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LASIODERMA SERRICORNE (COLEOPTERA: ANOBIIDAE): SPATIAL RELATIONSHIP BETWEEN TRAP CATCH AND DISTANCE FROM AN INFESTED PRODUCT

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Abstract

The cigarette beetle, *Lasioderma serricorne* (Fabricius), was selected as a representative stored-product beetle to test the validity of contour mapping of trap catch for pest monitoring in warehouses and retail stores. Three experiments, each replicated 5 times, were conducted in a 3.2 × 9.0-m aluminum shed. Each experiment involved releasing beetles at a single point and recording the numbers captured after 6, 24, and 48 h in each of 14 baited pitfall traps distributed over the floor of the shed. The experiments differed only with respect to the point of release. Beetles were released passively from rearing boxes placed at one of 3 release points, and consecutive contour maps of trap catch tracked their dispersal from each point. As the beetles dispersed and total trap catch increased, the outlying traps captured increasingly more insects, but cumulative trap catch remained highest near the release points. The rate of capture was highest immediately after release and declined with time, rapidly at first and then more slowly until it became nearly constant. The cumulative numbers captured by any trap after 6, 24, and 48 h decreased exponentially with distance from the point of release. The observed spatial patterns of trap catch relative to sources of infestation and the inverse relationship of trap catch to distance from a source support the validity of contour mapping as a means of monitoring stored-product insects and locating foci of infestation.

Key Words: pest monitoring, trapping, spatial analysis, stored-product insects, cigarette beetle

Resumen

El escarabajo del cigarillo, *Lasioderma serricorne* (Fabricius), fue seleccionado como un representante de un escarabajo de productos almacenados para probar la validez de un mapa de contorno de los especimenes capturados en trampas para un monitoreo de los almacenes y tiendas comerciales. Se realizaron tres experimentos, cada uno con 5 réplicas, en un cobertizo de lauminio de 3.2 × 9.0-m. Cada experimento envolvia liberar los escarabajos en un solo punto y registrar en número capturados despué de 6, 24, y 48 h en cada una de las 14 trampas con cebo de caida “pitfall” distribuidas sobre en piso del cobertizo. Los experimentos variaron solamente con respeto del punto de la liberación.Los escarabajos fueron liberados en una manera pasiva de las cajas de cria puestos en uno de los tres puntos de liberación, y su dispersión fue rastreada usando mapas contornos consecutivos de los especimenes capturados en cada punto. Mientras que los escarabajos se disparsaron y el número total de los especimenes capturado aumentó, las trampas remotas capturaron progresivamente más insectos, pero el número acumulativo de los especimenes capturados en las trampas cerca de los puntos donde fueron liberados permaneció en más alto. La razón de la captura fue la más alto inmediatamente después de la liberación y bajó con el tiempo, rapidamente al principio y luego más despacio hasta que quedó casi constante. El número acumulativo de escarabajos capturados en cualquier trampa después de 6, 24, y 48 h bajó exponencialmente según la distancia del punto de liberación. Los patrons espaciales observados de los escarabajos capturados en las trampas en relacción de las fuentes de infestación y la relación inversa de los escarabajos capturados a la distancia de la fuente apoya la validéz de loos mapas contornos como un medio papa hacer un monitoreo de insectos de productos almacenados y localizar los focos de infestación

The cigarette beetle, *Lasioderma serricorne* (Fabricius), is arguably the most ubiquitous of all stored-product insects. It occurs throughout the tropical and subtropical regions of the world, and although it is restricted by low temperature and humidity, it occurs commonly in warm buildings throughout the temperate regions. It breeds on a wide variety of commodities, including both plant and animal materials (Howe 1957; LeCato 1978; Ashworth 1993), and is one of several beetle pests that commonly infest warehouses and retail stores (Arbogast et al. 2000, 2002).

Regular monitoring for insect pests in buildings, such as rice, flour and provender mills,

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warehouses, and retail stores, has assumed greater importance as more emphasis is placed on integrated pest management. A combination of trapping and spatial analysis of trap catch by contour mapping has shown considerable promise as a reliable and practical method of monitoring (Brenner et al. 1998; Arbogast 2001; Subramanyam et al. 2002; Fields & White 2002) and has already gained some acceptance by the pest control industry. The value of the method lies in its ability to locate as well as detect infestation and in the utility of contour maps for documentation and communication. The maps provide graphic, easily understood evidence of insect infestation and the effectiveness of control intervention. They are thus of considerable value in communicating insect problems to managers and to maintenance, sanitation, and pest control personnel.

