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Characterizing spatial distribution of trap captures of beetles in retail pet stores using SADIE® software ☆

Christian Nansen[a,*], Bhadriraju Subramanyam[b], Rennie Roesli[b]

[a] *Department of Entomology and Plant Pathology, Oklahoma State University, 127 Noble Research Center, Stillwater, OK 74078, USA*
[b] *Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506, USA*

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Abstract

The weevils, *Sitophilus* spp., drug store beetle, *Stegobium paniceum* (L.), and red flour beetle, *Tribolium castaneum* (Herbst) in two retail pet stores in Kansas, USA, were sampled with pitfall traps on five separate occasions before and four separate occasions after a thorough sanitation in areas with high trap captures. Trap captures of *Sitophilus* spp. and *S. paniceum* in store 1 and those of *T. castaneum* and *Sitophilus* spp. in store 2, were analyzed using the Spatial Analysis of Distance IndicEs (SADIE®) software. Captures of *Sitophilus* spp. in store 1 and *T. castaneum* in store 2 increased immediately after sanitation, but subsequently were similar to levels before sanitation, whereas captures of *S. paniceum* in store 1 and *Sitophilus* spp. in store 2 were unaffected by sanitation. In store 1, *S. paniceum* trap captures were randomly distributed on all sampling occasions, while *Sitophilus* spp. captures were spatially aggregated immediately before and after sanitation. During the 6 months of trapping, the *Sitophilus* spp. trap capture centroids gradually moved northwards, and those of *S. paniceum* moved southwards. In store 2, trap captures of *T. castaneum* and *Sitophilus* spp. were uniformly distributed before sanitation and were predominantly spatially aggregated after sanitation. During the 6 months of trapping, trap capture centroids of both *T. castaneum* and *Sitophilus* spp. gradually moved northwards. The impact of a thorough sanitation performed once on the spatial distribution patterns of insects in the two retail stores was not consistent. Sanitation was also ineffective in reducing captures of the insect species.

Keywords: SADIE®; Spatial distribution; Sanitation; Stored-product beetles; Efficacy assessment

☆ This paper presents research results only. Mention of a proprietary product name does not constitute an endorsement for its use by Oklahoma State University and Kansas State University.

*Corresponding author. Tel.: +1-406-994-6132; fax: +1-406-994-6029.
E-mail address: cnansen@montana.edu (C. Nansen).

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1. Introduction

Insects are spatially distributed in uniform, random, or aggregated patterns (Southwood, 1984), primarily in response to the environment in which they live. Taylor (1984) considered the spatial distribution pattern of an organism as one of its most important ecological characteristics, because it tends to be more stable than the population density among generations and/or seasons. Depending on the spatial scale, most insects are aggregated due to the patchy distribution of food sources, temperature, humidity, predators, and oviposition sites (Campbell and Hagstrum, 2002).

The spatial distribution of insects in a given environment may change over time. Assessing changes in the spatial distribution pattern over time provides important information about how insects respond to a changing environment, and can be useful in the development of efficient sampling and integrated pest management strategies (Korie et al., 2000). Furthermore, such information can also be used for precision targeting of management measures (Brenner et al., 1998; Arbogast et al., 2000a, b).

Contour maps have been drawn from trap capture data of stored-product insects to qualitatively assess spatial distribution patterns of insects over time or evaluate effectiveness of a pesticide application (Arbogast et al., 1998, 2000a, b; Campbell et al., 2002). Spatial distribution patterns of insects in traps or product samples can be quantitatively analyzed by using spatial statistics. Nansen et al. (2004) used spatial statistics to analyze counts of adults and larvae of the Indian meal moth, *Plodia interpunctella* (Hübner), from different sampling methods in a maize storage facility during 15 consecutive weeks. They showed that counts of larvae obtained from maize samples were spatially aggregated for the entire sampling period, while adults in unbaited sticky traps were randomly distributed within the same storage facility. Korie et al. (2000) analyzed the spatial distribution pattern of a carabid, *Pterostichus melanarius* (Illiger), in an oat field during 15 daily sampling occasions including samples before and after harvest. They showed that the spatial distribution of *P. melanarius* captures were aggregated before harvest and random after harvest.

