Monitoring Insect Pests in Retail Stores by Trapping and Spatial Analysis

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ABSTRACT Stored-product insects are a perennial problem in retail stores, where they damage and contaminate susceptible merchandise such as food products and animal feed. Historically, pest management in these stores has relied heavily on chemical insecticides, but environmental and health issues have dictated use of safer methods, and these require better monitoring. A monitoring procedure that employs an array of moth and beetle traps combined with spatial (contour) analysis of trap catch was tested in three department stores and two pet stores. The rate of capture increased with the level of infestation but was essentially constant over 4- to 5-d trapping periods. Contour analysis effectively located foci of infestation and reflected population changes produced by applications of the insect growth regulator (S)-hydroprene. The most abundant insects were *Plodia interpunctella* (Hübner), *Lasioderma serricorne* (F.), *Oryzaephilus mercator* (Fauvel), *Tribolium castaneum* (Herbst), and *Cryptolestes pusillus* (Schönherr). The results indicate that contour analysis of trap counts provides a useful monitoring tool for management of storage pests in retail stores. It identifies trouble spots and permits selection, timing, and precision targeting of control measures to achieve maximum pest suppression with minimum pesticide risk. It permits managers and pest control operators to visualize pest problems over an entire store, to monitor changes over time, and to evaluate the effectiveness of control intervention. The contour maps themselves, along with records of control applications and stock rotation, provide permanent documentation of pest problems and the effectiveness of pest management procedures.

KEY WORDS stored-product insects, retail stores, insect trapping, insect monitoring, spatial analysis, precision targeting

STORED-PRODUCT INSECTS ARE a perennial problem in retail stores, where they damage and contaminate susceptible merchandise such as food products and animal feed. Their presence causes loss of customer good will, guarantees the presence of potential allergens (Brenner 1993, Brenner et al. 1991), and may result in citation by public health officials when the store sells groceries or includes a restaurant. These pests may be resident in stores or invade stores from nearby areas, but often they are introduced in products delivered from infested warehouses. As their numbers increase, introduced insects disperse to invade other products in the store. Spillage from broken packages that has accumulated under display and storage shelves, among clutter in stock rooms, or in other inaccessible places also becomes infested and provides a continuing source of infestation.

Effective management of the problem requires good sanitation, inspection of incoming goods, frequent rotation of stock, monitoring for pests, removal of infested stock, and judicious application of biorational or conventional chemical insecticides. Historically, retailers and pest control operators have relied heavily on chemical pesticides, but increasing awareness of risk to environmental quality and human health has made it necessary to seek safer methods. Early detection and location of infestation through improved monitoring will reduce risk by permitting application of pesticides only when and where they are needed. Improved monitoring will also provide a means to identify points of control failure and take corrective action.

Research over the last two or three decades has produced a variety of traps that are effective in detecting insect pests (Burkholder 1984, Vick et al. 1990, Mullen 1992), but the value of these traps for making pest management decisions has been limited by our ability to relate numbers of insects captured to numbers present, or to economic impact. Attempts to interpret trap catch in terms of population density have enjoyed only limited success (Arbogast and Mankin 1999). Wilkin and Fleurat-Lessard (1991) suggested that in stored grain, it may in fact be impossible to make such an interpretation, and they proposed that a risk factor system be devised instead. Thus, there are currently two possible systems for interpreting the results of trapping. These can be termed representa-

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tive and indicative (Arbogast and Mankin 1999). Representative interpretation makes the assumption that the number of insects captured represents a population density to which it can be converted mathematically, whereas indicative interpretation uses trap catch as an indicator of risk or action to be taken. Wilkin (1990) recognized two sorts of risk (probability that insects will be detected by a customer, and effect of further storage on quality) and presented a scheme for interpreting trap catch in terms of action to be taken. Pinniger (1991) outlined a scheme, based on action thresholds set by experience and the needs of industry, that can be adapted to different commercial facilities and pests.

Trapping and spatial analysis of numbers captured (Arbogast et al. 1998, Brenner et al. 1998) provide a powerful tool for indicative interpretation. Pierce (1994) used pheromone-baited traps and triangulation to locate hidden infestations of cigarette beetles, *Lasioderma serricorne* (F.), and pyralid moths in food warehouses. He based his method on the inverse relationship between numbers captured and the proximity of infestation. The current article reports studies of moth and beetle infestations in department and pet stores, primarily by contour analysis of numbers trapped at fixed points, and examines the practical value of spatial analysis for management of insect pests in retail stores.

Materials and Methods

The study included five retail stores in north-central Florida: three department stores with grocery and pet departments, and two pet stores. At the time of our study, no chemical insecticides had been used to control stored-product insects in the department stores for at least 3 mo. Instead, the pest control technician had recommended improved stock rotation and better sanitation in areas infested by the Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), and had installed traps for moth detection. The pet store managers had been given similar recommendations, and in November 1998, a program of Gentrol applications was initiated in both stores. Gentrol is a formulation of the IGR (S)-hydroprene (9% emulsifiable concentrate). It was applied as an aqueous spray at a concentration of 7.81 ml/liter (1 oz/gal of water), mainly to floor-wall junctions, between pallets, under and behind display and storage racks, and inside hollow rack supports. Application was repeated monthly for 3 mo, using 3.79 liters (1 gal) of spray in each application, and a different section of the store was treated each time. After this initial treatment, applications were done quarterly. No chemicals had been used in pet store 1 before November 1998, but Gentrol had been applied monthly for about a year in pet store 2.

The department stores were monitored only for moths, but the pet stores were monitored for both moths and beetles. Moths were monitored using pheromone-baited sticky traps (SP-Locator Moth Traps, Agrisense-BCS Limited, Mid Glamorgan, UK) and beetles using pitfall traps (Storgard FLĪTeTRAK M^2, TRÉCÉ, Salinas, CA) baited with cigarette beetle and confused flour beetle/red flour beetle pheromone lures and with oat oil as a food attractant. The moth traps (7 by 10 by 1.5 cm) were attached to a wall, a shelf rack, or the underside of a shelf (at heights of 1–2.5 m) by means of Velcro for easy removal and replacement when making counts. Most often, the traps were concealed under shelves. Beetle traps were placed on the floor, either under a shelf or against a wall.

