Phenology and Spatial Pattern of Tychaeus sertoreus (Coleoptera: Mycetophagidae) Infesting Stored Grain: Estimation by Pitfall Trapping

RICHARD T. ABRAGAST, PAUL E. KENDRA, DAVID K. WEAVER, AND BHUBANANU SUBRAMANYAM1

Center for Medical, Agricultural, and Veterinary Entomology, USDA-ARS, P.O. Box 1455, Gainesville, FL 32604

ABSTRACT The harry funga beetle, Tychaeus sertoreus (L.), occurs frequently in stored grains, often in large numbers. Populations infesting stored barley in Minnesota, corn in South Carolina, and wheat in Florida were sampled twice a month in winters of 1981–1982; Spatial distribution of T. sertoreus was examined by continuous analysis of bait catch. In South Carolina, corn was sampled at 2 stations over 2 storage seasons, and temperatures, storage content, and maliability records were measured. These data were used to examine methodology as well as spatial distribution, and showed peak trap catch shortly after harvest in the fall and in the spring. This pattern followed seasonal changes in grain temperature, but there was no apparent relationship of trap catch to monthly grain moisture content or maliability records. The populations of T. sertoreus were not distributed randomly, but were largely concentrated in a few aggregations associated with the "good-quality" region high in foreign material and high moisture that forms near the center of a bag at 3 height. Moreover, the spatial patterns were dynamic, exist on a very small time scale. Numbers of insects in aggregations were high, and the areas involved expanded and contracted, the center shifted, and secondary centers appeared and disappeared. These changes were apparent in response to changes in patterns of grain temperature and moisture content. Secondary centers of aggregation often formed in warmer grain along the walls.

KEY WORDS Tychaeus sertoreus, harry funga beetle, stored grain, phenology, spatial distribution, trapping

The harry funga beetle, Tychaeus sertoreus (L.), is a cosmopolitan storage pest that has been recorded from a variety of commodities and habitats: Cotton and food 1937, flowers 1943, and Okinawa (1958) and occurs frequently, often in large numbers, in stored grain Cardo and Thorne 1987, Barkal and Path 1983, Horton 1981, Horton 1984, 1985, Subramaniam and Haroon 1983, Weidner and Porter 1990. Although, it is generally considered a cold insect or associated with poor storage conditions, it has also been reported to damage grain, (Jacks 1988, Tizig and Pinniger 1994). In other cases, it should be considered a pest of substantial economic importance. Its frequent occurrence in large numbers causes contamination and may result in grain being assigned the wrong grade. Enfeuded (USDA 1987). Also, T. sertoreus can act as a carrier of damaged and because it can fly, it is capable of spreading the pathogen over long distances (Hald et al. 1995).

Despite its widespread and common occurrence in stored grain, there have been few studies of its biology. Jacob (1985) investigated the development of T. sertoreus over a range of constant temperatures and humidity to determine its potential as a pest. Tizig and Pinniger (1994) determined its susceptibility to propoxur, malathion, and malathion, and Weidner and Porter (1990) examined the resistance of a strain from Illinois to the same chemicals. The current article examines the phenology and spatial distribution of this species in bulk stored grain.