In this study, we analyzed beetle trap captures from two retail pet stores subjected to a single sanitation treatment with the primary objective of illustrating the utility of a statistical software package, Spatial Analysis of Distance IndicEs (SADIE®), for quantitatively examining changes in the spatial distribution patterns of stored-product beetles.

2. Materials and methods

2.1. Trapping and sanitation in stores

Two retail pet stores in Kansas, USA measuring 40 m × 20 m (store 1, Fig. 1a) and 40 m × 24 m (store 2, Fig. 2a) were used for this study. In each store, 30 pitfall traps (Flité-Trak M^2 or Dome traps, Trécé, Inc., Salinas, CA) were baited with a commercial blend of food oils (Trécé, Inc., Salinas, CA) and three separate pheromone lures (Trécé, Inc., Salinas, CA) containing sex pheromones for the cigarette beetle, *Lasioderma serricorne* (F.) and the drug store beetle, *Stegobium paniceum* (L.), *Trogoderma* spp., and an aggregation pheromone for *Tribolium* spp. In each store, traps were placed in a grid fashion on the floor, primarily underneath shelves or behind kick plates. The *x* and *y* coordinates of trap locations in each store were located according to a reference point (0, 0) in the southwest corner using a hand-held DISTO™ meter (Leica Geosystems, Heerbrugg, Switzerland). Here, we report trap captures of the two most abundant species in each retail pet store to illustrate the utility of the SADIE® software for quantitative assessment of temporal changes in the spatial distribution patterns. Complete information on the types and numbers of all species found in these two stores is given in Roesli et al. (2003). Adults in traps were identified to genus or species, and expressed as number of insects captured per trap per day. *Sitophilus oryzae* (L.) and *S. zeamais* Motschulsky were found in both stores but are not distinguished for the purposes of this paper.

In store 1, traps were first placed on February 5, 2001, and sampled on February 12, 26, March 12, 26, April 13, 30, May 14, June 5, and July 2, 2001. Sanitation was conducted on April 13 only, in areas where trap captures were consistently high. These areas included areas on and under the shelves where birdseed, dry dog food, dry cat food, and bulk-stored pet foods were displayed (Fig. 1). Dry dog and cat food products were present along five east–west aisles in the eastern part of the retail store. Bird seed was displayed on a stand in the northeastern corner and in an area that included three north–south aisles in the north central part of the store.

In store 2, traps were placed on February 5, 2001, and were sampled on February 12, 19, 26, March 12, 23, April 9, 30, May 14, and June 5, 2001. Sanitation was performed on March 23, in areas where trap captures were consistently high. These areas were similar to those described for store 1 (Fig. 2). Like store 1, dry dog and dry cat food products were present along six east–west aisles in the eastern part of the retail store. Bird seed and food for small pet animals (rodents, rabbits, etc.) were placed on two north–south aisles in the south central part of the store.

2.2. Sanitation

In both stores, sanitation included sweeping and vacuuming of spillage under kick plates, dust and dirt on floors, and cleaning of shelves with wild birdseed and small pet animal food products. In store 2, sanitation also included cleaning of the food bar table, located in the center of the retail store, where dry bulk-stored pet food products were displayed. Sanitation also included discarding the bulk-stored food products because they were infested. Furthermore, 19 bags of infested bird food products were removed from shelves in the southern part of the retail store. A total of 21 person hours was spent performing sanitation in each store. According to store managers the sanitation we performed was considerably more thorough than their routine daily sanitation.

2.3. Analyzing spatial distribution patterns of insects

SADIE® software for MS-DOS was used to determine random or aggregated spatial distribution of trap captures before and after sanitation and to determine sampling centroids and changes in position of trap capture centroids during the nine consecutive trapping occasions. Perry (1995, 1998) and Korie et al. (2000) provide detailed description of the SADIE®

procedures and the internet web site at http://www.rothamsted.bbsrc.ac.uk/pie/sadie/SADIE_home_page_1.htm includes references on the use of this software.

