RELATIONSHIPS AMONG FLIGHT TRAP, PITFALL PROBE TRAP, GRAIN TRIER AND DEEP CUP PROBE METHODS IN SAMPLING STORED WHEAT INSECTS

By

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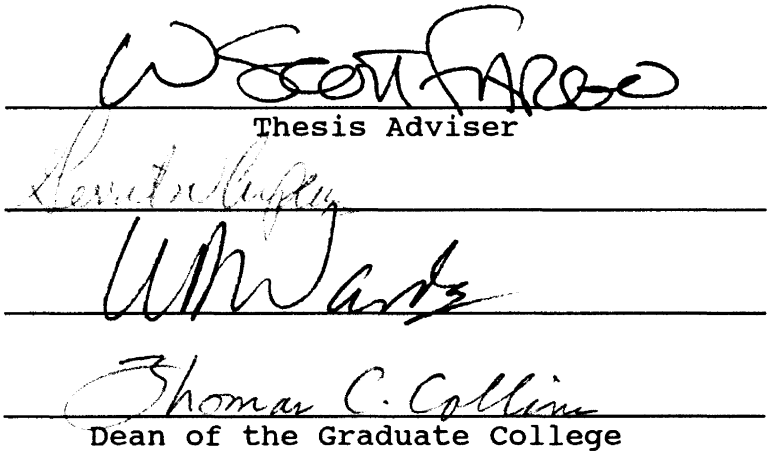

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PREFACE

This thesis contains a literature review on stored grain with special emphasis on sampling methods and factors which affect detection of stored grain insects. The subsequent chapters were prepared according to publication guidelines of the Entomological Society of America.

The realization and conclusion of this project have been possible thanks to the efforts of not one but many people. In particular, I wish to express my sincere and deep gratitude to my major advisor, Dr. W. Scott Fargo, for his support, guidance and patience throughout the course of this research and my studies. Sincere appreciation is also expressed to Dr. Gerrit W. Cuperus and Dr. William D. Warde, members of my advisory committee, for their advisement and assistance. To Dr. William A. Drew my gratitude for his confidence and encouragement to pursue this degree.

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CHAPTER I

LITERATURE REVIEW

Nationally, Oklahoma ranks third in wheat production (Cuperus et al. 1990b). Oklahoma is considered a high risk region for grain storage because of the long storage time and high ambient temperature to which the grain is exposed. High relative humidity also increases the risk of insect infestation (Noyes et al. 1991). In Oklahoma, insects are considered the major cause of grain spoilage followed by moisture and molds (Noyes et al. 1988, Noyes et al. 1991). Implementation of Integrated Pest Management (IPM) practices are important to reduce risk. Oklahoma producers and elevator operators use more protectants, fumigations and other stored grain practices than are reported in the northern areas (Cuperus et al. 1990b). Application of grain protectants in Oklahoma has had limited success due to pesticide breakdown caused by warm summer temperatures and insect pesticide resistance (Cuperus et al. 1986, Zettler & Cuperus 1990).

An axiom of pest management is that control actionsshould be directed only at pests when the benefits of these actions outweigh their costs (Nyrop et al. 1986). The

low cost of residual pesticides has increased the attractiveness of grain protectant treatments. In many cases treatments are applied "just in case" (Wilkin 1990). Blind application of pesticides represents an extra cost and time investment in stored grain management, increases the development of pesticide resistance, and increases public awareness of chemicals used on food. These factors support the development of better methods of monitoring stored grain insects. Accurate monitoring will help prescribe pesticide use only when they are needed.

Stored Grain Insect

Cotton & Ashley (1952) reported that in the hard red winter wheat region of the Great Plains, seven species of the order Coleoptera constitute more than 90 percent of the insect population in farmed stored wheat - These species were the flat grain beetle, *Cryptolestes pusillus* (Schönherr) (Cucujidae); lesser grain borer, *Rhyzopertha dominica* (F.) (Bostrichidae); red flour beetle, *Tribolium castaneum* (Herbst) (Tenebrionidae); longheaded flour beetle, *Latheticus oryzae* Waterhouse (Tenebrionidae), rice weevil, *Sitophilus oryzae* (L.) (Curculionidae), sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Cucujidae), and the cadelle, *Tenebrionides mauritanicus* (L.) (Trogositidae). These authors also stated that the Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) and the

almond moth, *Cadra cautella* (Walker) (Lepidoptera: Pyralidae) are not among the most abundant species, but they occasionally appear in great numbers where grain is stored.

In a study of insect populations in stored wheat in Oklahoma from 1982 to 1985, Cuperus et al. (1986) found that the lesser grain borer, rice weevil, *Cryptolestes* spp., *Tribolium* spp., Indianmeal moth and the sawtoothed grain beetle were the species most frequently found in the sampled bins. Also, in Oklahoma, grain samples taken from commercial or on-farm storage facilities during 1985 to 1988 revealed that the lesser grain borer is by far the most important pest, followed by *Cryptolestes* spp., *Tribolium* spp. and Indianmeal moth (Cuperus et al. 1990a).

Hagstrum & Flinn (1990) list five species of the order Coleoptera generally occurring in stored grain: sawtoothed grain beetle, lesser grain borer, rice weevil, red flour beetle, and rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Cucujidae). Mullen et al. (1991) cited the Indianmeal moth and the almond moth as serious pests of food in warehouses in the United States and throughout much of the world.

Sampling Methods

A primary objective of insect detection in stored grain is to monitor insect populations as they develop. Early detection allows the maximum opportunity for pest management

(Wilkin 1990, Hagstrum et al. 1991). Identification of damaging insect population levels is based upon the ability to detect and estimate the abundance and distribution of insect populations (Faustini et al. 1990). Although new methods such as acoustical monitoring (Vick et al. 1988, Webb et al. 1988, Hagstrum et al. 1990a) and infrared carbon dioxide analysis (Bruce 1988) have been studied for detecting and monitoring insect pests, the feasibility of these methods under actual storage conditions is still unknown. Because density estimates are needed that relate to marketing procedures, conventional grain sampling is the standard to monitor insect populations and plays a critical role in any stored-product management program (Cuperus et al. 1990a).

Throughout the marketing system, sampling insects has often been limited to counting the number of adult insects in the grain samples that are taken for the purpose of grain grading. Grading involves removing one kilogram samples of grain to determine test weight, levels of fines, broken kernel and foreign material in a lot of grain (Hagstrum et al. 1991).

The standard sampling technique for insects uses a hollow grain trier inserted into the grain mass, opened, then closed, and withdrawn from the grain. The sample is then sieved, and the insects passing through are counted. The use of grain triers to detect insect populations in

grain has been criticized for several reasons. Hagstrum et al. (1991) confirmed that grading factors are more evenly distributed in the grain mass than insects, and thus samples taken with grain triers cannot provide a representative sample of insect populations. Anderson et al. (1990) suggested that taking a representative sample with the purpose of grading grain is difficult since insect-damaged kernels (IDK) and foreign material are lighter than non-damaged kernels and segregate to the top of the grain surface when grain is transferred or moved. Another disadvantage of grain triers is that they are inserted and withdrawn immediately from the grain thus reducing the probability of insect detection, particularly when insect densities are low (Loschiavo & Atkinson 1967, 1973; White & Loschiavo 1986).

The cup probe was also specifically designed to sample grain, especially samples from deep within the grain mass. The problems associated with the use of cup probes for insect detection are similar to those for grain triers. In addition, cup probes sample less grain than grain triers.

The vacuum probe is a sampling device developed to take larger samples from deep within the grain mass (Hagstrum et al. 1991). The vacuum probe or pneumatic grain sampler pulls air carrying the grain up through an inner tube and replacement air passes down between this tube and an outer tube. The air with grain passes into a cyclone collector

which allows the grain to fall out. Insects present in grain samples are separated with hand sieve or an inclined sieve (Hagstrum 1989, Hagstrum et al. 1991).

Traps of several types are valuable because they detect insect problems early and increase the manager awareness (Wright & Hagstrum 1990). Traps have been developed for aerial insects, crawling stages of Coleoptera, and for insertion into bulk grain for a complex of grain-infesting Coleoptera (Barak et al. 1990).

Several sticky traps have been used for flying stored-product insects. In these traps, insects are entrapped by contact adhesives (Barak et al. 1990). Much of the recent entomological literature on sticky traps deals with pheromone baits used for attraction (Vick et al. 1990). Although the benefits of using pheromone lures and/or food attractants is well known (Leos-Martínez et al. 1986, Faustini et al. 1990, Pinniger 1990, Mullen et al. 1991), there is still concern regarding the interpretation of trap catches and defining the level at which action should be taken to correct a pest insect problem (Chambers 1990, Muller et al. 1990).

Probe traps, which are specifically designed for use within bulk grain, are perforated metal or plastic probes designed to be inserted into the grain mass. Insects crawl through the holes and fall into a removable cap or collection tube (Barak et al. 1990). Probe trap efficiency

is improved because they can be left in the grain for longer periods of time (Loschiavo & Atkinson 1967, 1973; Loschiavo 1975, Loschiavo & Smith 1986, Fargo et al. 1989, Cuperus et al. 1990a). For this reason, probe traps are important, versatile, and sensitive tools for detecting adult insects from very low to high densities (Loschiavo 1974, 1975; Barak & Harein 1982, Lippert & Hagstrum 1987, White et al. 1990). Also, because grain is not removed, disturbance of the grain mass is minimized and therefore probe traps may be better suited for studying the ecology of stored-product insects (Loschiavo & Atkinson 1967).

Loschiavo (1975) tested grain triers, probe traps and scoops for insect detection in different kinds of grain storages in Canada. He concluded probe traps were generally more efficient than grain triers for detecting insects.

Lippert & Hagstrum (1987) compared grain triers and probe traps as sampling devices in bulk-stored wheat. They found that for the four most common species (*R. dominica*, *T. castaneum*, *C. ferrugineus*, and *O. surinamensis*), probe traps were 1.7 to 2.6 times more likely to detect an infestation than grain triers.

Reed et al. (1991) compared numbers of insects in pitfall probe traps and grain samples taken with a vacuum probe in farm-stored wheat in Kansas. They found that each method was a more efficient detector of infestations than the other during certain seasons and for certain insects.

The center of the grain mass contained a greater percentage of the total number of insects in grain samples from September to January and a greater percentage of the trapped insects from July to March than other positions. Insect populations were greatest from September to November, with 25 insects captured in traps for each insect in grain samples.

Factors Affecting the Number of Insects Caught

All insect traps depend on insect movement, and any factor that influences insect movement will also influence trap capture (Cuperus et al. 1990a). Physical gradients are a common feature of stored grain and insect populations are rarely uniformly dispersed in the grain (Surtees 1965).

Grain triers remove an instantaneous sample of grain and insects. The number of insects in the sample depends on the grain condition at the time of sampling and also on insect behavior as it relates to grain condition and location of the sample (White et al. 1990). The probability of insect detection with grain triers increases with increasing insect density and number of samples taken (Cuperus et al. 1990a).

Insect behavior, trap design, pest density, type of pheromone, concentration of the pheromone per trap, and environmental conditions inside closed structures affecting pheromone dispersal are factors which influence the capture

of insects by pheromone baited sticky traps (Vick et al. 1990, Mullen et al. 1991).

Unbaited sticky traps capture flying insects randomly because flight is not directed by pheromone lures. Factors affecting insect capture with unbaited traps might be similar to those for baited traps with the exception of factors related to the use of pheromones. The location of the population to be sampled might be important since the confined and relatively small space of warehouses and bins is more likely to have a homogeneous density of insects in flight than a large open area (Leos-Martínez et al. 1986). Also, environmental factors such as wind and light are different inside and outside of storage structures, and may modify flight behavior. The behavior of the species to be captured is also important. The number of traps used needs to be considered since the number of traps needed for detection varies according to insect density (Hagstrum et al. 1991).

Five of the most important variables affecting probe trap catch are insect species, trapping duration, grain temperature, grain type and condition, and trap placement (Cuperus et al. 1990a). These variables, with the exception of trapping duration, can be applied to other grain sampling methods such as grain triers, vacuum probes, scoops, cup probes, and pelican samplers.

Population Development

Studies by McGregor (1964) showed that *T. castaneum* exhibits a high preference for grain with high dockage content. He recovered an average of 3.3 adults from clean wheat, as compared with 98.2 in wheat containing 13.5% dockage. Tuff & Teleford (1964) observed that *C. ferrugineus* was able to infest fractured wheat in the absence of a primary insect invader. However, this insect preferred wheat germ over fractured wheat when available.

Surtees (1965) observed that the factors influencing accumulation of five beetle species varied according to species behavior and grain condition. He noted that the accumulation of *O. surinamensis* took place in the warmest and dampest parts of the grain bulk. *T. castaneum* accumulated in the drier parts of a bulk and at places where the temperature was about 25°C. However, *T. castaneum* also accumulated in damp regions if the grain was mouldy. *C. ferrugineus* accumulation was influenced by feeding and oviposition behavior, with adult accumulation occurring in damp grain within drier bulks. The accumulation of *R. dominica* and *S. granarius* occurred in the driest part of the grain bulk and at the periphery of the grain bulk, respectively.

Watters (1969) observed that the locomotor activity of *C. ferrugineus* was influenced by moisture content (m.c.) of the grain, temperature and grain condition. More insects

emigrated from drier grain (9.8% m.c.) and lower temperatures (15°C) than from damper grain (17.8% m.c.) and higher temperatures (28°C). In general, this species exhibited a positive geotactic response (moving downward) in sound wheat but this behavior was changed (accumulation occurred) when exposed to damp and cracked wheat. Loschiavo (1983) also observed that the movement of *C. ferrugineus* was influenced by grain conditions. In grain of uniform dry conditions, he found that this species exhibited the positive geotactic response, accumulating at the bottom. However, in grain with moist regions, this species aggregated quickly in the moist pockets.

In a study of insects infesting barley in Minnesota, Subramanyam & Harein (1989) found that probe traps were less likely to capture adults of insect species that are less mobile in grain, form aggregation pheromones such as *R. dominica* or feed internally on kernels (i.e., *R. dominica* and *Sitophilus* spp.). Fargo et al. (1993), found that significantly more *C. ferrugineus* were captured in two types of pitfall probe traps than *T. castaneum*, *R. dominica*, and *S. oryzae*.

Barak & Harein (1981) found that grain condition greatly influences the number of insects in grain samples. The moisture content of samples containing more than 15 insects per sample was higher than that of other categories of insect numbers. Also, the lowest test weight and highest

percentage of broken corn and foreign materials occurred in the most infested samples. Storey et al. (1983) observed that the range of moisture contents and the average moisture contents were consistently higher in grain containing insects than in uninfested grain. In wheat samples, the percent incidence of insects increased progressively through each higher moisture content range with incidence in samples above 13% m.c. more than four times higher than in samples at 10% m.c. Loschiavo & Smith (1986) reported that the trap location with the highest moisture content in a steel granary resulted in consistently larger numbers of *C. ferrugineus* (60% of the total from all traps) recovered from this trap.

The effect of temperature on trap catch has been studied by several authors. Loschiavo & Smith (1986) reported that during the first five weeks of sampling, in which the temperature of the grain decreased from 31.5° to 18°C, about 6000 rusty grain beetles were recovered from all traps. Approximately 1100 beetles were collected in a period when the temperature of the grain decreased from 17° to 4°C. White & Loschiavo (1986) observed that more insects ($P < 0.05$) (*T. castaneum* and *C. ferrugineus*) were caught with germ baited traps at higher temperatures (15.5 to 30°C) than unbaited traps. Loschiavo et al. (1986) also found that the largest catches of beetles occurred in bins with the highest temperatures. In four bins with recorded grain temperatures

ranging from 28.5 to 32°C, nearly 17,300 rusty grain beetles were found in all traps in contrast with about 1,800 from three bins at 21.5 to 24°C. Hagstrum (1987) reported the effects of temperature gradients in two bins in Kansas on the spatial distribution of some species in the grain mass. As the wheat cooled from the outside and upper surfaces inward and downward, the percentage of *C. ferrugineus* in the lower center tended to increase as the percentage elsewhere tended to decrease. Two species of *Trogoderma* were found mainly near the bin wall and *R. dominica* was detected only in the center. Fargo et al. (1989) found that the overall effect of temperature on four stored grain insects (*S. oryzae*, *R. dominica*, *C. ferrugineus*, and *T. castaneum*) was that more insects were trapped at higher temperatures. When the effect of different temperatures (10, 21.1, and 32.2°C) on the number of insects caught within a species was analyzed, significance ($P < 0.05$) was found only in the number of *C. ferrugineus* trapped. The other species showed a similar trend although no significant differences were found. Within each temperature, *C. ferrugineus* was consistently trapped in the greatest numbers and *R. dominica* the fewest. No significant differences were found between the capture of *S. oryzae*, *T. castaneum* and *R. dominica*.

The importance of insect density, trap location and duration of trapping in the capture of *C. ferrugineus* was demonstrated by Loschiavo (1974) in a study under controlled

conditions. With regard to insect density, the mean number of insects found in traps placed for 24 h in wheat-filled jars containing 50, 150, or 200 insects were 0.3, 2.7, and 3.0, respectively, when insects had been introduced at the top of the containers; 0.7, 0.7, and 3.7, respectively, when introduced at the bottom; and 0.3, 1.0, and 2.0, respectively when insects were mixed through the grain. The insects caught increased linearly with the length of time the traps remained in the grain. A higher mean number of insects (71.8 versus 58.5) was recovered when 2-day examinations were delayed until 1 week after insects had been placed in the grain. Also, with regard to trap placement, he found more insects ($t > 2.5$) in the lowest one fifth layer of grain than in any other level in the containers. Loschiavo (1983) affirmed that because of the geotactic behavior of *C. ferrugineus* in wheat of uniform moisture, the placement of traps near the bottom will increase the probability of detecting this species. During the fall or winter when temperature differentials cause moisture migration and warmer temperatures in the central core, insects of this species are more likely to be detected in this area. Hagstrum et al. (1985) studied insect distribution in bulk-stored wheat using .5 kg grain trier samples in four bins. In addition to the variation existent between bins, he found that within a bin, the variation between samples at a site was generally the largest,

followed by variation between regions and then between areas within a region. Fargo et al. (1989) examined the importance of trapping duration in the capture of four stored grain insects (*T. castaneum*, *C. ferrugineus*, *S. oryzae*, and *R. dominica*) at 23°C under laboratory conditions. More insects were captured in the two longest periods tested (7 and 4 d) than in the shorter periods (1 and 2 d). Across durations, *C. ferrugineus* was captured in the largest quantity, and *R. dominica* the least. The other two species were trapped in intermediate numbers. Within species, the number of insects caught increased with longer durations. *C. ferrugineus* were caught in higher numbers at 7 and 4 d, and more *S. oryzae* were caught at 7 d.

Origin of Insect Infestations in Stored Grain

An understanding of the manner in which insects initially infest grain, disperse within the grain mass, and increase in number is important to sound insect pest management (Hagstrum 1989). Data collected by Wright et al. (1988) suggest that insects infest grain after binning. They found that before wheat harvest, wing traps showed a moderate to high infestation at various locations on farms. Within a month after harvest (July), pitfall traps indicated large numbers of insects in new grain. By September, insects trapped around farms had decreased and populations in bins had increased. Hagstrum (1989) following the vertical

distribution pattern of *C. ferrugineus* in four bins of newly harvested wheat on three Kansas farms during the first two months of storage, concluded that the population increased earlier in the top layer than in the middle layers. The logarithmic decrease in insect numbers corresponding with distance from the top grain surface suggests that the top layer was infested first and that grain infestation occurs after grain is stored.

Interpretation of Trap Catch

Trap efficiency must be determined to convert trap catches into absolute densities so that control measures can be based on economic thresholds (Wright & Hagstrum 1990). Hagstrum et al. (1990b) defined trap efficiency as the portion of total population per unit volume that is captured during a sampling period. Insect density is obtained by dividing trap catch by trap efficiency. However, the number of traps used and the environmental factors affecting trap catch must be considered so that more accurate absolute densities can be estimated from trap catches (Fargo et al. 1989, Cuperus et al. 1990a, White et al. 1990, Hagstrum et al. 1990b, Subramanyam & Harein 1990). Several efforts have been made to determine the sample size needed to improve insect detection with probe traps and accuracy of population density estimates with these devices (Lippert & Hagstrum 1987, Hagstrum et al. 1988, Subramanyam & Harein 1990).

The use of simulation models to predict the rate of insect infestations and the impact of different management practices on several insect species, and different environmental conditions (Hagstrum & Milliken 1988, Hagstrum & Throne 1989, Hagstrum & Flinn 1990, Flinn & Hagstrum 1990) has opened a broad spectrum of possibilities for improving the timing of management decisions. In the future, these models might reduce the effort and cost needed for sampling. Estimates of population densities obtained from trap catches in trapping programs are used in these prediction models. A better understanding of trap efficiency as a function of environmental factors affecting trap catch is necessary to improve the accuracy of predictions and the definition of action/economic thresholds.

References Cited

Anderson, K. B., R. T. Noyes & G. W. Cuperus. 1990. Insect-damaged kernels - Wheat. OSU Extension Facts No. 510. Cooperative Extension Service, Oklahoma State University, Stillwater.

Barak, A. V. & P. K. Harein. 1981. Insect infestation on farm stored shelled corn and wheat in Minnesota. J. Econ. Entomol. 74: 197-202.

Barak, A. V. & P. K. Harein. 1982. Trap detection of stored-grain insects in farm-stored, shelled corn. J. Econ. Entomol. 75: 108-111.

Barak, A. V., W. E. Burkholder & D. L. Faustini. 1990. Factors affecting the design of traps for stored-product insects. J. Kansas Entomol. Soc. 63: 466-485.

Bruce, W. A. 1988. Detection of hidden insect infestations by infrared dioxide gas analysis. *In* Proceedings, 17th Intl. Congress of Entomology. Vancouver, Canada.

Chambers, J. 1990. Overview on stored-product insect pheromones and food attractants. J. Kansas Entomol. Soc. 63: 490-499.

Cotton, R. T. & W. Ashley. 1952. Insect pests of stored grains and seed, p. 629. *In* Insects. The year of Agriculture. United States Department of Agriculture.

Cuperus, G. W., C. K. Prickett, P. D. Bloome & J. T. Pitts. 1986. Insect populations in aerated and unaerated stored wheat in Oklahoma. J. Kansas Entomol. Soc. 59: 620-627.

Cuperus, G. W., W. S. Fargo, P. W. Flinn & D. W. Hagstrum. 1990a. Variables affecting capture of stored-grain insects in probe traps. J. Kansas Entomol. Soc. 63: 486-489.

Cuperus, G. W., R. T. Noyes, W. S. Fargo, B. L. Clary, D. C. Arnold & K. Anderson. 1990b. Management practices in a high-risk stored-wheat system in Oklahoma. Amer. Entomol. 36: 129-134.

Fargo, W. S., D. Epperly, G. W. Cuperus, B. C. Clary & R. Noyes. 1989. Effect of temperature and duration of trapping on four stored grain insect species. J. Econ. Entomol. 82: 970-973.

Fargo, W. S., G. W. Cuperus, E. L. Bonjour, W. E. Burkholder & B. C. Clary. 1993. Influence of probe trap type and attractants on the trap capture of four stored grain insect species. J. stored Prod. Res. 29:(in press).

Faustini, D. L., A. V. Barak, W. E. Burkholder & J. Leos-Martínez. 1990. Combination-type trapping for monitoring stored-product insects - a review. J. Kansas Entomol. Soc. 63: 539-547.

Flinn, P. W. & D. W. Hagstrum. 1990. Simulations comparing the effectiveness of various stored-grain management practices used to control *Rhyzopertha dominica* (Coleoptera: Bostrichidae). Environ. Entomol. 19: 725-729.

Hagstrum, D. W. 1987. Seasonal variation of stored wheat environment and insect populations. Environ. Entomol. 16: 77-83.

Hagstrum, D. W. 1989. Infestation by *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) of newly harvested wheat stored on three Kansas farms. J. Econ. Entomol. 82: 655-659.

Hagstrum, D. W. & P. W. Flinn. 1990. Simulations comparing insect species differences in response to wheat storage conditions and management practices. J. Econ. Entomol. 83: 2469-2475.

Hagstrum, D. W. & G. A. Milliken. 1988. Quantitative analysis of temperature, moisture content, and diet factors affecting insect development. Ann. Entomol. Soc. Am. 81: 539-546.

Hagstrum, D. W. & J. E. Throne. 1989. Predictability of stored-wheat insect population trends from life history traits. Environ. Entomol. 18: 660-664.

Hagstrum, D. W., G. A. Milliken & M. S. Waddell. 1985. Insect distribution in bulk-stored wheat in relation to detection or estimation of abundance. Environ. Entomol. 14: 655-661.

Hagstrum, D. W., R. L. Meagher & L. B. Smith. 1988. Sampling statistics and detection or estimation of diverse populations of stored-product insects. Environ. Entomol. 17: 377-380.

Hagstrum, D. W., K. W. Vick & J. C. Webb. 1990a. Acoustical monitoring of *Rhyzopertha dominica* (Coleoptera: Bostrichidae) populations in stored wheat. J. Econ. Entomol. 83: 625-628.

Hagstrum, D. W., P. W. Flinn, Bh. Subramanyam, D. W. Keever & G. W. Cuperus. 1990b. Interpretation of trap catch for detection and estimation of stored-product insect populations. J. Kansas Entomol. Soc. 63: 500-505.

Hagstrum, D. W., W. S. Fargo & P. K. Flinn. 1991. How to sample grain, pp. 65-69. *In* Management of grain, bulk commodities, and bagged products. Okla. State Univ. Coop. Ext. Serv. Circ. No. E-912.

Leos-Martínez, J., T. A. Granovsky, H. J. Williams, S. B. Vinson & W. E. Burkholder. 1986. Estimation of aerial density of the lesser grain borer (Coleoptera: Bostrichidae) in a warehouse using dominicalure traps. J. Econ. Entomol. 79: 1134-1138.

Lippert, G. E. & D. W. Hagstrum. 1987. Detection or estimation of insect populations in bulk-stored wheat with probe traps. J. Econ. Entomol. 80: 601-604.

Loschiavo, S. R. 1974. Laboratory studies of a device to detect insects in grain, and of the distribution of adults of the rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), in wheat-filled containers. Can. Entomol. 106: 1309-1318.

Loschiavo, S. R. 1975. Field tests of devices to detect insects in different kinds of grain storages. Can. Entomol. 107: 385-389.

Loschiavo, S. R. 1983. Distribution of the rusty grain beetle (Coleoptera: Cucujidae) in columns of wheat stored dry or with localized high moisture content. J. Econ. Entomol. 76: 881-884.

