making them more difficult to detect by other methods currently available. Thus, there is an urgent need to develop better training and maintenance methods to improve detection rates and reduce false-positive findings.

Acknowledgments

This project was partially funded by Associated Pest Services, Copesan Pest Services, GIE Media, the New Jersey Pest Management Association, the New Jersey Agricultural Experiment Station, and by the U.S. Department of Agriculture–National Institute for Food and Agriculture Hatch Multistate project number NJ08127. Susan McKnight donated interceptors. Boyd Gonnerman and Marcus Kwasek provided assistance during inspections. We are grateful to the canine scent detection teams that donated their time, energy, and support throughout the informed studies. We like to thank P.L. Waggoner for critical review of an earlier version of the manuscript and would also like to thank property management and the residents of the participating communities for their patience and cooperation during the repeated visits by researchers and canine teams to their apartments. This is New Jersey Experiment Station Publication No. D-08-08117-02-14.

References Cited

Brooks, S. E., F. M. Oi, and P. G. Koehler. 2003. Ability of canine termite detectors to locate live termites and discriminate them from non-termite material. J. Econ. Entomol. 96: 1259–1266.

Browne, C., K. Stafford, and R. Fordham. 2006. The use of scent-detection dogs. Ir. Vet. J. 59: 97–102.

Cablik, M. E., and J. S. Heaton. 2006. Accuracy and reliability of dogs surveying for desert tortoise (*Gopherus agassizili*). Ecol. Appl. 16: 1926–1935.

Cooper, R. 2007. Are bed bug dogs up to snuff? Pest Control 75(1): 49–51.

Davies, T.G.E., L. M. Field, and M. S. Williamson. 2012. The re-emergence of the bed bug as a nuisance pest: implications of resistance to the pyrethroid insecticides. Med. Vet. Entomol. 26: 241–254.

Doggett, S. L., C. J. Orton, D. Lilly, and R. C. Russell. 2011. Bed bugs: the Australian response. Insects 2: 96–111.

Duggan, J. M., E. J. Heske, R. L. Schooley, A. Hurt, and A. Whitelaw. 2011. Comparing detection dog and livetrapping surveys for a cryptic rodent. J. Wildl. Manage. 75: 1209–1217.

Eddy, C., and S. C. Jones. 2011. Bed bugs, public health, and social justice: part 1, a call to action. J. Environ. Health 73: 8–14.

Furton, K. G., and L. J. Myers. 2001. The scientific foundation and efficacy of the use of canines as chemical detectors for explosives. Talanta 54: 487–500.

Furton, K., J. Greb, and H. Holness. 2010. The scientific working group on dog and orthogonal detector guidelines (SWGDOG), p. 155. National Criminal Justice Reference Service, U.S. Department of Justice, Rockville, MD.

Garner, K. J., L. Busbee, P. Cornwell, J. Edmonds, K. Mullins, K. Rader, J. M. Johnston, and J. M. Williams. 2001. Duty cycle of the detector dog: a baseline study. Final Report. FAA Grant #97-G-020. Institute for Biological Detection Systems. Auburn University, Auburn, AL.

Gazit, I., A. Goldblatt, and J. Terkel. 2003. Explosives detection by sniffer dogs following strenuous physical activity. Appl. Anim. Behav. Sci. 81: 149–161.

Gazit, I., A. Goldblatt, and J. Terkel. 2005. The role of context specificity in learning: the effects of training context on explosives detection dogs. Anim. Cogn. 8: 143–150.

Johnston, J. M. 1999. Canine detection capabilities: operational implications of recent R&D findings. Institute for Biological Detection Systems. Auburn University, Auburn, AL.

Lewis, V. R., C. F. Fouche, and R. L. Lemaster. 1997. Evaluation of dog-assisted searches and electronic odor devices for detecting the western subterranean termite. For. Prod. J. 47: 79–84.