The method rests on the tacit assumption that there is a relationship between trap catch (number captured by a trap in a specified period of time) and proximity to a source of infestation. Although the results of studies in commercial warehouses, processing plants, and retail stores (Rees 1999; Arbogast et al. 2000, 2001, 2002; Campbell et al. 2002) have supported this assumption, experimentation in a less complex environment is needed to verify its validity and to determine the quantitative nature of the relationship. The present paper reports the results of such experimentation, using *L. serricorne* as a representative stored-product beetle.

MATERIALS AND METHODS

Laboratory cultures of *L. serricorne* were established with adults collected from ground cumin in a Gainesville, FL household in December 1999. The insects were reared at 27 ± 1°C and 60 ± 5% RH with a 12-h photoperiod on a diet of whole wheat flour (10 parts), white cornmeal (10 parts), and brewers' yeast (1.5 parts). Each culture was contained in a 0.95-l mason jar capped with filter paper over screen.

Experiments were conducted in an aluminum shed (about 3.2 × 9.0 m) between June and October 2001. The walls and ceiling of the shed were covered with sheet rock over styrofoam insulation to moderate temperature changes, and the wooden floor, which was elevated about 0.25 m above a concrete slab supporting the shed, was covered with asphalt floor tile. Fourteen pitfall traps (Dome Traps, Trécé, Inc., Salinas, CA) baited with cigarette beetle pheromone lures and a food attractant oil provided with the traps were positioned on the floor as illustrated in Figs. 1-3. No heating or air conditioning was used to regulate temperature. Air temperature at floor level was monitored with HOBO temperature loggers (HO-001-02, Onset Computer Corp., Bourne, MA) placed at the trap sites and set to record temperature at 1-h intervals.

We conducted three experiments, all of which involved releasing beetles and monitoring trap catch over a 48-h period. The experiments differed only with respect to the point of release, which was either at the center of the shed (Fig. 1), near the southwest corner (Fig. 2), or near the northeast corner (Fig. 3). Each experiment was replicated 5 times. For each replicate (48-h trapping run), 2000 newly emerged adults were collected from cultures (46-47 d old) and divided equally between 2 plastic boxes (19 × 14 × 9.5 cm), each containing a shallow layer (about 300 ml) of the rearing diet. The boxes were placed side by side on the floor of the shed at one of the release points, and the lids were removed. All releases were made between 10:00 and 11:00 am, and the number of beetles in each trap was recorded after 6, 24 and 48 h. The beetles remaining in the boxes after 48 h were counted and the number remaining was subtracted from 2000 to obtain the number that had dispersed. The shed was disinfested between replicates by removing the plastic boxes and vacuuming all beetles from the walls, floor and ceiling. Also, the traps were emptied, cleaned, and provided with fresh oil, but pheromone lures were replaced only between experiments. The HOBOs were launched at the beginning of each replicate, and temperature data were downloaded at the end.

The numbers of beetles captured at each trap site were averaged over the five replicates of each experiment, and contours of mean trap catch were drawn for 6, 24 and 48 h using Surfer 8 (Golden Software, Inc., Golden, CO) (Figs. 1-3). The Multiquadric function (Radial Basis Functions) was used as the interpolation algorithm with default values of the function parameters R^2 (smoothing) and h (anisotropy). Radial Basis Functions comprise a group of interpolation methods that attempt to honor data points (that is, they are exact interpolators). The Multiquadric method is considered by many to be the best in ability to fit a data set and to produce a smooth surface (Krajewski & Gibbs 1996; Golden Software 2002), and with most small data sets (<250 observations), it produces a good representation of the data (Golden Software 1999).

