# The utility of spatial analysis in management of storage pests[1]

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*Abstract*

The risk posed by chemical pesticides to environmental quality and human health makes it necessary to seek safer methods of pest management New programs, which would make judicious use of chemicals but rely mainly on alternative methods, will require comprehensive monitoring procedures to estimate degree and location of insect infestation Spatial analysis by contour mapping of trap counts is useful for this purpose, as well as for assessing the effectiveness of control intervention Spatial analysis will often provide the only form of trap interpretation needed Its utility in managing stored-product insects in various storage situations is illustrated by examples taken from field studies.

## Introduction

Historically, management of stored-product insects has relied heavily on application of chemical pesticides, but increasing awareness of the risks these chemicals pose to environmental quality and human health, has made it necessary to seek safer methods Development of insecticide resistance has aggravated the problem and increased the need to develop pest management programs that are less chemical-dependent. These new programs, which would make judicious use of chemical pesticides but rely mainly on alternative methods, will require accurate and comprehensive monitoring of pest populations Monitoring will not only detect infestation, but also estimate its degree and location Thus monitoring will guide the timing and targeting of control applications, eliminate the need for routine preventive treatment, reduce the area treated with insecticides, and aid in the application of nonchemical methods.

Research over the last two or three decades has produced a variety of traps that are effective in detecting insect pests in bulk commodities and storage structures (Burkholder 1984, Cogan et al 1991, Loschiavo 1975, Loschiavo and Atkinson 1973, Mullen 1992, Trematerra et al. 1994, Vick et al 1990, White et al 1990). Currently available traps are better for this purpose than conventional grain sampling methods, but development of theory needed to interpret trap catch has lagged behind. Trap catch can be defined as the number of insects captured by a given type of trap in a specified period of time The value of traps in monitoring pest populations is diminished by our limited ability to relate trap catch to population density, or some action to be taken. This limitation is widely recognized by storage specialists. Wilkin and Fleurat-Lessard(1991) showed that detection and estimation of low-level infestation (<5 insects/kg) in grain bulks by spear sampling is unreliable, and noted the serious problem this poses for calibration of trapping methods. They concluded, in fact, that it may be impossible to relate trap catch to population density and suggested that some system of risk factor be devised instead Their conclusion is supported by the findings of Lippert and Hagstrum (1987) in a study of wheat stored on Kansas farms, which showed poor correlation between number of insects trapped and number of insects in grain samples Yet, Roesli and Jones (1994) reported good correlation between numbers of psocids in spear samples of wheat and numbers captured in probe, pitfall and bait bag traps Also, Haines et al. (1991) found that bait bags captured insects in proportion to their population density in stacks of bagged milled rice Wilkin (1990) recognized two categories of risk – the probability that insects would be detected by a customer and the effect of further storage on quality and presented a scheme for interpreting trap catch in terms of action to be taken Pinniger (1991) pointed out the need, in commercial facilities, for a trapping strategy designed specifically for each trap type, pest species and situation. He outlined a scheme, based on action thresholds set by experience and the needs of industry, that can be adapted to different environments and pests

There are clearly two types of trap interpretation, for which we propose the terms 'representative' and 'indicative' Representative interpretation posits that trap catch represents a population density to which it can be converted mathematically Attempts to determine the required mathematical relationships empirically have had mixed results, as already noted There has been some progress in deriving the relationships theoretically (from

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first principles) Wileyto (1994a, 1994b, 1994c, 1995) and Wileyto et al (1994), for example, developed a self-marking recapture method based on a Markov chain model, and Jansen (1979) proposed a method for interpreting pitfall trap capture by treating insect movements as two-dimensional Brownian motion

Indicative interpretation posits that trap catch is an indicator of action to be taken. Indicator values may be either numerical ('When mean trap catch in the stored wheat exceeds two insects, control intervention is indicated.') or numerical-spatial ('Control intervention is indicated for all areas of the store in which the probability of capturing two or more insects per trap exceeds 95%'). Numerical-spatial values are more useful, because they not only indicate when treatment is needed but also where