Loschiavo, S. R. & J. M. Atkinson. 1967. A trap for the detection and recovery of insects in stored grain. Can. Entomol. 99: 1160-1163.

Loschiavo, S. R. & J. M. Atkinson. 1973. An improved trap to detect beetles (Coleoptera) in stored grain. Can. Entomol. 105: 437-440.

Loschiavo, S. R. & L. B. Smith. 1986. Population fluctuations of the rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), monitored with insect traps in wheat stored in a steel granary. Can. Entomol. 118: 641-647.

McGregor, H. E. 1964. Preference of *Tribolium castaneum* for wheat containing various percentages of dockage. J. Econ. Entomol. 57: 511-513.

Mullen, M. A., H. A. Highland & F. H. Arthur. 1991. Efficiency and longevity of two commercial sex pheromone lures for Indianmeal moth and almond moth (Lepidoptera: Pyralidae). J. Entomol. Sci. 26: 64-68.

Muller, D., L. Pierce, H. Benezet & V. Krischik. 1990. Practical application of pheromone traps in food and tobacco industry. J. Kansas Entomol. Soc. 63: 548-553.

Noyes, R. T., B. L. Clary & G. W. Cuperus. 1988. Maintaining quality of stored grain by aeration. OSU Extension Facts No. 1100. Cooperative Extension Service, Oklahoma State University.

Noyes, R. T., R. Weinzierl & G. W. Cuperus. 1991. Stored grain management techniques, pp. 71-79. *In* Management of grain, bulk commodities and bagged products. Okla. State Univ. Coop. Ext. Serv. Circ. No. E-912.

Nyrop, J. P., R. E. Foster & D. W. Onstad. 1986. Value of sample information in pest control decision making. J. Econ. Entomol. 79: 1421-1429.

Pinniger, D. B. 1990. Food-baited traps; past, present and future. J. Kansas Entomol. Soc. 63: 533-538.

Reed, C. R., V. F. Wright, T. W. Mize, J. R. Pedersen & J. Brockschmidt Evans. 1991. Pitfall traps and grain samples as indicators of insects in farm-stored wheat. J. Econ. Entomol. 84: 1381-1387.

Storey, C. L., D. B. Sauer & D. Walker. 1983. Insect populations in wheat, corn, and oats stored on the farm. J. Econ. Entomol. 76: 1323-1330.

Subramanyam, Bh. & P. K. Harein. 1989. Insects infesting barley stored on farms in Minnesota. J. Econ. Entomol. 18: 1817-1824.

Subramanyam, Bh. & P. K. Harein. 1990. Accuracies and sample sizes associated with estimating densities of adult beetles (Coleoptera) caught in probe traps in stored barley. J. Econ. Entomol. 83: 1102-1109.

Surtees, G. 1965. Ecological significance and practical implications of behaviour patterns determining the spatial structure of insect populations in stored grain. Bull. Entomol. Res. 56: 201-213.

Tuff, D. W. & H. S. Teleford. 1964. Wheat fracturing as affecting infestation by *Cryptolestes ferrugineus*. J. Econ. Entomol. 57: 513-517.

Vick, K. W., J. C. Webb, B. A. Weaver & C. Litzkow. 1988. Sound detection of stored product insects that feed inside kernels of grain. J. Econ. Entomol. 81: 1489-1493.

Vick, K. W., R. W. Mankin, R. R. Cogburn, M. Mullen, J. E. Throne, V. F. Wright & L. D. Cline. 1990. Review of pheromone-baited sticky traps for detection of stored product insects. J. Kansas Entomol. Soc. 63: 526-532.

Watters, F. L. 1969. The locomotor activity of *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) in wheat. Can. J. Zool. 47: 1177-1182.

Webb, J. C., D. C. Slaughter & C. A. Litzkow. 1988. A computerized acoustical detection system for monitoring larvae in grain and other post-harvest commodities. *In* Proceedings, 17th Intl. Congress of Entomology. Vancouver, Canada.

White, N.D.G. & S. R. Loschiavo. 1986. Effects of insect density, trap depth, and attractants on the capture of *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) in stored wheat. J. Econ. Entomol. 79: 1111-1117.

White, N.D.G., R. T. Arbogast, P. G. Fields, R. C. Hillmann, S. R. Loschiavo, Bh. Subramanyam, J. E. Throne & V. F. Wright. 1990. The development and use of pitfall and probe traps for capturing insects in stored grain. J. Kansas Entomol. Soc. 63: 506-525.

Wilkin, D. R. 1990. Detection of insects in bulk grain. J. Kansas Entomol. Soc. 63: 554-558.

Wright, F. W. & D. W. Hagstrum. 1990. Trapping technology for monitoring stored-product insects. J. Kansas Entomol. Soc. 63: 464-465.

Wright, V. F., T. W. Maize & J. R. Pedersen. 1988. Using traps to monitor stored grain insects on the farm. *In* Proceedings, 17th Intl. Congress of Entomology. Vancouver, Canada.

Zettler, J. L. & G. W. Cuperus. 1990. Pesticide resistance in *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Rhyzopertha dominica* (Coleoptera: Bostrichidae) in wheat. J. Econ. Entomol. 83: 1677-1681.

CHAPTER II

IMMIGRATION AND POPULATION DYNAMICS OF GRAIN INHABITING INSECTS

Abstract

Relationships among insects trapped by unbaited flight and pitfall probe traps, and grain trier and cup probe samples were studied in 1991 in three farm bins in North Central Oklahoma. The most abundant species sampled were *Cryptolestes* spp., *Tribolium* spp., *Rhyzopertha dominica* (F.), *Ahasverus advena* (Waltl) and *Thyphaea stercorea* (L.). Placement of flight traps at the eaves of the bin resulted in higher insect catches than at other positions. In the grain mass, insects were more likely to be found in the central core, mainly during the first weeks of storage. However, no differences were found among temperatures, moisture contents or level of fines at the different regions sampled to explain why insects favor the center of the grain mass. More insects were found at depths of 30.5 and 61.0 cm than on the surface or 91.4 cm. The increase in numbers of insects with depth and time of storage and the pattern of capture of grain insects by flight traps suggested that infestation occurred after grain binning. Correlation coefficients suggested higher levels of infestation with increased temperature and moisture content.

Introduction

Because of high temperatures, high relative humidities and early harvest dates, the Southern High Plains are considered a high risk management area for stored wheat. In Oklahoma, insects are considered the major cause of grain spoilage followed by moisture and molds (Noyes et al. 1988, Noyes et al. 1991). The lesser grain borer, *Rhyzopertha dominica*, is by far the most important pest, followed by *Cryptolestes* spp., *Tribolium* spp., and the Indianmeal moth, *Plodia interpunctella* (Cuperus et al. 1990b).

The primary objective of insect detection in stored grain is to locate insects at an early stage of infestation which allows the maximum opportunity for pest management (Wilkin 1990, Hagstrum et al. 1991). Traps detect insect problems early and can increase managers' awareness (Wright & Hagstrum 1990).

Several sticky traps have been used for stored-product insects that fly. In these traps, insects are entrapped by contact adhesives (Barak et al. 1990). Probe traps, which are specifically designed for use within the bulk grain, are perforated metal or plastic probes inserted into the grain mass. Insects crawl through the holes and fall into a removable cap or collection tube (Barak et al. 1990).

Insect detection using probe traps is improved because they can be left in the grain for long periods of time (Loschiavo & Atkinson 1967, Loschiavo & Atkinson 1973, Loschiavo 1975, Loschiavo & Smith 1986, Fargo et al. 1989, Cuperus et al. 1990a). Grain triers and deep cup probes are specifically designed to sample grain. Since they are inserted and immediately withdrawn from the grain the probability of insect detection is low, especially in lightly infested grain (Loschiavo & Atkinson 1973).

All insect traps depend on insect movement, and any factor that influences insect movement will also influence trap capture (Cuperus et al. 1990a). Unbaited sticky traps capture randomly flying insects by interception. Environmental factors such as light, wind direction, wind speed, the site of the population to be sampled, trap placement and insect behavior affect flight trap catches. Five of the most important variables affecting probe trap catch are insect species, trapping duration, grain temperature, grain type and condition, and trap placement (Cuperus et al. 1990a). The number of insects in grain samples depends on the grain condition at the time of sampling and location of the sample (White et al. 1990).

Temperature and moisture gradients are a common feature of stored grain and insect populations are rarely uniformly dispersed in the grain (Surtees 1965). A better understanding of the way stored grain becomes infested and

determining the source of infestation would allow managers to take preventive measures to reduce the probability of insect infestation after binning. Also, a better understanding of insect distribution in the grain mass would improve sampling strategies to allow early detection of stored pests.

In this study the relationships between the number of insects captured in unbaited flight traps, pitfall probe traps, grain trier and cup probe samples were examined with the following objectives: to determine the effectiveness of flight traps in a management program, to determine the optimum location of flight traps with regard to insect activity, to determine the progressive insect infestation in the upper grain region, and to determine the distribution of stored grain insects in the grain mass.

Materials and Methods

Three steel farm bins located in North Central Oklahoma, with capacities of 141.52 metric tons (5,200 bu), 68.04 metric tons (2,500 bu)[1], and 136.08 metric tons (4,500 bu) and filled with hard red winter wheat (*Triticum aestivum* L.) were used for this study. Before grain binning (May 17), the bins were cleaned according to standard integrated pest management (IPM) procedures including the removal of grain residue and fumigation of empty bins with chloropicrin.

Before wheat harvest (May 24), 16 unbaited flight traps (Pherocon II traps; Trécé Inc., Salinas, CA) were fastened

to ropes on the outside of the grain bins in the four cardinal directions (N, S, E, and W). The traps were placed at four heights in each direction: ground level, one-third height, two-thirds height, and at the outside eaves. The ropes passed through small pulleys at the eaves so that traps could be lowered for inspection. After wheat binning (June 17, July 1, and July 8 on the three farms), four additional traps were placed at the inside eaves in the bins in cardinal directions.

Plastic pitfall traps (WB Probe II traps; Trécé Inc., Salinas, CA) were placed in the bins (July 8, July 1, and July 8) in nine locations in the grain mass. Two probe traps were placed per cardinal direction at ≈ 30.5 cm from the bin wall and at one-half the bin radius. Additionally, one probe trap was placed in the center of each bin.

Standard samples were taken using a 1.6 m brass non-partitioned grain trier (650 g capacity; Seedburo Equipment Co., Chicago, IL) at the nine probe trap locations (starting on July 16, July 8, and July 16). Also, cup probe samples (38.1 cm deep bin cup (265 g capacity; Seedburo Equipment Co., Chicago, IL) were drawn from the grain mass at the same locations and at four depths: 91.4, 61.0, 30.5, and 0 cm from the surface, resulting in 36 samples. Samples at 61.0, 30.5, and 0 cm corresponded to the depth of the probe traps.

Monitoring of both trapping methods and collection of grain trier and cup probe samples were carried out weekly.

Flight traps were replaced and taken to the laboratory for processing. Samples taken with the grain trier and cup probe, as well as insects collected from pitfall probe traps were placed in plastic bags, labelled, and taken to the laboratory for processing. Insects found in flight traps and probe traps were identified and counted. Only insects which were related to grain were included in the count.

An inclined sieve similar to that described by Hagstrum et al. (1985) was used to separate insects from grain in trier and cup probe samples. Insects were then identified and counted. Weight and moisture content of the grain were determined using an electronic balance (Ohaus Lume-O-Gram balance; Ohaus Scale Corp., Florham Park, NJ) and an hygrometer (Agromatic WK II; ASIDIC Ltd., Clear Lake, IA).

When the insect count in trier samples averaged two primary insects[2] ($\approx$ 2 insects per 500 g), which is the generally accepted treatment threshold, one of the bins was fumigated (August 31). The other two bins were sampled until September 27. At the end of the sampling period, additional grain trier samples were taken for determining the level of fines in the different regions of the bins.

Thermocouples were used to determine grain temperature at the time of sample collection. Temperatures were recorded at the center of the bin and at one-half the bin radius in cardinal directions at the depths corresponding to the cup probe samples.

Differences among species collected by the different sampling methods and among trap and sampling locations were determined by Fisher's least significant difference (LSD) multiple comparison technique with $\alpha = 0.05$ using SAS General Linear Models (GLM) (SAS Institute 1988). A log transformation was used on insect counts ($\log_{10}(No+1)$) (Little & Hills 1978). GLM with LSD multiple range tests were also used to determine if the mean temperature and mean moisture content differed among the different locations sampled in the grain mass. The mean percentage of fines in the different regions sampled were compared using an arcsine square root transformation (Little & Hills 1978).

Sets of independent contrasts (SAS Institute 1988) were computed to compare mean number of insects in the center and cardinal directions in the grain mass. Two-sample t tests were used to determine differences between the mean number of insects captured by flight traps inside and outside of bins on the different sampling dates. Two-sample t tests were also used to determine differences between the mean number of insects detected in the center and cardinal directions sampled, and to compare the number of insects detected at different depths throughout the sampling period.

Pearson product-moment correlations were computed to determine the degree of linear relationship between temperature and moisture content and the number of insects detected in the grain mass.

Tables of analysis of variance for the different sampling methods, temperature, moisture content and level of fines are presented in appendix A.

Results

Occurrence of Insect Species. Except for the Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), all other insects detected were beetles (Coleoptera). The most commonly occurring species in the four sampling methods were *Cryptolestes* spp. (Cucujidae) (rusty grain beetle, *C. ferrugineus* (Stephens) and flat grain beetle, *C. pusillus* (Schönherr)); foreign grain beetle, *Ahasverus advena* (Waltl) (Cucujidae); *Tribolium* spp. (Tenebrionidae) (red flour beetle, *T. castaneum* (Herbst) and confused flour beetle, *T. confusum* Jacquelin du Val); hairy fungus beetle, *Thyphaea stercorea* (L.) (Mycetophagidae); lesser grain borer, *Rhyzopertha dominica* (F.) (Bostrichidae); and *Corticaria* spp. (Lathridiidae). Other species found in fewer numbers were the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Cucujidae); rice weevil, *Sitophilus oryzae* (L.) (Curculionidae); larger black flour beetle, *Cynaeus angustus* (Le Conte) (Dermestidae); and other insects of the families Dermestidae and Anthicidae that were not identified. Mites were also detected, however, no effort was made to distinguish flour or grain mites from predatory mites, and therefore, they were not quantified. In addition, parasitic wasps (Hymenoptera) were detected. These

wasps were recorded as an order in the counts and were not identified.

Flight Traps. Flight traps began collecting insects before wheat harvest. As soon as the harvest of wheat started (June 17) the average number of insects captured by flight traps increased (Fig. 1). Flight traps detected all species mentioned above (Fig. 2). Differences were detected in the average number of the six most abundant species (F = 181.47; df = 5, 4752; P = 0.0001). The hairy fungus beetle was detected in the highest numbers followed by *Cryptolestes* spp., and the foreign grain beetle. The Indianmeal moth, lesser grain borer and *Tribolium* spp. were captured in lesser numbers (Table 1).

The pattern of capture by flight traps of the six most abundant species throughout the sampling period varied. The lesser grain borer was the only species detected during the first two weeks of sampling (Fig. 3 E). The hairy fungus beetle, *Cryptolestes* spp., foreign grain beetle and Indianmeal moth were first detected by outside flight traps during the third week of sampling which coincided with wheat harvest and binning (Fig. 3 A, B, C, and D). Hairy fungus beetles, foreign grain beetles, and lesser grain borers were captured in a cyclic pattern with hairy fungus beetles being most abundant during the first seven weeks of sampling (Fig. 3 A), foreign grain beetles during the mid-portion of the sampling period (Fig. 3 C), and lesser grain borers at the

end of the sampling period (Fig. 3 E). *Cryptolestes* spp. started to increase in number after the fifth week of sampling, with a steady increase until September 6 and declined thereafter (Fig. 3 B). Indianmeal moths were captured in high numbers at grain binning (Fig. 3 D). Their numbers decreased during the following weeks, and increased again by late July and early August . *Tribolium* spp. were first detected in flight traps in mid-July (July 16), and became more abundant towards the end of the sampling period (Fig. 3 F).

Flight traps placed on the north and west sides of the bins trapped more insects (F = 32.93; df = 3, 4752; P = 0.0001) than those placed on the east and south sides (Fig. 4). During the first and second weeks of sampling, insects were captured only by flight traps on the south and west sides of the bins, respectively (Fig. 5). By June 17 when wheat started to be harvested and placed in the bins, there was an increase in the number of insects captured from all four cardinal directions. Traps placed in the north side consistently detected more insects throughout the sampling period. Paired t tests revealed differences between the number of insects captured on the north side and the other directions for the majority of the sampling dates (Table 2). The ratio of the average number of insects detected in the east and west was different only on July 16, July 30 and September 6. Traps on the south side generally captured

fewer insects; however, the south/west and south/east ratios did not differ on most of the sampling dates.

The number of insects captured by flight traps at different positions varied (F = 24.50; df = 4, 4752; P = 0.0001). More insects were captured by flight traps at the eaves than in the other positions (Fig. 6). Before grain binning, stored grain insects were detected only in traps placed at the outside eaves (Fig. 7). At grain binning on June 17 an increase in the number of insects captured in all five positions occurred (Fig. 7). Independent contrasts indicated that the average number of insects captured by traps placed outside the bins differed from the average number of insects found in the inside flight traps (F = 24.45; df = 1, 4752, P = 0.0001). No difference was found when the eaves (inside and outside) were compared (F = 0.28; df = 1, 4752; P = 0.5942). According to paired t tests, flight traps outside the bins detected more insects than the inside flight traps on August 21 (t = 2.76; df = 11; P = 0.0185). Comparison of insect catches by traps at the eaves (outside and inside), on the different sampling dates, indicated that more insects were captured on the outside eaves on August 21 (t = 5.59; df = 11; P = 0.0002), August 28 (t = 2.31; df = 11; P = 0.0416), and September 27 (t = 2.67; df = 11; P = 0.0322).

There was a significant interaction between cardinal direction and species captured (F = 5.87; df = 15, 4752; P =

0.0001). Hairy fungus beetle, *Cryptolestes* spp. and *Tribolium* spp. were detected in higher numbers by flight traps on the north side, whereas, foreign grain beetle, lesser grain borer and the Indianmeal moth were captured in higher numbers in both the north and west sides (Fig. 8). The average number of insects by species also varied with trap position (F = 5.21; df = 20, 4752; P = 0.0001). Hairy fungus beetle, *Tribolium* spp. and the lesser grain borer were detected in higher numbers by traps placed on the outside eaves of the bins (Fig. 9). Foreign grain beetles and Indianmeal moths were found mainly in inside flight traps, while *Cryptolestes* spp. were captured in high numbers at the eaves (both inside and outside).

A significant interaction was also found between cardinal direction and trap position (F = 2.61; df = 12, 4752; P = 0.0018). Traps placed at the outside eaves on the north and west sides detected more insects. On the east and south sides, more insects were found in the inside flight traps (Fig. 10).

Pitfall Probe Traps. Pitfall probe traps detected insects in the grain mass during the first week of sampling (June 24). However, because some grain had to be removed from the bins to facilitate sampling, probe traps were not replaced until July 1.

After the fourth week of sampling (July 23) the number of insects found in pitfall probe traps increased, reaching

a maximum by the beginning of September (Fig. 1). Probe traps captured the same species detected in flight traps (Fig. 11). Differences occurred in the average number of insects of the five most abundant species in pitfall probe traps (F = 342.82; df = 4, 1305, P = 0.0001). *Cryptolestes* spp. were trapped in higher numbers than any other species present in these traps (Table 3). The average number of foreign grain beetles and *Tribolium* spp. captured by probe traps was not different. The hairy fungus beetle and the lesser grain borer were detected in fewer numbers. Although *Corticaria* spp. were captured in larger numbers than lesser grain borers (Fig. 11), they were not included in the statistical analysis because they are not important pests of stored grain.

Foreign grain beetles and hairy fungus beetles were detected in the grain mass by pitfall probe traps during the first week of sampling (Fig. 12 B and D, respectively). The number of foreign grain beetles found in probe traps fluctuated during the sampling period (Fig. 12 B). The number of hairy fungus beetles did not vary much on the different sampling dates with the exception of July 8, when they were trapped in high numbers (Fig. 12 D). *Cryptolestes* spp. and lesser grain borers were detected the second week of sampling (Fig. 12 A and E, respectively). The average number of insects of these species increased steadily, reaching a maximum on September 6 and August 28,

respectively. The decrease in the number of these species observed after August 28 should be viewed with caution because the means for the last four weeks represent only two bins. *Tribolium* spp. were detected in the grain mass late in the sampling period and were more abundant during the last four weeks of sampling (Fig. 12 C).

More insects were detected by probe traps in the center of the bins (F = 5.51; df = 8, 1305; P = 0.0001) (Table 4). The average number of insects captured by all traps placed by the wall was higher than the average number of insects found in traps at one-half the bins radius (F = 7.14; df = 1, 1305; P = 0.0076). A significant difference (F = 31.35; df = 1, 1305; P = 0.0001) was found when the number of insects found in the center was compared with that in other cardinal directions. Sets of independent contrasts indicated no difference among the average number of insects captured in the different cardinal directions. Throughout the sampling period more insects were found in the center of the bins than in the other directions (Fig. 13). Paired t tests detected more differences between the mean number of insects captured in the center and the mean catches on the south and east in the different sampling dates. From July 16 through August 21, with the exception of August 13, the mean number of insects captured by probe traps at the center was higher than the mean of all other directions.

The average number of insects of a particular species

captured by probe traps varied with trap position (F = 1.80; df = 32, 1305; P = 0.0001). Foreign grain beetles, Hairy fungus beetles, and *Tribolium* spp. were captured in higher numbers by traps located in the center and west side (Fig. 14). Lesser grain borers were more abundant in the center and north side, while *Cryptolestes* spp. were detected mainly in the center. With regard to the lateral distribution, most species were found in higher numbers close to the bins wall, except for *Cryptolestes* spp. which were detected in higher numbers at one-half the bin radius (Fig. 15).

Grain Trier. Insects were found in grain trier samples beginning the first week that samples were taken with this device (July 8). The average density of insects increased throughout the sampling period reaching a maximum at the end of August (Fig. 1). The reduction in the average density of insects after this date can be attributed in part to the fumigation of one of the bins. Grain trier samples detected all species found in flight traps and pitfall probe traps except the larger black flour beetle and Indianmeal moth (Fig. 16). The average density of insects of the five most abundant species in grain trier samples differed (F = 66.04; df = 4, 1305; P = 0.0001). *Cryptolestes* spp. were present in higher densities, followed by *R. dominica*, and *Tribolium* spp. (Table 5). Hairy fungus beetles and foreign grain beetle were present in grain trier samples in lesser numbers. *Corticaria* spp. were more abundant in grain trier

samples than hairy fungus beetles and foreign grain beetles (Fig. 16) but were not included in the statistical analysis because they are minor stored grain pests.

The lesser grain borer and the hairy fungus beetle were found in grain trier samples the first week of sampling (July 8) (Fig. 17 B and D, respectively). *Cryptolestes* spp. and *Tribolium* spp. and the foreign grain beetle were all detected the second week of sampling (Fig. 17 A, C, and E, respectively). *Cryptolestes* spp. and *Tribolium* spp. were more abundant at the end of the sampling period (Fig. 17 A and C, respectively). Lesser grain borers peaked by the end of August (Fig. 17 B). Their reduction in density after August 28 was the result of fumigating one of the bins in which they were more abundant. Hairy fungus beetles were found mainly during the first half of the sampling period (Fig. 17 D). Foreign grain beetles were detected only on three sampling dates (Fig. 17 E).

Higher densities of insects were found in the center grain trier samples than in any of the other regions sampled ($F = 3.90$; df = 8, 1305; $P = 0.0001$) (Table 6). No differences were found among the other sampling positions. However, comparison of the average density of insects by cardinal direction showed that samples on the east side detected significantly more insects than those on the south side ($F = 4.25$; df = 1, 1305; $P = 0.0393$). Independent contrasts also showed that the center detected more insects

(F = 24.76; df = 1, 1305; P = 0.0001) when compared to the other cardinal directions. No significant difference was found between the average density of insects detected at 30.5 cm from the bins wall and at one-half the bins radius (F = 0.0; df=1, 1305; P = 0.9920). Paired t tests detected differences in the ratios of the mean densities of insects in the center and all other directions on July 30 (center/north: t = 2.09, df = 32, P = 0.0451; center/south: t = 2.09, df = 32, P = 0.0451; center/east: t = 2.26, df = 32, P = 0.0311; and center/west: t = 2.13, df = 32, P = 0.0412) (Fig. 18). Differences between the center and north, and the center and east were detected on August 6 (t = 2.26; df = 32; P = 0.0305 and t = 2.06; df = 32; P = 0.048, respectively). The center differed from the west on August 13 (t = 2.16; df = 32; P = 0.0387). The mean insect density in the central core was higher than the mean of all other directions on July 30 (t = 2.17; df = 32; P = 0.0374). The discrepancy in the rank of the means over time is an artifact of the transformation.

The average densities of adult insects of a particular species varied with location from which the samples were taken (F = 1.76; df = 32, 1305; P = 0.0059). Except for *Tribolium* spp., all other species were found in higher numbers in the center of the bins (Fig. 19). *Tribolium* spp. were found mainly in the north and west. Foreign grain beetles were not detected in the north or south. With regard

to the lateral distribution, *Cryptolestes* spp. were more abundant at one-half the bins radius (Fig. 20). *Tribolium* spp. were found in higher densities by the bin wall. Lesser grain borers and foreign grain beetles were found in approximately the same numbers at 30.5 cm from the bin wall and at one-half the bin radius. Hairy fungus beetles were more abundant at the bin wall.

Deep Cup Probe. Cup probe samples detected insects the first week of sampling with this device (July 16). The average density of insects in cup probe samples increased throughout the sampling period (Fig. 1). The reduction in the number of insects detected after August 28 can be attributed in part to the fumigation of one of the bins. Larger black flour beetles were not detected by cup probe samples. All species captured by flight and pitfall probe traps were found in these samples except for this species. Also, this device detected Indianmeal moths which were not detected by the grain trier (Fig. 21). The average density of the five most abundant species found in cup probe samples varied (F = 100.26; df = 4, 5040; P = 0.0001). *Cryptolestes* spp. were present in higher numbers, followed by lesser grain borers and *Tribolium* spp. (Table 7). Hairy fungus beetles and foreign grain beetles were present in cup probe samples in lesser numbers. Four of the five most abundant species were detected by cup probe samples the first week this sampling device was used (Fig. 22 A, B, D, and E). *Cryptolestes* spp.

and *Tribolium* spp. were more abundant at the end of the sampling period (Fig. 22 A and C, respectively). Lesser grain borers peaked at the end of August (Fig. 22 B). The decrease in density of lesser grain borers after August 28 can be attributed in part to the fumigation of the bin were they were more abundant. Hairy fungus beetles were detected throughout the sampling period in a cyclical pattern similar to that found with other sampling devices (Fig. 22 D). Foreign grain beetles were found the first week of sampling and during the month of August (Fig. 22 E).