The data used in spatial analysis are topographical; that is, each data element consists of two independent location variables, and a dependent or functional variable (number of insects captured). Thus, a basic requirement for spatial analysis is that trap locations be specified on a two-dimensional coordinate system. We established a rectangular (x, y) coordinate system for each store with the origin at one corner, and used it to lay out a grid of trap positions (Fig. 1). Trap positions were first laid out on a floor plan of the store, then located in the store itself and labeled. To locate positions in the store, we used measurements and reference to various physical features, such as doorways, shelving, support columns, and floor tiles. We used 50 moth traps in each of two department stores (department stores 1 and 3) (Fig. 1 A and C) and 61 in the third (department store 2) (Fig. 1B), which was larger. Trapping was conducted: 8–11 August 1997 in store 1; 2–6 September 1997 in store 2; and 4–9 August 1997 in store 3. We used 25 traps in a second, follow-up, trapping campaign (16–20 September 1997) that was limited to the infested area (the pet department and adjacent areas) of store 3 (Fig. 1F). Ideally, traps should be spaced evenly, but this is not a strict requirement and is impossible in retail stores because locations suitable for trap placement are not uniformly available. Also, to minimize the number of traps needed, it is desirable to place more traps in areas likely to support insect infestation than elsewhere. Accordingly, we distributed traps throughout each store with more in the pet and grocery departments and fewer in departments such as hardware, electronics, and clothing. The number of moths captured in each trap was recorded after 1 and 4 h and then daily for 4 d.

We used 40 moth traps and 40 beetle traps in each of the pet stores (Fig. 1 D and E). These were distributed throughout the stores, except for the checkout areas, with one moth trap and one beetle trap at each location. Numbers of insects captured were recorded daily for 5 d. We ran two trapping campaigns in pet store 1 (14–19 September 1998 and 11–15 May 1999) and one in pet store 2 (7–12 December 1998).

The x,y-coordinates of the trap positions and the corresponding numbers of insects captured were entered in Surfer 6.02 (Keckler 1995) for contour analysis. This software posts observed trap catch to the appropriate coordinates on a floor plan of the store, which has been entered as a base map, and then creates a denser grid of trap catch values by interpolation, using one of several algorithms. We used radial

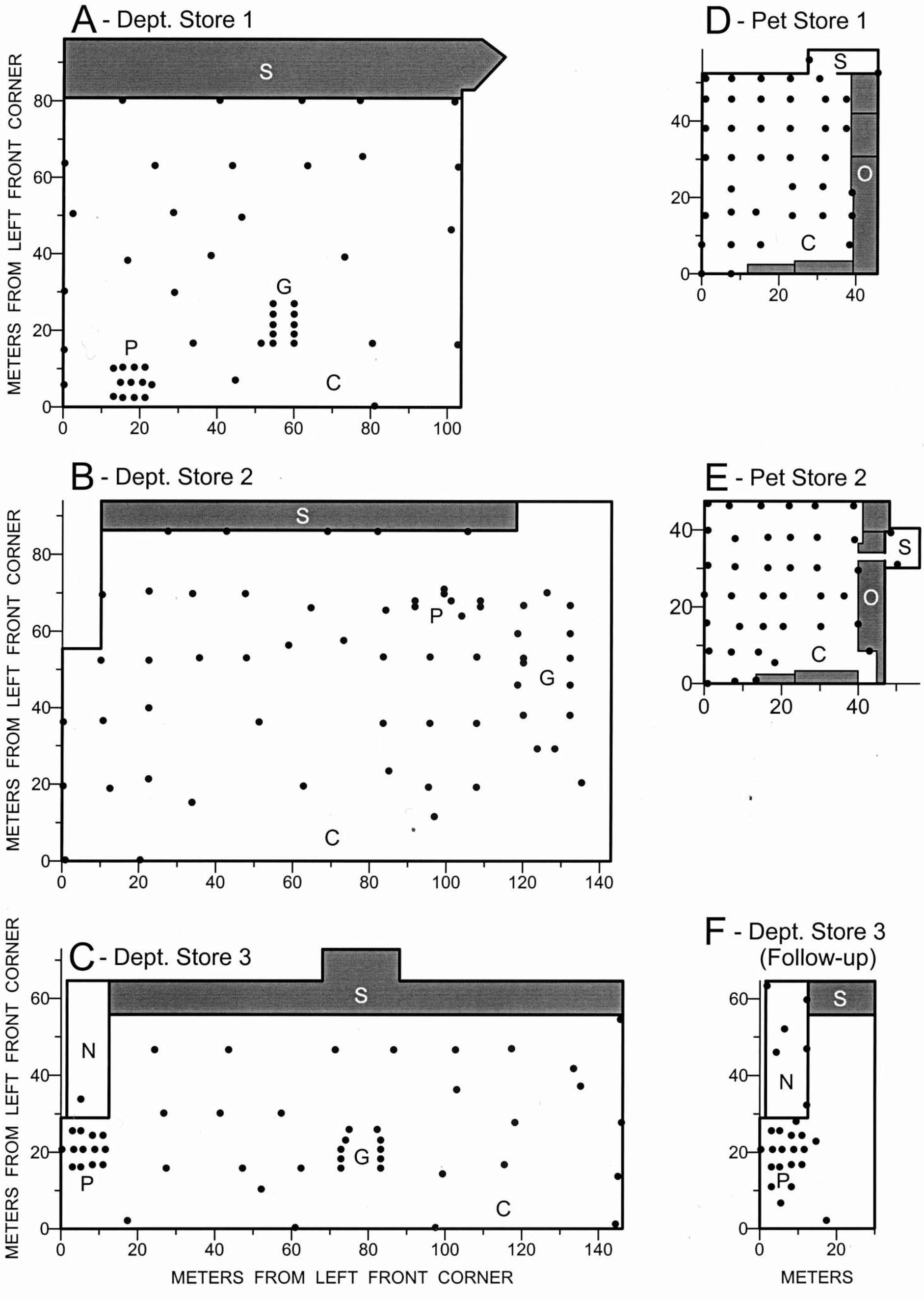

Fig. 1. Floor plans of the retail stores in which the study was done. Areas sampled by trapping were as follows: 8,370 m^2 (department store 1); 12,209 m^2 (department store 2); 8,217 m^2 (department store 3); 1,730 m^2 (pet department and surrounding area of department store 3); 2,073 m^2 (pet store 1), and 1,984 m^2 (pet store 2). There was a moth trap and a beetle trap at each of the locations indicated by dots. Moth traps were attached to a wall, a shelf rack, or the underside of a shelf at a height of 1–2.5 m above the floor. Beetle traps were placed on the floor, either under a shelf or against a wall. C, check-out area; G, groceries; N, nursery (garden shop); O, office; *P*, pet supplies; S, stock room. Shaded areas indicate portions of the stores not included in the trapping studies.