Pierce (1994) successfully located hidden infestations of cigarette beetles and pyralid moths in food warehouses using pheromone-baited traps and triangulation based on the inverse relationship between the number of insects in a trap and the proximity of an infestation Geostatistical techniques (Isaaks and Srivastava 1989, Rossi et al 1992, Liebold et al. 1993) can also be applied to discover the spatial distribution of insect populations (Brenner 1993, Breneer and Pierce 1991, Arbogast et al. 1998, Brenner et al. 1998). These techniques have not yet been applied extensively in a storage context, but they offer means of describing spatial patterns in grain bulks, warehouses, processing plants and retail stores. Their application will improve pest management capability by locating foci of infestation and points of control failure. The present paper treats spatial analysis of insect populations by contour analysis of trap catch. This is a powerful method of indicative interpretation, the utility of which will be illustrated by a number of examples from field studies

## Materials and Methods

### Spatial analysis

Spatial analysis is a three-dimensional analysis in which two dimensions ($x, y$) represent the positions of points on a horizontal plane, and the third ($z$) represents data associated with the points. The data can be visualized as elevations above or below the plane. Data consist of: (1) measured numerical values (numbers of insects, temperature, moisture content, insecticide residue, etc.) or derived numerical values (differences, ratios, probabilities, etc.) associated with fixed points on the horizontal plane and (2) the $x, y$-coordinates of the fixed points. All variables are treated as continuous although insect counts are discrete. The points are fitted to a three-dimensional surface representing the variable ($z$-axis) as a function of position on the $x, y$-plane. The surface can be represented in two dimensions by a contour map, which shows the configuration of the surface by means of isolines (contours), drawn at regular intervals of $z$, on the $x, y$-plane throught the origin Each contour represents the intersection of a horizontal plane with the surface, which means that all points on a contour have the same $z$-value.

We used Surfer Version 6.02 (Golden Software, Golden, Colorado) for contour analysis. This software posts observed $z$-values to coordinates on a map of the facility (storage bin, warehouse, retail store, etc.), entered as a base map, and then creates a denser grid of $z$-values by interpolation, using one of several available algorithms. We used radial basis functions with multiquadric algorithm, which is flexible and provides a good overall interpretation of most data sets (Keckler 1995). After interpolating, the software produces contours of $z$, based on the interpolated grid values. Goodness of fit is estimated by calculating residuals – differences between observed numbers and numbers predicted by the fitted surface

Residuals and other derived values, such as differences and probabilities, can also be mapped by means of contour analysis. Spatial changes are best examined by grid subtraction, which is done by subtracting the value of each node in a grid from the corresponding node values of a second, identical grid; the differences are then assigned to corresponding nodes of a third grid and difference contours drawn. Areas of increase are indicated on difference plots by positive contours and areas of decline by negative contours.

In targeting areas for treatment, it is helpful to draw contours of indicator variables, rather than raw trap counts, because indicator variables are affected less by unusually large counts Indicator variables are obtained by converting trap catch to probability. Trap locations are first sorted in descending order by the number of insects captured, then cumulative and normalized trap catch are calculated for each location. The normalized catch (cumulative trap catch divided by the total number of insects in all traps) gives the probability of an equal or higher catch. An indicator value of 1 is assigned to all locations for which probability equals or exceeds some set level or action threshold (determined by experience and the needs of industry) and a value of 0 is assigned to the remainder.

### Bulk grain

Seed grain is stored in bulk for various periods of time until it can be processed and bagged. Insect pests present a threat during storage, so the grain is usually fumigated immediately after storage and again whenever serious infestation becomes evident. During the summer of 1996, we monitored insect populations in oats stored at a seed processing plant in north central Florida. The oats were stored on June 25 in a cylindrical metal bin (5.5 m high by 5.5 m in diameter) and fumigated with phosphine 2 days later On July 17, we placed eight polyethylene grain probe