Materials and Methods

Storage Situation. We studied infestations of T. sertoreus in barley stored on a farm in northeastern Minnesota (Marshall County), in corn stored on 2 farms in southern South Carolina (Barnwell County and Bamberg County), and in wheat stored at a seed processing plant in north-central Florida (Levy County). Storage was in galvanized steel bins ranging in capacity from ~120 to ~320 t. Barley (~50 t) was harvested in 1981 and had been stored for ~4 yr when the insect populations were sampled (Subramaniam and Haroon 1995). Trapping in the corn and wheat began shortly after storage and continued until the grain was removed from the bins. The South Carolina
study spanned 2 storage seasons (grain harvested in 1982 and 1983). After the bins in Bemidji County were filled to near capacity and contained 90% of corn, this corn was conveyed to grower facilities in Bemidji County for storage. The corn was conveyed on a conveyor belt at 91 m/s (300 ft/min) for most of the area. In both years, 3% of the corn was applied to the soil at the point of loading on top of the bin. In 1982, the bins in Bemidji County were filled to ~80% capacity (448 t), and in 1983, it was filled only about half (34% t). A 1% malted dent and 9% straw, which was fumigated with phosphine and removed shortly before the wheat was loaded. The wheat was fumigated in late August by placing aluminum plus- phide tablets on the grain surface and in the aeration duct, after which the duct was sealed. Grain Temperature, Moisture Content, and Mala-
tioned Residue. These parameters were reported only for the South Carolina locations. Temperature was measured and recorded by means of an Easy Logger Field Unit (model FA-100) and TTH1 thermometer tem-
perature probes (Onset Data, Logan, UT). The unit's 8-cell batteries, which were used to replace the 2 gels cells backed up by a solar panel on the bin roof. The gel cells are small rechargeable batteries, and the solar panel provided low-level (tickle) charging during periods of sunlight. With this arrangement, the batteries did not require servicing during the storage period. The Easy Logger was protected by a lightning arrester mounted inside the bin. The battery was wired to the solar panel, the logger, and to a copper ground rod adjacent to the bin. Temperature was measured every 15 min, and hourly averages were recorded in a data storage module (Onset Data, model DM100) for later downloading to computer storage. Note that the temperature was recorded along the north-south and east-west diameters of the bin measured grain temperature at various points near the surface of the bin (model FA-100). One probe was located at the center of the bin, at a distance of ~15 cm from the bin wall, and 4 probe bolts between the center of the bin and the end (1.4 cm from the center, depending on the diameter of the bin). Each probe was secured with a rope to a 5-cm length of a 1.5-cm dowel rod, burlap pointed at one end. The rods were pushed into the grain so that the sensor, which rested in a shallow groove near the pointed end, was 18 cm below the surface. For each sensor, the recorded variables were mean temperatures, averaged using the SAS means pro-
cedure, and these in turn were averaged to obtain overall means. Weekly minimum and maximum temperatures were also calculated for each sensor, using this SAS means procedure. Mean, mean minimum, and mean maximum grain temperature; (SE) for the bin were then calculated by averaging the weekly means, the
weekly minima, and the weekly maxima for the 9 sensors in the grain. At weekly intervals, we took one 0.5-liter sample of grain from the next two or three temperature probe for measurement of moisture content and maltation. The samples were held in 50 mm polypropylene jars until moisture content could be measured with a Mettler model 500 Automatic Grain Moisture Tester (Staples, John, Salinas, CA). Maltation readings were determined using the general method for organophosphates, as described in Arthur et al. (1988). Malation results were determined at regular intervals during the 1st storage season (1982-83), but were determined weekly during the 2nd season. Measurements of moisture content and maltation readings were saturated with Microsoft Excel 97® (Ponsen, 1997) spreadsheets for calculation of descriptive sta-
tistics. Maltation readings were fitted to two-param-
ents, single exponential decay curves, using SigmaPlot (SPSS, Chicago, IL). The spatial distribution of grain temperature and moisture content was mapped with contour analysis (Abou-Zeid et al. 1988), using Surfer (Golden Software, Golden, CO), with radial basis functions, multiquadric algorithm for interpolation. This is a flexible algorithm that provides flexible interpolation of point data sets (Koller 1995).

Insect Tapping in Wheat (Florida). The traps were Ateasone Grain Probes (L. and B. Taps) and a modified automatic grain probe (Shuman et al. 1995). The traps were inserted into the grain with the trap tip just below the grain surface, and insects were removed weekly from 20 August to 2 October 1998.

Insect Tapping in Wheat (Florida). The traps were Ateasone Grain Probes (L. and B. Taps) and a modified automatic grain probe (Shuman et al. 1995). The traps were inserted into the grain with the trap tip just below the grain surface, and insects were removed weekly from 20 August to 2 October 1998.
and the bin wall. In 1993, 28 traps were evenly dis-
symmetrical around the centers of the bins in 3 concentric
rings with radii 0.17, 0.30, and 0.83 times the radius
of the bin (Fig. 1 A and B). There were 4 traps in the
inner 8 in the middle, and 16 in the outer circles. The
traps were emptied at weekly intervals and returned
to the same locations.

Analysis of Trap Catch. Insect counts were entered
into Microsoft Excel 97 spreadsheets for calculation of
descriptive statistics. The ratio of variance to mean
was calculated as a measure of dispersion (Southwood
1978). For regular distributions, this ratio has a value
of 0, and for Poisson (random) distributions it has a
value of 1. It increases in value as distributions become
more aggregated, so its departure from unity provides

a measure of aggregation. An index of dispersion ($\lambda = \frac{\text{variance}}{\text{mean}}$) was calculated to test the null
hypothesis that variance, mean = 1 (distribution of
trap counts is Poisson). Southwood 1978).