The sampling centroid is the unweighted mean of x and y coordinates of all trap locations. The trap capture centroid corresponds to the mean x and y coordinates of trap sites in which trap captures are used as a linear weighting factor. The trap capture centroid provides a simple measure of the spatial arithmetic mean of trap captures (Korie et al., 2000). A change in trap capture centroid following sanitation would suggest an impact on insect capture and consequently its spatial distribution.

In each store, spatial distribution patterns of insects captured in traps and changes in position of trap capture centroids were determined. The spatial distribution pattern on each sampling occasion was based upon 500 randomized redistributions of trap captures. A paired t-test (critical $P = 0.05$) was used to compare the eastern and northern coordinates of the beetle trap capture centroids. Trap captures from the nine sampling occasions were plotted as discrete scale-sized points using SigmaPlot® software for Windows (Version 6) to visualize spatial differences in beetle captures. Compared to contour maps (e.g. Arbogast et al., 2000a, b), plotting trap captures as discrete scale-sized points allows easy comparisons of temporal changes in trap captures at specific trap locations.

3. Results

3.1. Spatial distribution patterns of insects within stores

Positions of consecutive trap capture centroids of *Sitophilus* spp. and *S. paniceum* in store 1 remained within a fairly restricted part of the store and close to the sampling centroid (Fig. 1a). However, *Sitophilus* spp. trap capture centroids were located significantly more to the east when compared with *S. paniceum* centroids ($t = 4.548$, d.f. $= 8$, $P = 0.002$). There was no significant difference in the north and south positions of trap capture centroids for these two beetle pests ($t = 1.083$, d.f. $= 8$, $P = 0.310$). The centroids of *Sitophilus* spp. gradually moved northwards while those of *S. paniceum* gradually moved southwards during the nine sampling occasions (Fig. 1b). The spatial distribution of *Sitophilus* spp. trap captures was not significantly different ($P > 0.05$) from a random pattern in the first four sampling occasions before sanitation, while the spatial distribution showed a significantly aggregated pattern ($P < 0.05$) on the 5th sampling occasion (date of sanitation) and in the two sampling occasions immediately following sanitation (Table 1). The distribution of *S. paniceum* trap captures did not deviate from a random pattern ($P > 0.05$) on any of the nine sampling occasions.

Positions of consecutive trap capture centroids of *Sitophilus* spp. and *Tribolium castaneum* (Fig. 2a) in store 2 indicated that both species were captured consistently in high numbers in the eastern part of the pet store where most of the pet food products were displayed. A close-up (Fig. 2b) of the trap capture centroids indicated that these beetle species gradually moved northwards over the nine sampling occasions. *Tribolium castaneum* trap capture centroids were located significantly more to the east than those of *Sitophilus* spp. ($t = 5.568$, d.f. $= 8$, $P < 0.001$), while there was no significant difference in the north and south positions of trap capture centroids between the beetle species ($t = 0.543$, d.f. $= 8$, $P = 0.602$). The spatial distribution of *T.*