Lewis, V. R., S. E. Moore, R. L. Tabuchi, A. M. Sutherland, D. -H. Choe, and N. D. Tsutsui. 2013. Researchers combat resurgence of bed bug in behavioral studies and monitor trials. Calif. Agric. 67: 172–178.

Lin, H., W. Chi, C. Lin., Y. Tseng, W. Chen, Y. Kung, and Y. Lien. 2011. Fire ant-detecting canines: a complimentary method in detecting red imported fire ants. J. Econ. Entomol. 104: 225–231.

Lit, L., and C. A. Crawford. 2006. Effects of training paradigms no search dog performance. Appl. Anim. Behav. Sci. 98: 277–292.

Lit, L., J. B. Schweitzer, and A. M. Oberbauer. 2011. Handler beliefs affect scent detection dog outcomes. Anim. Cogn. 14: 387–394.

Oxley, J. C., and L. P. Waggoner. 2009. Detection of explosives by dogs, pp. 27–40. *In* M. Marshall and J. C. Oxley (eds.), Aspects of explosives detection. Elsevier, Amsterdam, The Netherlands.

Pfiester, M., P. G. Koehler, and M. Pereira. 2008. Ability of bed bug-detecting canines to locate live bed bugs and viable bed bug eggs. J. Econ. Entomol. 101: 1389–1396.

Pinto, L. J., R. Cooper, and S. K. Kraft. 2008. Bed bug handbook-the complete guide to bed bugs and their control. Pinto & Associates, Inc., Mechanicsville, MD.

Potter, M. F. 2011. The history of bed bug management-with lessons from the past. Am. Entomol. 57: 102–104.

Potter, M. F., K. F. Haynes, M. Henrikson, and B. Rosenberg. 2011. The 2011 bed bugs without borders survey. Pest World (Nov/Dec): 4–15.

SAS Institute. 2011. SAS/STAT user's guide, version 9.3. SAS Institute, Cary, NC.

Savidge, J. A., J. W. Stanford, R. N. Reed, G. R. Haddock, and A. A. Yackel Adams. 2011. Canine detection of free-ranging brown tree snakes on Guam. N.Z.J. Ecol. 35: 174.

Smith, D. A., K. Ralls, A. Hurt, B. Adams, M. Parker, B. Davenport, M. C. Smith, and J. E. Maldonado. 2003. Detection and accuracy rates of dogs trained to find scats of San Joaquin kit foxes (*Vulpes macrotic mutica*). Anim. Conserv. 6: 339–346.

Waggoner, P. L., M. H. Jones, M. Williams, J. M. Johnston, C. C. Edge, and J. A. Petrousky. 1998. Effects of extraneous odors on canine detection, pp. 355–362. *In* A. T. DePersia and J. J. Pennella (eds.), Proceedings of the Conference on Enforcement and Security Technologies, vol. 3575. SPIE, Bellingham, WA.

Wallner, W. E., and T. L. Ellis. 1976. Olfactory detection of gypsy moth pheromone and egg masses by domestic canines. Environ. Entomol. 5: 183–186.

Wang, C., and R. Cooper. 2011. Environmentally sound bed bug management solutions, pp. 44–63. *In* P. Dhang (ed.), Urban Pest Management: An Environmental Perspective. CAB International, Wallingford, United Kingdom.

Wang, C., and R. Cooper. 2012. The future of bed bug monitoring. PestWorld (Jan/Feb): 4–9.

Wang, C., T. Gibb, and G. W. Bennett. 2009. Evaluation of two least toxic integrated pest management programs for managing bed bugs (Heteroptera: Cimicidae) with discussion of a bed bug intercepting device. J. Med. Entomol. 46: 566–571.

Wang, C., W. Tsai, R. Cooper, and J. White. 2011. Effectiveness of bed bug monitors for detecting and trapping bed bugs in apartments. J. Econ. Entomol. 104: 274–278.

Welch, J. B. 1990. A detector dog for screwworms (Diptera: Calliphoridae). J. Econ. Entomol. 83: 1932–1934.

Received 9 May 2014; accepted 17 September 2014.