traps (Barak et al. 1990) just below the grain surface (Fig. 1). For convenience, trap locations were expressed in polar corrdinates (with $\theta$ = degrees measured counterclockwise from east and $r$ = distance from the center of the bin) and then converted to rectangular coordinates ($x = r \cos\theta$, $y = r \sin\theta$) for contour analysis Insects were removed from the traps and counted at weekly intervals until September 12, when a second fumigation became necessary. We removed the traps on that date, and the grain was fumigated 3 days later by placing aluminum phosphide tablets on the grain surface and in the aeration duct, which was then sealed. The traps were replaced on September 24, after the phosphine level had declined to 0.07 ppm Trap data for psocids, collected before and after the second fumigation, are presented as an example of spatial analysis in bulk grain for assessment and documentation of treatment efficacy Psocids were selected, not because of their pest status in this particular situation, but because their large numbers provided excellent data for purposes of illustration.

### Warehouses

In the spring of 1998, we had an opportunity to study an insect infestation of bagged saw palmetto berries, *Serenoa repens* (Bartram) Small, stored in a steel warehouse (30.5 by 15.2 m) in central Florida. The berries, which are ground and used as a nutritional supplement for prostate and urinary well-being, are harvested from their natural habitats, largely pine flatwoods in southeastern U. S They are then heat dried, bagged, and stored until they can be shipped to end processors in Europe and elsewhere

The infestation in the Florida warehouse involved mainly five species of stored-product insects: *Plodia interpunctella* (Hubner), *Cadra cautella* (Walker), *Lasioderma serricorne* (Fabricius), *Tribolium castaneum* (Herbst), and *Oryzaephilus mercator* (Fauvel). Moths were monitored with phermone-baited sticky traps (SP-Locator traps with Minimoth lures, AgriSense, Mid Glamorgan, UK), and beetles were monitored with pitfall traps (FLĪT-TRAK M$^2$, TRÉCÉ, Salinas, California) baited with *L serricorne* and *Tribolium* pheromones and a food attractant oil (furnished with the traps). A moth trap and a beetle trap were placed at each of the locations indicated in Fig 3. Trap location was specified in rectangular coordinates with the origin at one corner of the warehouse Some moth traps were attached, by means of Velcro, to the walls of the warehouse, with the sticky surface oriented horizontally. Others were attached, to the tops of wooden stakes supported by stands on the floor or to bags on top of the stacks They were located at heights ranging from 1.2 – 3.8 m. Beetle traps were placed either on the floor or on top of the stacks (0.0 – 3.4 m). Trap catch was recorded daily for 4 days, and insects were removed from the beetle traps. Moth traps (but not the lures) were replaced as necessary, usually every day.

This study illustrates spatial analysis of trap counts for mapping the distributions of several insect species in a warehouse containing packaged raw commodities Total numbers of *C. cautella* and *O mercator* trapped over the 4-day period were selected for purposes of illustration.

### Retail stores

Our third example is from a study of *P. interpunctella* infestations in retail department stores. Much of the area in these stores is devoted to merchandise not susceptible to moth infestation, but the stores also carry highly susceptible items such as pet food, and these items are sometimes damaged and contaminated by insects. Flying moths can occur anywhere in a store, and because retail department stores often include restaurant facilities, the moths sometimes cause problems with health inspectors. Retailers and pest control operators that service retail stores need monitoring methods that are quick, easy to use, inexpensive, and inconspicuous.

We monitored moth populations in three stores using SP-Locator traps. These traps are small enough (7 by 10 by 1.5 cm) to conceal under shelves, to which they were attached with Velcro for easy removal and replacement when making counts. For spatial analysis of trap counts, trap locations were specified in rectangular coordinates with the origin at one corner of the store. The traps were distributed as well as possible throughout each store, but locations suitable for trap placement were not uniformly available. To minimize the number of traps with no captures, we placed more in areas likely to support insect infestation, such as in the pet food and grocery departments. Moths were counted 1 hour after the traps were set and again after 4, 24, 48,72 and 96 hours Moths were detected in all three stores, but the level of infestation varied considerably from one to another. In the most heavily infested store, we did two trapping tests, separated by about five weeks. The first test involved the entire store, and the second was limited to pet supplies and adjacent sections Our example is based on the cumulative mumber of moths captured over a 96-hour period during the second test Twenty-five traps were deployed in these sections as shown in Fig. 4, with the 14 traps in pet supplies located as in the initial test.