The average density of insects detected by cup probe samples in the different sampling locations in the grain mass varied (F = 11.95; df = 8, 5040; P = 0.0001). Samples taken at the center contained the highest density of insects (Table 8). Highest densities of insects were found at depths of 30.5 and 61.0 cm than at 91.4 cm within the grain mass (Table 9). No significant interaction was found between the density of insects captured at different depths within a sampling position.

Comparison of the density of insects in the cardinal directions showed differences between the south and the west (F = 6.60; df = 1, 5040; P = 0.0103). Highest densities were found in the center when compared with the mean of all other directions (F=75.97; df = 1, 5040; P = 0.0001). No difference was found between the mean density of insects captured at 30.5 cm from the bin wall and at one-half the

bins radius (F = 0.69; df = 1, 5040; P = 0.4067). From July 16 through August 28, with the exception of July 23, cup probe samples taken at the center detected higher densities of insects than samples taken at any of the other cardinal directions. The same was observed when the mean density of insects at the center was compared with the mean of all other directions in the different sampling dates (Fig. 23).

During the first two weeks, samples taken at the grain surface contained higher densities of insects than those taken at 30.5 and 61.0 cm depth, respectively (Fig. 24). On August 6, 21 and 28 (only 61.0 cm), the density of insects at the surface had significantly decreased compared with those at 30.5 and 61.0 cm depths. Towards the end of the sampling period, the density of insects decreased at the depth of 91.4 cm.

The average density of insects of the five most abundant species in cup probe samples varied with location in the grain mass (F = 5.63; df = 32, 5040; P = 0.0001). *Cryptolestes* spp., lesser grain borers and foreign grain beetles were present mainly in cup probe samples taken from the center of the bins (Fig. 25). *Tribolium* spp. were found in higher numbers in the west, while hairy fungus beetles were more abundant in the east, south and west sides. In regard to the lateral distribution in the bins, hairy fungus beetle, *Tribolium* spp. and the lesser grain borer were more abundant by the bin walls (Fig. 26). *Cryptolestes* spp. were

detected in higher densities at one-half the bin radius, while foreign grain beetles were found in approximately the same densities in both locations.

The average density of insects of the five most abundant species varied with depth in the grain mass (F = 6.52; df = 12, 5040; P = 0.0001). The foreign grain beetle and the hairy fungus beetle were found in higher densities on the grain surface (0 cm) (Fig. 27). The density of lesser grain borers increased with depth. *Tribolium* spp. were found at higher densities in samples taken at 61.0 cm depth and at the surface, while *Cryptolestes* spp. were found in higher densities in the two intermediate layers (30.5 and 61.0 cm).

Temperature and Moisture Content. The mean moisture contents for grain trier and cup probe samples were 10.83 ± 1.0 and 10.70 ± 1.87, respectively. No significant differences were found among the moisture contents of grain trier samples (F = 0.78; df = 162; P = 0.9176) or cup probe samples (F = 0.75; df = 648; P = 0.9994).

Grain temperatures did not differ among regions with a mean temperature of 31.83°C ± 2.53 (F = 1.62; df = 4, 332; P = 0.1677). However, mean grain temperatures at each depth were significantly different from one another (F = 195.88; df = 3, 332; P = 0.0001). Grain temperatures were 27.39 ± 4.17, 32.54 ± 1.84, 33.39 ± 2.76 and 34.0 ± 2.89°C at depths 0, 30.5, 61.0 and 91.4 cm, respecively. No significant interaction was found between direction and grain depth.

The percentage of dockage at the end of the experiment was higher in the central core. However, no significant differences in the percentage of dockage in the different grain regions sampled were detected (F = 0.16; df = 8, 18; P = 0.9943).

No correlation was found between the total number of insects (all species) detected in grain trier samples and temperature or moisture content. Correlation coefficients were different from zero only for *Tribolium* spp. and temperature (r = -0.301; P = 0.0004) and *Cryptolestes* spp. and moisture content (r = 0.126; P = 0.0388).

Correlation coefficients associating temperature and moisture content with the total number of insects in cup probe samples, suggest that more insects were found in the warmest regions of the grain mass (r = 0.128; P = 0.0031) and in samples with high moisture content (r = 0.076; P = 0.0135). When the number of insects of a particular species was correlated with temperature, a negative correlation was found for the hairy fungus beetle (r = -0.114; P = 0.0085). Positive correlations were found for the lesser grain borer (r = 0.114; P = 0.0087) and *Cryptolestes* spp. (r = 0.174; P = 0.0001). Moisture content correlations with species indicated that the hairy fungus beetle, and *Tribolium* spp. were more abundant in drier samples (r = -0.071; P = 0.0217 and r = -0.065; P = 0.0354, respectively) while *Cryptolestes* spp. were associated mainly with higher moisture contents (r

= 0.156; P = 0.0001).

No correlation was found between the total number of insects (all species) captured by pitfall probe traps and temperature and moisture content[3]. Correlations of temperature with a particular species in pitfall probe traps indicated that *Corticaria* spp., the hairy fungus beetle and the sawtoothed grain beetle were associated with high temperatures (r = 0.279, P = 0.0001; r = 0.222, P = 0.0091; and r = 0.192, P = 0.0243, respectively), while *Tribolium* spp. were associated with low temperatures (r = -0.274; P = 0.0012). In regard to the degree of association with moisture content, correlation coefficients did differ from zero for the foreign grain beetle (r = -0.143; P = 0.0186), hairy fungus beetle (r = 0.242; P = 0.0001), lesser grain borer (r = -0.150; P = 0.0137), *Tribolium* spp. (r = -0.136; P = 0.0258) and the sawtoothed grain beetle (r = 0.313; P = 0.0001).

Discussion

In a four year study of insect populations in stored wheat in Oklahoma, Cuperus et al. (1986) found that the lesser grain borer, rice weevil, *Cryptolestes* spp., *Tribolium* spp., and the sawtoothed grain beetle were the species most frequently sampled using grain trier and deep cup probe. In contrast, our results indicate that foreign grain beetle and hairy fungus beetle were the second and fourth most abundant species in the bins sampled.

Explanation for these differences might be attributed to environmental factors and additional sampling methods used in our study. Hairy fungus beetle numbers increased after periods of rain, and these insects were collected in flight traps outside the bin in large proportions. Indianmeal moth, rice weevil and sawtoothed grain beetle were not very abundant.

Studies reported by Hagstrum (1989) suggested that the origin of infestations was from insects coming from outside the storage structure. Our results indicate that flight traps start detecting insects before grain harvest (Fig. 1) and that these insects were detected by the traps placed in the outside eaves. After grain binning the number of insects captured increased, which indicated an increase in the number of insects attracted to the grain in the storage structure. Variations in the number of insects captured in the cardinal directions may be explained in part by dominant winds during the sampling period. The winds are mainly south-southwest during this part of the year. The greater number of insects captured by flight traps on the north side of the bins could be a result of insects flying upwind, attracted to the stored grain. The abundance of insects in flight traps placed on the west side could be explained by insects that are carried by the wind and randomly land in the storage structures. However, the south traps would also be expected to capture more insects. In addition,

differences in the locations of the bins and adjacent structures may have had some effect on differences in flight trap catch.

Flight traps placed at the eaves (inside and outside the bins) captured more insects than those in other positions. Before grain harvest, traps placed at the outside eaves on the south and west sides were the only ones to detect grain insects. Since the bins contained no grain at this time, these insects might have landed at random, carried by the wind. Why insects were detected at the outside eaves and not in the other trap positions outside the bins is not known. Also, before wheat harvest, traps inside of the bins were not available to determine if insects were actually inside the storage structures before grain binning. One week after binning, inside flight traps had detected insects, which indicates a rapid movement of insects to the inside of the storage structures.

The pattern and timing of capture of the different species by flight traps varied. Vick et al. (1990) stated that insect behavior, pheromone concentration per trap, and environmental conditions inside closed structures which affect pheromone dispersal are factors which influence the capture of insects by pheromone baited sticky traps. Unbaited sticky traps capture insects by interception when the insects are flying at random because flight is not directed by pheromone lures. The factors affecting capture

with unbaited sticky traps might be similar to those affecting baited traps with the exception of factors related to the use of pheromones. Factors such as distance of the insect populations to the storage structures, behavior of the species, wind direction, and wind speed, affect the pattern and timing of capture of insects by outside flight traps. Although no differences were found in the mean number of insects caught by inside and outside flight traps at the eaves, the site of capture is important because the confined and relatively small space of bins is more likely to have a homogeneous density of insects in flight than a large open area (Leos-Martínez et al. 1986). The interaction between trap position and cardinal direction may be attributed to differences on environmental factors such as wind and light inside and outside the storage structures.

A total of 568 insects and 4 insects (0.03 insects per 500 g) were detected by pitfall probe traps and grain trier samples, respectively, on the first date of collection (July 8). Cup probe samples had 30 insects (0.05 insects per 500 g) by July 16. The period between grain binning (June 17) and the first day of collection with pitfall probe traps and grain trier could explain the existence of insects in the grain when the first samples were collected. Studies by Wright et al. (1988) suggested that before wheat harvest, flight traps detected a moderate to high infestation at various locations on farms. The first month after harvest,

probe traps captured large numbers of insects in new grain, and by September, insects trapped on flight traps had decreased and populations in bins had increased. Insect catches with the different sampling methods in our study followed similar patterns to those observed by Wright et al. (1988) (Fig. 1).

Hagstrum (1989) used a different approach to determine the origin of insect infestations. Following the vertical distribution pattern of *C. ferrugineus*, he concluded that the top layer was infested first because the insect population increased earlier in the top grain layer than in the middle layers, and there was a logarithmic decrease in insect numbers with increased distance from the grain surface. Therefore, grain infestation occurs after grain is stored. In this study, during the first two weeks of sampling, cup probe samples taken at the grain surface contained more insects than those taken at 30.5 and 91.4 cm within the grain mass (Fig. 24). By August the number of insects in the surface had decreased while those at depths of 30.5 and 61.0 cm had increased. This would indicate that infestation does occur after grain binning. However, a definite pattern did not exist. Because of the period between grain binning and grain sampling, the first phase of insect infestation was lost. By the end of the sampling period, samples taken at 30.5 and 61.0 cm contained more insects than those at 91.4 cm (Fig. 24). Although the

overall analysis for moisture content was not significant, moisture content was higher at 31.5 and 61.0 cm (11.12 ± 1.30 and 10.84 ± 1.17, respectively) than on the surface and at 91.4 cm (10.12 ± 2.81 and 10.73 ± 1.05, respectively). The higher moisture contents could explain increased insect accumulation in these layers. Insects such as *Cryptolestes* spp. and *Tribolium* spp. in which accumulation is influenced by moisture content (Surtees 1965, Loschiavo 1983, Loschiavo & Smith 1986) were found mainly in these two layers (Fig. 27).

Insect counts for the three sampling methods used in the grain mass indicated that insects accumulate in the center of the bins. Temperature and moisture content play an important role in insect distribution (Surtees 1965) and affect trap and sample catches (Loschiavo 1983, Storey et al. 1983, Loschiavo & Smith 1986, Fargo et al. 1989). Temperature, moisture content and percentage of dockage in the central core did not differ from other regions in the grain mass in our study. Although, no differences were found, there was a tendency for the center to have higher a moisture content, temperature and percentage of fines in our study. This could have biological significance for insects to be found in higher numbers in this region. The central core is known to have the highest level of dockage in bins where the grain is binned without the use of a spreader (Noyes et al. 1988). Since the bins studied were loaded

without a spreader, we assumed that the central core had the greater level of fines throughout the sampling period. Higher levels were detected at the end of the study. In addition, species known to be influenced by the level of fines such as *Cryptolestes* spp. and *Tribolium* spp. (McGregor 1964, Tuff & Teleford 1964, Watters 1969) were found in higher numbers in this region. Hagstrum (1987) also found that during the first 12 weeks of storage, neither the temperature nor the moisture content were sufficiently different to explain why insects favor the center of the bins. He concluded that the level of fines in this region might explain the concentration of insects in the center early in the storage period.

Correlations of temperature and moisture content with the total number of insects were significantly different from zero only in the case of cup probe samples. These correlation coefficients indicated that more insects were detected at higher temperatures and higher moisture contents, although correlations were weak. Studies by Loschiavo & Smith (1986), White & Loschiavo (1986) and Fargo et al. (1989) have found that significantly more insects were captured at higher temperatures. Additionally, the higher the level of grain moisture, the greater the population of stored-grain insects and molds (Noyes et al. 1988, Noyes et al. 1991, Hagstrum 1987).

Surtees (1965) observed that the factors influencing

the accumulation of five beetle species varied according to species behavior and also depended on grain condition. He noted that the accumulation of the foreign grain beetle took place in the warmest and dampest parts of the grain bulk, while *T. castaneum* accumulated in the drier parts of a bulk and at places were the temperature was about 25°C. However, *T. castaneum* also accumulated in damp regions if the grain was mouldy. *C. ferrugineus* accumulation was influenced by feeding and oviposition behavior, with adult accumulation occurring in damp grain within drier bulks. The accumulation of *R. dominica* occurred in the driest part of a grain bulk.

In our study, correlations between the number of insects by species with temperature and moisture content were in the most part not significant, and all correlation coefficients that were found to differ from zero were < 0.5. Insect populations may not have been high enough to detect an association or particular species may not have been detected in high enough numbers by the different sampling methods. Also, temperature and moisture content did not vary much during the study.

Correlation coefficients between temperature and moisture content with insect density in grain trier samples suggested that *Tribolium* spp. were found in higher densities in the cooler regions of the bins, while *Cryptolestes* spp. were more abundant in samples with higher moisture contents. Correlations with probe trap catches indicated that foreign

grain beetles, lesser grain borers and *Tribolium* spp. were more abundant in drier regions while hairy fungus beetles and sawtoothed grain beetles were found mainly in areas with higher moisture contents.

In cup probe samples, hairy fungus beetles were associated with cool temperatures while lesser grain borers were associated with warm temperatures. *Cryptolestes* spp. were associated with high moisture contents and hairy fungus beetles and *Tribolium* spp. were found in higher densities in samples with low moisture contents. Species correlations did agree with results found by Surtees (1965) in the case of *Tribolium* spp., *R. dominica*, *O. surinamensis* and *Cryptolestes* spp. However, contradictory results were obtained for the hairy fungus beetle and the foreign grain beetle. These species are known fungivores and scavengers and will increase rapidly in areas of high moisture content and high percentage of fines (Barak & Harein 1981).

The correlation coefficient between pitfall probe traps and moisture content for *A. advena* ($r = -0.143$) indicated that this species was associated with low moisture contents. On the other hand, correlation coefficients for *T. stercorea* numbers between pitfall probe traps and cup probe samples with moisture content were 0.242 and -0.071, respectively. The correlation coefficient for probe traps indicate that this species was associated with high moisture contents, while for cup probe samples it was associated with low

moisture contents. This discrepancy could be because of the difference in insect numbers of this species detected by the two methods. Hairy fungus beetles were present in low numbers in cup probe samples as compared with numbers of this species present in pitfall probe traps (Figs 11 and 21). No correlation analysis was carried out to determine the degree of association between the percentage of fines and insect numbers since samples used to determine the level of dockage in the grain were taken only at the end of the sampling period.

In conclusion, flight traps are important in detecting insects before and after grain binning. Before grain harvest, the outside eaves of the bins were the best location for these traps in regard to insect numbers captured. After grain harvest and binning, flight traps placed at both the inside and outside eaves gave a good indication of insect activity in the storage structures. All three sampling methods used in the grain mass indicated that the central core was where insects are most likely to be found. Increased numbers of insects with depth through time and the pattern of capture of stored grain insects by flight traps indicated that infestation occurs after grain binning. Sampling of grain should begin as soon as grain is binned to determine an accurate pattern of infestation.

References Cited

Barak, A. V. & P. K. Harein. 1981. Insect infestation on farm stored shelled corn and wheat in Minnesota. J. Econ. Entomol. 74: 197-202.

Barak, A. V., W. E. Burkholder & D. L. Faustini. 1990. Factors affecting the design of traps for stored-product insects. J. Kansas Entomol. Soc. 63: 466-485.

Cuperus, G. W., C. K. Prickett, P. D. Bloome & J. T. Pitts. 1986. Insect populations in aerated and unaerated wheat in Oklahoma. J. Kansas Entomol. Soc. 59: 620-627.

Cuperus, G. W., W. S. Fargo, P. W. Flinn & D. W. Hagstrum. 1990a. Variables affecting capture of stored-grain insects in probe traps. J. Kansas Entomol. Soc. 63: 486-489.

Cuperus, G. W., R. T. Noyes, W. S. Fargo, B. L. Clary, D. C. Arnold & K. Anderson. 1990b. Management practices in a high-risk stored-wheat system in Oklahoma. Amer. Entomol. 36: 129-134.

Fargo, W. S., D. Epperly, G. W. Cuperus, B. C. Clary & R. Noyes. 1989. Effect of temperature and duration of trapping on four stored grain insect species. J. Econ. Entomol. 82: 970-973.

Hagstrum, D. W. 1987. Seasonal variations of stored wheat environment and insect populations. Environ. Entomol. 16: 77-83.

Hagstrum, D. W. 1989. Infestation by *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) of newly harvested wheat stored on three Kansas farms. J. Econ. Entomol. 82: 655-659.

Hagstrum, D. W., G. A. Milliken & M. S. Waddell. 1985. Insect distribution in bulk-stored wheat in relation to detection or estimation of abundance. Environ. Entomol. 14: 655-661.

Hagstrum, D. W., W. S. Fargo & P. K. Flinn. 1991. How to sample grain. pp. 65-69. *In* Management of grain, bulk commodities, and bagged products. Okla. State Univ. Coop. Ext. Serv. Circ. No. E-912.

Little, T. M. & F. J. Hills. 1978. Transformations (what to do when data break the rules). pp. 139-165. *In* Agricultural experimentation design and analysis. John Wiley & Sons. New York.

Leos-Martínez, J., T. A. Granovsky, H. J. Williams, S. B. Vinson & W. E. Burkholder. 1986. Estimation of aerial density of the lesser grain borer (Coleoptera: Bostrichidae) in a warehouse using dominicalure traps. J. Econ. Entomol. 79: 1134-1138.

Loschiavo, S. R. 1975. Field tests of devices to detect insects in different kinds of grain storages. Can. Entomol. 107: 385-389.

Loschiavo, S. R. 1983. Distribution of the rusty grain beetle (Coleoptera: Cucujidae) in columns of wheat stored dry or with localized high moisture content. J. Econ. Entomol. 76: 881-884.

Loschiavo, S. R. & J. M. Atkinson. 1967. A trap for the detection and recovery of insects in stored grain. Can. Entomol. 99: 1160-1163.Loschiavo, S. R. & J. M. Atkinson. 1973. An improved trap to detect beetles (Coleoptera) in stored grain. Can. Entomol. 105: 437-440.

Loschiavo, S. R. & J. M. Atkinson. 1973. An improved trap to detect beetles (Coleoptera) in stored grain. Can. Entomol. 105: 437-440.

Loschiavo, S. R. & L. B. Smith. 1986. Population fluctuations of the rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), monitored with insect traps in wheat stored in a steel granary. Can. Entomol. 118: 641-647.

McGregor, H. E. 1964. Preference of *Tribolium castaneum* for wheat containing various percentages of dockage. J. Econ. Entomol. 57: 511-513.

Noyes, R. T., B. L. Clary & G. W. Cuperus. 1988. Maintaining quality of stored grain by aeration. OSU Extension Facts No. 1100. Cooperative Extension Service, Oklahoma State University.

Noyes, R. T., R. Weinzierl & G. W. Cuperus. 1991. Stored grain management techniques. pp. 71-79. *In* Management of grain, bulk commodities and bagged products. Okla. State Univ. Coop. Ext. Serv. Circ. No. E-912.

SAS Institute. 1988. SAS/STAT™ user's guide, release 6.03 ed. SAS Institute, Cary, NC.

Storey, C. L., D. B. Sauer & D. Walker. 1983. Insect populations in wheat, corn, and oats stored on the farm. J. Econ. Entomol. 76: 1323-1330.

Surtees, G. 1965. Ecological significance and practical implication of behaviour patterns determining the spatial structure of insect populations in stored grain. Bull. Entomol. Res. 56: 201-203.

Tuff, D. W. & H. S. Teleford. 1964. Wheat fracturing as affecting infestation by *Cryptolestes ferrugineus*. J. Econ. Entomol. 57: 513-517.

Vick, K. W., R. W. Mankin, R. R. Cogburn, M. Mullen, J. E. Throne, V. F. Wright & L. D. Cline. 1990. Review of pheromone-baited sticky traps for detection of stored product insects. J. Kansas Entomol. Soc. 63: 526-532.

Watters, F. L. 1969. The locomotor activity of *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) in wheat. Can. J. Zool. 47: 1177-1182.

White, N.D.G. & S. R. Loschiavo. 1986. Effects of insect density, trap depth, and attractants on the capture of *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) in stored wheat. J. Econ. Entomol. 79: 1111-1117.

White, N.D.G., R. T. Arbogast, P. G. Fields, R. C. Hillmann, S. R. Loschiavo, Bh. Subramanyam, J. E. Throne & V. F. Wright. 1990. The development and use of pitfall and probe traps for capturing insects in stored grain. J. Kansas Entomol. Soc. 63: 506-525.

Wilkin, D. R. 1990. Detection of insects in bulk grain. J. Kansas Entomol. Soc. 63: 554-558.

Wright, F. W. & D. W. Hagstrum. 1990. Trapping technology for monitoring stored-product insects. J. Kansas Entomol. Soc. 63: 464-465.

Wright, V. F., T. W. Maize & J. R. Pedersen. 1988. Using traps to monitor stored grain insects on the farm. *In* Proceedings, 17th Intl. Congress of Entomology. Vancouver, Canada.

FOOTNOTES:

1. Filled to one-third of its capacity.

2. Primary insects are insects which penetrate and destroy whole sound kernels (e.g. - lesser grain borer, and the rice weevil (Noyes et al. 1988).

3. Moisture contents of cup probe samples taken at depths 0, 30.5 and 61.0 cm were used for correlations with pitfall probe trap catches.

Table 1. Differences in the number of adult insects of the six most abundant species in unbaited flight traps

Species	Mean no.[a] (n = 812)	SD range[b]
T. stercorea	1.090a	-0.169, 4.256
Cryptolestes spp.	0.843b	-0.229, 3.408
A. advena	0.422c	-0.232, 1.630
P. interpunctella	0.136d	-0.222, 0.660
R. dominica	0.122de	-0.195, 0.538
Tribolium spp.	0.051e	-0.169, 0.329
F	188.65	
df	5, 4752	
P	0.0001	

Means with different letters are significantly different ($P = 0.0001$; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}X$) - 1).

[b]Lower SD = antilog($\log_{10}X$ - $\log_{10}SD$) - 1. Upper SD = antilog($\log_{10}X$ + $\log_{10}SD$) - 1.

Table 2. Differences detected in the ratios of the mean number of insects captured by flight traps in cardinal directions throughout the sampling period according to paired t tests (n = 165)

Date	N/S[a]	N/W[a]	N/E[a]	S/E[a]	S/W[a]	E/W[a]
Jun. 3	ns	-	-	ns	ns	-
Jun. 10	-	ns	-	-	ns	ns
Jun. 17	ns	ns	ns	ns	ns	ns
Jun. 24	* (+)	* (+)	* (+)	ns	ns	ns
Jul. 1	* (+)	* (+)	* (+)	ns	ns	ns
Jul. 8	* (+)	* (+)	* (+)	ns	ns	ns
Jul. 16	* (+)	* (+)	ns	* (-)	* (-)	* (+)
Jul. 23	* (+)	ns	ns	* (-)	* (-)	ns
Jul. 30	* (+)	ns	* (+)	ns	ns	* (-)
Aug. 6	* (+)	* (+)	* (+)	* (-)	ns	ns

Table 2. Continued

Aug. 13	ns	ns	* (+)	ns	ns	ns
Aug. 21	* (+)	* (+)	* (+)	ns	* (-)	ns
Aug. 28	* (+)	* (+)	* (+)	ns	* (-)	ns
Sept. 6	ns	ns	* (+)	ns	ns	* (-)
Sept. 13	* (+)	* (+)	* (+)	ns	ns	ns
Sept. 20	* (+)	* (+)	ns	ns	ns	ns
Sept. 27	ns	ns	ns	ns	ns	ns

Data were $\log_{10}(X+1)$ transformed before differences were computed.

[a]ns, no significant difference ($P > 0.05$); *, significant difference ($P < 0.05$); a plus sign (+) indicates a positive difference; a minus sign (-) indicates a negative difference.

Table 3. Differences in the number of adult insects of the five most abundant species in unbaited pitfall probe traps

Species	Mean no.[a] (n = 270)	SD range[b]
Cryptolestes spp.	210.170a	27.278, 1575.94
A. advena	6.814b	1.559, 22.86
Tribolium spp.	5.542b	-0.099, 46.55
T. stercorea	2.500c	1.559, 22.86
R. dominica	1.445d	-0.393, 8.85
F	342.82	
df	4, 1305	
P	0.0001	

Means with different letters are significantly different ($P = 0.0001$; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}X$) - 1).

[b]Lower SD = Antilog($\log_{10}X - \log_{10}SD$) - 1. Upper SD = antilog($\log_{10}X + \log_{10}SD$) - 1.

Table 4. Distribution of adult insects in the different regions sampled with pitfall probe traps

Trap position	Mean no.[a] (n = 360)	SD range[b]
Center	18.422a	0.326, 283.594
West (wall)	11.451b	0.384, 111.043
North (wall)	9.912bc	0.459, 80.608
South (wall)	8.310bcd	0.023, 83.704
East (wall)	7.594cd	0.342, 70.416
West (1/2 r)	7.460cd	-0.178, 86.100
East (1/2 r)	7.280cd	-0.081, 73.612
North (1/2 r)	6.970cd	-0.131, 72.110
South (1/2 r)	6.359d	-0.213, 67.819
F	5.51	
df	8, 1305	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}$X) - 1).

[b]Lower SD = Antilog($\log_{10}$X - $\log_{10}$SD) - 1. Upper SD = antilog($\log_{10}$X + $\log_{10}$SD) - 1.