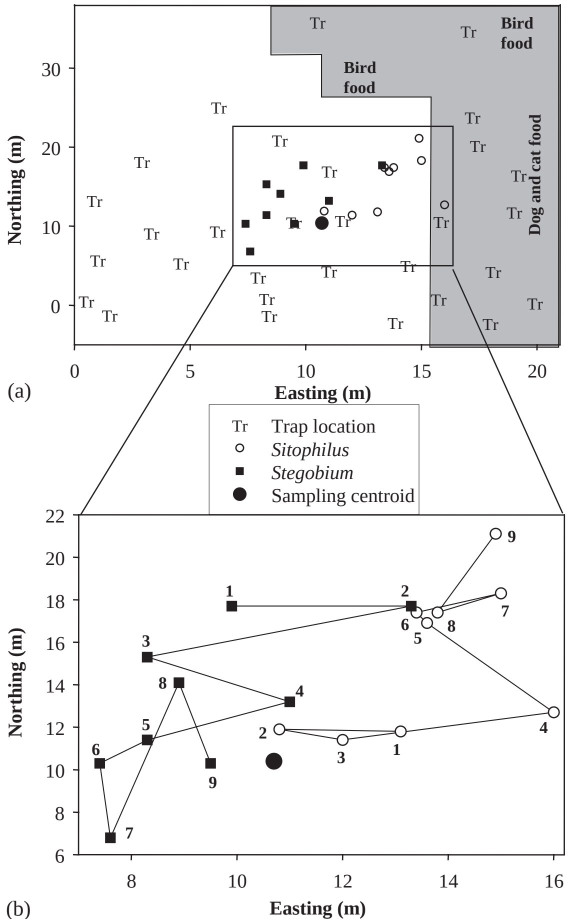

Fig. 1. (a) Trap locations (Tr) in store 1, and the weekly trap capture centroids (spatial mean of trap captures) for *Sitophilus* spp. (open circle) and *S. paniceum* (solid square) are presented. The large solid circle denotes the position of the sampling centroid, which is the mean *x* and *y* coordinates of trap locations. Gray areas denote where sanitation was conducted. **(b)** A section of store 1 was amplified to show the relative position of weekly trap capture centroids throughout the sampling period, and the numbers 1–9 denote the consecutive sampling occasions.

castaneum trap captures was not significantly different ($P > 0.05$) from a random pattern in three of the five sampling occasions before sanitation, while the spatial pattern of trap captures was significantly aggregated ($P < 0.05$) on all four sampling occasions after sanitation (Table 1). The spatial distribution pattern of *Sitophilus* spp. trap captures was random ($P > 0.05$) in four of the five sampling occasions before sanitation, and it was significantly aggregated ($P < 0.05$) in three of the four sampling occasions after sanitation (Table 1).

3.2. Mean captures of insects

Mean captures of *Sitophilus* spp. in store 1 ranged from 0.06 to 1.16 adults/trap/day (Fig. 3a), and the trap captures increased six-fold immediately after sanitation. Mean daily trap captures of

Table 1
Index of aggregation of the most abundant beetle pests in two retail pet stores in Kansas

Sampling occasion	Store 1		Store 2	
	Sitophilus spp.	*S. paniceum*	*T. castaneum*	*Sitophilus* spp.
1	1.070	1.175	1.321	1.270
2	0.821	1.248	1.323	1.318
3	1.008	1.139	**1.536**	1.371
4	1.305	1.048	**1.430**	**1.497**
5	**1.658**	1.026	1.411	1.260
6	**1.694**	0.959	**1.573**	**1.408**
7	**1.518**	1.107	**1.603**	**1.414**
8	1.236	1.016	**1.581**	1.358
9	1.387	0.967	**1.493**	**1.400**

Note: Insects were sampled on nine consecutive occasions, five before and four after sanitation in each retail pet store. Values represent the index of aggregation (I_a) from the SADIE® analysis of the spatial distribution pattern. Values in plain text denote sampling occasions in which the beetle species was randomly distributed among traps, while values in bold text represent sampling occasions in which the beetle species was significantly aggregated ($P<0.05$) among traps.

Sitophilus spp. in store 1 were generally low in all parts of the pet store before sanitation, while after sanitation there was a marked increase in captures at a couple of trap locations in the northeastern part of the store (Fig. 4). The marked increase in daily mean captures of these species within a restricted part of the retail store explains the change from random distribution before sanitation to an aggregated spatial distribution pattern after sanitation (Table 1). The comparative increase in trap captures in the northeastern part of the pet store after sanitation also explains the northwards shift of *Sitophilus* spp. trap capture centroids (Fig. 1b).

Mean captures of *S. paniceum* in store 1 ranged from 0.03 to 0.14 adults/trap/day (Fig. 3a). Captures of *S. paniceum* were consistently higher in the western part of the store, and consequently trap capture centroids were located in that part of the store (Fig. 5). The southwards shift of these centroids is due to a gradual increase in *S. paniceum* trap captures in the southern part of store 1.