Variation in rate of capture with time following release was examined by determining the cumulative number of beetles captured in each replicate 6, 24, and 48 h after release. The totals were averaged over the 15 replicates, and the regression of mean cumulative total on hours following release was plotted and analyzed (Fig. 4). The influence of distance from a source of infestation on numbers of insects captured was examined by combining the results of the three experiments, calculating mean trap catch for each distance, and plotting and analyzing the regression of mean trap catch on distance 6, 24, and 48 h after release (Fig. 5). The number of observa-

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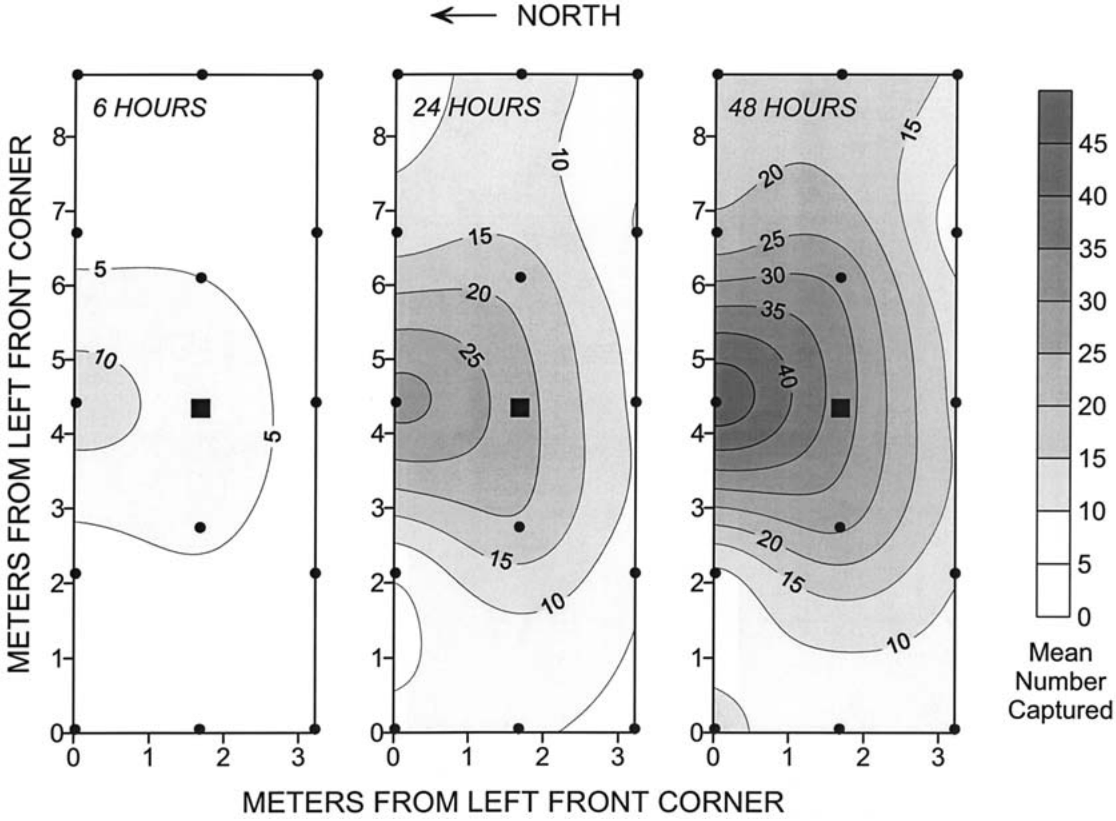

Fig. 1. Contour maps illustrating the changing spatial distribution of *Lasioderma serricorne*, as indicated by trap catch 6, 24, and 48 h after the beetles were released at the center of the shed. The release point is indicated by a solid square and trap positions by solid circles. The contours indicate mean numbers captured (5 replicates).

tions contributing to each mean ranged from 5 to 20. SigmaPlot 2001 (SPSS, Chicago, IL) was used for all regression analyses.

The mean, minimum, and maximum temperatures at each trap position were determined for each experiment, and isothermal maps were drawn to portray spatial variation in temperature over the floor of the shed. Isothermal analysis was done with Surfer 8 as already described for contour analysis of trap catch.

Hourly temperature records were used to calculate hourly means, minima, and maxima, which were then plotted against time of day to illustrate overall diurnal variation during the 15 trapping runs (Fig. 6A). The maximum temperature difference (temperature range = maximum - minimum) among trap sites was determined for each hour of each replicate and used to calculate the mean, minimum, and maximum hourly ranges for the 15 replicates combined. These ranges were then plotted against time of day to illustrate spatial variation and diurnal changes in spatial variation (Fig. 6B).