Table 5. Differences in the number of adult insects of the five most abundant species present in grain trier samples

Species	Mean density[a] (n = 270)	SD range[b]
Cryptolestes spp.	0.780a	-0.106, 2.541
R. dominica	0.424b	-0.366, 2.197
Tribolium spp.	0.136c	-0.183, 0.580
T. stercorea	0.025d	-0.092, 0.158
A. advena	0.006d	-0.053, 0.069
F	66.04	
df	4, 1305	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}$X) - 1).

[b]Lower SD = Antilog($\log_{10}$X - $\log_{10}$SD) - 1. Upper SD = antilog($\log_{10}$X + $\log_{10}$SD) - 1.

Table 6. Distribution of adult insects in the different regions sampled with grain triers

Sample position	Mean density[a] (n = 360)	SD range[b]
Center	0.501a	-0.329, 2.356
East (wall)	0.274b	-0.296, 1.304
West (1/2 r)	0.267b	-0.287, 1.253
North (1/2 r)	0.228b	-0.245, 1.000
East (1/2 r)	0.224b	-0.284, 1.092
North (wall)	0.216b	-0.214, 0.882
West (wall)	0.213b	-0.251, 0.965
South (wall)	0.156b	-0.227, 0.731
South (1/2 r)	0.142b	-0.273, 0.795
F	3.90	
df	8, 1305	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}$X) - 1).

[b]Lower SD = Antilog($\log_{10}$X - $\log_{10}$SD) - 1. Upper SD = antilog($\log_{10}$X + $\log_{10}$SD) - 1.

Table 7. Differences in the number of adult insects of the five most abundant species present in cup probe samples

Species	Mean density[a] (n = 1044)	SD range[b]
Cryptolestes spp.	0.509a	-0.292, 2.213
R. dominica	0.307b	-0.398, 1.839
Tribolium spp.	0.206c	-0.278, 1.013
T. stercorea	0.049d	-0.178, 0.337
A. advena	0.006d	-0.075, 0.095
F	100.26	
df	4, 5040	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}X$) - 1).

[b]Lower SD = Antilog($\log_{10}X$ - $\log_{10}SD$) - 1. Upper SD = antilog($\log_{10}X$ + $\log_{10}SD$) - 1.

Table 8. Distribution of adult insects in the different regions sampled with cup probes

Sample position	Mean density[a] (n = 1392)	SD range[b]
Center	0.441a	-0.379, 2.343
North (wall)	0.244b	-0.306, 1.229
West (1/2 r)	0.217bc	-0.332, 1.216
East (1/2 r)	0.201bc	-0.355, 1.238
West (wall)	0.191bcd	-0.272, 0.950
East (wall)	0.152cd	-0.291, 0.870
South (wall)	0.147cd	-0.276, 0.817
South (1/2 r)	0.129d	-0.261, 0.724
North (1/2 r)	0.125d	-0.273, 0.743
F	11.95	
df	8, 5040	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}$X) - 1).

[b]Lower SD = Antilog($\log_{10}$X - $\log_{10}$SD) - 1. Upper SD = antilog($\log_{10}$X + $\log_{10}$SD) - 1.

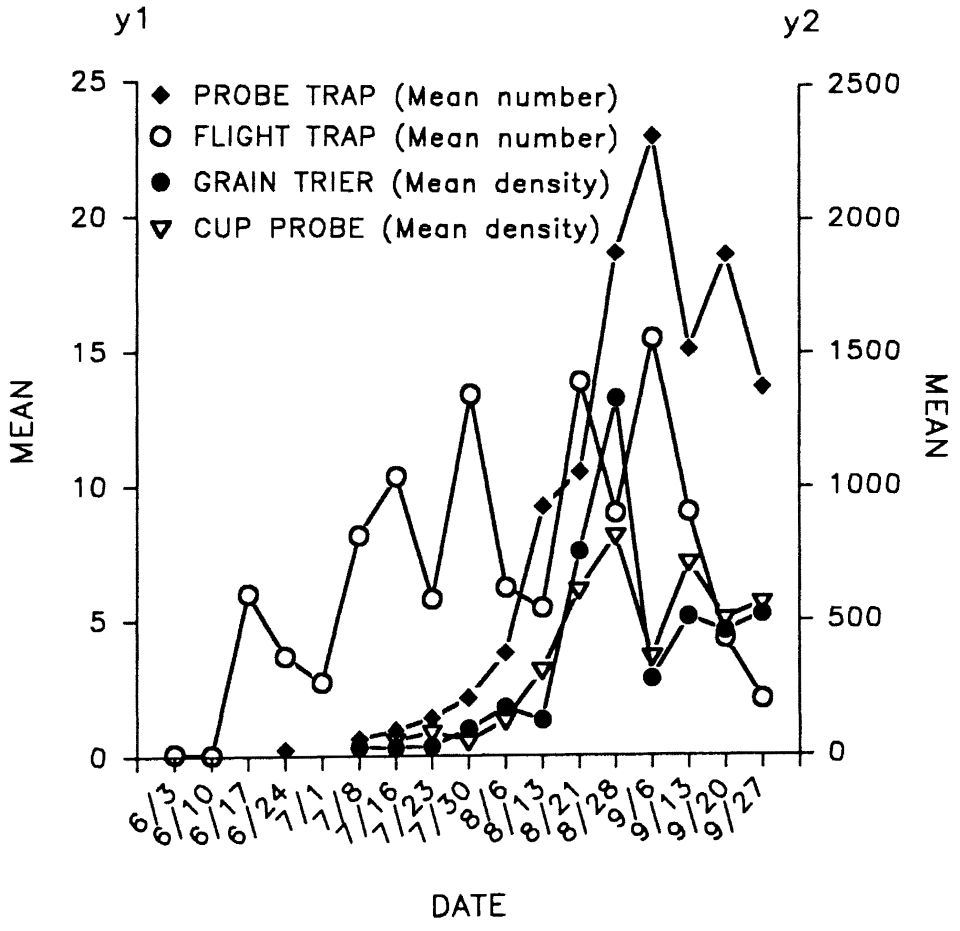
Table 9. Distribution of adult insects in the different depths sampled with cup probes

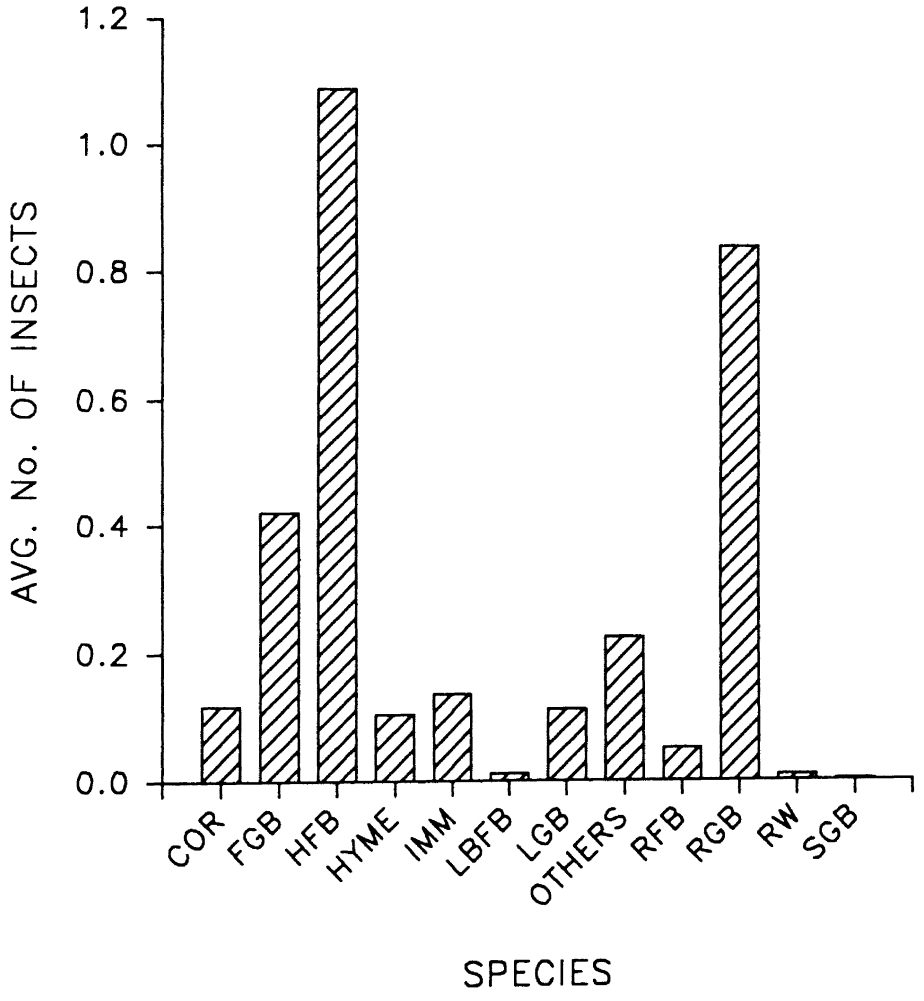
Depth	Mean density[a] (n = 3132)	SD range[b]
0 cm	0.233a	-0.341, 1.305
30.5 cm	0.225ab	-0.324, 1.220
60.1 cm	0.180bc	-0.274, 0.917
90.4 cm	0.172c	-0.326, 1.037
F	3.06	
df	3, 5040	
P	0.0272	

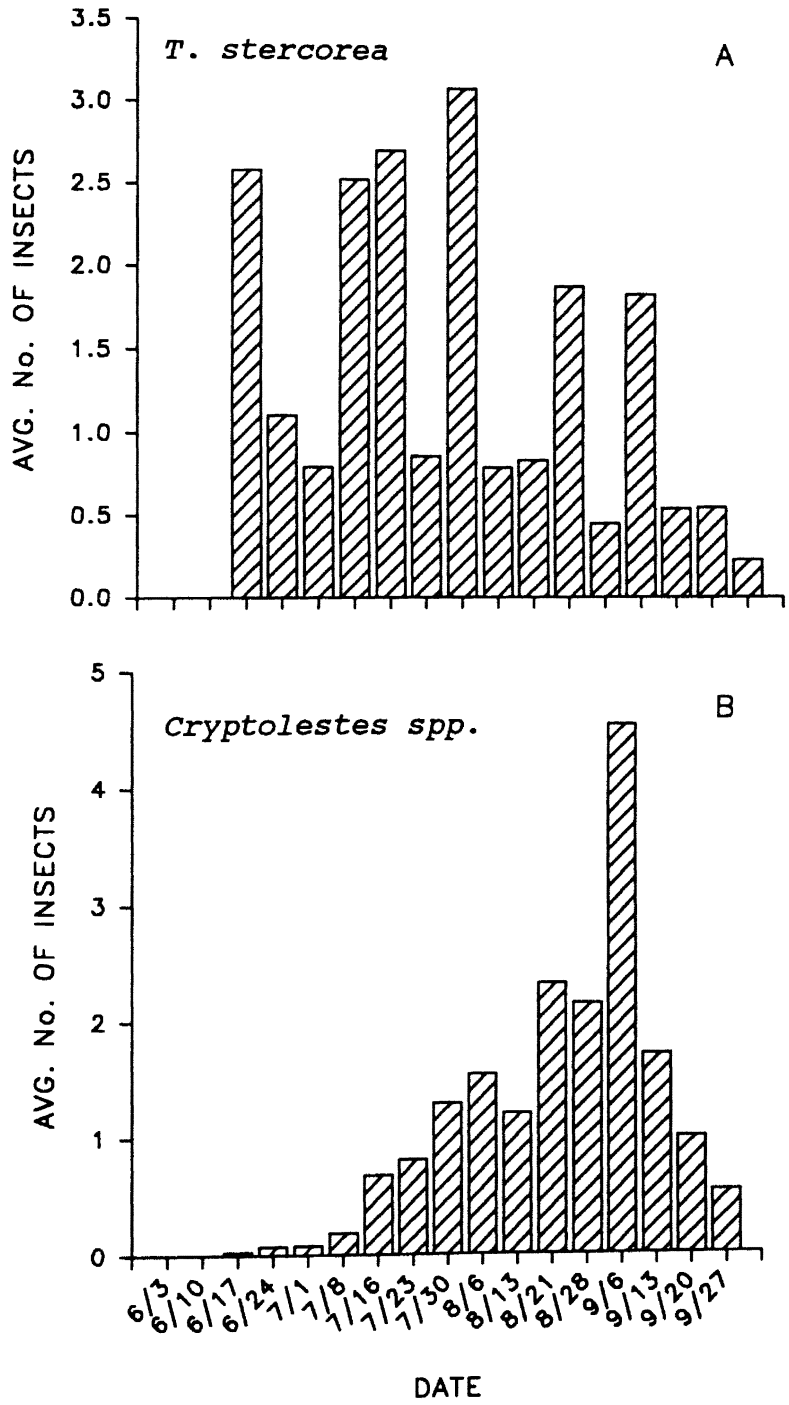
Means with different letters are significantly different ($P = 0.0001$; Fisher's least significant difference [SAS Institute 1988]).

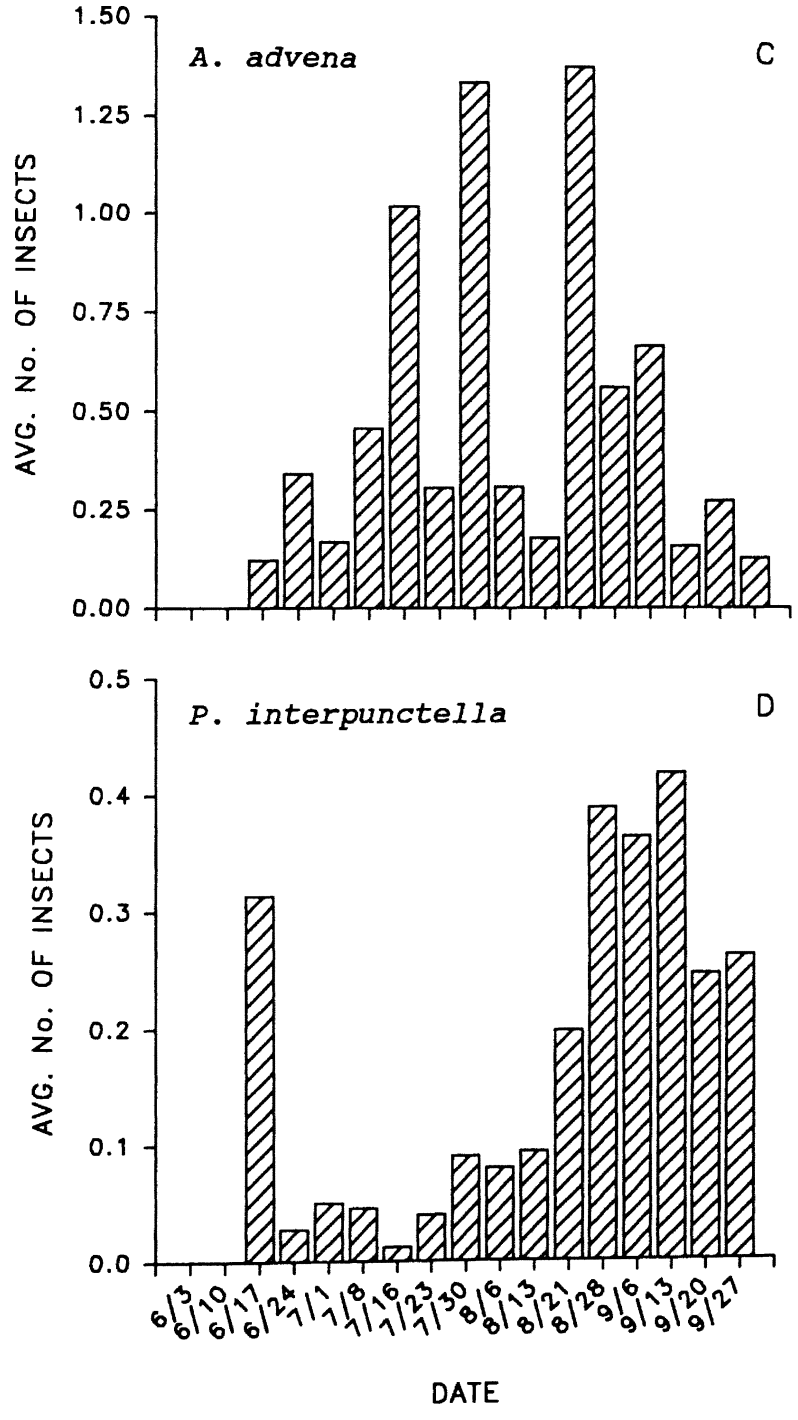
[a]Means are geometric means (antilog($\log_{10}X$) - 1).

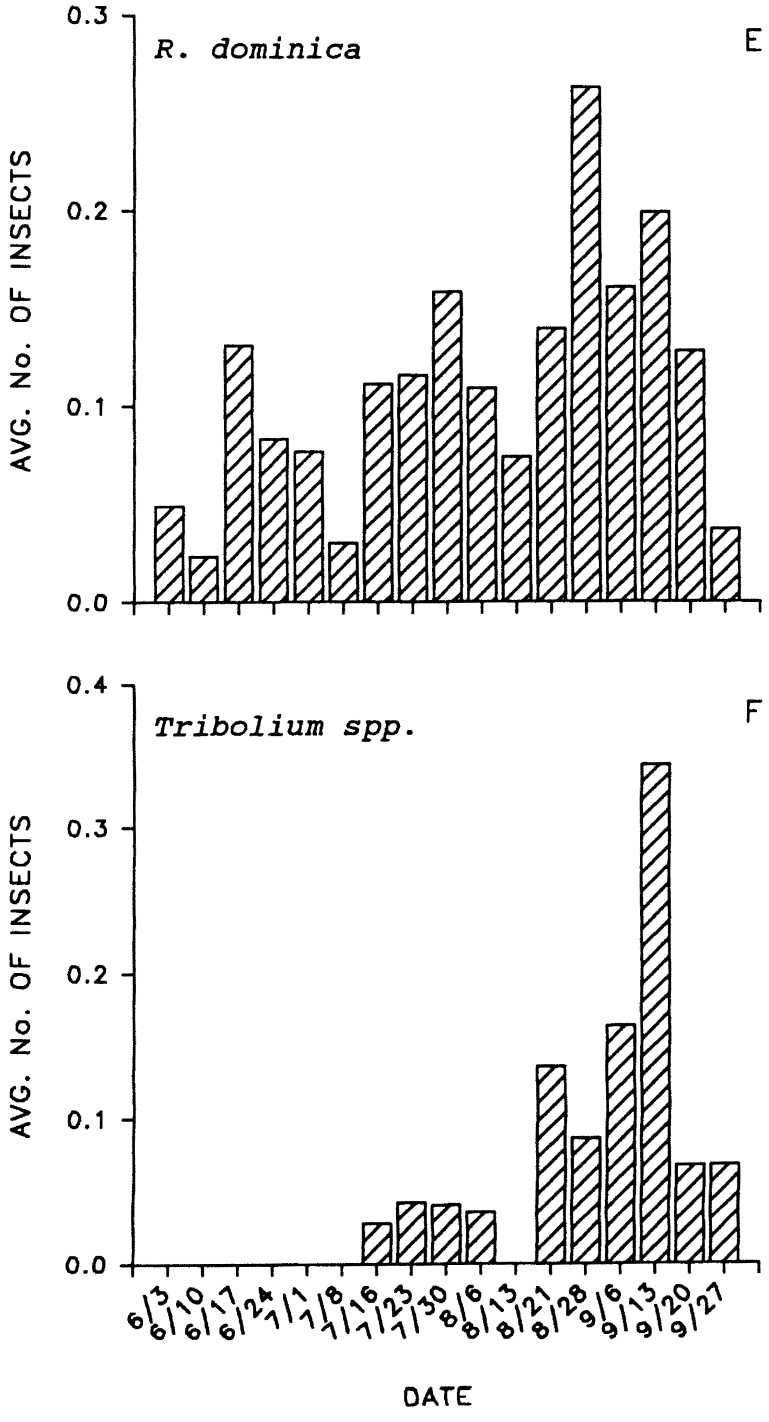
[b]Lower SD = Antilog($\log_{10}X$ - $\log_{10}SD$) - 1. Upper SD = antilog($\log_{10}X$ + $\log_{10}SD$) - 1.

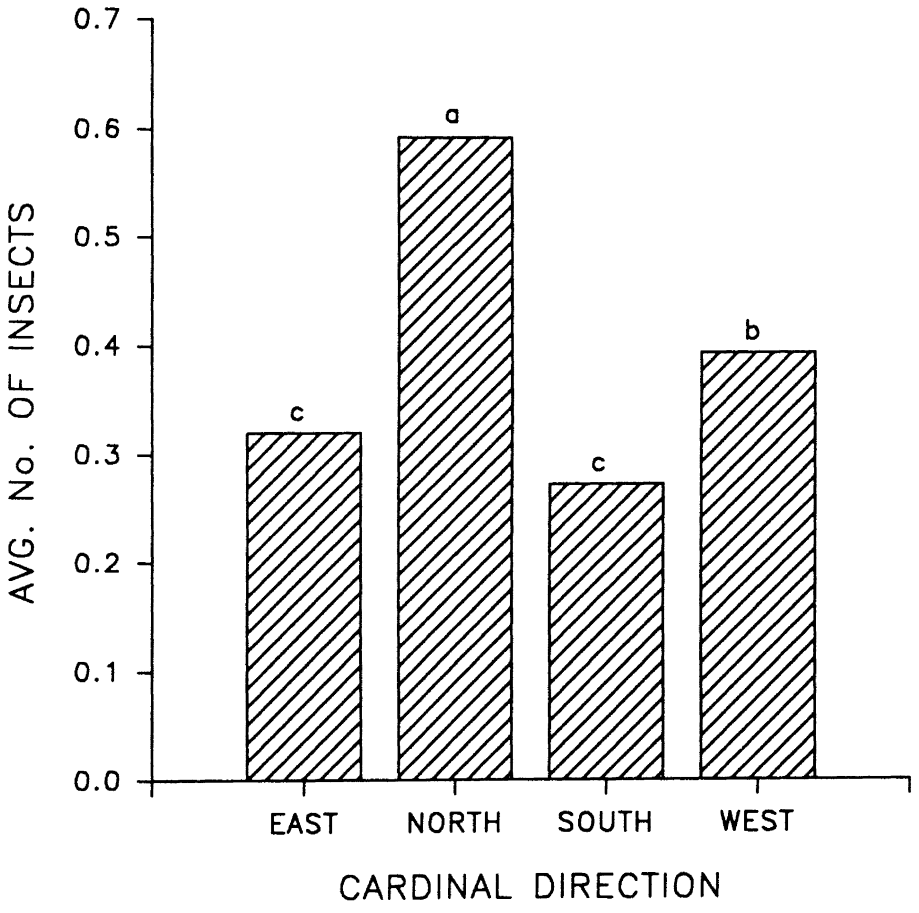

y1
y2
25
20
15
10
5
0
2500
2000
1500
1000
500
0
MEAN
MEAN
PROBE TRAP (Mean number)
FLIGHT TRAP (Mean number)
GRAIN TRIER (Mean density)
CUP PROBE (Mean density)
6/3
6/10
6/17
6/24
7/1
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

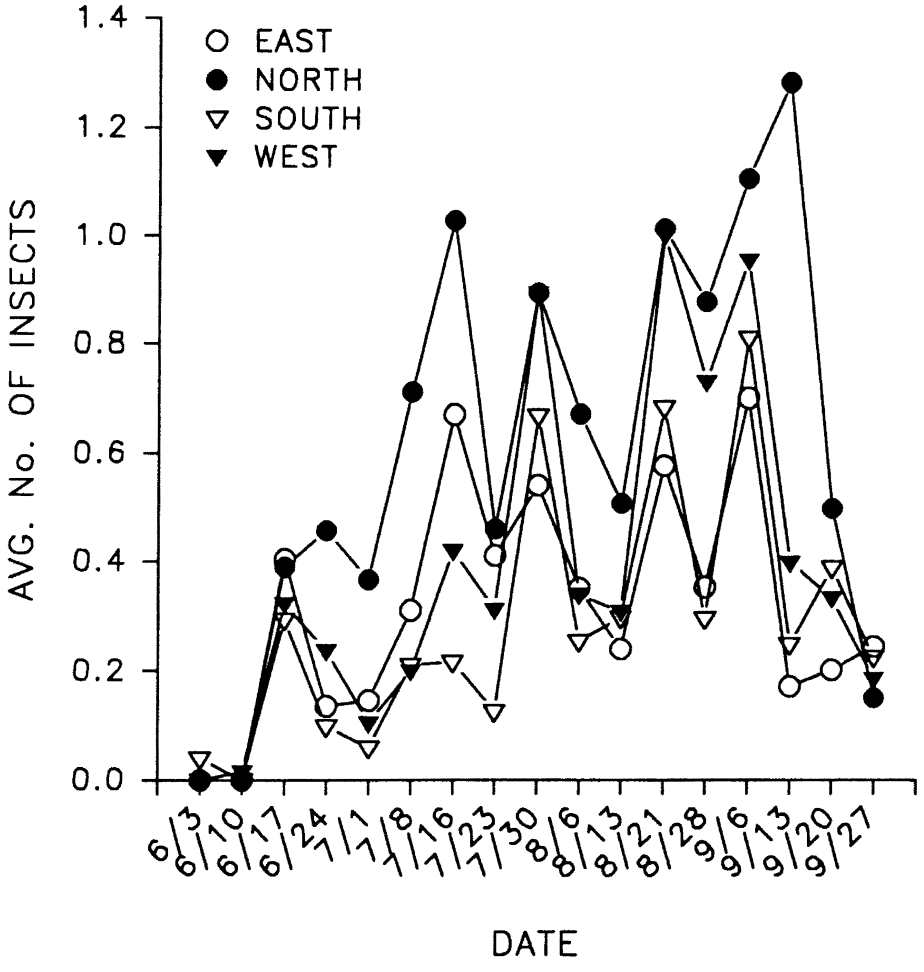

1.2
1.0
0.8
0.6
0.4
0.2
0.0
AVG. No. OF INSECTS
COR
FGB
HFB
HYME
IMM
LBFB
LGB
OTHERS
RFB
RGB
RW
SGB
SPECIES

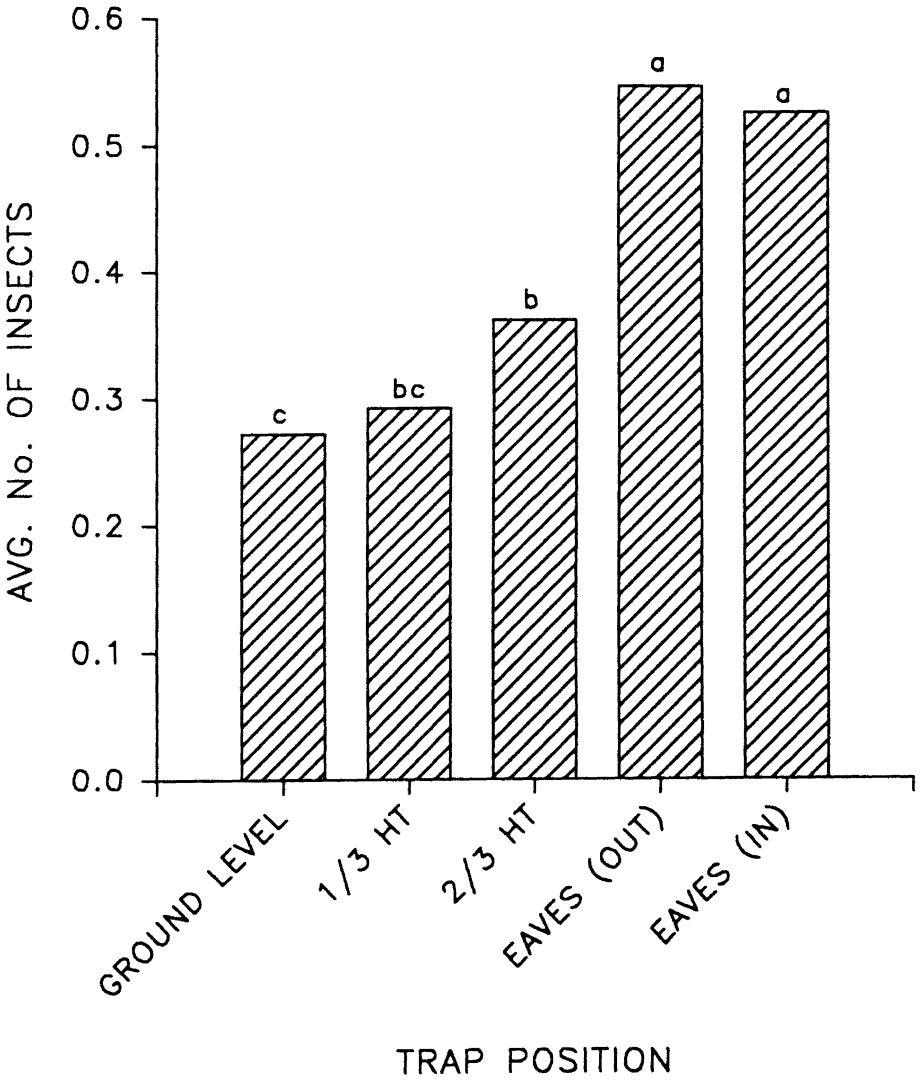

T. stercorea
A
AVG. No. OF INSECTS
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Cryptolestes spp.
B
AVG. No. OF INSECTS
5
4
3
2
1
0
6/3
6/10
6/17
6/24
7/1
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