Mean captures of *T. castaneum* in store 2 ranged from 0.43 to 4.74 adults/trap/day (Fig. 3b), and the captures increased two-fold after the sanitation (Fig. 6). The observed increase in mean trap captures of this species after sanitation mainly occurred in the northeastern part of the pet store. The change from a random spatial distribution pattern before sanitation to an aggregated pattern after sanitation can be explained by the large increase in trap captures in the northeastern part of the store.

Mean trap captures of *Sitophilus* spp. in store 2 ranged from 0.03 to 2.43 adults/trap/day (Fig. 3b) and were greatest in the northeastern part of the pet store (Fig. 7), but trap captures of *Sitophilus* spp. were decreasing before sanitation and did not increase after sanitation.

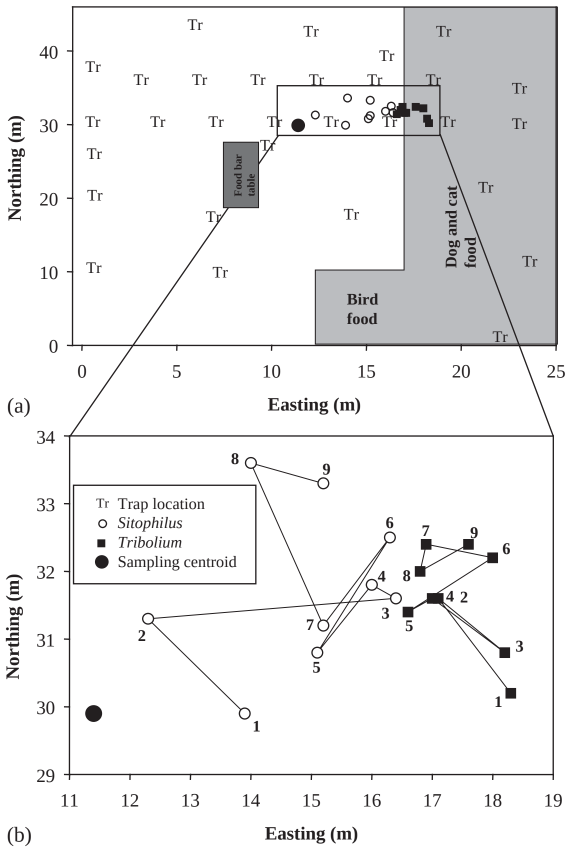

Fig. 2. (a) Trap locations (Tr) in store 2, and the weekly trap capture centroids (spatial mean of trap captures) for *Sitophilus* spp. (open circle) and *T. castaneum* (solid square). The large solid circle denotes the position of the sampling centroid, which is the mean x and y coordinates of trap locations. Gray areas denote where sanitation was conducted. (b) A section of store 2 was amplified to show the relative position of weekly trap capture centroids throughout the sampling period, and the numbers 1–9 denote the consecutive sampling occasions.

4. Discussion

Pest management practices in retail stores include sanitation, inspection of incoming products, stock rotation, pest monitoring, and use of pesticides. Methods have not been developed for examining incoming products and products on shelves for determining insect infestation rates. Similarly, absolute sampling methods, as described in Southwood (1984), have not been developed for insects associated with retail pet stores.

The daily sanitation performed by employees in the two stores sampled was designed to keep the aisles clean, and no sanitation was performed under shelves and behind kick plates or on shelves. Food spillage on shelves from damaged bags, product accumulations on folds of metal shelves, or underneath shelves and behind kick plates in the two stores provided ample