The spatial distribution of trap counts was mapped by
contour analysis, using the same methods that were
used for temperature and moisture content.

Correlation and Regression. The relationship of
trap catch to weekly mean grain temperature, and
to percentage grain moisture content was examined by
correlation and regression analysis, using SigmaStat
(SSI, Chicago, IL). Because the data failed to meet
all of the assumptions for a parametric test, Spearman's
rank order correlation we used. Spearman correlation
coefficients were calculated for each location, and for

Fig. 1. Layout of traps (open circles) and temperature sensors (solid circles) at grain stored in used-engine oil bins. (A) Com., Barberton County, SC; (B) Corn, Barrow County, NC; (C) Wheat, Low County, FL; (D) Barley, Marshall County, MN.
combined locations in each bin over the storage period. A correlation coefficient was also calculated for the combined locations of both bins. The independent effects of temperature and moisture content on trap catch were examined by multiple (partial) linear regression, as described by Andrews et al. (1983). Variation in trap catch, temperature, and moisture content over time were each fitted to a 3rd-order polynomial, with weeks of storage as the independent variable. The residuals calculated from these equations were then fitted to a multiple linear expression, with trap catch residual as the dependent variable. The coefficients of the 2 independent variables in the expression measure the independent effects of temperature and moisture content on trap catch.

Results and Discussion

Phenology (South Carolina). T. mesopotami was frequently captured on the 2 South Carolina farms during 1982-1984, and the data collected over 2-4 storage seasons provided an opportunity to examine the impact of storage climate on the seasonal abundance of this species in traps. It was most abundant in September and October, shortly after the newly harvested grain was placed in the bins (Fig. 2). It declined in numbers as the grain cooled and became abundant again in May and June (Figs. 2 and 5). A late harvest on 1 farm during 1982 delayed storage until November (Fig. 2B). The initial peak in abundance that followed storage in September never occurred, and T. mesopotami was not found in significant numbers until the following May. On the same farm in 1984, the grain was removed from storage in early April, before the spring peak in abundance (Fig. 3D).

Correlation analysis (Table 1) showed a strong association between trap catch and mean grain temperature, caused largely by parallel variation with season (Table 2). Mean temperatures fell below 15°C in December and rose above 15°C again in late March or early April (Fig. 2). Abundance of T. mesopotami declined to very low levels during December and did not increase again until May (Fig. 3). Thus, trap catch responded immediately to declining grain temperature, but responded more slowly to increasing temperature, and there was a lag of ≈1 mo between the time the grain warmed to 15°C and the time that T. mesopotami again became abundant. Mean trap catch for any week during the period from December through April, was usually <1 insect per trap, but a weak hot spot that occurred on the Bartwell County farm during 1983-1984 persisted into December created an anomaly in this pattern (Fig. 2D). A hot spot is a region within a grain mass that has become heated by the
Fig. 3. Grain temperature measured in corn stored on farms in South Carolina. (A) Bamberg County, 1982-1983. (B) Darlington County, 1982-1984. (C) Bamberg County, 1983-1984. (D) Darlington County, 1982-1984. Vertical bars indicate SE.

Table 1. Correlation of grain temperature (T) and moisture content (MC) with number of P. serrana captured in pitfall traps in stored corn

<table>
<thead>
<tr>
<th>Location</th>
<th>Traps</th>
<th>Moisture</th>
<th>Coefficient</th>
<th>p-value</th>
<th>Coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darlington County</td>
<td>28</td>
<td>0.785</td>
<td>0.000</td>
<td>20</td>
<td>-0.577</td>
<td>0.000</td>
</tr>
<tr>
<td>Bamberg County</td>
<td>28</td>
<td>0.357</td>
<td>0.031</td>
<td>20</td>
<td>-0.465</td>
<td>0.000</td>
</tr>
<tr>
<td>Darlington County</td>
<td>14</td>
<td>0.949</td>
<td>0.000</td>
<td>20</td>
<td>-0.926</td>
<td>0.000</td>
</tr>
<tr>
<td>Bamberg County</td>
<td>14</td>
<td>0.249</td>
<td>0.030</td>
<td>20</td>
<td>-0.267</td>
<td>0.000</td>
</tr>
<tr>
<td>Darlington County</td>
<td>14</td>
<td>0.077</td>
<td>0.000</td>
<td>20</td>
<td>-0.102</td>
<td>0.000</td>
</tr>
<tr>
<td>Bamberg County</td>
<td>14</td>
<td>0.172</td>
<td>0.000</td>
<td>20</td>
<td>-0.250</td>
<td>0.000</td>
</tr>
<tr>
<td>Darlington County</td>
<td>14</td>
<td>0.395</td>
<td>0.000</td>
<td>20</td>
<td>-0.347</td>
<td>0.000</td>
</tr>
<tr>
<td>Bamberg County</td>
<td>14</td>
<td>0.913</td>
<td>0.000</td>
<td>20</td>
<td>-0.802</td>
<td>0.000</td>
</tr>
<tr>
<td>Darlington County</td>
<td>14</td>
<td>0.080</td>
<td>0.000</td>
<td>20</td>
<td>-0.080</td>
<td>0.000</td>
</tr>
<tr>
<td>Bamberg County</td>
<td>14</td>
<td>0.452</td>
<td>0.000</td>
<td>20</td>
<td>-0.452</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Temperature influences trap catch both directly, through feeding on moth activity, and indirectly, through its impact on population growth. Thus, the observed seasonal variation in trap catch may have resulted from variations in activity level, changes in