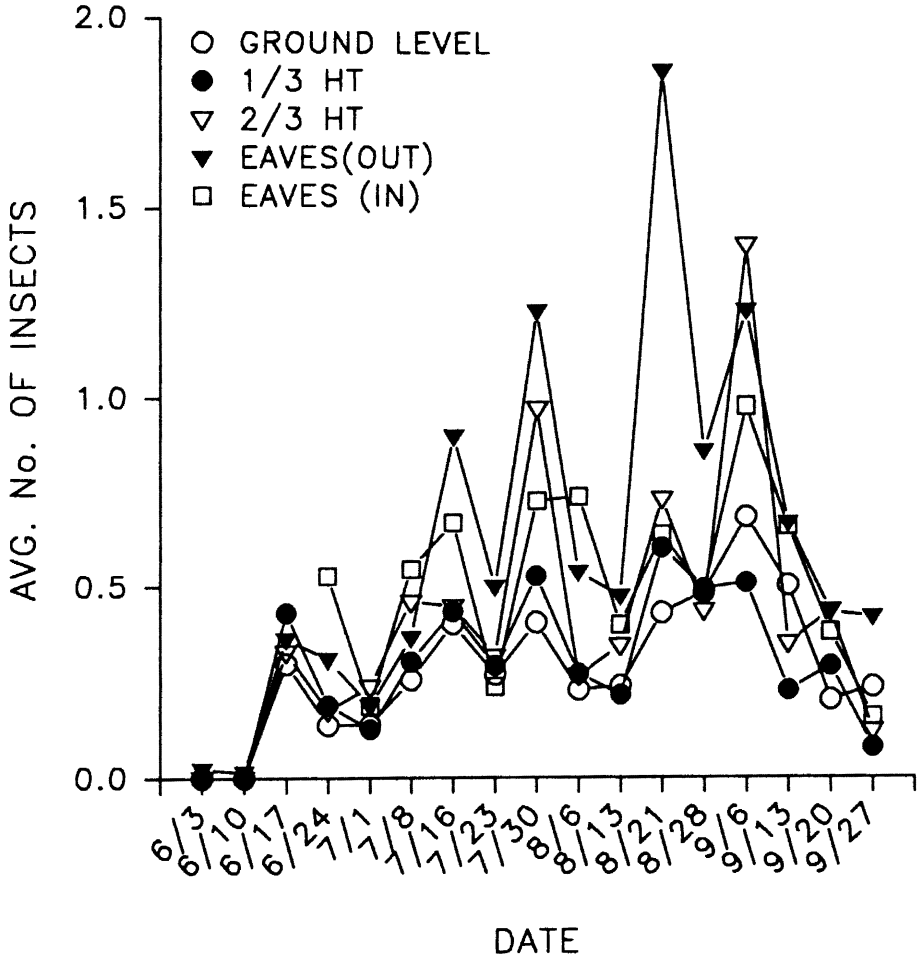

A. advena
C
AVG. No. OF INSECTS
1.50
1.25
1.00
0.75
0.50
0.25
0.00
P. interpunctella
D
AVG. No. OF INSECTS
0.5
0.4
0.3
0.2
0.1
0.0
6/3
6/10
6/17
6/24
7/1
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

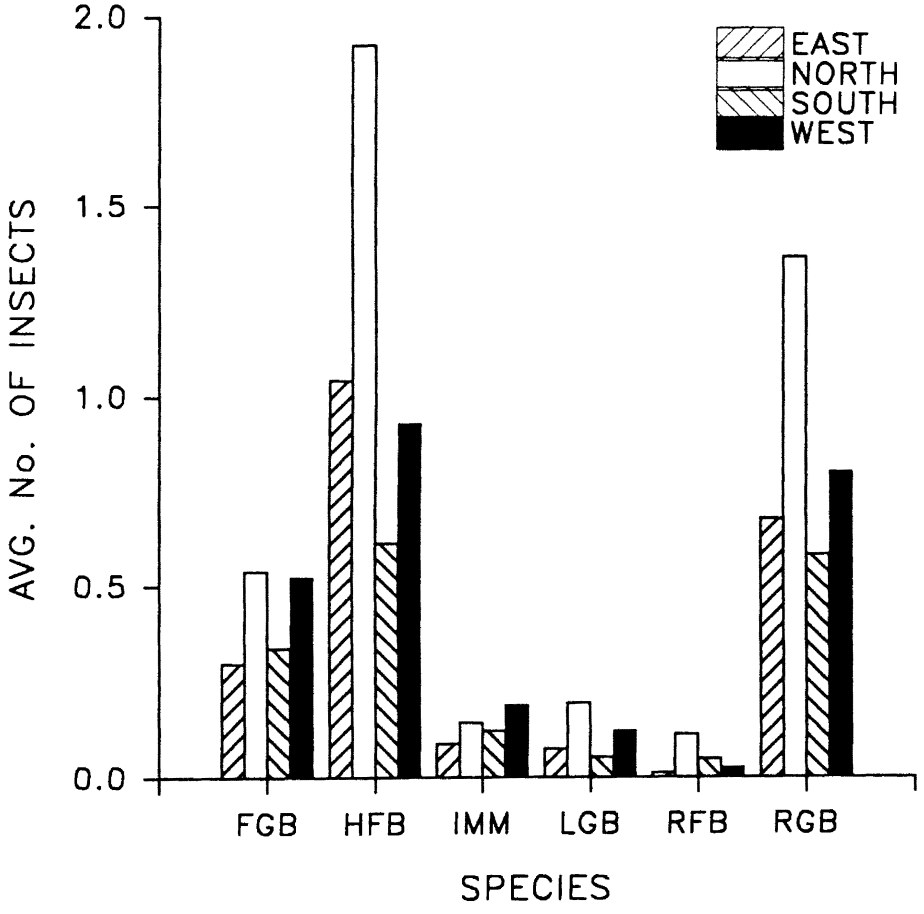

R. dominica
E
AVG. No. OF INSECTS
0.3
0.2
0.1
0.0
Tribolium spp.
F
AVG. No. OF INSECTS
0.4
0.3
0.2
0.1
0.0
6/3
6/10
6/17
6/24
7/1
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

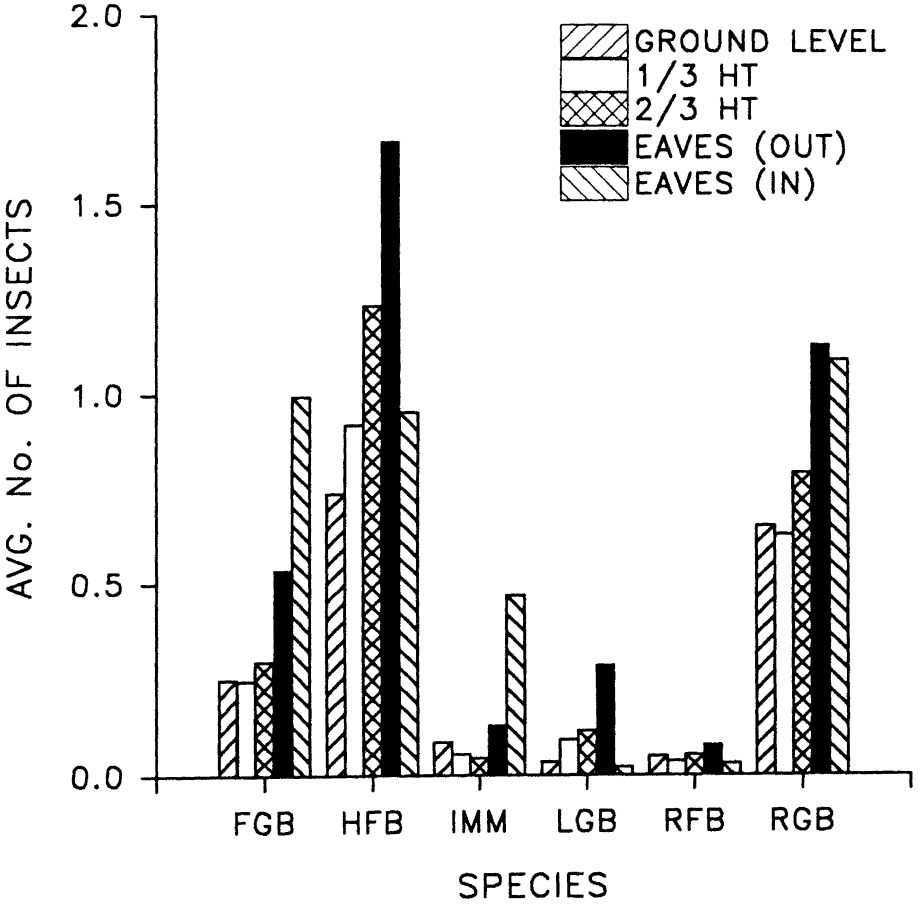

0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
AVG. No. OF INSECTS
a
b
c
c
EAST
NORTH
SOUTH
WEST
CARDINAL DIRECTION

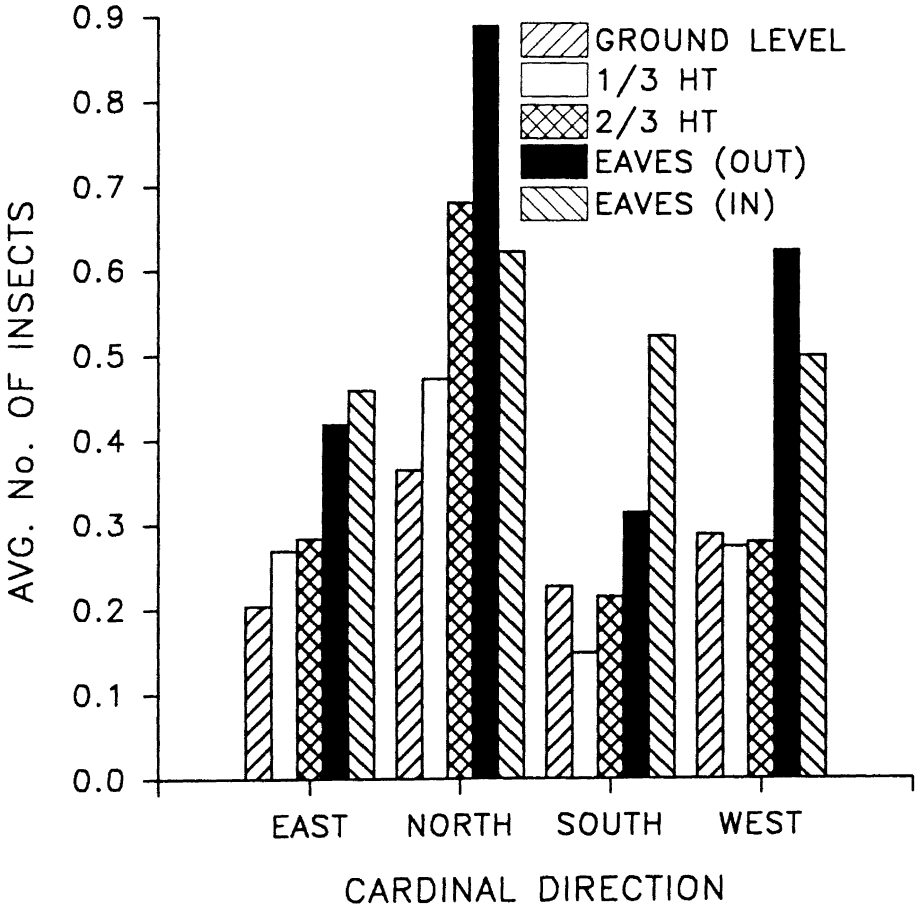

EAST
NORTH
SOUTH
WEST
AVG. No. OF INSECTS
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
6/3
6/10
6/17
6/24
7/1
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

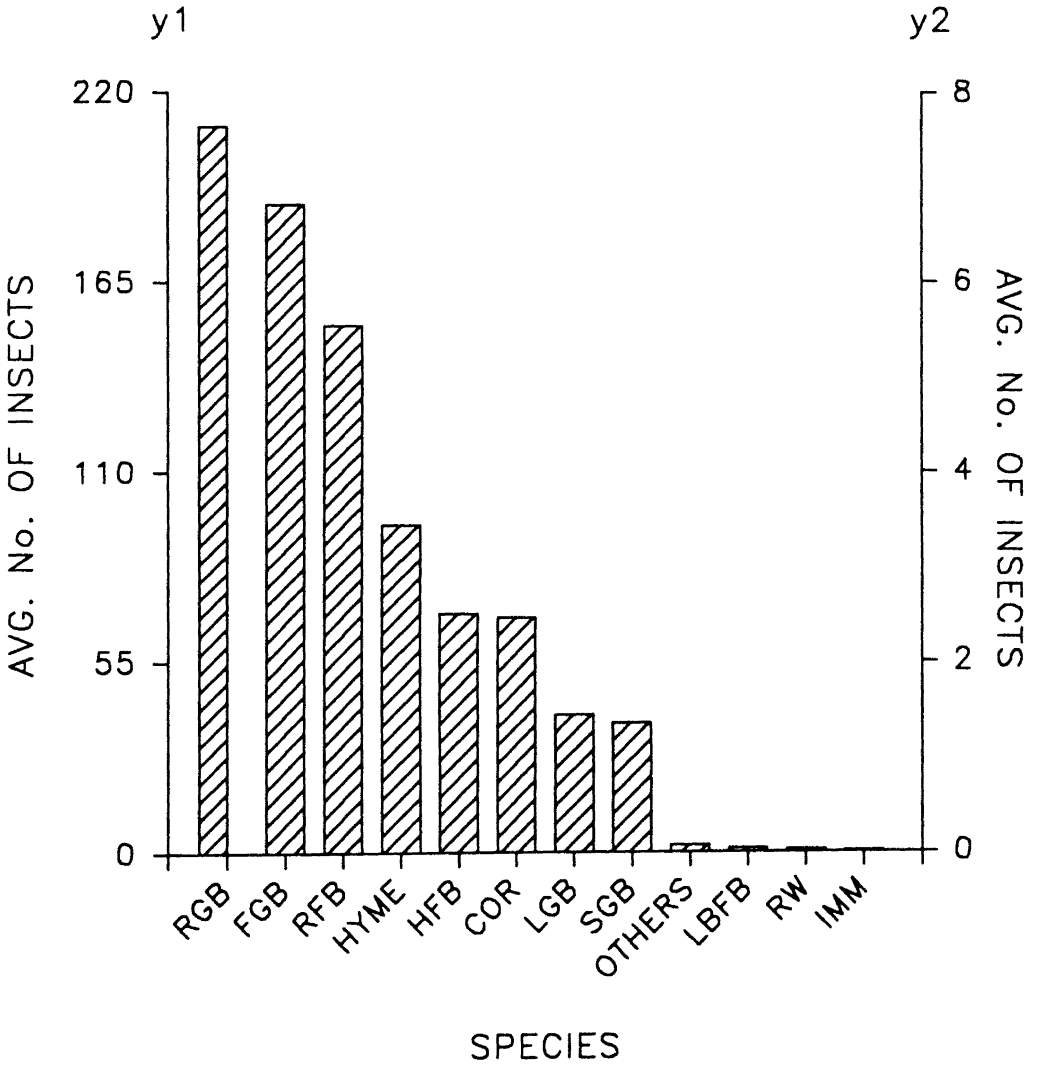

0.6
0.5
0.4
0.3
0.2
0.1
0.0
AVG. No. OF INSECTS
c
bc
b
a
a
GROUND LEVEL
1/3 HT
2/3 HT
EAVES (OUT)
EAVES (IN)
TRAP POSITION

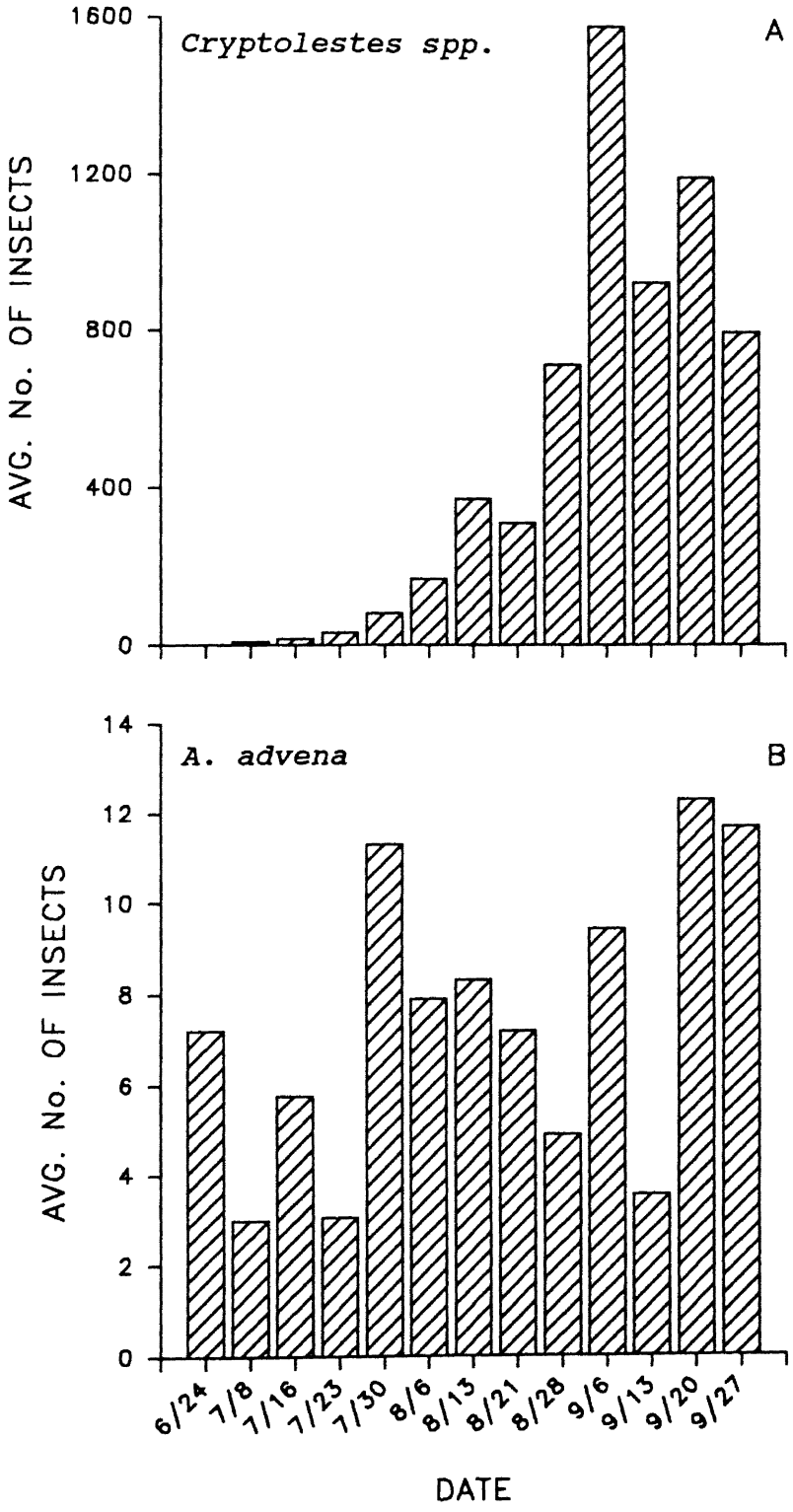

2.0
1.5
1.0
0.5
0.0
AVG. No. OF INSECTS
GROUND LEVEL
1/3 HT
2/3 HT
EAVES(OUT)
EAVES (IN)
6/3
6/10
6/17
6/24
7/1
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

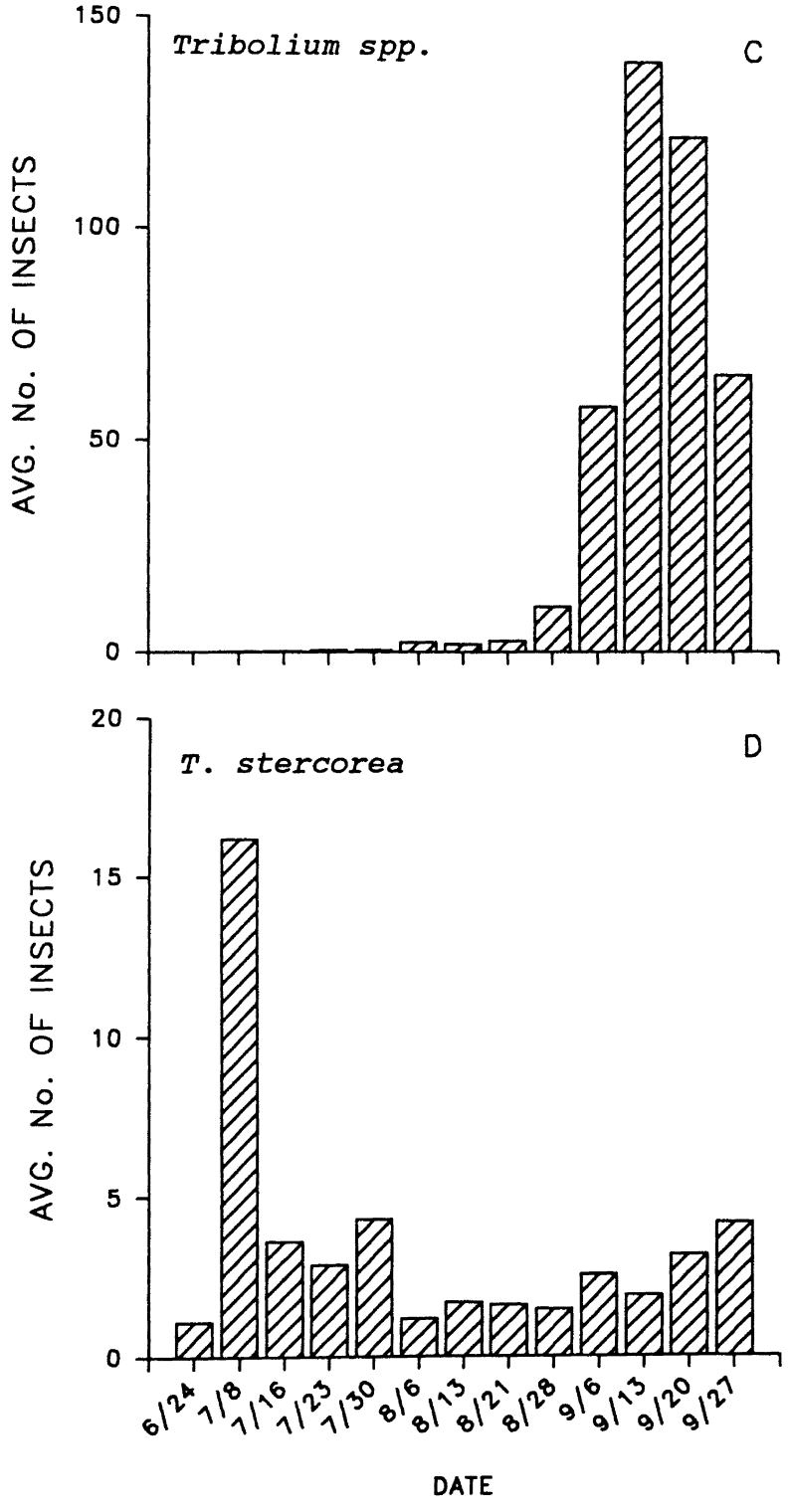

2.0
1.5
1.0
0.5
0.0
AVG. No. OF INSECTS
EAST
NORTH
SOUTH
WEST
FGB
HFB
IMM
LGB
RFB
RGB
SPECIES

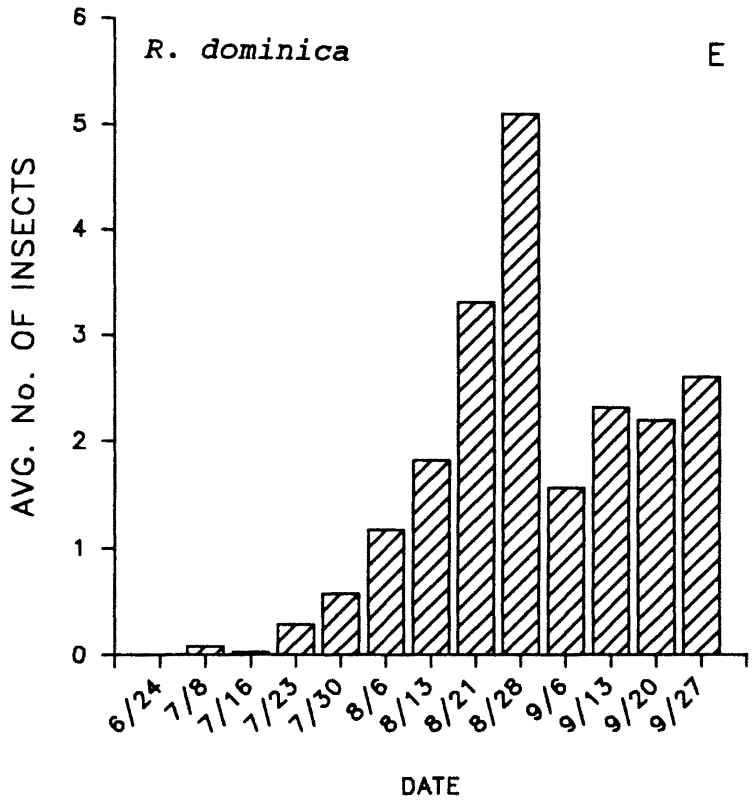

2.0
1.5
1.0
0.5
0.0
AVG. No. OF INSECTS
GROUND LEVEL
1/3 HT
2/3 HT
EAVES (OUT)
EAVES (IN)
FGB
HFB
IMM
LGB
RFB
RGB
SPECIES