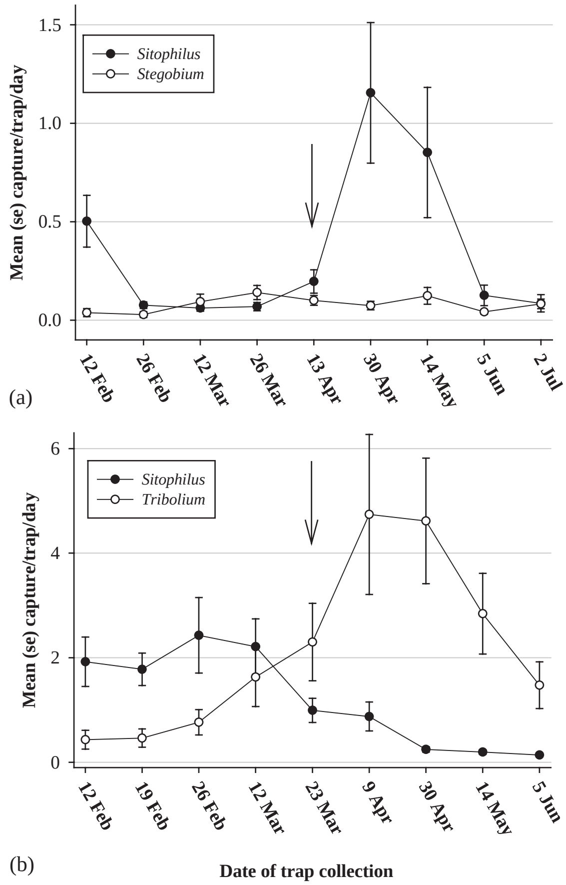

Fig. 3. Mean daily trap captures of beetle pests in store 1 (a) and store 2 (b). The arrows indicate the dates when sanitation was conducted.

opportunities for stored-product insects to survive and flourish. The pest control company servicing these stores placed eight pheromone-baited sticky traps for *P. interpunctella*, especially near shelves where the birdseed was stored. The pest control technician during monthly visits spends about 30 min in each store to check pheromone traps, rodent traps/stations, do a visual assessment of store sanitation, and look for signs of insect and rodent activities. Pesticides are seldom applied in these stores because of live pets such as parrots, reptiles, rodents, and fish. The store employees did not inspect incoming products or products on shelves for infestation, and did not follow proper (first in, first out) stock rotation practices. Therefore, it is not surprising to find insects throughout the store. Both the trapping program and level of sanitation we performed were considerably more thorough than those of the pest control company and store employees. The pest control company servicing the two stores did not place food-baited or pheromone-baited traps for stored-product beetle pests.

The marked increase in trap captures of *Sitophilus* spp. in store 1 and *T. castaneum* in store 2 immediately after sanitation was probably due to removal of spillage, which likely resulted in an

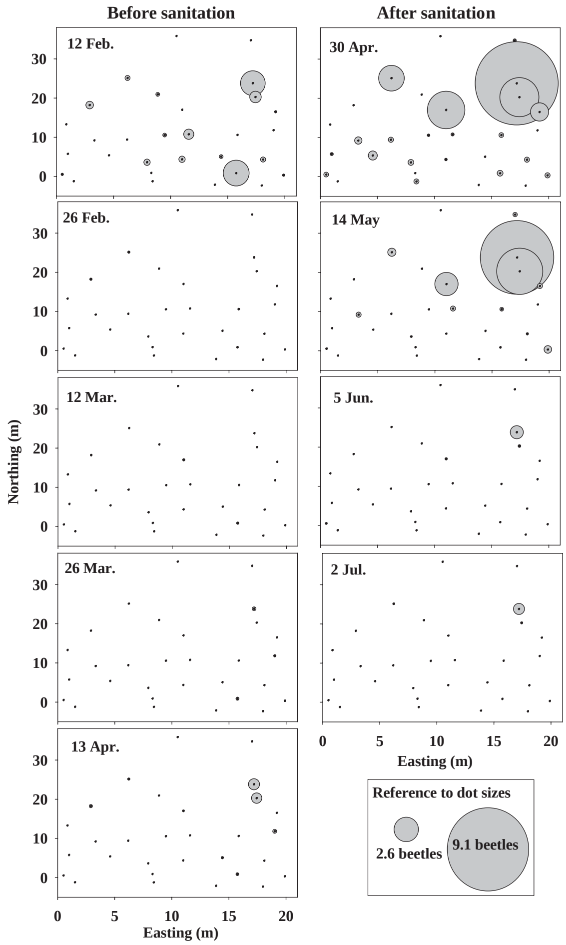

Fig. 4. Map of *Sitophilus* spp. trap captures in store 1 as scale-sized dots for each of the nine consecutive sampling occasions. Trap locations are indicated by black dots, and the gray circles indicate the relative magnitude of trap captures.