Metabolic activity of insects, fungi, or the grain itself. Although abundance still declined, it remained at somewhat higher levels. This can be attributed to unusually high rates of capture by 2 traps located within the hot spot.
Table 2. Temporal trends in trap catch, temperature, and moisture content of trap catch.

<table>
<thead>
<tr>
<th>Region/Provenance</th>
<th>Polynomial order 1 regression</th>
<th>Multiple linear regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$y = a + bx$</td>
<td>$y = a + bx + cz$</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.30$</td>
<td>$R^2 = 0.30$</td>
</tr>
<tr>
<td></td>
<td>$p &lt; 0.001$</td>
<td>$p &lt; 0.001$</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.29$</td>
<td>$R^2 = 0.29$</td>
</tr>
<tr>
<td></td>
<td>$p &lt; 0.001$</td>
<td>$p &lt; 0.001$</td>
</tr>
</tbody>
</table>

Population density, or both. Although we cannot yet quantify the relative contributions made by changed activity and changing population density to seasonal variation in trap catch, it is clear that change in popu-
lation density had a significant effect. This is indi-
cated by the lag time between grain warming and the resurgence of T. sternae in the spring. Trap catch declined during the coldest months and increased again in the spring. We would expect such a winter decline to be caused by mortality, coupled with slowed or arrested oviposition and development, as well as by diminished activity. If the population den-
sity had remained static and trap catch had declined only because of reduced insect activity, we would expect trap catch to equal or exceed almost immediately when the grain warmed to the threshold temperature for activity. Multiple linear regression (Table 2) pro-
vides further evidence of population decline during winter. This analysis suggested that the direct effect of temperature on trap catch, independent of other vari-
able, is significant but weak. Although the tempera-
ture coefficients (0.051 and 1.140) are highly sig-
nificant, they are small, and the coefficients of determination (0.069 and 0.035) indicate that the di-
rect effect of temperature and humidity accounted for only approximately 4.7% of the variation in trap catch.

In contrast to temperature, seasonal variation in neither grain moisture content nor mealworm resid-

Table 3. Influenced seasonal variation in numbers of T. sternae trapped (Figs. 2 and 4). Malathion residue de-
cayed exponentially throughout the storage period, and seems to have had little impact on T. sternae, even at the highest levels imposed. Malathion residues were initially an order of magnitude higher, and were less variable, on the farm in Bamberg County (Fig. A and G), where the chemical was applied as a spray, than on the farm in Barnwell County (Fig. B and D), where it was applied by hand as a dust. Mean mealworm content declined over the storage period, especially during the last 3-4 mo of storage, but usually did not fall below 12-13% (Fig. B). Correlation analysis (Table 2) showed a positive association between moisture content and trap catch, which was significant only for the Barnwell County farm. This correlation resulted from the coincidence of moisture loss by the grain and population growth of T. sternae during spring. These seasonal trends are apparent in Figs. 3 A and B, and 4 (A and B). Table 2 and the regression equations relating trap catch or moisture content to weeks of storage (Table 2). But multiple linear regression (Table 2) showed that the direct effect of moisture content on trap catch, independent of other variables, is not sig-
nificant.