basis functions (with the multiquadric function), which is a flexible algorithm that provides good overall interpretation of most data sets (Keckler 1995). Contour analysis was done for each set of observations and for most of the insect species detected, but mostly the final observations (cumulative trap catch over the

Table 1. Assignment of indicator values to trap locations when the pest management threshold has been set at about 90% suppression or the trap threshold set at four or more insects

Trap location	No. captured (n_i)	Cumulative total (c_i)	Calculated cumulative frequency (f_i)	Assigned cumulative frequency (f'_i)	Indicator value (P)
12	54	54	0.196	0.196	1
19	25	79	0.287	0.287	1
18	19	98	0.356	0.356	1
7	17	115	0.418	0.418	1
5	14	129	0.469	0.520	1
6	14	143	0.520	0.520	1
21	12	155	0.564	0.564	1
11	10	165	0.600	0.600	1
15	9	174	0.633	0.665	1
33	9	183	0.665	0.665	1
2	8	191	0.695	0.724	1
8	8	199	0.724	0.724	1
22	7	206	0.749	0.800	1
32	7	213	0.775	0.800	1
36	7	220	0.800	0.800	1
17	6	226	0.822	0.822	1
3	4	230	0.836	0.895	1
9	4	234	0.851	0.895	1
23	4	238	0.865	0.895	1
27	4	242	0.880	0.895	1
31	4	246	0.895	0.895	1
4	3	249	0.905	0.927	0
29	3	252	0.916	0.927	0
37	3	255	0.927	0.927	0
14	2	257	0.935	0.925	0
20	2	259	0.942	0.925	0
25	2	261	0.949	0.925	0
26	2	263	0.956	0.925	0
28	2	265	0.964	0.925	0
30	2	267	0.971	0.925	0
35	2	269	0.978	0.925	0
38	2	271	0.985	0.925	0
1	1	272	0.989	1.000	0
16	1	273	0.993	1.000	0
24	1	274	0.996	1.000	0
34	1	275	1.000	1.000	0
10	0	275	1.000	1.000	0
13	0	275	1.000	1.000	0
39	0	275	1.000	1.000	0
40	0	275	1.000	1.000	0

Number of beetles captured by pitfall traps in pet store 1, 14–19 September 1998. Columns 1 and 2 were sorted in descending order by number captured. Cumulative totals (c_i) and calculated cumulative frequencies (f_i) were then calculated as follows:

$$c_i = \begin{cases} n_i & i = 1 \\ n_i + c_{i-1} & i > 1 \end{cases} \text{ and } f_i = c_i / \Sigma n_i, \text{ where } i = 1 \text{ to } 40 \text{ is the row number.}$$

Assigned cumulative frequencies differed from calculated cumulative frequencies only when equal numbers of insects were captured in two or more traps. In that case, the highest calculated cumulative frequency was assigned all traps. Indicator value = 1 when $f_i' \leq 0.895$. Otherwise, indicator value = 0.

trapping period) for the Indianmeal moth and for all beetles combined were used as illustrations.

The utility of contour analysis can be enhanced by assigning indicator variables, rather than raw trap counts, to trap locations (Brenner et al. 1998). We used an indicator variable (P) obtained by converting trap catch to probability. The data manipulations required to assign values of P to trap locations were performed in an Excel 97 spreadsheet (Microsoft, Redmon, WA) and are illustrated by the example in Table 1. Trap locations (designated 1–40) and number of insects captured by each trap (n_i) were sorted in descending order by numbers captured. Cumulative totals (c_i) and cumulative frequencies (f_i) were then calculated as indicated by the equations at the bottom of Table 1. Traps that captured the same number of insects were grouped together, and the highest cumulative frequency in the group was assigned to all traps in the group (Table 1). The assigned cumulative frequency (f_i') for any trap, thus indicates the proportion of the total catch represented by the combined catch of traps with an equal or greater number of insects. It estimates the probability that any one trap will capture an equal or greater number of insects, given the size and spatial distribution of the population.

If we assume that the spatial distribution of trap catch reflects the spatial distribution of the insect population, we can then use the cumulative frequency distributions derived from trap samples (Table 1) to

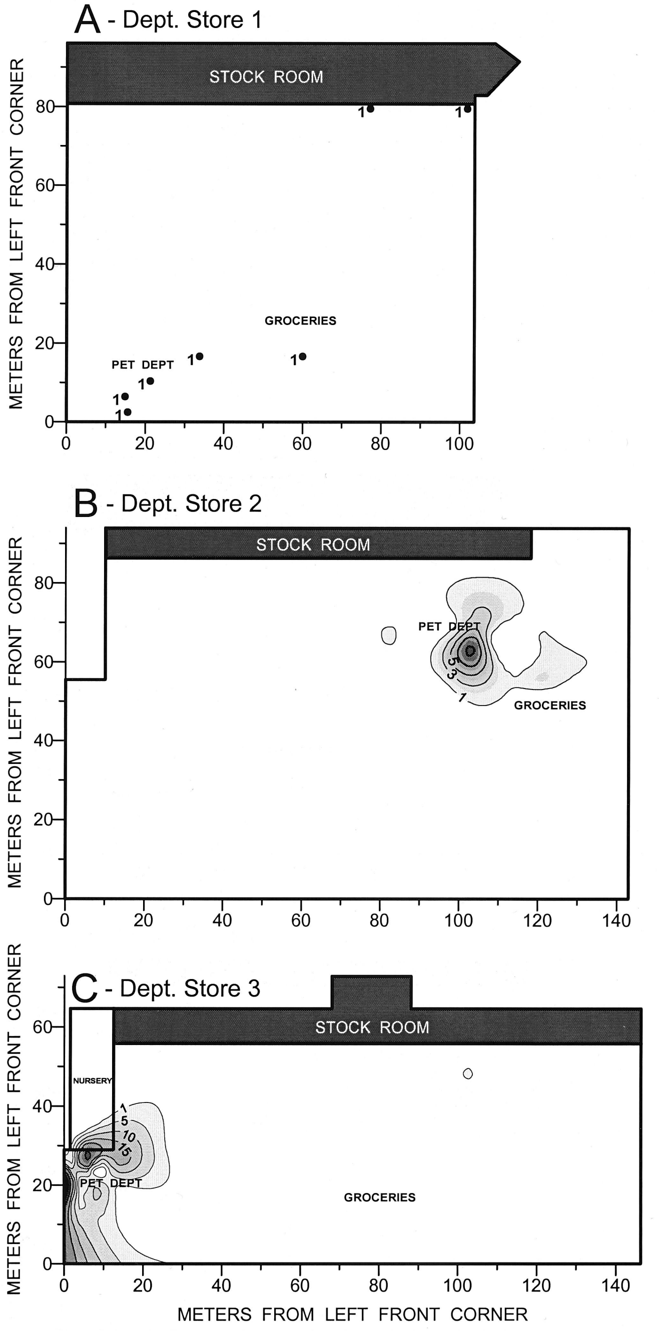

Fig. 2. Spatial distribution of Indianmeal moths in department stores. Contours represent numbers captured in 50 (A, C) or 61 (B) traps over a 4-d period.