## Results and Discussion

### Bulk grain

During the week immediately preceding fumigation, the mean trap catch (± SE) of Psocoptera in the oats at the Florida seed processing plant was 195.9 (± 61.3) insects/trap, and the popultaion was concentrated along a north-south line with the highest numbers just southwest of the bin center (Fig. 1A). About two weeks later, following the

second fumigation, mean trap catch ( ± SE) had declined to 50.0 ( ± 13.9) and the spatial distribution had changed markedly (Fig. 1B). The population center had shifted to a point just northeast of the bin center. Difference contours show a decline in trap catch over most of the grain surface, but with two small areas of population increase (Fig. 1C). The contour maps (Fig. 1) show that the second fumigation reduced the psocid population significantly but did not eliminate the infestation. Changes in density and distribution of the population following fumigation are shown more graphically by three-dimensional portrayal of the contour surfaces (Fig. 2). The contour maps above the surfaces are the same as those in Figs. 1A and 1B, but displayed from a different perspective.

The problem with the fumigation can be explained in part by the way it was done. First, the storage bin was not gas tight, and no effort was made to seal it. Second, the aluminum phosphide pellets were simply placed on the grain surface or in the aeration duct (which was not used). None were probed into the grain, so penetration of the gas into the bulk was probably poor, as indicated by areas showing low levels of population decline or even slight population increase. These areas, in which gas penetration was apparently more imparied than elsewhere (possibly by concentrations of fine material blocking the intergranular space), should be given special attention if a corrective treatment is done. The potential value of spatial analysis in guiding follow-up spot treatments is evident, even in the rather small grain bulk of our example. But its greatest value would be realized in treatment of much larger grain bulks.

## Warehouses

Trapping and contour analysis effectively mapped the distribution of each pest species in the warehouse, and located foci of infestation, mostly in the stacks of bagged saw palmetto berries (Fig. 3.) *Oryzaephilus mercator* was limited to stacks S-2, S-3, and S-4, with the major center of infestation in S-4 (Fig. 3A). *Cadra cautella* was widely distributed with major centers in stacks S-3 and S-5 and in an area, adjacent to the store room and rest room, used for storage of empty burlap bags and equipment (Fig. 3B).

The situation at the time of our study presented a difficult pest management problem. Consumers want a pure product free of chemical contamination, so no pesticides could be applied to the berries. Treatment with modified atmospheres was considered, but rejected as economically unfeasible. Finally, the berries were run through the drier a second time (at about 52 to 57℃) to eliminate the insect infestation before shipment. The costs accrued (moisture loss, fuel, and labor) were significant.