Spatial Pattern in Barley (Minnesota). Numbers of T. sternae captured in barley on the Minnesota farm showed a general decline in abundance over the winter-

week trapping period (mid-August to October). Mean weekly trap catches (CFE) ranged from 5.3 (5.4) to 0.7 (5.1), the number captured in any 1 trap ranged from 0 to 44 during the 1st wk and from 0 to 8 during the last. The trap counts were aggregated. Mean variance ratios ranged from 14.9 to 5.5, and all were significantly $>1$. Contour analysis confirmed the ag-
egregation and revealed a spatially distinct center of aggregation (G). In August, when trapping began, the beetle population was concentrated in several centers joined by areas of lesser density, and a large area of the grain surface was devoid of captures (Fig. 5A). At the population de-

creased, concentrations of beetles disappeared, except for the largest, which was located in the south-

east quadrant of the bin (Fig. 5 B and C).

Spatial Pattern in Wheat (Florida). During the first 3 wk of trapping (7-21 August), mean trap catch (CFE) increased from 2.9 (3.1) to 34.3 (5.3), and during this brief period, the spatial organization of the population changed markedly (Fig. 1D-E). Initially, there was a weak concentration of beetles near the southeast bin wall and a lesser concentration west of the bin center. Within a week, the pattern changed to one dominated by a single large concentra-
tion centered around the south trap and involving most of the southern half of the grain. It is interesting that the south trap captured no T. sternae during the 1st wk, but captured 175 during the 2nd. The mean variance ratios increased from 73.3 to 166.3, and the indices of dispersion calculated from the ratios indicated a significant departure from Poisson. The traps were removed on 21 August, the bin was fumi-
gated, and the traps were replaced on 18 September. Trap catch was significantly reduced by the fumiga-

April 2000
tion, but the population was not eliminated (Fig. 5F).

Mean trap catch (±SE) during the first 3 wk after the traps were replaced ranged from 1.9 (±0.4) to 1.4 (±0.2) and the distribution of trap catch no longer differed significantly from Poisson. By the time the grain was removed on 15 October, mean trap catch had increased to 2.3 (±0.3) and the distribution was again approximated.

Spatial Pattern In Corn. (South Carolina). The mean number (±SE) of T. abnormis captured per week for the entire storage period on the Bamberg County farm in 1992-1993 ranged from 23.0 (±5.6) in the central trap to 33.3 (±1.0) in the north trap. On the Bamberg County farm, mean captures per week ranged from 20.3 (±3.5) in the central trap to 5.8 (±2.4) in the north trap. In 1993-1994, the mean number of captures per week on the Bamberg County farm ranged from 22.3 (±1.0) to 9.9 (±2.4), with most captures occurring in the 4 inner east traps. On the Barnwell County farm, the mean number of captures ranged from 1.3 (±0.3) to 5.8 (±0.4), and again most of the captures occurred in the 4 inner east traps.

The distribution of captures differed significantly from Poisson on both farms during both storage seas-

![Image](image-url)
Fig. 5. Spatial distribution of T. sternae in stored grain. (A-C) Barley stored on a farm in northwestern Minnesota after 4 yr plus 1 wk. (B) Wheat stored at a seed processing plant in Levy County, FL, during the 3rd, 4th, and 5th wk of storage. Contour lines indicate the numbers of insects captured during 1 wk. The wheat was fumigated with phosgene after the 4th wk.
Fig. 4. Spatial distribution of Z. sternius (A-C) and grain temperature (D-F) in corn stored on a farm in Barnwell County, SC during the 1st (A-C, 15 September 1993), the 2nd (D-E, 22-26 September 1993), and the 3rd (F, 7-11 October 1993) weeks of storage. Contour lines indicate the number of insects captured during the week (A-C) and mean grain temperature for the week (D-F).
Fig. 7. Spatial distribution of T. serratus (A-C) and grain temperature (D-F) in corn stored on a farm in Barnwell County, SC, during the 2nd, 12th September–6 October 1990 (A, D), 9th–17th October–1 November 1990 (B, E), and 11th November–1 December 1990 (C, F). Contour lines indicate the numbers of insects captured during the week (A-C) and mean grain temperature for the week (D-F).
for south and west, although it remained in the area occupied by the spotline (Fig. 6B). It first intensified and then diminished as the grain in this area rotted. Finally, during the 7th week, a 2nd center appeared against the south wall (Fig. 6C).