define areas in which action thresholds for pest management are exceeded. A threshold can be either an insect count typically associated with the maximum tolerable level of damage or contamination (trap threshold), or it can be a proportion of the pest population that must be suppressed (Brenner et al. 1998). Thresholds, which in practice would be chosen on the basis of experience and pest management needs (goals), were used to assign values of P to trap locations. This was done as follows: $P = 0$ when $f_i' >$ threshold and $P = 1$ when $f_i' \leq$ threshold. Because P represents a probability, it can assume any value between 0 and $1 (0 \leq P \leq 1)$ at various points in a store. Intermediate values in areas between trap locations

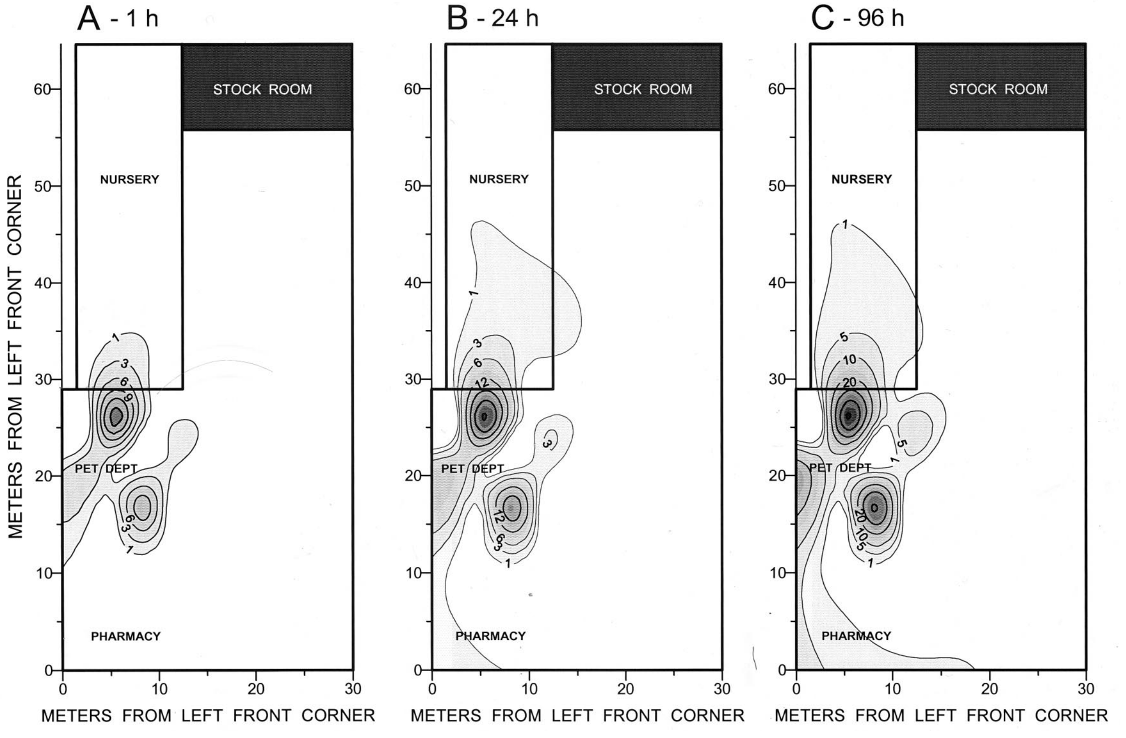

Fig. 3. Spatial distribution of Indianmeal moths in the pet department and adjacent areas of department store 3 during follow-up trapping, ≈5 wk after the first trapping campaign. Contours represent cumulative numbers captured in 25 traps after 1 h (A), 24 h (B), and 96 h (C).

were generated by interpolation during the contouring process (using radial basis functions in Surfer).

Now consider an example in which our goal is to eliminate ≈85% of the pest population represented by the sample in Table 1. The target proportion (cumulative frequency f_i) would be 0.85, which is most closely approximated in Table 1 by 0.851. This proportion corresponds to the second of five traps that each captured four insects. All of these traps have an assigned cumulative frequency (f_i') of 0.895, so we choose 0.895 as a threshold for assigning values of 0 or one to P. This establishes our pest management goal at ≈90% pest suppression, and the trap threshold becomes ≥4 insects. Conversely, we could have chosen a trap threshold of ≥4 insects on the basis of maximum tolerable damage or some other factor, and this would have dictated a pest management goal of 90% suppression. In either case, for all traps with four or more insects $P = 1$, and for all others $P = 0$ (Table 1).

We ran contour analyses to map the spatial distribution of P in the stores, using contour values of $P =$ 0.0, 0.5, and 1.0. The value of P ($0 \leq P \leq 1$) at each point on these contour maps estimates the probability that a trap placed at that point will capture a number of insects that equals or exceeds the trap threshold. The contours also estimate areas occupied by various percentages of the pest population; the percentages in each case being determined by the threshold chosen to define values of P and by the contour interval. In our example (Table 1), we chose a threshold of 0.895, or

Table 2. Beetles captured by 40 pitfall traps in two pet stores during three, 5-d periods of trapping

Species	Common name	Family	No. trapped	% total
L. serricorne[a]	Cigarette bettle	Anobiidae	147	44.3
S. paniceum	Drugstore beetle	Anobiidae	1	0.3
O. mercator[a]	Merchant grain beetle	Silvanidae	146	44.0
A. rectus		Silvanidae	1	0.3
C. pusillus	Flat grain beetle	Laemophloeidae	11	3.3
Corticaria sp.		Lathridiidae	1	0.3
T. castaneum[a]	Red flour beetle	Tenebrionidae	19	5.7
T. parallelopipedum		Lyctidae	1	0.3
S. oryzae	Rice weevil	Curculionidae	5	1.5

Storgard FLĪTeTRAK M^2 traps baited with cigarette beetle and red flour beetle/confused flour beetle pheromone lures and with oat oil.
[a] Count includes larvae and adults. Other counts are adults only.