Mean, minimum, and maximum temperatures, calculated for each replicate (14 trap sites × 48 hours = 672 temperature records), were used to examine the association of temperature with the number of beetles leaving the boxes (dispersing) and with the total number that were captured. Spearman's rank order correlation coefficient (R_s) was calculated for the pooled data (15 replicates) using SigmaStat 2.03 (SPSS Science, Inc., Chicago, IL). Correlation analysis was chosen because none of the variables were fixed at a constant level, and all contained sampling variability. The nonparametric Spearman rank order correlation was used, because we could not assume bivariate normality and common variance.

RESULTS AND DISCUSSION

Contours of trap catch 6, 24, and 48 h after release (Figs. 1-3) tracked the dispersal of beetles from the release point (source of infestation). Intuitively, we would expect the probability of capturing an insect at a fixed point in time to

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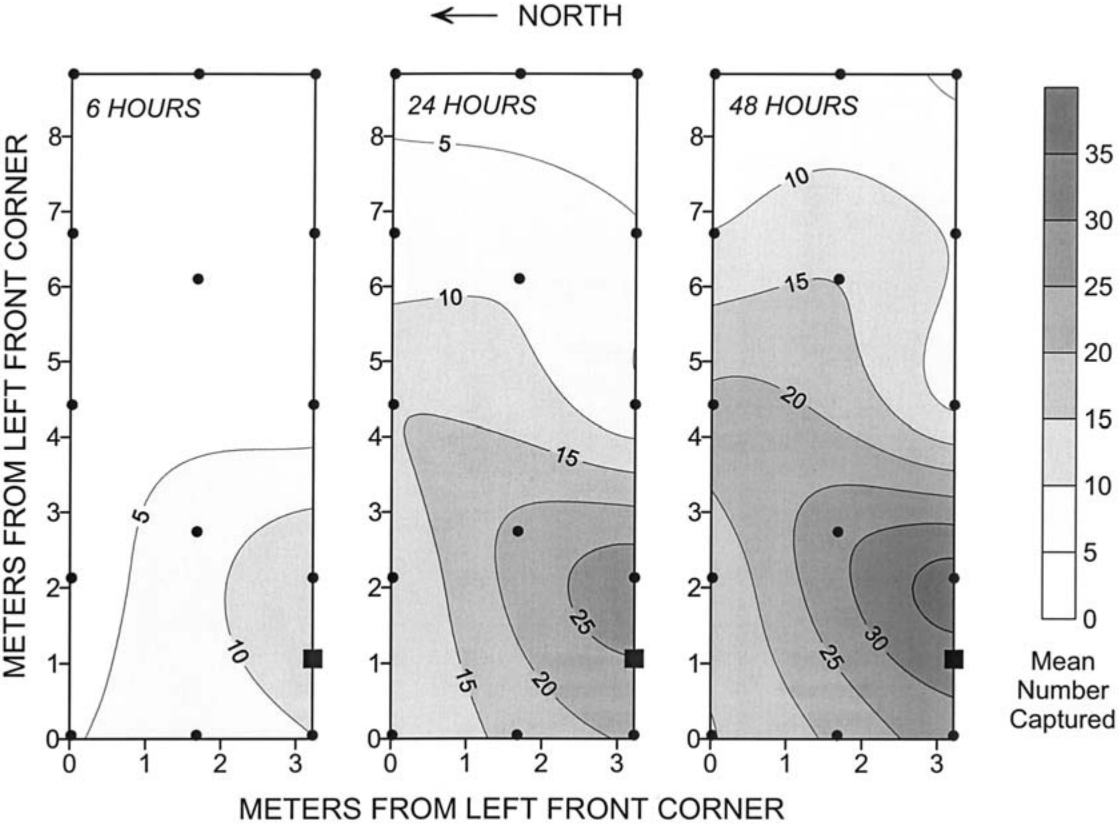

Fig. 2. Contour maps illustrating the changing spatial distribution of *Lasioderma serricorne*, as indicated by trap catch 6, 24, and 48 h after the beetles were released near the southwest corner of the shed. The release point is indicated by a solid square and trap positions by solid circles. The contours indicate mean numbers captured (5 replicates).