In the farwell bin (Fig. 7), extremely large number of T. stercorosum were concentrated along with other species, in an area just north of the bin center during the 2nd wk of storage (Fig. 7A). The mean grain temperature in this area was 22°C, but the warmest temperatures (24°C) occurred along the south wall (Fig. 7D). Grain moisture content was high (>15%) over the entire grain surface, but was lowest in the vicinity of this concentration of insects (Fig. 7A). This changed markedly during the next 4 wk, and in fact a weak hot spot developed in this area and persisted into December. By the 6th week, T. stercorosum had declined in numbers and the population center had spread out (Fig. 7B). The highest temperature (>31°C) occurred along the south wall, but a ridge of relatively higher temperatures extended northward beyond the center of the bin (Fig. 7E). The area of highest temperature (>31°C) and grain moisture content (>15.5%) coincided with the concentration of insects (Fig. 7B and F and S B). By the 11th wk (December), the grain had become considerably cooler and drier, but a ridge of relatively higher temperature extended from the south wall toward the northwest (Fig. 7F), and the highest moisture content was 16.6% (Fig. 7C).

In conclusion, T. stercorosum frequently infests stored grain and is often most abundant shortly after storage, as indicated by the literature already cited and the observations of the current study. This is not surprising, because it has been reported to infest standing crops in the field (Cotton and Winstead 1944, USDA 1946) and probably moves passively into storage with harvested grain. In the South, it is active and flies throughout most of the year, especially when temperature is above 20°C (Throne and Chine 1994), so infestation almost certainly occurs by active migration as well. The seasonal distribution in storage bins on South Carolina farms, with peak trap catch in the fall and spring, seems to follow changes in grain temperature and may be the usual pattern, at least in the southeastern states. But longer storage periods may produce additional peaks.

In the bins we studied, the pattern was not influenced by grain moisture content or malathion residue, but this was not held in general. The grain moisture content we observed remained relatively high. Dryness or lower moisture content would certainly cause populations to decline. The lack of response to malathion residue can probably be attributed to resistance. Resistance to malathion and parathion-methyl has been demonstrated in populations of T. stercorosum in other states (Wiegardt and Porter 1990). Also, Tigar and Pinzger (1996) found that malathion applied to corn at rates of 0.9 mg/kg gave protection of about 80% of T. stercorosum after 4 wk, even at the highest rate, and control had broken down completely by 12 wk.

Fig. 8. Spatial distribution of grain moisture content in corn stored on a farm in Barnwell County, SC, after the 5th (29 September-6 October 1993) (A), 8th (25 October–November 1993) (B, C, and D); 11th (1-8 December 1993) (C); 14th (9-16 December 1993) (D) weeks of storage.
Populations of T. sternae, like those of other storage pests that occur in bulk grain, are not distributed randomly, but occur in aggregations, often comprising very large numbers of individuals. The nature and behavior of these aggregations has not previously been studied by statistical analysis, and some of the conclusions drawn for T. sternae may apply to other species as well. In newly stored grain, T. sternae occurs largely in 1 aggregation, or at least in a small number of aggregations, associated with the surface near the center of the bin. The distribution observed in the barley, which had been in storage for 4 yr, although clearly aggregated, was less organized and may be one of long standing infestations. The spatial pattern we observed were dynamic, even on a very small time scale (week to week), and this is probably true for populations of storage pests in general. Numbers of insects in aggregations rose and fell, the areas involved expanded and contracted, the centers of aggregations shifted (but usually remained anchored in the area of the spoilage), and secondary centers appeared and disappeared. These changes seem to be in response to changing patterns of grain temperature and moisture content, and secondary centers of aggregation often occurred in warmer grain along bin walls.

Acknowledgements
We are indebted to our cooperation in industry for making their facilities available for research. We thank R. V. Baird and B. R. Pahlow for their help with the field work in South Carolina and M. Carton, who assisted in the laboratory by counting and identifying the insects and calculating data. We thank K. Coren and P. Sun for their help with the field work in Florida, and R. Goss for technical assistance in the laboratory, including tabulation and analysis of data. Finally, we express our appreciation to J. E. Baker and B. L. Moger for their critical review of an earlier version of the manuscript and for their helpful suggestions.

References Cited
Cotton, R. T., and T. F. Winburn. 1941. Field infestation of wheat by insects attacking it in storage. J. Econ. Entomol. 34, 12-16.
Perkins, R. E. 1987. Using Microsoft Excel 7.0, Qual Corp., Indianapolis, IN.
SAS Institute, Inc. 1988. SAS procedures guide. 3.0 ed. SAS Institute, Cary, NC.
Received for publication 22 September 1989, accepted 7 June 1990.