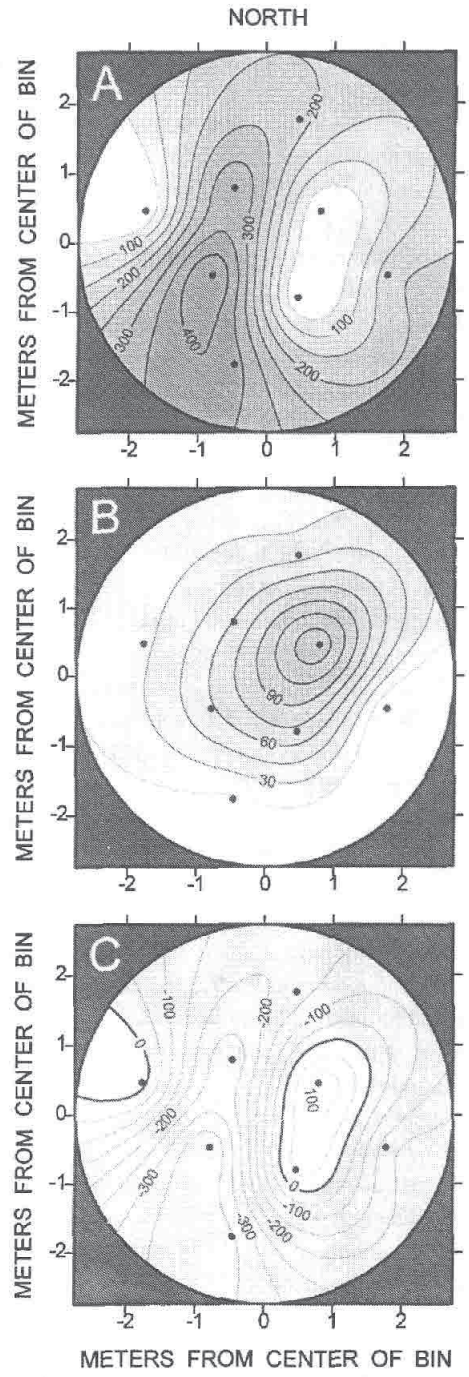


**Fig. 1.** Spatial distribution of Psocoptera captured in grain probe traps just below the surface of oats stored in a metal bin in north central Florida. Solid dots indicate trap positions. Contours in A and B indicate the total number of insects captured in one week. (A) Distribution just before phosphine fumigation. (B) Distribution about two weeks later, after phosphine fumigation. (C) Difference contours showing change in distribution. Negative contours indicate areas of population decline (shaded) and positive contours represent areas of population increase.

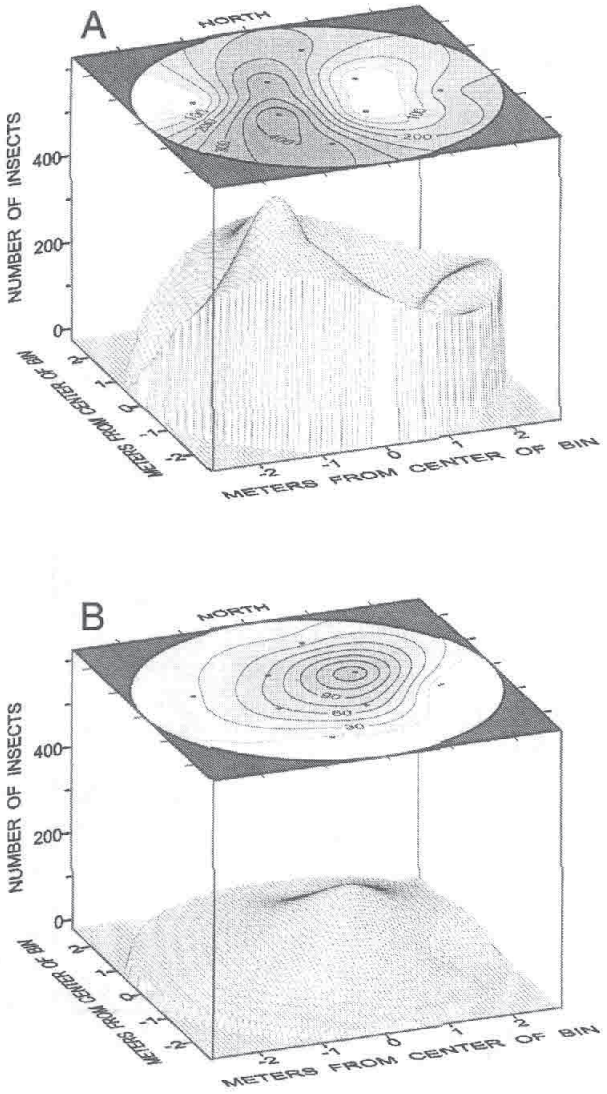


**Fig. 2.** Spatial distribution of Psocoptera captured in grain probe traps just below the surface of oats stored in a metal bin in north central Florida, illustrated by contour maps and the three-dimensional surfaces they represent. Solid dots indicate trap positions. Contours indicate the total number of insects captured in one week. (A) Distribution before phosphine fumigation. (B) Distribution about two weeks later, after phosphine fumigation.