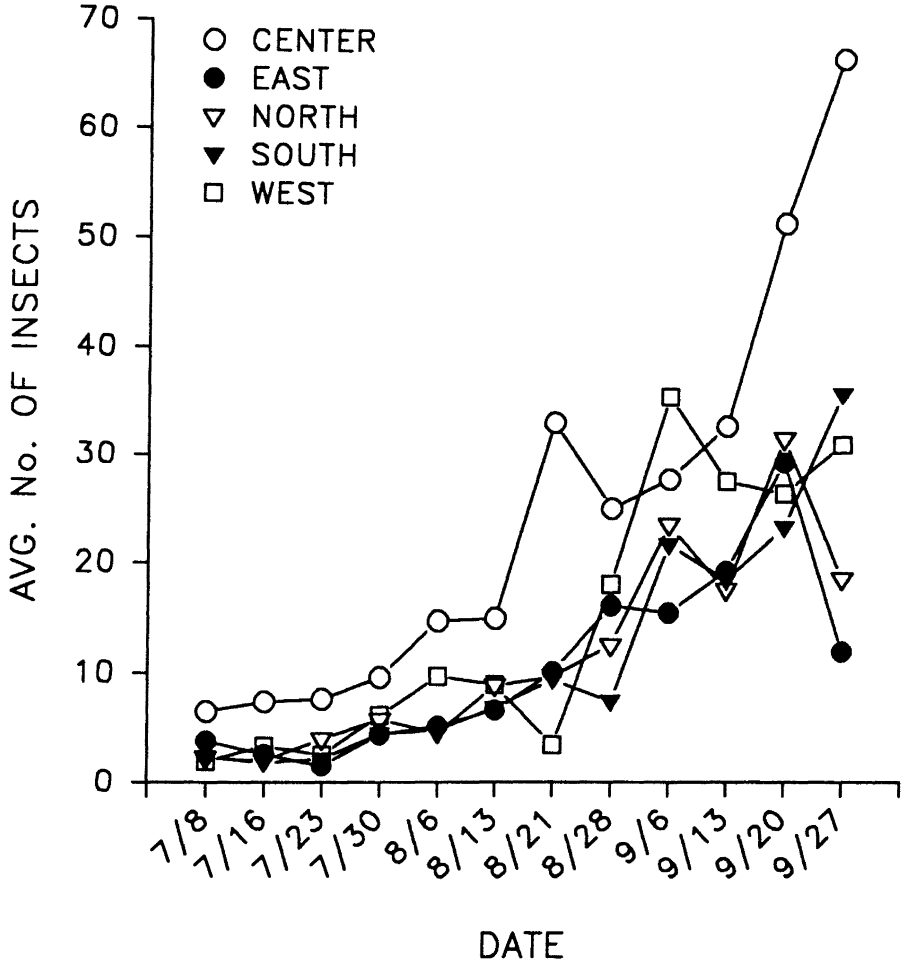

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
AVG. No. OF INSECTS
GROUND LEVEL
1/3 HT
2/3 HT
EAVES (OUT)
EAVES (IN)
EAST
NORTH
SOUTH
WEST
CARDINAL DIRECTION

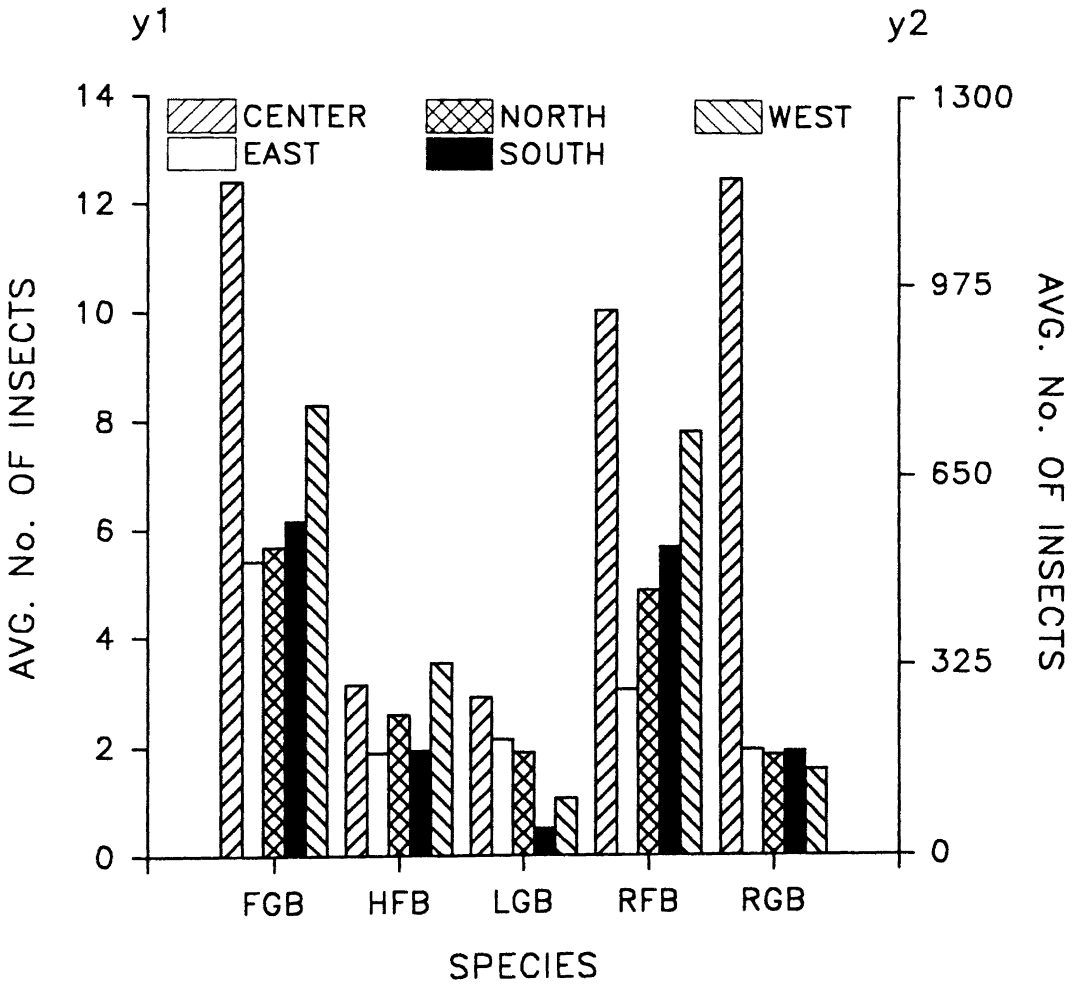

y1
y2
220
165
110
55
0
8
6
4
2
0
AVG. No. OF INSECTS
AVG. No. OF INSECTS
RGB
FGB
RFB
HYME
HFB
COR
LGB
SGB
OTHERS
LBFB
RW
IMM
SPECIES

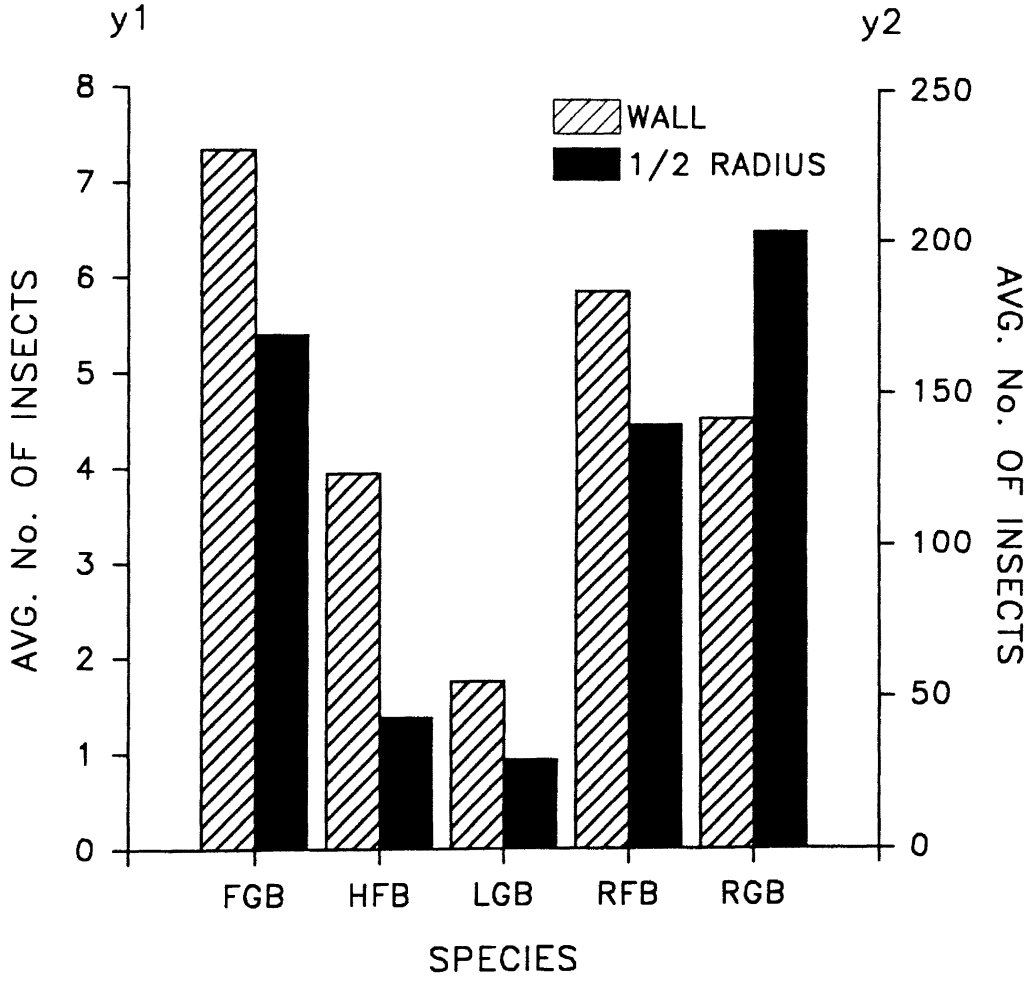

Cryptolestes spp.
A
AVG. No. OF INSECTS
1600
1200
800
400
0
A. advena
B
AVG. No. OF INSECTS
14
12
10
8
6
4
2
0
6/24
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

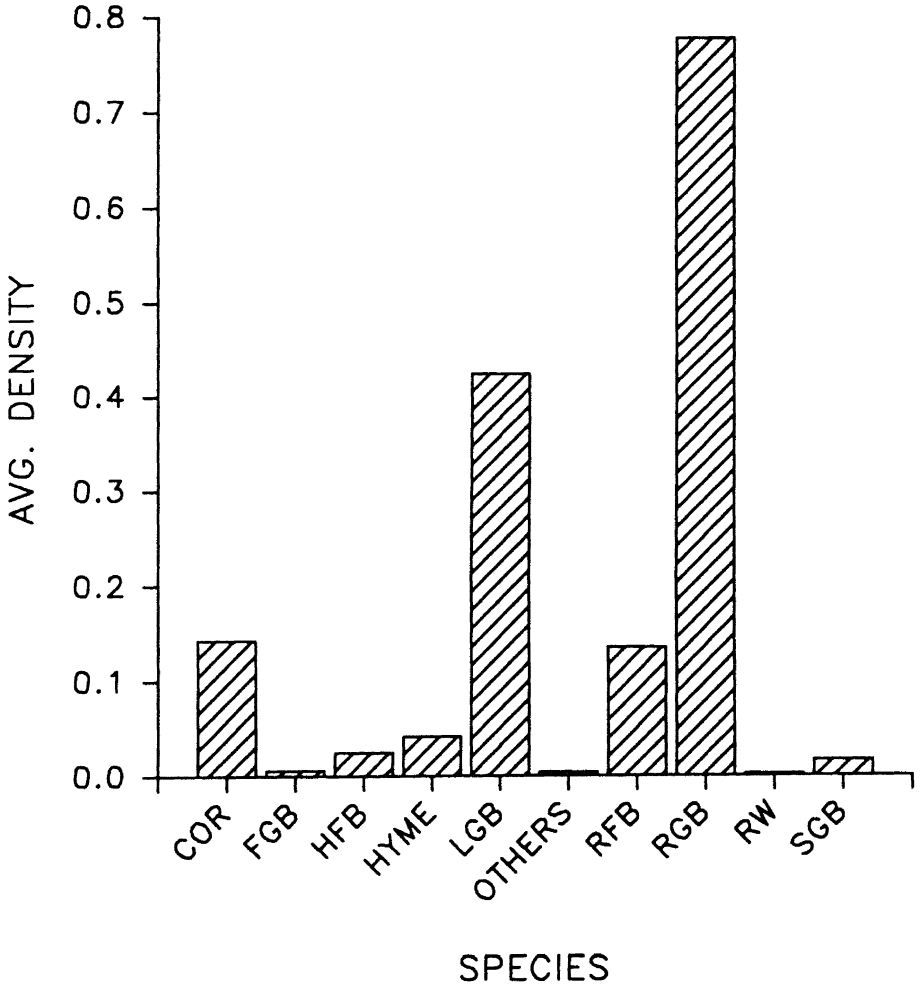

Tribolium spp.
C
AVG. No. OF INSECTS
150
100
50
0
T. stercorea
D
AVG. No. OF INSECTS
20
15
10
5
0
6/24
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

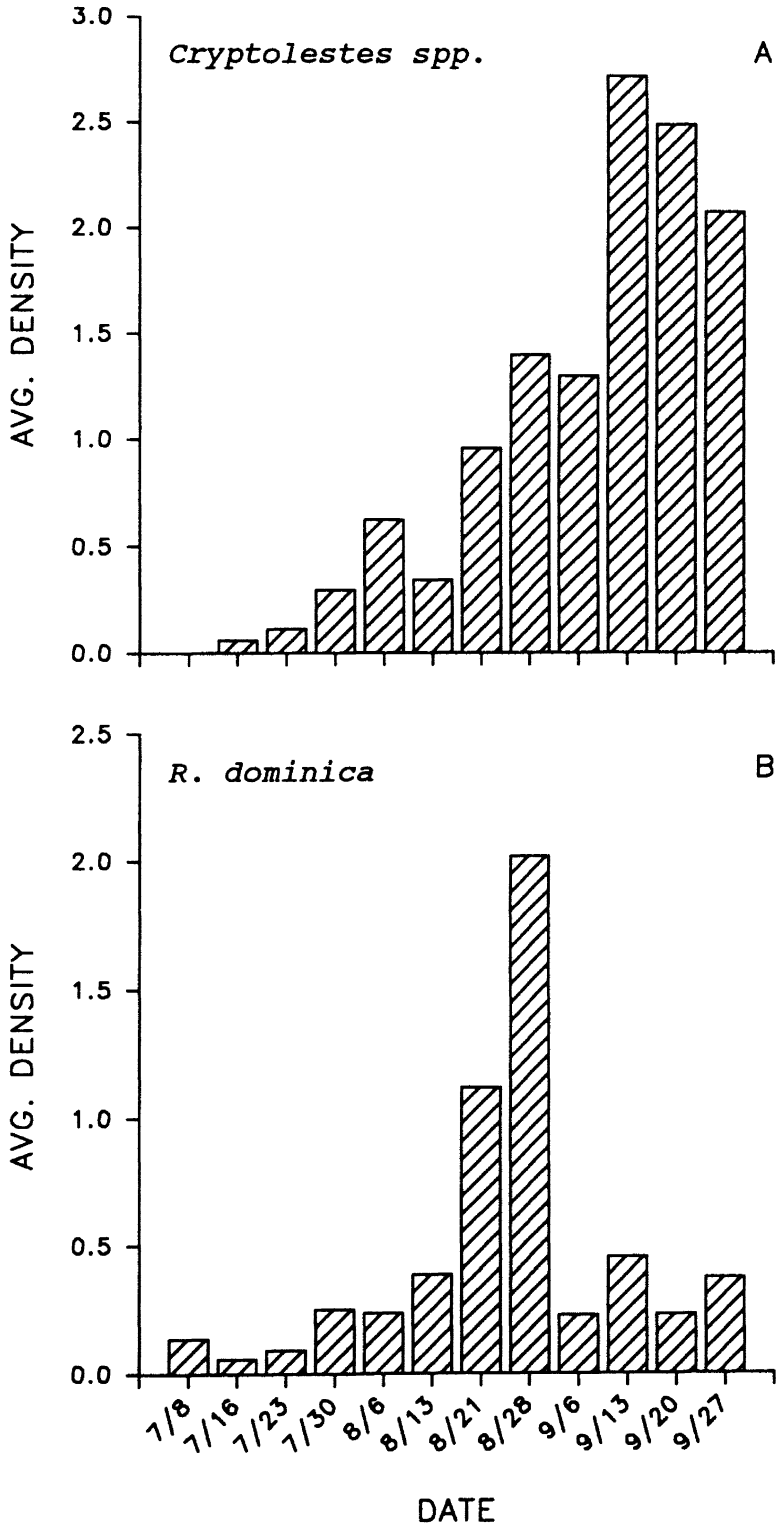

R. dominica
E
AVG. No. OF INSECTS
0
1
2
3
4
5
6
6/24
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

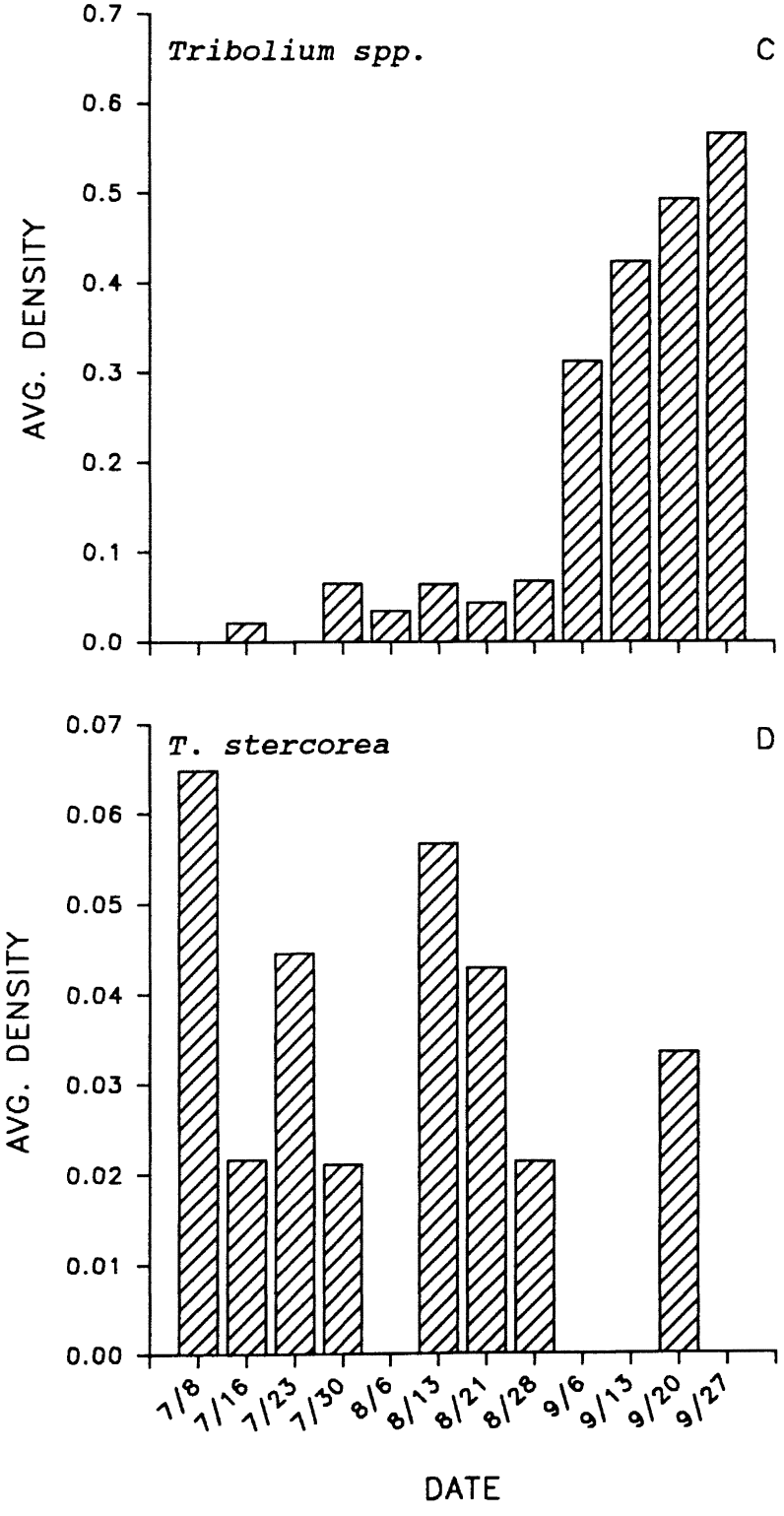

CENTER
EAST
NORTH
SOUTH
WEST
AVG. No. OF INSECTS
0
10
20
30
40
50
60
70
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

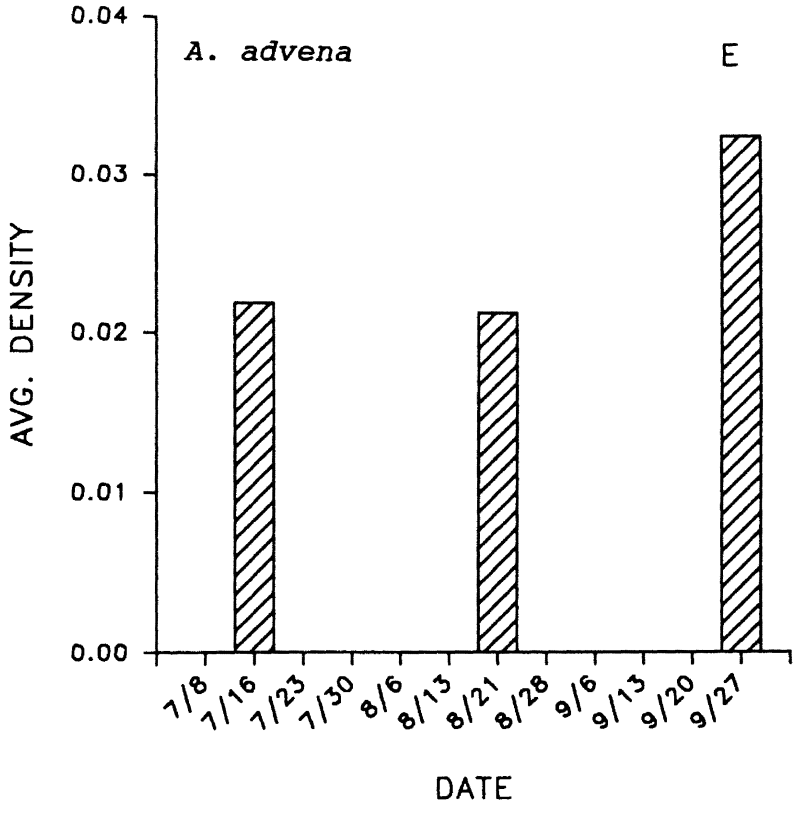

y1
y2
CENTER
NORTH
WEST
EAST
SOUTH
14
12
10
8
6
4
2
0
1300
975
650
325
0
AVG. No. OF INSECTS
AVG. No. OF INSECTS
FGB
HFB
LGB
RFB
RGB
SPECIES

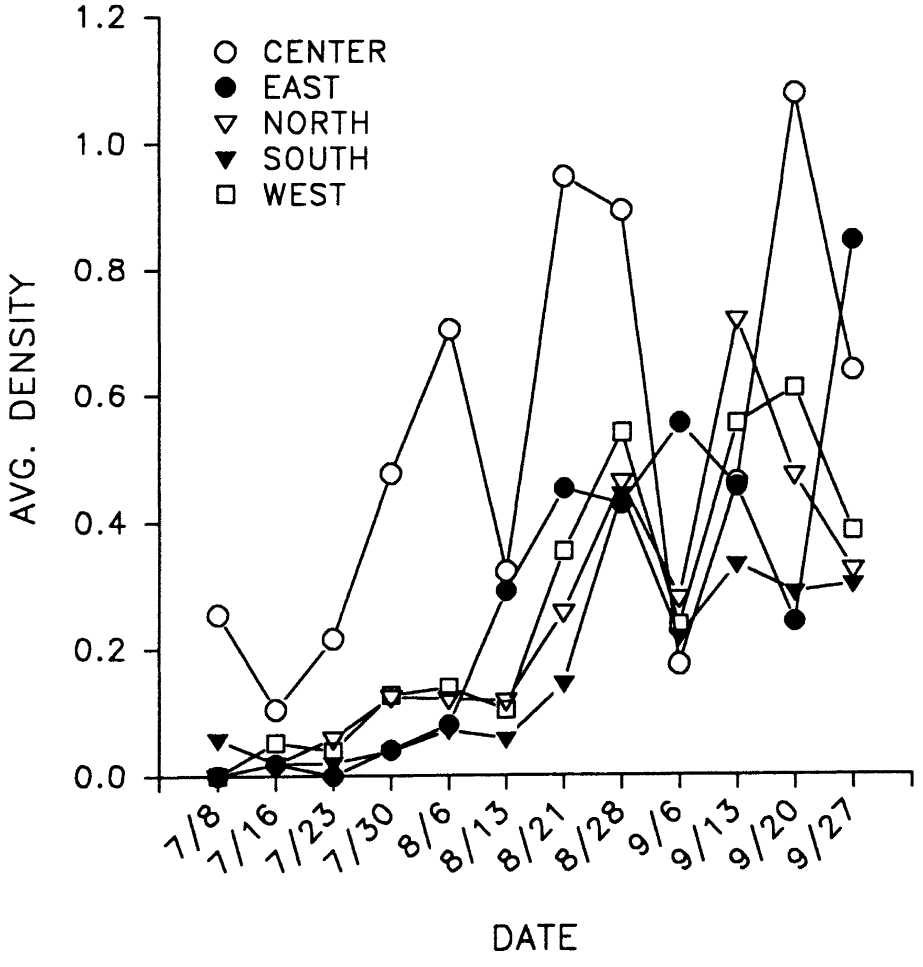

y1
y2
WALL
1/2 RADIUS
AVG. No. OF INSECTS
AVG. No. OF INSECTS
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
FGB
HFB
LGB
RFB
RGB
SPECIES