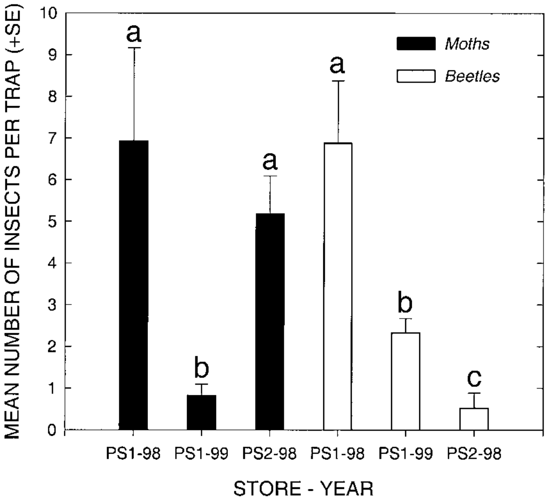

Fig. 4. Mean number (±SE) of beetles or Indianmeal moths per trap captured in 40 traps in pet stores during a 5-d period. There were two trapping campaigns in store 1, one before and another 6 mo after initiation of Gentrol treatments. There was only one trapping campaign in store 2, which had been treated before trapping began. When letters above any two bars within orders (beetles or moths) are not the same, the difference between stores or trapping periods is statistically significant (Wilcoxon signed rank test, $P < 0.001$).

≈90% of the population, for assigning P a value of 1. Therefore, ≈90% of the pest population is expected to occur inside contour 1.0 (Fig. 5C). Of the remaining 10%, ≈5% is expected to occur between contours 0.0 and 0.5 and ≈5% between contours 0.5 and 1.0.

The average level of infestation in a store was expressed as the mean number of beetles or moths captured per trap during the trapping period (total captured/number of traps). Beetles and moths were not compared statistically with one another, but within each group, pairwise comparisons were made between stores and trapping periods, using the Wilcoxon signed ranks test in SigmaStat 2.0 (SPSS 1997). This nonparametric test was selected over a *t*-test because the trap counts were not normally distributed. Beetle and moth totals were accumulated from observation to observation, and regression analysis of the cumulative totals versus time was used to examine rates of capture. Regression analysis of cumulative numbers captured in all traps versus time was done with SigmaStat, SigmaPlot 5.0 (SPSS 1998), and the REG Procedure of SAS (SAS Institute 1988).

Results and Discussion

Department Stores. We found Indianmeal moths in all three department stores, but the level of infestation differed greatly among stores. The lightest infestation occurred in department store 1 (Fig. 2A), where only seven moths were captured over the 4-d period, three in the pet department and four in other parts of the store. The pattern of capture suggested an origin in the pet department, but the data were too sparse to identify foci of infestation. In department store 2 (Fig. 2B), a single focus of infestation, associated with bagged sunflower seeds in the pet department, became evident within 1 h. The number of captures, and the area in which they occurred, increased steadily over the next 4 d until the whole department was involved, but the center remained fixed on the sunflower seeds. There were scattered captures elsewhere in the store, but no additional foci could be identified. The heaviest infestation occurred in department store 3 (Fig. 2C), where all but one capture occurred in or near the pet department. The most intense focus of infestation occurred in association with bagged birdseed on shelves along one wall, and this was readily apparent within the first hour of trapping. After 4 d, two additional foci appeared, one associated with birdseed and another with items not susceptible to infestation, including cat litter and flea treatments. Follow-up trapping in the pet department and adjacent areas (Fig. 3), showed four well-defined foci of infestation that encompassed shelves with birdseed, dog food, and nonsusceptible products (Arbogast and Mankin 1999). In all of the foci of infestation, we found accumulations of infested pet food and bird seed in the enclosed space between the bottom shelves and the floor. Two of the foci were already apparent after 1 h (Fig. 3A), three after 1 d (Fig. 3B), and all four after 4 d (Fig. 3C).

Pet Stores. We found Indianmeal moths and nine species of beetles (Table 2) in the two pet stores. Eight of the species are commonly encountered in stored products, and, of these, the most abundant were *L. serricorne, Oryzaephilus mercator* (Fauvel), *Tribolium castaneum* (Herbst), and *Cryptolestes pusillus* (Schönherr). *Ahasverus rectus* (Le Conte), *Sitophilus oryzae* (L.), *Stegobium paniceum* (L.), and *Corticaria* sp. were captured in smaller numbers. Most beetles captured were adults, although we captured larvae of *L. serricorne, O. mercator,* and *T. castaneum. Trogoxylon parallelopipedum* (Melsheimer) is a wood borer commonly intercepted from pallets by the Division of Plant Industry, Florida Department of Agriculture and Consumer Services (M. C. Thomas, personal communication) and probably entered the store with a pallet.

The numbers of beetles and moths captured in pet store 1 were much lower after Gentrol treatments began than before (Fig. 4). Fewer beetles were captured in pet store 2 than in store 1, either before or after treatment, but the number of moths captured in store 2 did not differ significantly from store 1 before treatment. We have no pretreatment data for comparison in store 2, but it appears that a combination of sanitation, stock rotation, and Gentrol applications had prevented serious beetle infestation. There was a serious moth infestation, but this was recently established and had been traced to dog food that arrived infested from the warehouse.

The spatial distribution of moths and beetles in the pet stores is illustrated by the contour maps in Figs. 5–7. In September 1998, there were two prominent foci of beetle infestation in pet store 1 (Fig. 5A). One (upper left in figure), associated with dry cat food, dry