We learned of the infestation after most of the berries in the warehouse had been shipped. The infestation had become severe, and the remainder of the berries were due to be shipped. We did a study to determine if trapping and spatial analysis would be effective in locating foci of infestation, thus indicating potential for the method in long term monitoring. Because our results were positive, we are now planning a study to determing the effectiveness of the method in detecting and pinpointing low levels of infestation in natural product warehouses, so spot treatments can be applied when and where they are needed.

## Retail stores

Initial trapping in the retail store indicated a heavy infestation of *P. interpunctella* involving most of the the pet supply department. The infestation was apparently restricted to this department, because only three moths were captured elsewhere, and two of these were captured nearby. Follow-up trapping, which was restricted to pet supplies and adjacent areas, showed four well-defined foci of infestation (Fig. 4). These encompassed shelves with birdseed and dog food as well as items not susceptible to infestation, such as cat litter and flea treatments. However, in all foci, the enclosed space between the bottom shelves and the floor held accumulations of infested pet food and birdseed. A few moths were captured in the garden shop and in the pharmacy area immediately adjacent to pet supplies, and these captures are reflected in the contours of raw trap counts (Fig. 4A). However, most of the traps in the pharmacy captured no moths, and the contours near the left-front corner of the store are an artifact of interpolation. This artifact illustrates the importance of assuring that the edges of an area to be mapped are adequately represented by traps. The artifact could have been avoided by placing a few traps along the wall near the origin. This was not done, because this corner of the store was occupied by the prescription center and was not accessible.

The foci of infestation are shown more clearly by contours of indicator variables (Fig. 4B) calculated from the raw trap counts (Fig. 4A). Indicator variables are defined to suit the needs of a particular situation, as determined by some action threshold. Here they were defined so that the contours representing a value of 1 enclose an area in which >95% of the moths were captured. Stated another way, these contours enclose an area in which 95% of trap captures are expectd to occur. This is the area that requires treatment. Treatment in this case would consist of removing infested items, cleaning the floor under the bottom shelves, and perhaps applying an insecticide in some areas. Long-term pest management would require improved sanitation and better rotation of stock. Sanitation would be made easier by eliminating the kickplates that cover the space beneath the bottom shelves.

The results of this study suggest that a sufficient number of well-distributed pheromone traps followed by spatial analysis of trap counts is enough to detect infestations of *P. interpunctella* and locate foci of infestation, which are two of the main objectives of monitoring in retail stores. A third objective is to assess the effectiveness of treatment by follow-up monitoring. Spatial analysis of trap counts serves all three purposes, and no other form of trap interpretation is required.