increase with proximity to a source of infestation. We would also expect the probability of capture at a fixed distance from a source to increase with time. The temporal changes in contour pattern observed with all three release points were consistent with these expectations. As the beetles dispersed and total trap catch increased, the outlying traps captured more insects, but cumulative trap catch remained highest near the release point. This pattern of change in consecutive contour maps simulates temporal changes in contour pattern that have been observed in retail stores with infested products (Arbogast et al. 2000). Infested products in stores often harbor continuously breeding populations of insects that provide a more or less constant source of dispersing insects. Placing traps in an infested store is analogous to releasing insects in our shed experiments after the traps were already in place, but time is measured from trap placement rather than from insect release. We have observed that sources (foci) of infestation in stores are first detected by the closest traps; the number of insects captured and the area in which the captures occur increase steadily over time, so that the contour pattern surrounding a focus intensifies and spreads outward (Arbogast et al. 2000).

We expected the beetles to disperse equally in all directions unless their freedom of movement was constrained by the walls of the shed, but this did not happen. When the beetles were released at the center of the shed, movement was predominately toward the midpoint of the north wall (Fig. 1). The same bias in dispersal pattern was evident when the beetles were released near the southwest corner (Fig. 2). Although this directional bias in dispersal from the release point shows that factors other than proximity to a focus of infestation can influence trap catch, it did not render trapping and contour analysis ineffective as a means of locating these foci. In both cases, and also when the beetles were released near the northeast corner (Fig. 3), the greatest number of beetles captured after 6, 24, or 48 h were captured by the traps nearest the release point. Although real world situations are more complex, so that

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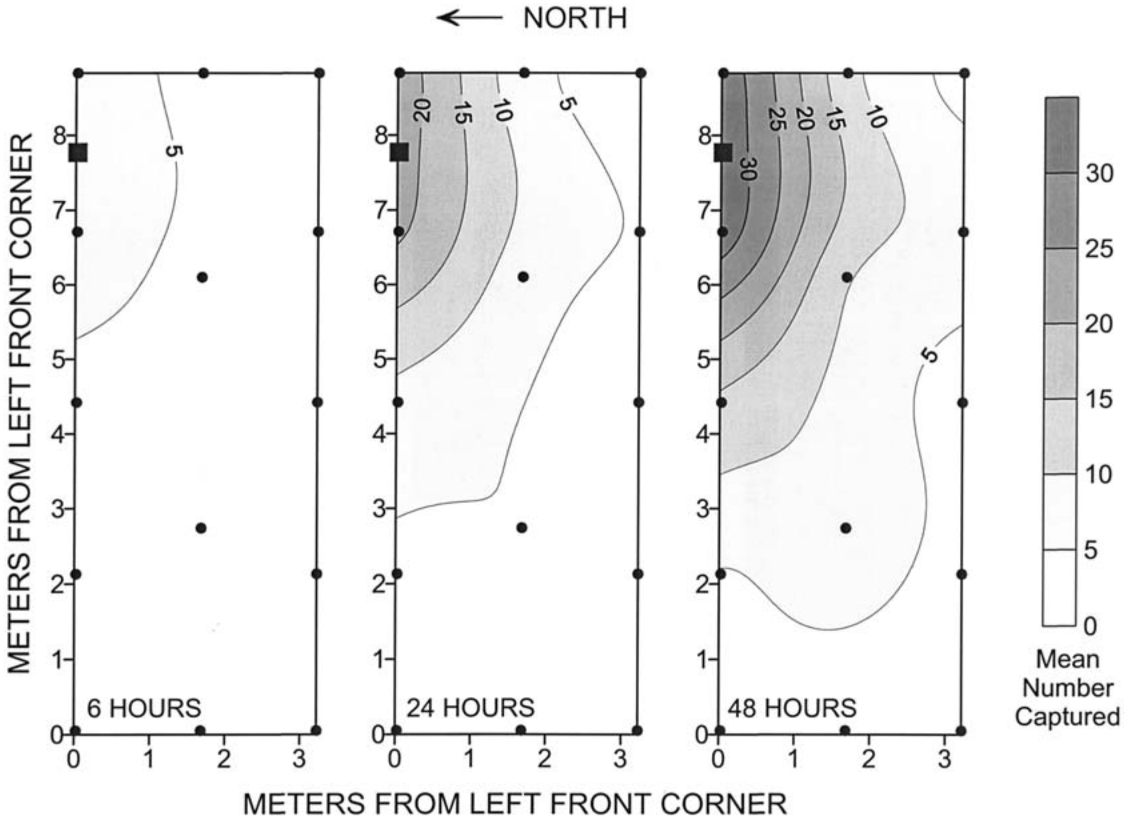