increased search for food by adult beetles. It is, however, not clear why the spatial distribution patterns of *S. paniceum* in store 1 and *Sitophilus* spp. in store 2 appeared to be less affected by the sanitation. Both these species were captured in small numbers in traps, and *Sitophilus* spp. numbers were decreasing just before and after sanitation.

Summarising our results, the mean trap captures of the two most abundant beetle species in each retail pet store indicated that the sanitation was not very effective in greatly reducing trap captures of beetles. In both pet stores, bagged food products, especially the birdseed and cat/dog foods, on shelves were infested (Roesli et al., 2003). The store employees did not identify and remove infested products on shelves. Insects captured in traps following sanitation could have originated from infested products brought into the store and those on the shelves, and from unknown infestation sources within the store. Increased capture of *P. interpunctella* in

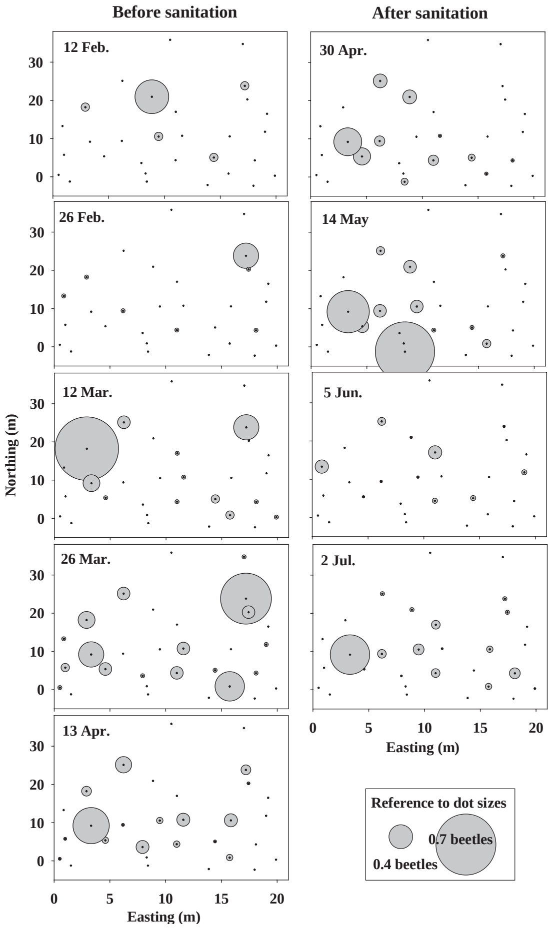

Fig. 5. Map of *S. paniceum* trap captures in store 1 as scale-sized dots for each of the nine consecutive sampling occasions. Trap locations are indicated by black dots, and the gray circles indicate the relative magnitude of trap captures.

pheromone-baited sticky traps following a methyl bromide fumigation of a mill was reported by Doud and Phillips (2000). The source of *P. interpunctella* males was not clearly known, but Doud and Phillips (2000) suspected the likely source to be males present outside the mill. Understanding the sources of insects in retail stores and movement between infested products and product spillage on floors is therefore important for interpreting the observed trap captures.