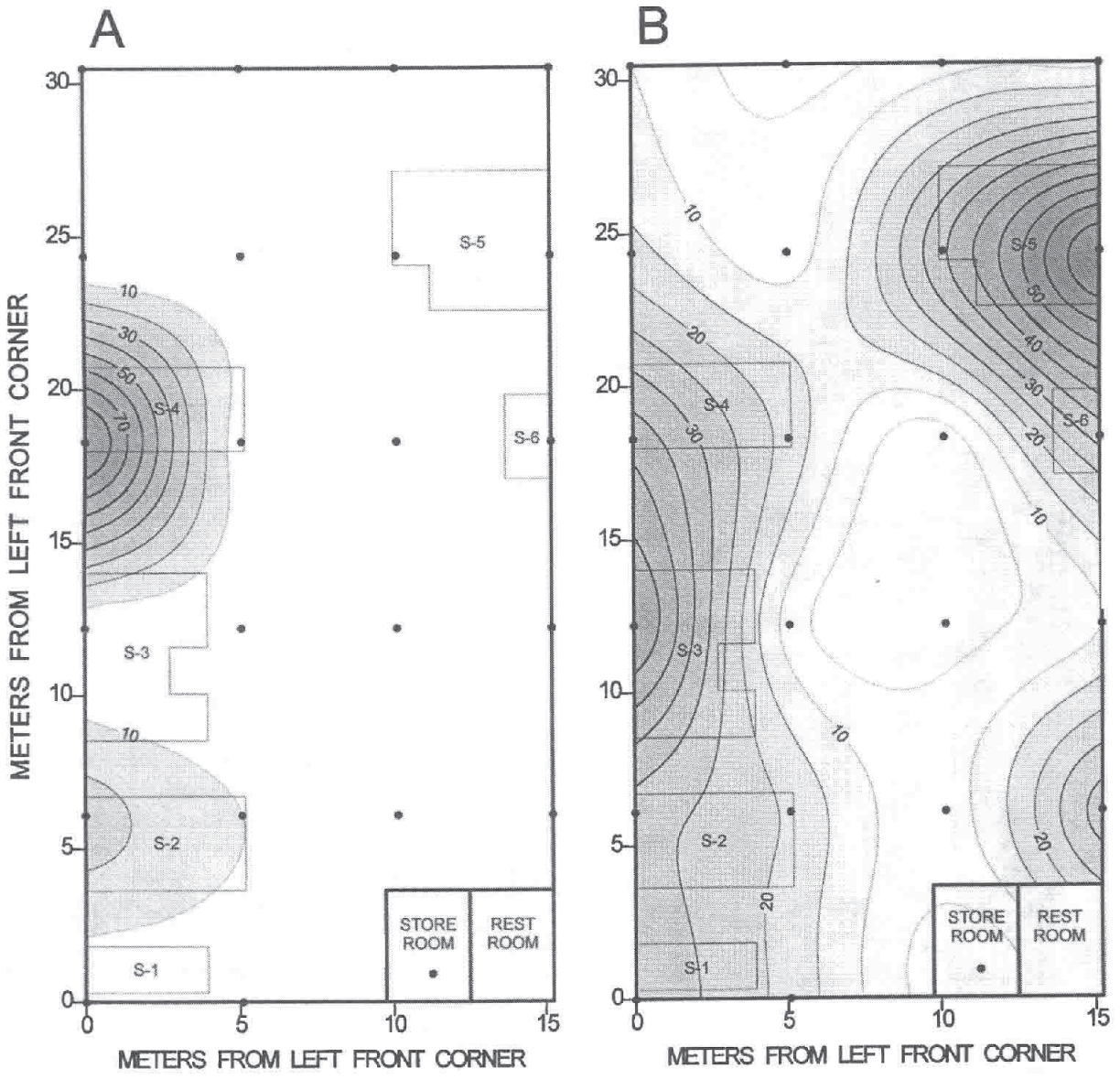


**Fig. 3.** Spatial distribution of insects infesting bagged saw palmetto berries in a warehouse in central Florida. Fine lines enclosing designations S-1, S-2, ··· indicate stacks of bags. Solid dots indicate trap positions. Contours indicate the total number of insects captured in four days. (A) *Oryzaephilus mercator* sampled with baited pitfall traps. (B) *Cadra cautella* sampled with pheromone-baited sticky traps.

## Conclusions

The three cases presented illustrate the utility of spatial analysis of trap counts in monitoring storage pests. Contour maps provide excellent visuals that show storage and retail store mangers the extent and location of pest problems. They provide decision support in determining the type, timing, and targeting of control intervention. They document the results of control intervention and indicate the extent and location of control failure. Finally, they reduce pesticide risk by eliminating the need for routine chemical treatment, by making it possible to precisely target pesticide applications, and by suggesting and guiding the application of nonchemical methods. The case study, presented earlier in this conference by David Rees, of monitoring phycitine moths in a cereal plant, provides an excellent example of how trapping and contour analysis can be used in concert to eliminate the need for chemical treatment altogether. This technique should find increasing use in the future, as pressure to eliminate pesticide risk continues to mount.