Fig. 3. Contour maps illustrating the changing spatial distribution of adult *Lasioderma serricorne*, as indicated by trap catch 6, 24, and 48 h after the beetles were released near the northeast corner of the shed. The release point is indicated by a solid square and trap positions by solid circles. The contours indicate mean numbers captured (5 replicates).

locating infestation is more difficult, studies in commercial warehouses (Arbogast et al. 2002) and retail stores (Arbogast et al. 2000) have, nevertheless, shown the method to be useful.

The rate of capture in the shed was highest immediately after release of the beetles and declined with time, rapidly at first and then more slowly until it became nearly constant (Fig. 4). Without further research, we can only speculate about the cause of this initially rapid decline, but we would expect such a temporal pattern if there were a burst of dispersal immediately after release, followed by a decline and eventual stabilization of dispersal at a much lower rate. The same pattern should also occur when a trap is first set in an infested building, such as a pet store, if the rate of capture is positively correlated with the number of insects available to be captured. In this case, the rate of capture would decline as the adult population becomes depleted and would eventually stabilize when recruitment of adults from infested commodities just balances their removal. In a trapping study of *Plodia interpunctella* (Hübner) and various beetles in-

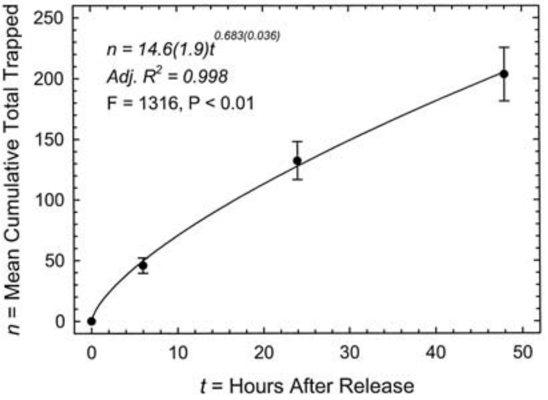

Fig. 4. Variation in rate of capture of adult *Lasioderma serricorne* with elapsed time (t) after release. Mean cumulative totals (n) are based on all trap sites, replicates, and experiments combined (210 observations). Error bars indicate standard errors of the means. The numbers in parentheses are standard errors associated with estimates of the parameters a and b in the fitted equation: $n = at^b$.

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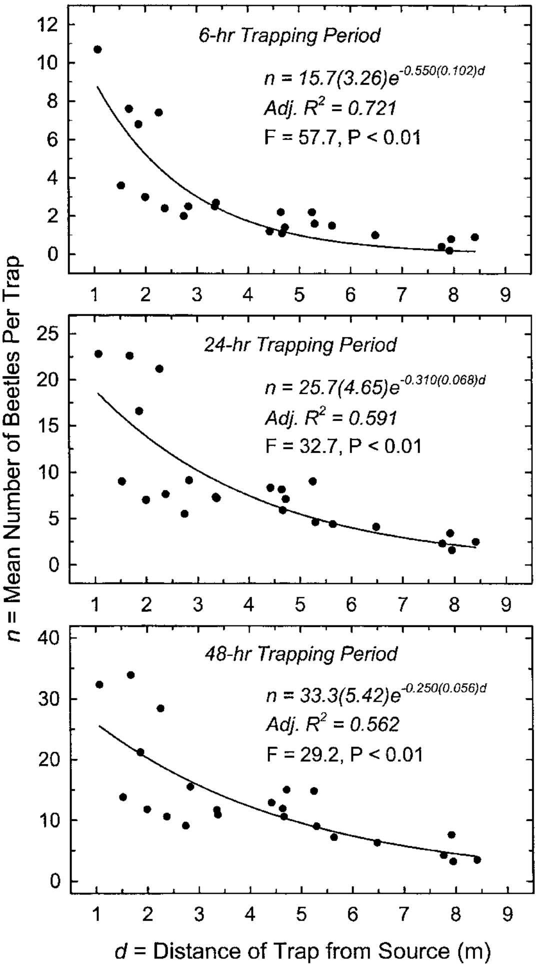