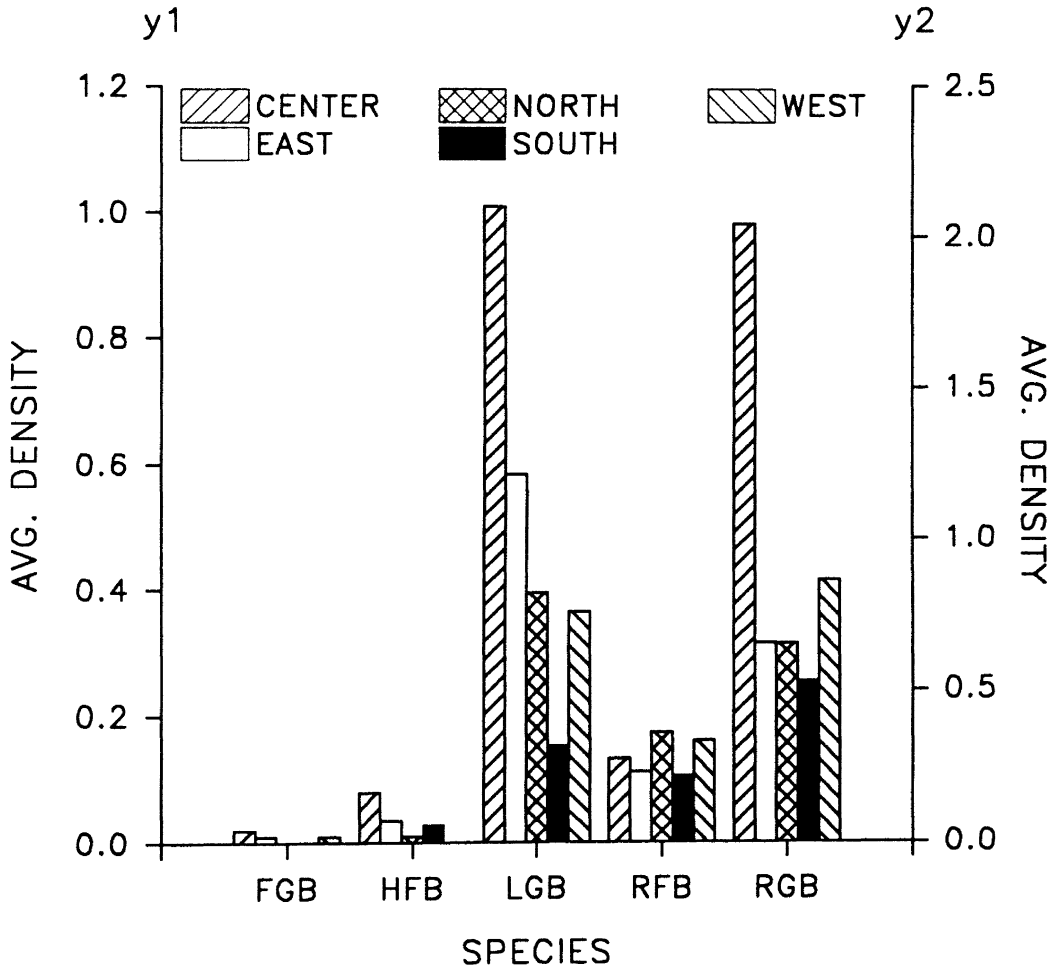

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
AVG. DENSITY
COR
FGB
HFB
HYME
LGB
OTHERS
RFB
RGB
RW
SGB
SPECIES

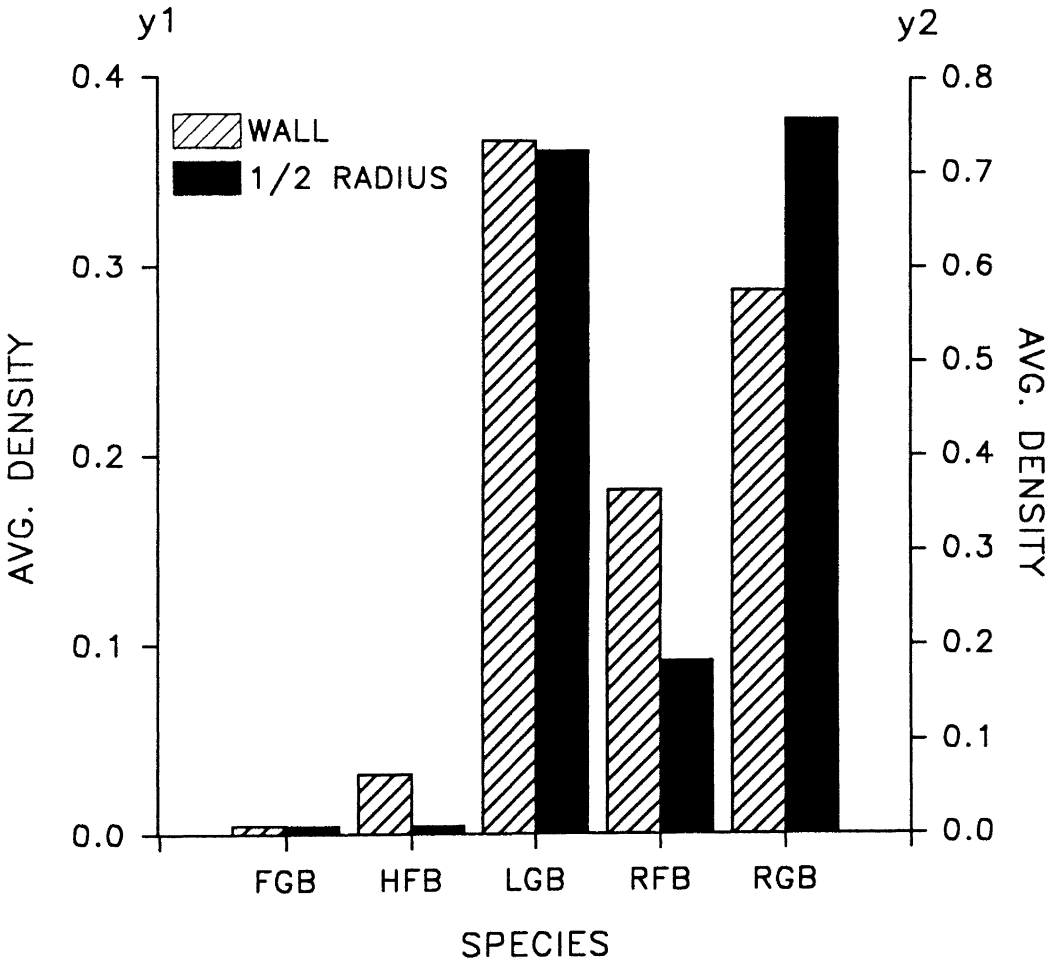

Cryptolestes spp.
A
AVG. DENSITY
3.0
2.5
2.0
1.5
1.0
0.5
0.0
R. dominica
B
AVG. DENSITY
2.5
2.0
1.5
1.0
0.5
0.0
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE

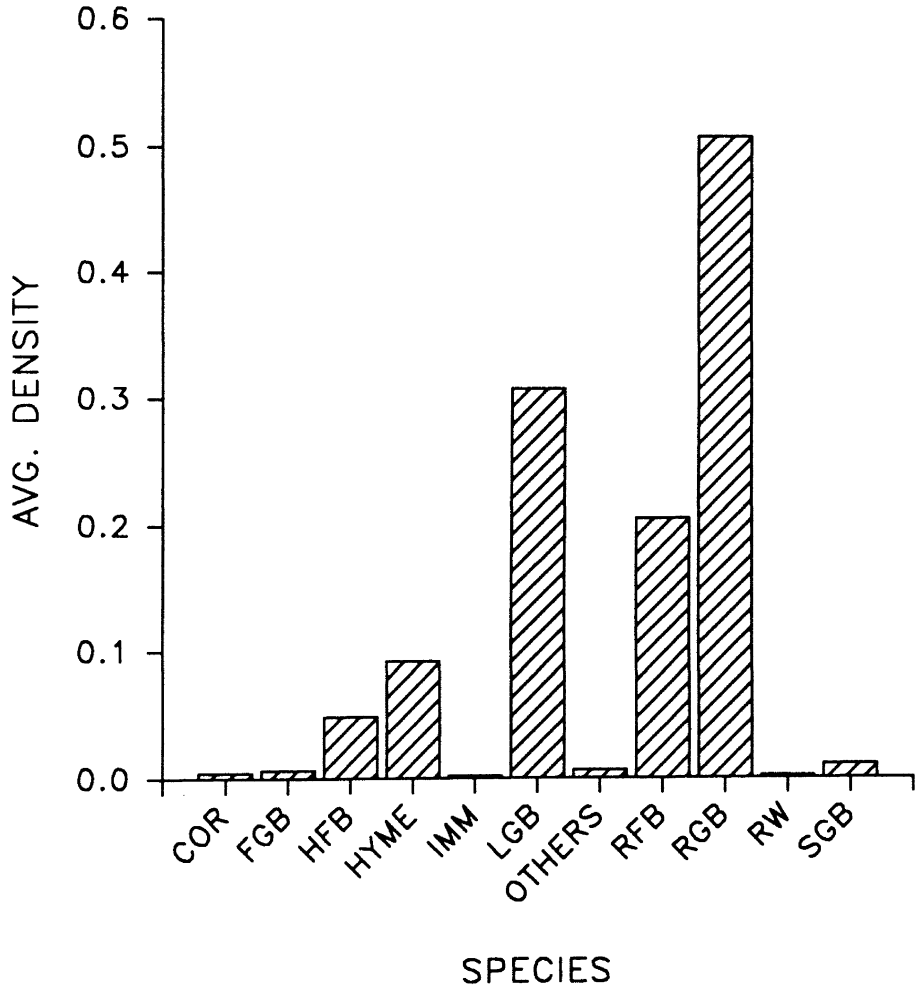

Tribolium spp.
C
AVG. DENSITY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
T. stercorea
D
AVG. DENSITY
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE


A. advena
E
AVG. DENSITY
0.04
0.03
0.02
0.01
0.00
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE


1.2
1.0
0.8
0.6
0.4
0.2
0.0
AVG. DENSITY
CENTER
EAST
NORTH
SOUTH
WEST
7/8
7/16
7/23
7/30
8/6
8/13
8/21
8/28
9/6
9/13
9/20
9/27
DATE


y1
y2
CENTER
NORTH
WEST
EAST
SOUTH
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2.5
2.0
1.5
1.0
0.5
0.0
AVG. DENSITY
AVG. DENSITY
FGB
HFB
LGB
RFB
RGB
SPECIES


y1
y2
0.4
0.3
0.2
0.1
0.0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
WALL
1/2 RADIUS
AVG. DENSITY
AVG. DENSITY
FGB
HFB
LGB
RFB
RGB
SPECIES


0.6
0.5
0.4
0.3
0.2
0.1
0.0
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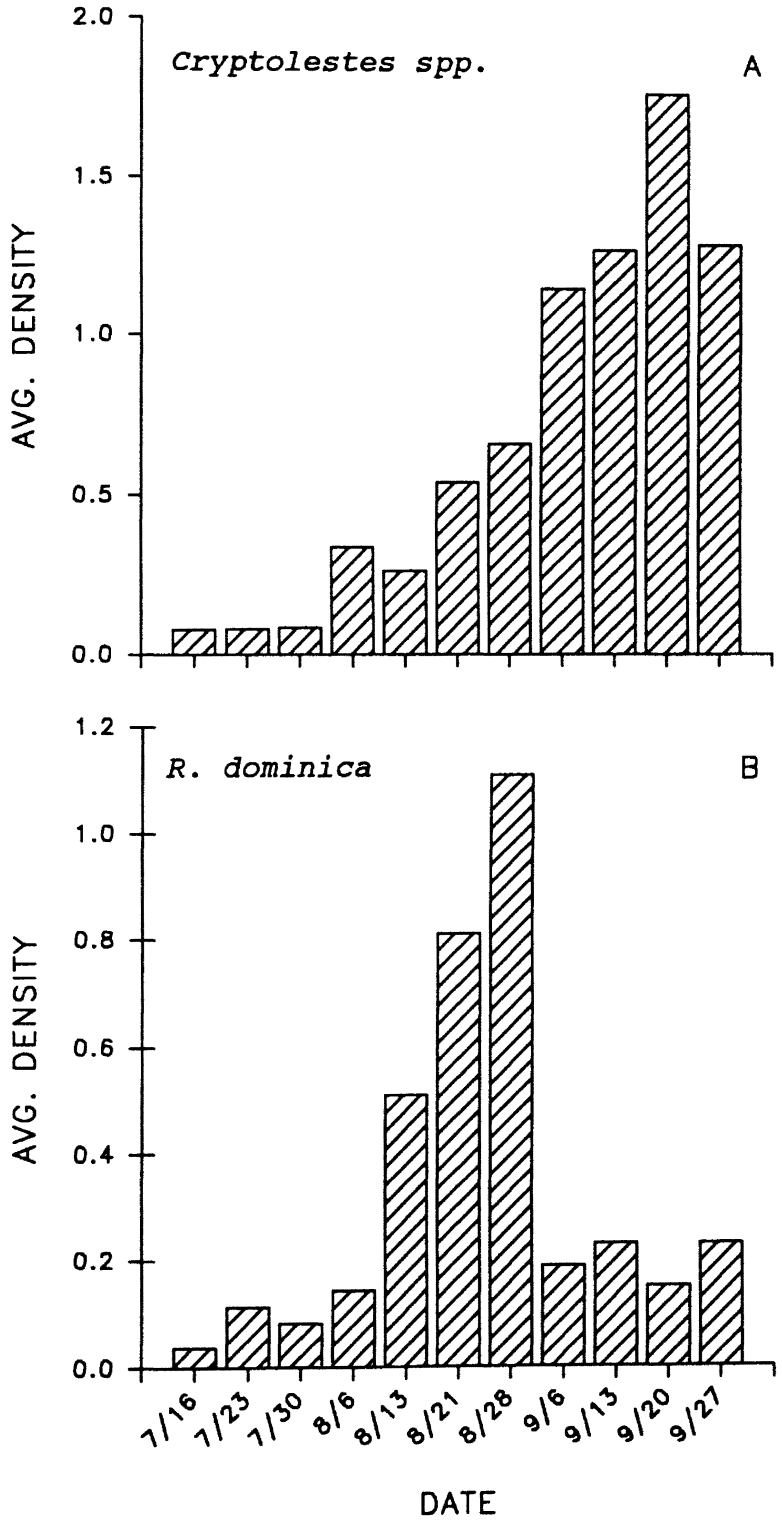
HFB
HYME
IMM
LGB
OTHERS
RFB
RGB
RW
SGB
SPECIES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0.0
R. dominica
B
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1.0
0.8
0.6
0.4
0.2
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7/30
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8/21
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9/20
9/27
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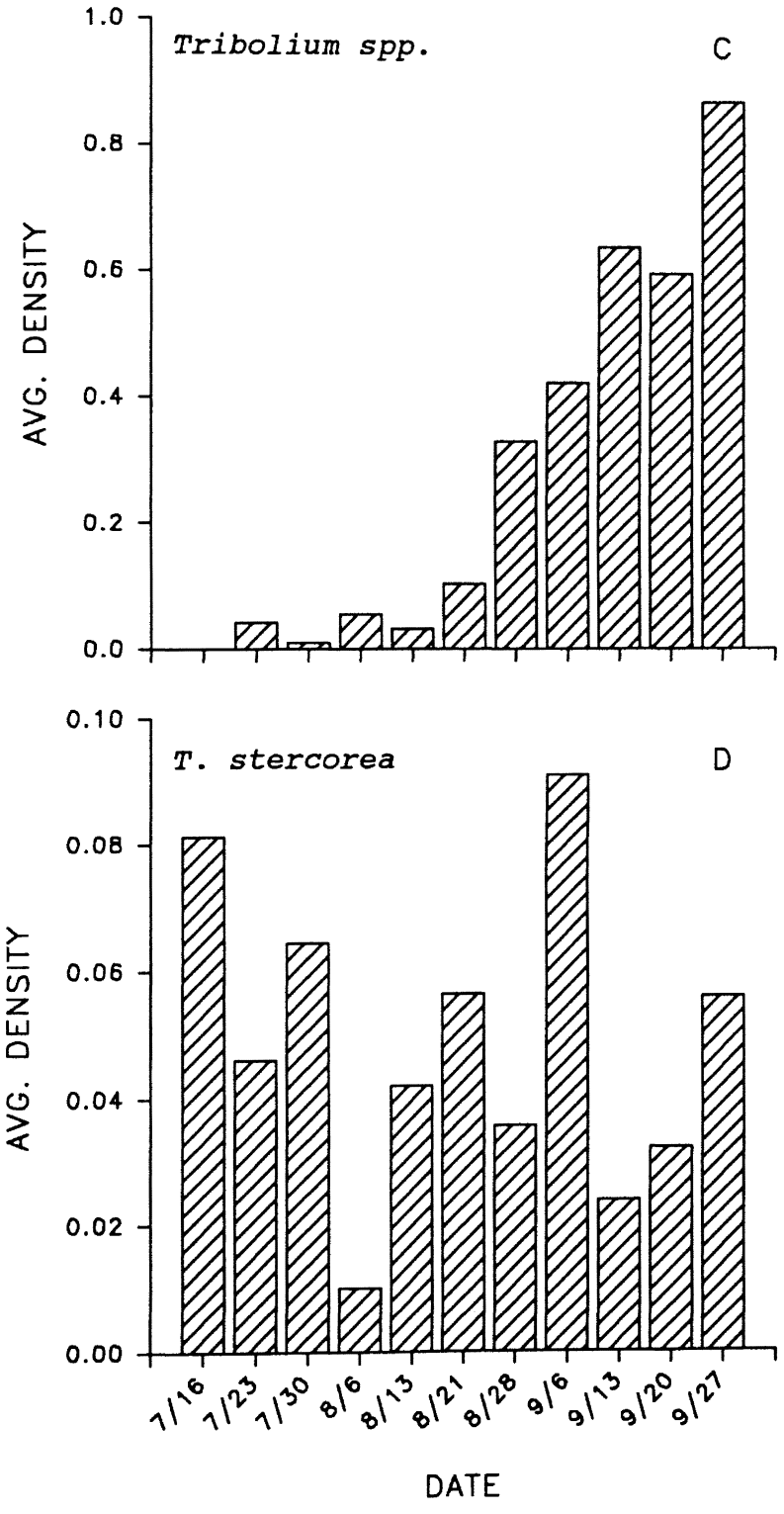
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0.0
T. stercorea
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AVG. DENSITY
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0.08
0.06
0.04
0.02
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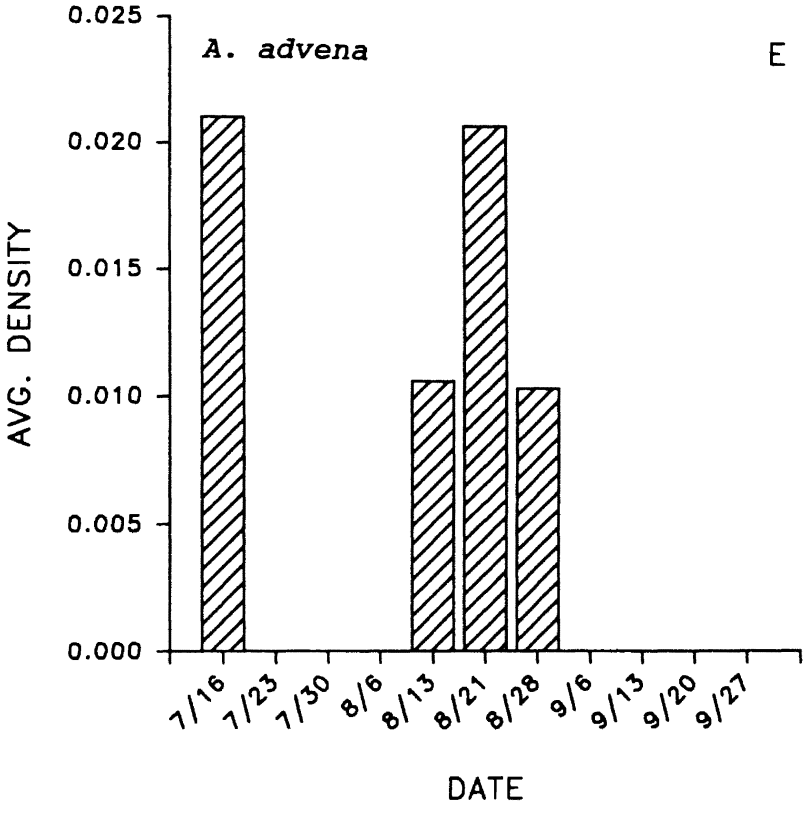
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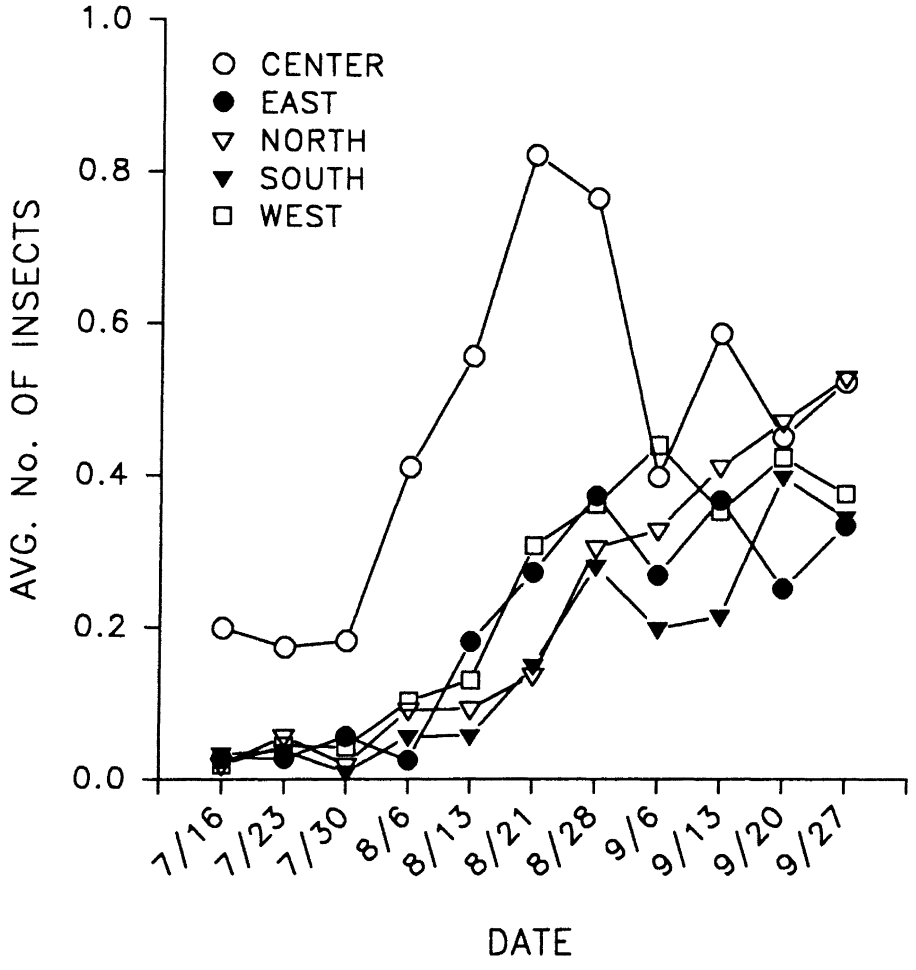
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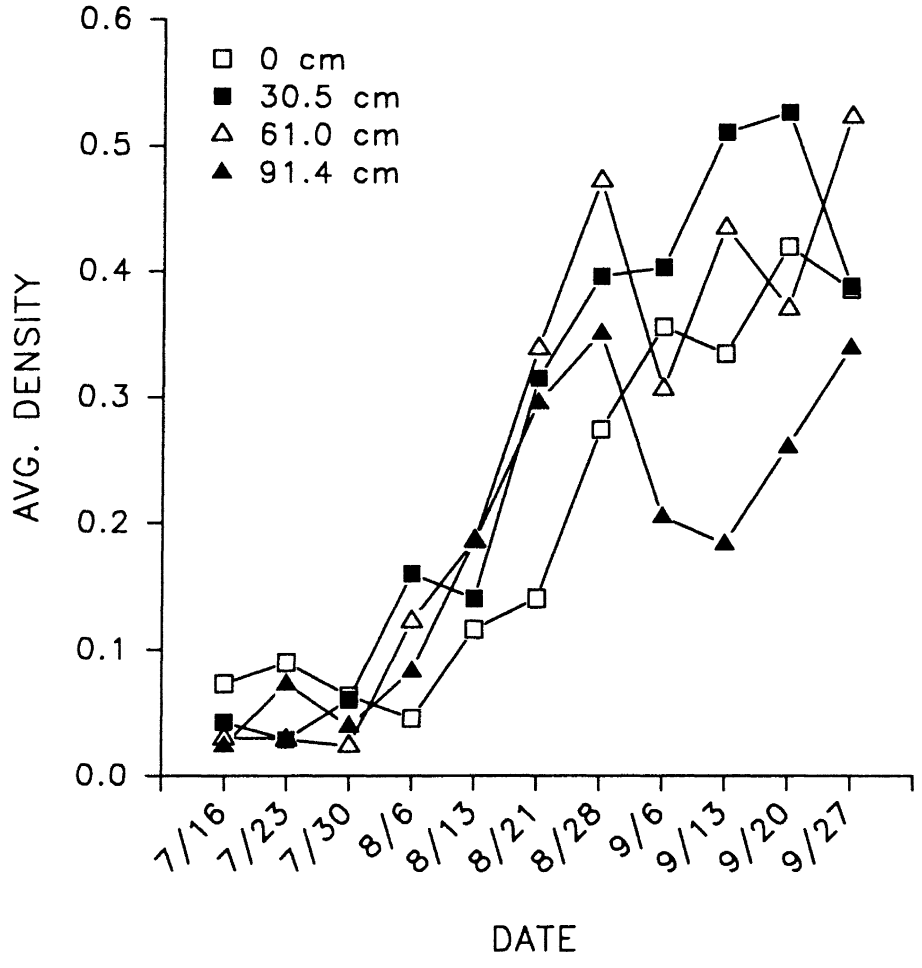
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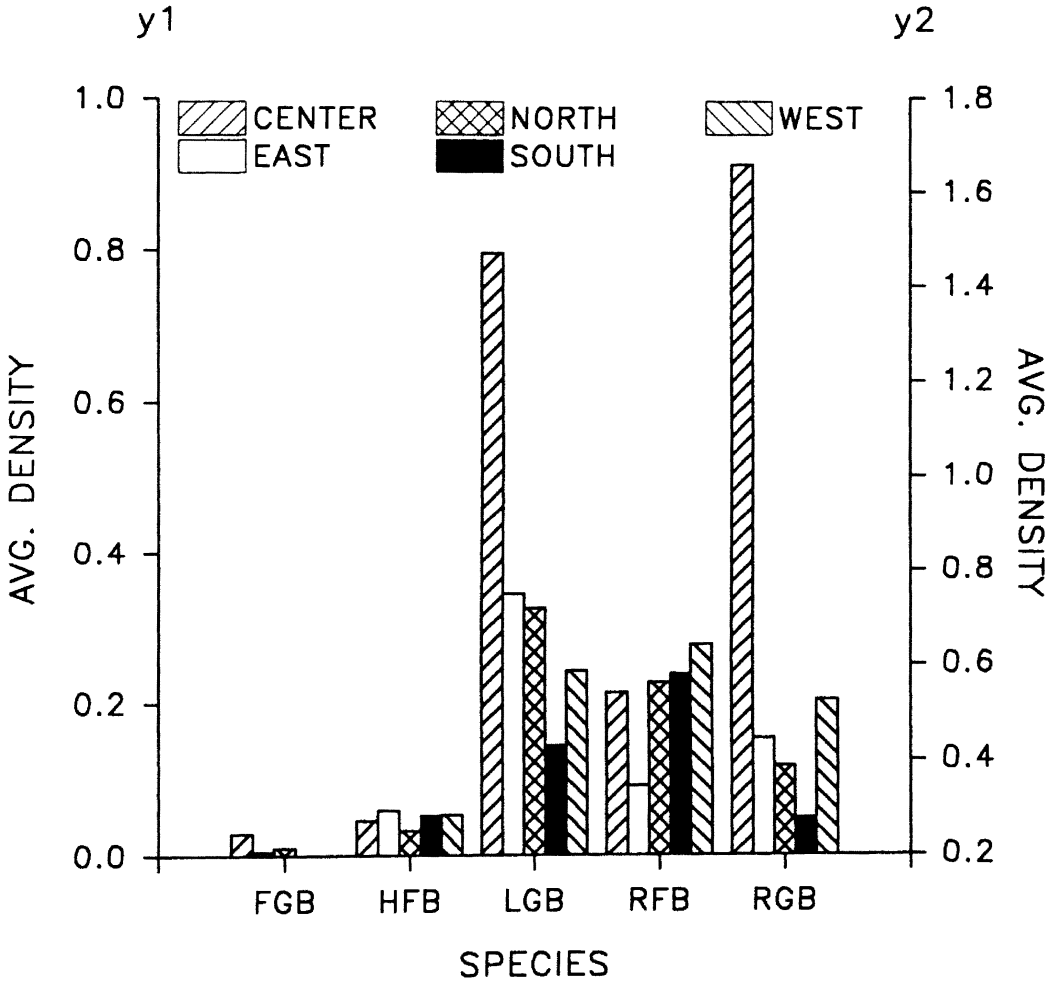
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0.8
0.6
0.4
0.2
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SOUTH
WEST
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FGB
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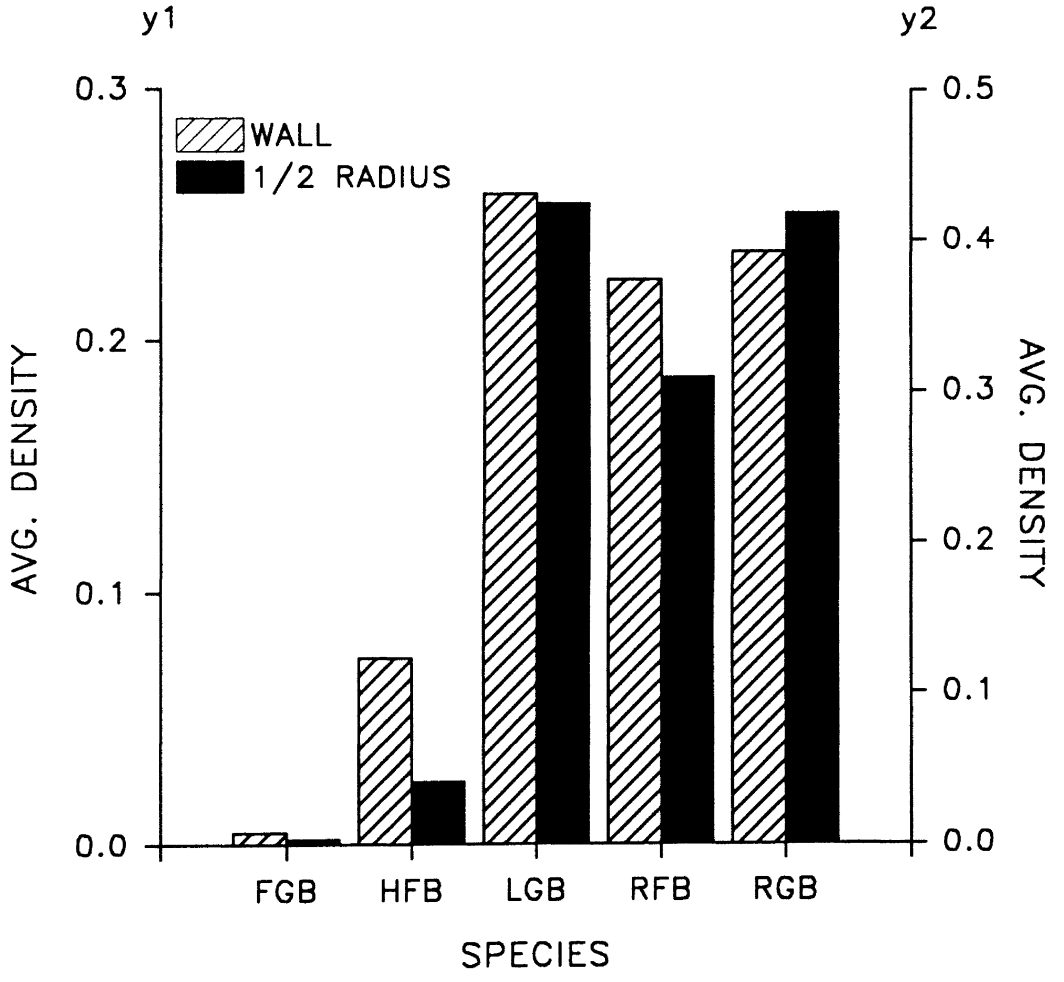
LGB
RFB
RGB
SPECIES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FGB
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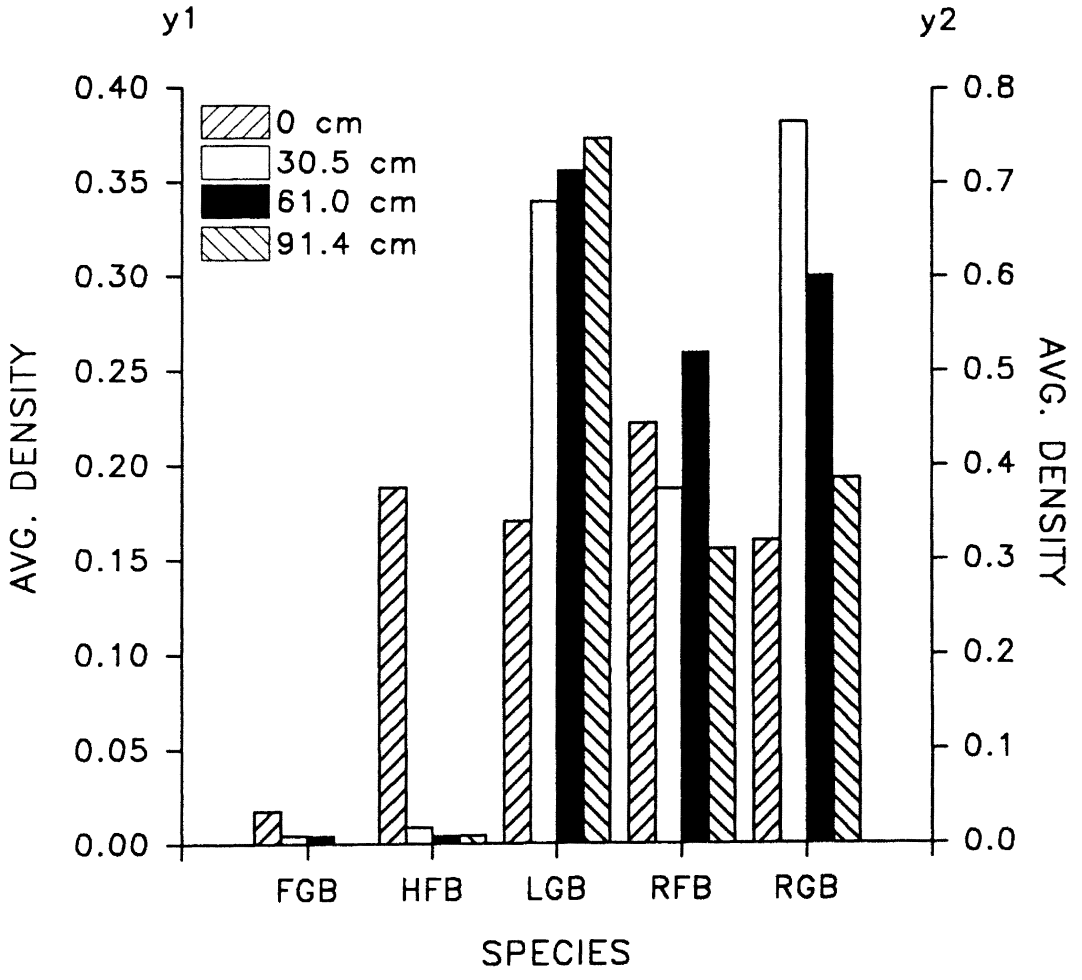
LGB
RFB
RGB
SPECIES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0.5
0.4
0.3
0.2
0.1
0.0
0 cm
30.5 cm
61.0 cm
91.4 cm
AVG. DENSITY
AVG. DENSITY
FGB
HFB
LGB
RFB
RGB
SPECIES