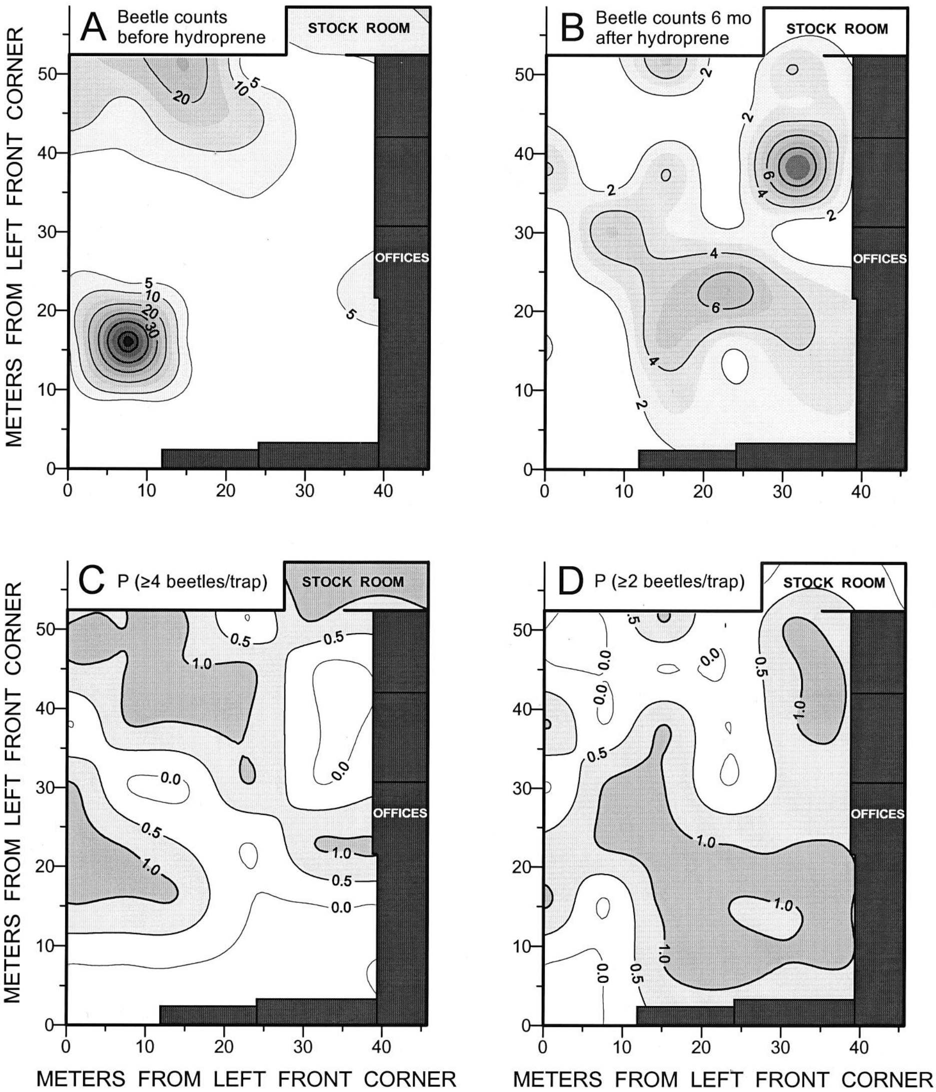

Fig. 5. Spatial distribution of beetles in pet store 1. Contours in A and B represent numbers captured in 40 traps over a 5-d period before and 6 mo after initiation of (S)-hydroprene applications. Contours in C and D represent corresponding indicator values based on cumulative frequency thresholds of 0.895 (C) and 0.903 (D), which gave trap thresholds of ≥4 and ≥2, respectively. The contours indicate the probability that the number captured in any trap will equal or exceed the trap threshold.

dog food, and horse scratch feed along the back wall, consisted mostly of merchant grain beetles. We found adults and larvae on the floor under the bottom shelves along with spilled food. The highest trap catch was near the horse feed, which may have been the source of infestation. The second focus (lower left in figure) consisted mostly of cigarette beetles, but the source of infestation was uncertain. Although there were seeds and hamster food in the affected area, the greatest numbers were captured near artificial logs and aquarium supplies. Peak numbers were much lower in May 1999, about 6 mo after initiation of Gentrol treatment, and the beetles occurred mainly in three foci (Fig. 5B). A small focus on the back wall indicated a remnant merchant grain beetle infestation, and the remaining two consisted mostly of cigarette beetles. There were two major concentrations of Indianmeal moths in September 1998, with lesser infestations in a back corner and in the stock room (Fig. 6A). There were fewer moths in May 1999 after Gentrol treatments. The largest concentration was gone, but the others persisted (Fig. 6B).

Most of the beetles captured in pet store 2 were red flour beetles captured under shelves with canned cat food (Fig. 7A), but the source of infestation was not determined. Moths were widespread (Fig. 7B) and