We have illustrated a method for evaluating the impact of pest management intervention on trap captures of beetle pests in retail stores. In general, a thorough sanitation performed once did not greatly reduce trap captures. The impact of multiple sanitation cycles on trap captures warrants further study. Interpreting changes in trap captures following an intervention would be greatly improved if we understood the sources and magnitude of insect infestation in products

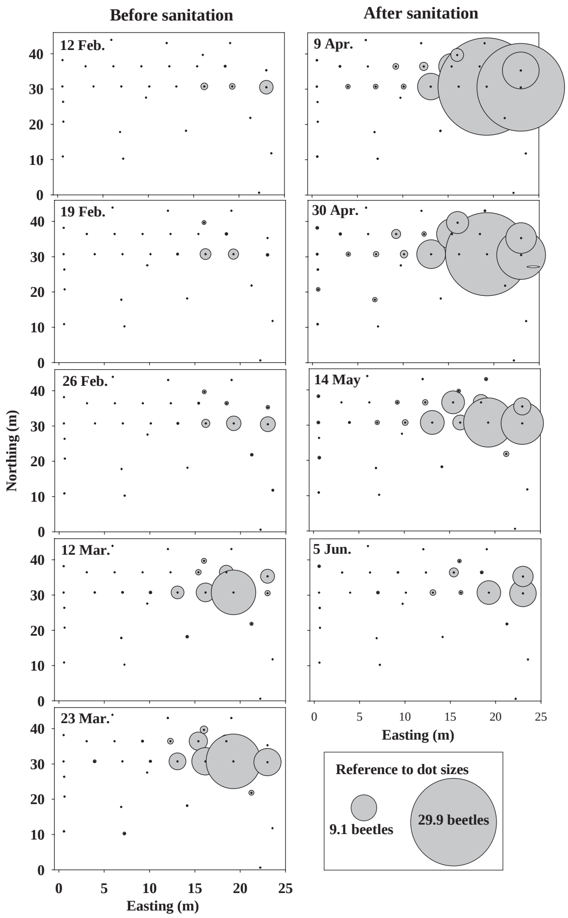

Fig. 6. Map of *T. castaneum* trap captures in store 2 as scale-sized dots for each of the nine consecutive sampling occasions. Trap locations are indicated by black dots, and the gray circles indicate the relative magnitude of trap captures.

being brought into the store or on the shelves, and the utilization of spilled patchy resources by insects within the store.

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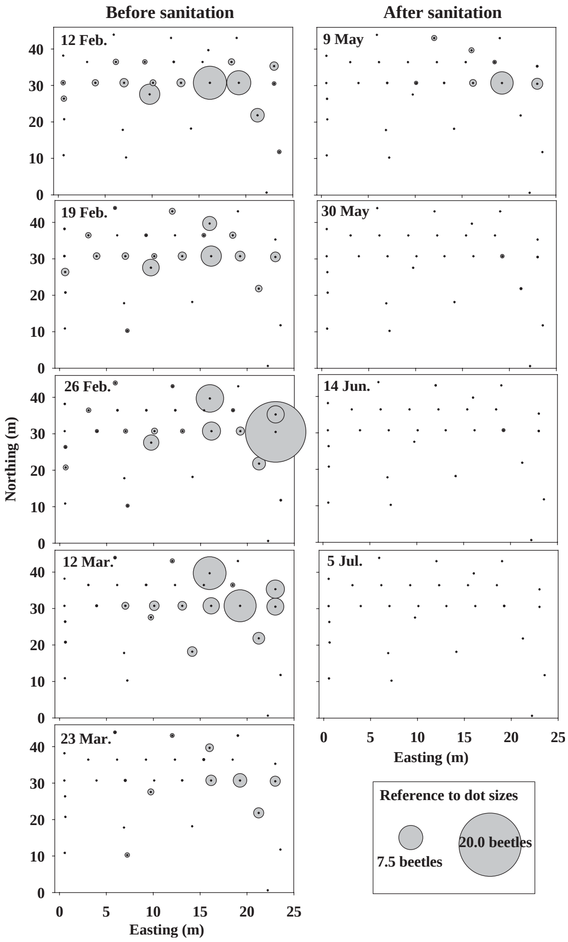

Fig. 7. Map of *Sitophilus* spp. trap captures in store 2 as scale-sized dots for each of the nine consecutive sampling occasions. Trap locations are indicated by black dots, and the gray circles indicate the relative magnitude of trap captures.

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