Fig. 5. Relationship between mean number of adult *Lasioderma serricorne* per trap (n) and distance (d) of the traps from a source of infestation (point of release) after 6, 24, and 48 h. The plots are based on all 3 experiments (points of release) combined. The number of counts in each mean ranged from 5 to 20. The numbers in parentheses are standard errors associated with estimates of the parameters a and b in the fitted equation: $n = ae^{-bd}$.

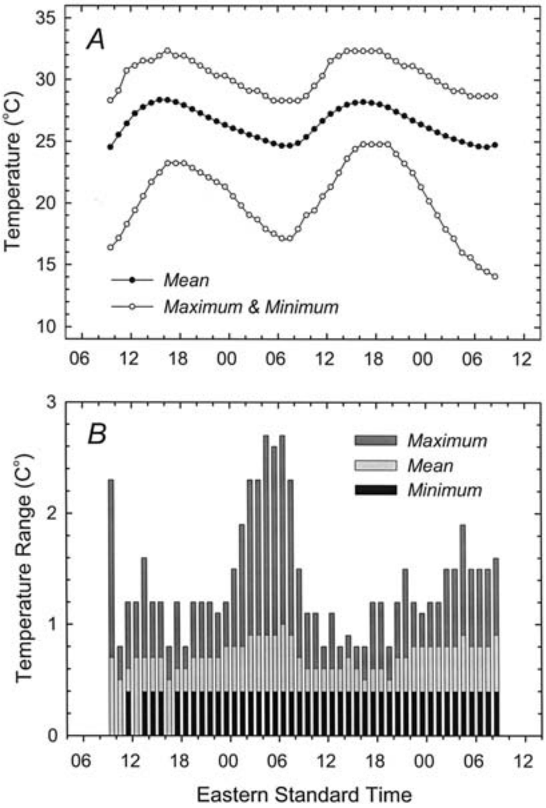

Fig. 6. Variation in temperature on the floor of the shed with time of day. (A) Mean, minimum, and maximum temperatures for each hour based on temperature records for all trap sites, replicates, and experiments combined (210 records). The maxima and minima for each time of day are the highest and lowest temperatures recorded for that time over the course of the entire study. (B) Mean, minimum, and maximum temperature ranges (differences between trap sites with the highest and lowest readings) for each time of day. Ranges were determined for each hour of each replicate, and all replicates were then combined to determine mean, minimum, and maximum ranges for the study. The range of each temperature statistic can be read from the top of the shading representing that statistic.

festing pet and department stores, Arbogast et al. (2000) found that the relationship between days of trapping and cumulative numbers captured over periods of 4-5 days was well described by straight lines. However, these authors noted some evidence that the rate of capture may actually have decreased with time during the first day or two.

The number of beetles (n) that had been captured by any trap in the shed 6, 24, or 48 h after release declined as an exponential decay function of distance (d) from the source of infestation (Fig. 5). The effect of distance on numbers captured became less pronounced with time as the dispersing beetles spread out and occupied more of the shed. Pierce (1994) successfully located infestations of *L. serricorne* and pyralid (phycitine) moths using a triangulation method based on the assumption (implied although not explicitly stated) that there is an inverse relationship between trap catch and the distance of the trap from a source of infestation. The results of the present study, as well as Pierce's success in locating infestations, support the validity of his assumption.

Temperature inside the shed varied over the course of the study (Fig. 6), but the seasonal range of variation was apparently insufficient to affect dispersal of beetles from the point of release, or the

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TABLE 1. NUMBERS OF CIGARETTE BEETLES THAT DISPERSED FROM RELEASE SITES AND NUMBERS THAT WERE CAPTURED IN PITFALL TRAPS DURING 48-H TRAPPING PERIODS.