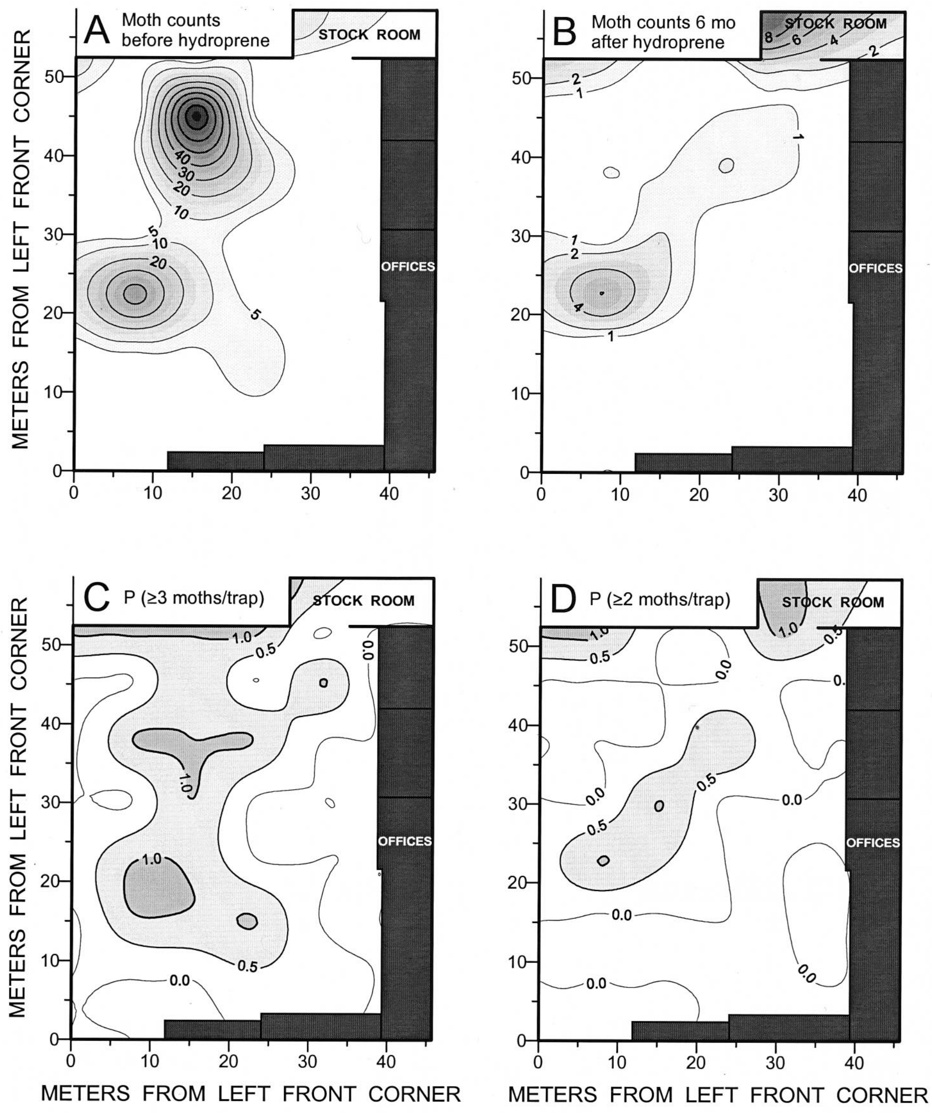

Fig. 6. Spatial distribution of Indianmeal moths in pet store 1. Contours in A and B represent numbers captured in 40 traps over a 5-d period before, and 6 mo after initiation of (S)-hydroprene applications. Contours in C and D represent corresponding indicator values based on cumulative frequency thresholds of 0.899 (C) and 0.758 (D), which gave trap thresholds of ≥3 and ≥2, respectively. The contours indicate the probability that the number captured in any trap will exceed the trap threshold.

there was a large focus of infestation in the stock room associated with infested dog food that had been moved there to await disposal.

In practice, as already noted, experience and pest management goals would be used to determine trap thresholds, but for purposes of illustration, we hypothetically set our goal at suppressing the pest population by ≈85%. With this goal, the assigned cumulative frequencies (f_i') chosen for assigning values of one or 0 to the indicator variable ranged from ≤ 0.76 to ≤ 0.93. The average (±SE) was ≤0.87 ± 0.03. This range resulted from variation among cumulative frequency distributions with pest species, time, and place. The resulting trap thresholds ranged from ≥2 to ≥4 insects, and the contours in Figs. 5 C and D, 6 C and D, and 7 C and D indicate the probability that the number of insects captured by any trap will equal or exceed these thresholds. The 1.0 contours also estimate the areas in which 76–93% of the pest populations occur, depending on the cumulative frequency chosen for assigning indicator values. Thus, elimination of pests from these areas by control intervention would be expected to achieve ≈73–93% pest suppression in the stores. If chemical control were used, the reduction in pesticide risk achieved by limiting application to these areas is obvious. Also, careful exami-

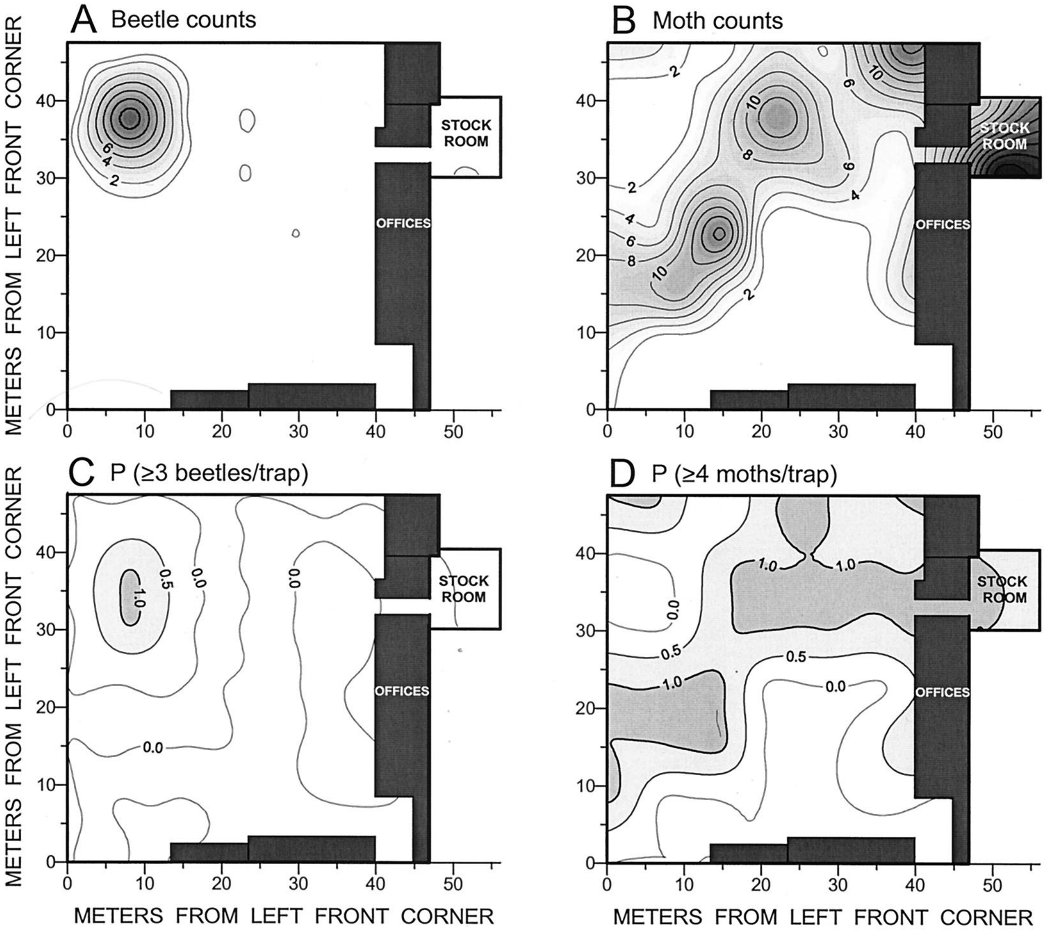

Fig. 7. Spatial distribution of beetles and Indianmeal moths in pet store 2. Contours in A and B represent numbers of beetles and moths, respectively, captured in 40 traps over a 5-d period after ≈1 yr of monthly (S)-hydroprene applications. Contours in C and D represent corresponding indicator values based on cumulative frequency thresholds of 0.810 (C) and 0.932 (D), which gave trap thresholds of ≥3 and ≥4, respectively. The contours indicate the probability that the number captured in any trap will exceed the trap threshold.

nation of heavily infested areas could suggest nonchemical alternatives, such as cleaning up spills or removing infested products.