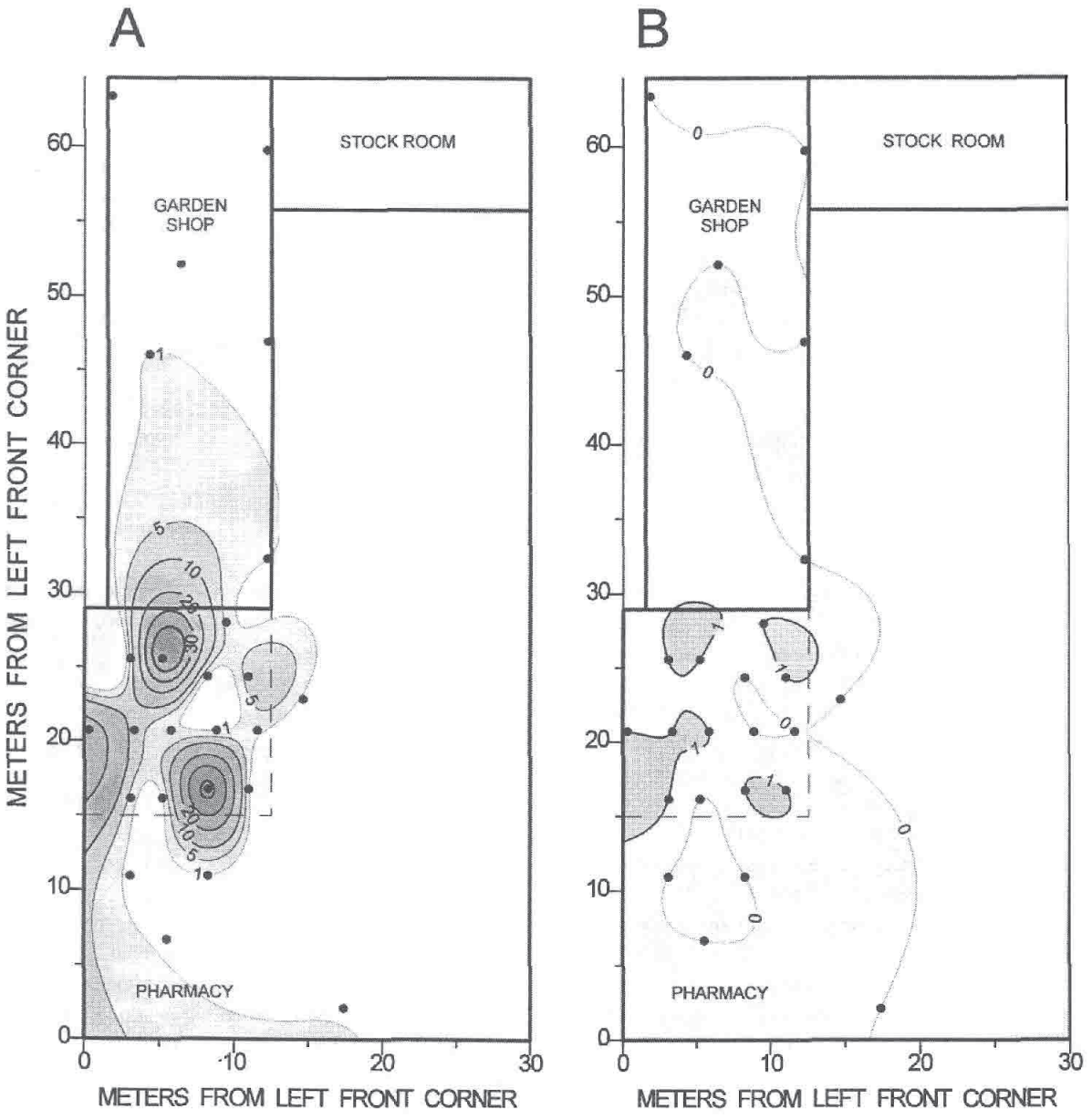


**Fig.4.** Spatial distribution of *Plodia interpunctella* infesting the pet supply department and adjacent areas of a large retail department store. Solid dots indicate trap positions. Dashed lines indicate the extent of the pet supply department. (A) Contours of raw trap counts (number of moths captured in 96 hr). (B) Indicator contours obtained by assigning a value of 1 to all traps with normalized catch $\leqslant 0.95$ and a value of 0 to all others. At least 95% of captures would be expected to occur within the shaded areas.

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