Trapping run	Beetles dispersed[1] Total	Beetles dispersed[1] Percentage	Beetles trapped[2] Total	Beetles trapped[2] Percentage[3]
Experiment 1: Beetles released at center of shed				
27-29 Jun	1570	78.5	251	16.0
10-12 Jul	1629	81.4	326	20.0
17-19 Jul	1103	55.2	150	13.6
23-25 Jul	1334	66.7	162	12.1
06-08 Aug	1923	96.2	319	16.6
Experiment 2: Beetles released near southwest corner of shed				
14-16 Aug	1507	75.4	220	14.6
23-25 Aug	938	46.9	80	8.5
28-30 Aug	1558	77.9	326	20.9
05-07 Sep	1498	74.9	217	14.5
10-12 Sep	976	48.8	297	30.4
Experiment 3: Beetles released near northeast corner of shed				
19-21 Sep	838	41.9	142	17.0
24-26 Sep	683	34.2	119	17.4
02-04 Oct	1060	53.0	83	7.8
09-11 Oct	1198	59.9	172	14.4
15-17 Oct	1745	87.2	188	10.8

[1] Number of beetles out of 2,000 that dispersed from the plastic boxes at the release point during the 48-h trapping run.
[2] Combined number of beetles captured by 14 traps during the 48-h trapping run.
[3] Of the beetles that dispersed, the percentage that were trapped.

numbers captured. The number of beetles (out of a possible 2000) that dispersed from the diet during any 48-h trapping run ranged from 683 to 1923, and the total number of dispersing beetles captured by the 14 traps ranged from 80 to 326 (Table 1). Correlation analysis of data pairs for all three experiments combined showed no significant association between number of beetles dispersed and mean ($R_s = 0.12$, $P = 0.67$), minimum ($R_s = 0.11$, $P = 0.70$), or maximum ($R_s = 0.15$, $P = 0.58$) temperature. Correlation analysis also indicated no significant association between trap catch and mean ($R_s = 0.36$, $P = 0.18$), minimum ($R_s = 0.38$, $P = 0.15$), or maximum ($R_s = 0.35$, $P = 0.19$) temperature. The temperature range among trap sites varied with time of day, but the ranges of the means, maxima, and minima never exceeded 0.4, 1.0, and 2.7°C, respectively (Fig. 6B). A frequency distribution of the temperature ranges for all experiments, replicates and hours combined (720 ranges) showed that 86.5% were ≤1.0°C and that 99.0% were ≤1.9°C. Consequently, isothermal maps showed very weak temperature gradients on the floor of the shed, and comparison of these maps with contour maps of trap catch revealed no clear effect of temperature gradients on movement of the beetles.

Several studies have shown that a combination of trapping and contour analysis of trap catch provides a useful, albeit less than perfect, method for monitoring stored product insects and locating foci of infestation in buildings such as warehouses, mills, and retail stores (Rees 1999; Arbogast et al. 2000, 2001, 2002; Campbell et al. 2002). The spatial pattern of trap catch relative to sources of infestation indicated by the contour maps in the present study, and the inverse relationship of trap catch to distance from the source, further support the validity of contour mapping as a method of monitoring stored-product insects and locating foci of infestation. Although the action of one or more factors other than distance from a source of infestation was evident in two of the experiments, the highest trap catch, nevertheless, occurred at one of the sites closest to the source. Campbell et al. (2002), however, noted that high trap captures in the warehouse portion of a food processing plant may have resulted from three distinct factors: proximity to a large infestation, proximity to a major route of insect movement, and proximity to a major source of attractive odor. The influence of various factors (in addition to proximity of infestation) on the spatial distribution of trap catch clearly needs further investigation.

Contouring has some advantages over the triangulation method used by Pierce (1994). One advantage is the utility of contour maps in documenting and communicating insect problems, as

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already noted. Another is the fact that traps need not be arranged in a regular rectangular array as required by Pierce's method, a requirement that cannot always be satisfied in commercial settings. Contouring software employs various algorithms to create regular arrays of data points by interpolation between irregularly spaced observations, and contours are then fitted to the interpolated values at these points. This advantage, however, is not as great as it may appear at first glance, because the more widely an arrangement of traps deviates from a regular rectangular array, the weaker the agreement between observed and predicted values at the trap sites. Arbogast et al. (2003) examined this and other sources of error in predicting insect distribution by trapping and contour analysis, and pointed out measures that can be taken to minimize them.

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