Capture Rates. Capture rates were essentially constant over the entire trapping period for both beetles and moths in all samples, so the relationship between days of trapping and cumulative numbers of insects captured was described well by straight lines (Figs. 8–9). Yet, there was some evidence that the rate of capture may actually have decreased with time during the first day or two. All of the regression lines were forced through the origin, because initially (time = 0) there were no insects in any of the traps. When nonzero intercepts were allowed, two of the three lines in Fig. 8 and one in Fig. 9 had intercepts that differed significantly from 0, which could indicate curvature of the lines near the origin. This implies that, in these three instances, the rate of capture was highest immediately after the traps were put out, but decreased with time and stabilized at a lower level. As would be

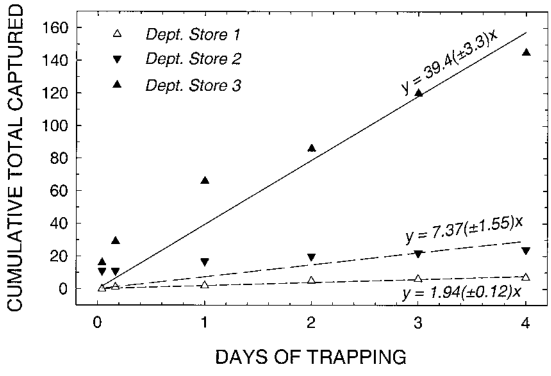

Fig. 8. Cumulative trap catch of Indianmeal moths in department stores. Regression is through the origin. Numbers in parentheses following regression coefficients are standard errors. Department store 1: $P < 0.01$, $R^2 = 0.97$, adjusted $R^2 = 0.96$. Department store 2: $P < 0.01$, $R^2 = 0.82$, adjusted $R^2 = 0.78$. Department store 3: $P < 0.01$, $R^2 = 0.98$, adjusted $R^2 = 0.98$.

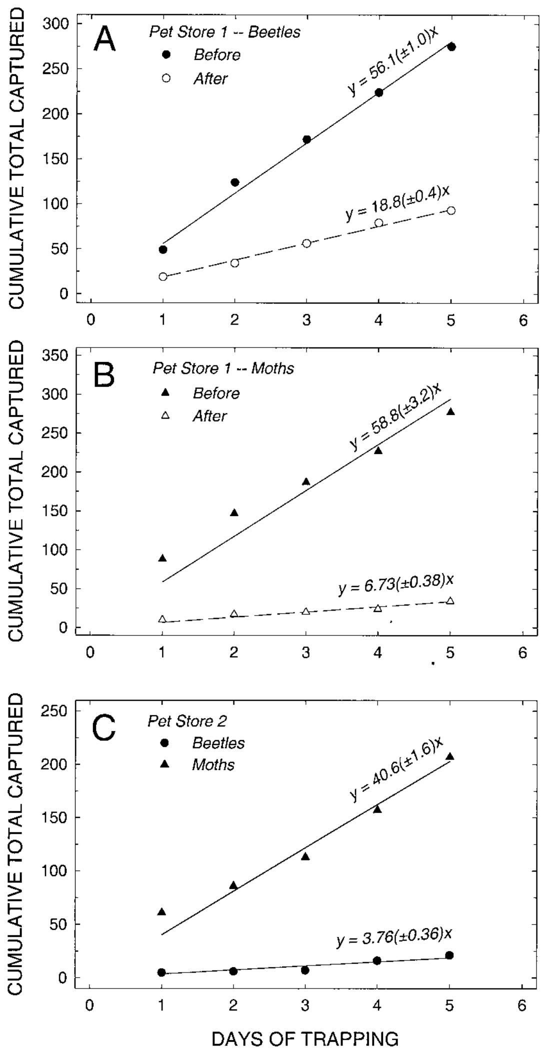

Fig. 9. Cumulative trap catch of beetles and Indianmeal moths in pet stores before and after initiation of monthly (S)-hydroprene treatments. Regression is through the origin. Numbers in parentheses following regression coefficients are standard errors. (A) Numbers of beetles captured before and ≈6 mo after treatments began in pet store 1. (Before: $P < 0.01$, $R^2 = 1.00$, adjusted $R^2 = 0.99$. After: $P < 0.01$, $R^2 = 1.00$, adjusted $R^2 = 0.99$.) (B) Numbers of Indianmeal moths captured before and ≈6 mo after treatments began in pet store 1. (Before: $P < 0.01$, $R^2 = 0.99$, adjusted $R^2 = 0.99$. After: $P < 0.01$, $R^2 = 0.99$, Adjusted $R^2 = 0.98$.) (C) Numbers of beetles and Indianmeal moths captured after ≈1 yr of monthly treatments in pet store 2. (Beetles: $P < 0.01$ $R^2 = 0.97$, adjusted $R^2 = 0.96$. Moths: $P < 0.01$, $R^2 = 0.99$, adjusted $R^2 = 0.99$.)

expected, the rate of capture was higher when the level of infestation was higher.

Trap Range and Precision Targeting. For spatial analysis, traps with a short range of attraction are desirable, because they more effectively resolve local components of an insect population and thus provide a sharper picture of spatial pattern. In the current study, the moth traps regularly showed differences in numbers captured, even when spaced only ≈5 m apart, enabling precise location of infestations. Part of this precision probably stems from the limited range of the SP-Locator pheromone dispensers. Previous studies with the SP-Locator system showed that the range of these traps was <4 m (Mankin et al. 1999). Traps of such limited range are ideal for situations in which the goal is not simply to detect, but also to pinpoint infestations.

In conclusion, contour analysis of trap counts obtained from an array of well-placed traps yields a map of insect infestation that provides a practical tool for monitoring and management of storage pests in retail stores. This tool identifies trouble spots, which we have referred to as foci of infestation, and permits selection, timing, and precision targeting of control measures to achieve maximum pest suppression, with minimum pesticide risk to human health and the environment. A well-designed trap array should cover as much as possible of the area to be mapped, because partial coverage encourages artifact in the contour analysis. Spacing of traps within the array should be as nearly uniform as possible to minimize biasing the contour map by trap placement, although this does not appear to be a serious problem. Successive trapping campaigns, with a fixed array of traps and comparison of sequential contour maps, will allow store managers and pest control operators to visualize pest problems over an entire store at a glance and to monitor changes that occur over time. Changes can be related to time of delivery and placement of new products received from warehouses. Sequential contour maps also indicate the effectiveness of control measures, and along with records of control applications and stock rotation, they provide permanent documentation of pest problems and their management. The length of the trapping period and the frequency of observation can be varied according to the needs and capabilities of the user.

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