CHAPTER III

RELATIONSHIPS AMONG PITFALL PROBE TRAPS, GRAIN TRIER AND CUP PROBE IN SAMPLING STORED WHEAT INSECTS

Abstract

Relationships among the number of insects found in unbaited pitfall probe traps and grain trier and cup probe samples were studied in three farm bins in North Central Oklahoma in 1991. Species detected and mean numbers of insects varied with sampling method. Probe traps were more sensitive than the other sampling methods used in the grain mass in detecting active species such as *Cryptolestes* spp. and *A. advena*. In contrast, less mobile insects such as *R. dominica* were better detected by trier and cup probe samples. A significant correlation was found for numbers of insects in traps and estimated insect densities from both grain trier and cup samples. Association between numbers of individual species and estimated densities from both grain sampling devices was found for *Cryptolestes* spp., *Tribolium* spp., and *R. dominica*. Treatment thresholds for pitfall probe traps obtained from simple linear regressions with densities estimated from cup probe samples were 7.7 and 14.4% larger than thresholds computed using grain trier densities for *Cryptolestes* spp. and *R. dominica*, respectively. Treatment thresholds for *Tribolium* spp. were 35.3% larger than density estimates from grain trier samples. Traps proved to be a more sensitive tool for

detecting insect infestations. However, trier and cup probe samples were also important in detecting insects that were less likely to be captured by pitfall probe traps.

Introduction

Stored grain insects are a major cause of stored grain damage in Oklahoma (Noyes et al. 1988). Identifying damaging insect population levels is based upon the ability to detect and estimate the abundance and distribution of insect populations (Faustini et al. 1990). Although new methods such as acoustical monitoring (Vick et al. 1988, Webb et al. 1988, Hagstrum et al. 1990a) and infrared carbon dioxide analysis (Bruce 1988) have been studied for detecting and monitoring insect pests, the feasibility of these methods under actual storage conditions is unknown. Conventional grain sampling is still the standard way to detect insect populations (Cuperus et al. 1990).

The standard sampling method for grain grading is the use of a grain trier. Other methods have been developed to detect insect populations. These techniques include the use of vacuum probes, cup probes, and flight and probe traps (with or without food and/or pheromone baits).

Grain triers, cup probes, and vacuum probes were specifically designed to sample grain. The probability of insect detection with grain triers and cup probes is low because of small grain sample size and the fact that they are inserted and immediately from the grain, especially in

lightly infested grain. The efficiency of grain triers and cup probes is not improved by leaving them in the grain for longer periods of time since insects can move in and out freely (Loschiavo & Atkinson 1973).

The vacuum probe takes samples from deep within the grain mass. This method, as with the grain trier and cup probe, presents the problem of grain removal which causes mixing of different layers of grain. Disturbance of microhabitats makes studies of the ecology of grain insects difficult. Again, this method yields instantaneous samples. Also, an estimation of insect density per kilogram of grain can be obtained (Hagstrum et al. 1985).

Probe traps (baited or unbaited) were designed to capture insects. These devices have the advantage that they can remain in the grain mass for long periods of time, and therefore, more readily detect low densities of insects. However, with the use of traps, grain samples are not obtained and thus, supplementary probing is needed for grain quality determinations (Barak & Harein 1982).

Factors such as temperature, grain moisture, presence of molds, and insect behavior affect the distribution of insects within a grain mass. A good sampling program and the use of more sensitive trapping methods to detect low insect densities would allow managers to develop alternative management strategies (Wilkin 1990, Hagstrum et al. 1991). The determination of trap efficiency would permit insect

density estimates and thus enable the application of control measures only when they are necessary and cost effective.

In this study, the relationships between the number of insects captured in unbaited pitfall probe traps, grain trier and cup probe samples were examined with the following objectives: to compare the effectiveness of pitfall probe traps with the grain trier and cup probe in a management program and to determine probe trap treatment thresholds for the most important stored wheat species in Oklahoma.

Materials and Methods

Three steel farm bins located in North Central Oklahoma, with capacities of 141.52 metric tons (5,200 bu), 68.04 metric tons (2,500 bu)[1], and 136.08 metric tons (4,500 bu) and filled with hard red winter wheat (*Triticum aestivum* L.) were used for this study. Before grain binning (May 17, 1991), the bins were cleaned according to standard integrated pest management (IPM) procedures including the removal of grain residue and treatment of bin floors with chloropicrin fumigant.

Plastic pitfall traps (WB Probe II traps; Trécé Inc., Salinas, CA) were placed in the bins (July 8, July 1, and July 8) in nine locations in the grain mass. Two probe traps were placed per cardinal direction at ≈ 30.5 cm from the bin wall and at one-half the bin radius. Additionally, one probe trap was placed in the center of each bin.

Standard samples were taken using a 1.6 m brass grain

trier (650 g capacity; Seedburo Equipment Co., Chicago, IL) at the nine probe trap locations (starting on July 16, July 8, and July 16). Also, cup probe samples (38.1 cm deep bin cup (265 g capacity; Seedburo Equipment Co., Chicago, IL) were drawn from the grain mass at the same locations and at four depths: 91.4, 61.0, 30.5, and 0 cm from the surface, resulting in 36 samples. Samples at 61.0, 30.5, and 0 cm corresponded to the depth of probe traps.

Monitoring of both trapping methods and collection of grain trier and cup probe samples were carried out weekly. Flight traps were replaced and taken to the laboratory for processing. Samples taken with the grain trier and cup probe, as well as insects collected from pitfall probe traps, were placed in plastic bags, labelled, and taken to the laboratory for processing. Insects found in flight traps and probe traps were identified and counted. Only insects which were related to grain were included in the count.

An inclined sieve similar to that described by Hagstrum et al. (1985) was used to separate insects from grain in trier and cup probe samples. Insects were then identified and counted. Weight and moisture content of the grain were determined using an electronic balance (Ohaus Lume-O-Gram balance; Ohaus Scale Corp., Florham Park, NJ) and an hygrometer (Agromatic WK II; ASIDIC Ltd., Clear Lake, IA).

When the insect count in a bin averaged two primary insects[2] in trier samples (≈ 2 insects per 500 g), which is

the generally accepted treatment threshold, the bin was fumigated. One of the bins was fumigated on August 31 while the other two bins were sampled until the end of the study (September 27). At the end of the sampling period, additional grain trier samples were taken for determining the level of fines in the different regions of the bins.

Thermocouples were used to determine grain temperature at the time of sample collection. Temperatures were recorded at the center of the bin and at one-half the bin radius in cardinal directions at the depths corresponding to the cup probe samples.

Differences among species collected by the different sampling methods and among trap and sampling locations were determined by Fisher's least significant difference (LSD) multiple comparison technique with $\alpha = 0.05$ using SAS General Linear Models (GLM) (SAS Institute 1988). A log transformation was used on insect counts ($\log_{10}(No+1)$) (Little & Hills 1978). GLM with LSD multiple range tests were also used to determine if the mean temperature and mean moisture content differed among the locations sampled in the grain mass. The mean percentage of fines in the different regions sampled were compared using an arcsine square root transformation (Little & Hills 1978).

Sets of independent contrasts (Proc GLM, SAS Institute 1988) were computed to compare mean number of insects in the center with cardinal directions in the grain mass. Pearson

product-moment correlations were computed to assess the degree of linear relationship between the number of insects in pitfall probe traps, grain trier samples, and cup probe samples.

Simple linear regressions were used to determine the degree of linear relationship between pitfall probe trap catches and insect density estimates from grain trier samples and cup probe samples for the lesser grain borer, *R. dominica*, *Cryptolestes* spp. and *Tribolium* spp. Regression coefficients and standard treatment thresholds (USDA 1990) were used to estimate treatment thresholds for pitfall probe traps.

Tables of analysis of variance for the different sampling methods, temperature, moisture content and level of fines are presented in appendix A.

Results

Occurrence of Insect Species. Most of the insects found were beetles (Coleoptera). The most commonly occurring species in the three sampling methods were *Cryptolestes* spp. (Cucujidae) (rusty grain beetle, *C. ferrugineus* (Stephens), and flat grain beetle, *C. pusillus* (Schönherr)); foreign grain beetle, *Ahasverus advena* (Waltl) (Cucujidae); *Tribolium* spp. (Tenebrionidae) (red flour beetles, *T. castaneum* (Herbst), and confused flour beetles, *T. confusum* Jacquelin du Val); hairy fungus beetle, *Thyphaea stercorea* (L.) (Mycetophagidae); lesser grain borer, *Rhyzopertha*

dominica (F.) (Bostrichidae); *Corticaria* spp. (Lathridiidae). Other species found in smaller proportions were the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Cucujidae); rice weevil, *Sitophilus oryzae* (L.) (Curculionidae); Larger black flour beetle, *Cynaeus angustus* (Le Conte) (Dermestidae); and other insects of the families Dermestidae and Anthicidae that were not identified. The Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae) was sporadically detected. Mites were also detected but no effort was made to distinguish flour or grain mites from predatory mites and they were not quantified. In addition to stored grain insects, parasitic wasps (Hymenoptera) were detected and registered as an Order in the counts but were not identified.

Pitfall Probe Traps. Pitfall probe traps detected insects in the grain mass during the first week of sampling (June 24). However, because grain had to be removed from the bins to facilitate sampling, probe traps were not replaced until July 1.

After the fourth week of sampling (July 23) the number of insects found in pitfall probe traps increased, reaching a maximum by the beginning of September (Fig. 1). A total of 254,056 adult insects of 11 different species was counted in pitfall probe traps during the entire experiment (Table 1). The average number of adult insects of the five most abundant species in pitfall probe traps varied (F = 342.82;

df = 4, 1305; *P* = 0.0001). *Cryptolestes* spp. were trapped in significantly higher numbers than any other species present in these traps (Table 2). The average number of foreign grain beetles and *Tribolium* spp. captured by probe traps was not different. Hairy fungus beetles and lesser grain borers were the least abundant of the five species. More *Corticaria* spp. were captured than lesser grain borers (Table 1), however, they were not included in the analysis because they are not important pests of stored grain.

Significantly more insects were detected by probe traps in the center of the bins than in the other positions (*F* = 5.51; df = 8, 1305; *P* = 0.0001) (Table 3). Traps placed at 30.5 cm from the bin walls tended to capture more insects than those placed at one-half the bin radius. The average number of insects captured by all traps placed by the wall was significantly larger than the average number of insects found in traps at one-half the bin radius (*F* = 7.14; df = 1, 1305; *P* = 0.0076). A significantly higher (*F* = 31.35; df = 1, 1305; *P* = 0.0001) number of insects was found in the center compared with all other positions in the bins. No difference was found in the number of insects captured in the different cardinal directions.

The average number of insects of a particular species varied with trap position (*F* = 1.80; df = 32, 1305; *P* = 0.0001). Foreign grain beetles, hairy fungus beetles, and *Tribolium* spp. were captured in higher numbers by pitfall

probe traps located in the center and west side (Fig. 2). Lesser grain borers were more abundant in the center and east side, while *Cryptolestes* spp. were detected predominately in the center. In regard to the lateral distribution, most species were found in higher numbers close to the bin wall, except for *Cryptolestes* spp. which were distributed in greater numbers at one-half the bin radius (Fig. 3).

Grain Trier. Insects were found in grain trier samples beginning with the first week that samples were taken with this device (July 8). The average density of insects increased throughout the sampling period reaching a maximum by the end of August (Fig. 1). The reduction in the average density of insects after this date can be attributed in part to the fumigation of one of the bins sampled. Grain trier samples detected all species found in pitfall probe traps but the larger black flour beetle and Indianmeal moth (Table 1). The average density of adult insects of the five most abundant species in grain trier samples differed (F = 66.04; df = 4, 1305; P = 0.0001). *Cryptolestes* spp. were present in higher densities, followed by the lesser grain borer and *Tribolium* spp. (Table 4). Hairy fungus beetles and foreign grain beetles were present in lesser densities. *Corticaria* spp. had a higher density in grain trier samples than foreign grain beetles (Table 1) but they were not included in the statistical analysis because they are minor pests.

A significantly higher density of insects was detected by grain trier samples in the center than in any of the other regions sampled (F = 3.90; df = 8, 1305; P = 0.0001) (Table 5). No differences were found among the other sampling positions. The average density of insects found in the east side was higher than in the south side (F = 4.25; df = 1, 1305; P = 0.0393). Higher densities were found in the center when compared with the mean of all other positions (F = 24.76; df = 1, 1305; P = 0.0001). No significant difference (F = 0.0; df = 1, 1305; P = 0.9920) was found between the average density of insects detected at 30.5 cm from the bin wall and at one-half the bin radius.

The average density of adult insects of a particular species varied with sample location (F = 1.76; df = 32, 1305; P = 0.0059). Except for *Tribolium* spp., all other species were found in higher densities in the center of the bins (Fig. 4). *Tribolium* spp. were found mainly in the north and west sides. Foreign grain beetles were not detected by grain trier samples taken in the north or south sides.

With regard to lateral distribution, *Cryptolestes* spp. had a higher density at one-half the bin radius (Fig. 5). *Tribolium* spp. and hairy fungus beetles were found in higher densities by the bin wall. Lesser grain borers and foreign grain beetles were found in approximately the same densities at 30.5 cm from the bin wall and at one-half the bin radius.

Deep Cup Probe. Cup probe samples detected insects the first

week of sampling with this device (July 16). The average density of insects increased throughout the sampling period (Fig. 1). The reduction in the density of insects detected after August 28 can be attributed in part to the fumigation of one of the bins sampled. Cup probe samples did not detect larger black flour beetles (Table 1). The average density of insects of the five most abundant species found in cup probe samples varied (F = 100.26; df = 4, 5040; P = 0.0001). *Cryptolestes* spp. were present in higher densities, followed by lesser grain borers and *Tribolium* spp. (Table 6). Hairy fungus beetles and foreign grain beetles were present in cup probe samples in the lowest density.

The average density of insects detected by cup probe samples in the different sampling locations in the grain mass varied (F = 11.95; df = 8, 5040; P = 0.0001). Samples taken at the center had the highest density of insects (Table 7). Significantly higher densities of insects were found at 30.5 and 61.0 cm from the grain surface than at the 91.4 cm depth (F = 3.06; df = 3, 5040; P = 0.0272) (Table 8). No significant interaction was found between the density of insects captured at different depths within a sampling position. The density of insects in the west side was higher than in the south side (F = 6.60; df = 1, 5040; P = 0.0103). A significantly higher density of insects was found when the center was compared with the mean of all other locations (F = 75.97; df = 1, 5040; P = 0.0001) . No significant

difference (F = 0.69; df = 1, 5040; P = 0.4067) was found between the mean density of insects captured at 30.5 cm from the bin wall and at one-half the bin radius.

The average density of insects of the five most abundant species in cup probe samples varied with location in the grain mass (F = 5.63; df = 32, 5040; P = 0.0001). *Cryptolestes* spp., lesser grain borers and foreign grain beetles had higher densities in samples taken at the center of the bins (Fig. 6). *Tribolium* spp. were found in higher densities in the west, while hairy fungus beetles had higher densities in the east, south and west sides. In regard to the lateral distribution of the species in the bins, hairy fungus beetles, *Tribolium* spp. and the lesser grain borer had higher densities by the bin wall (Fig. 7). *Cryptolestes* spp. were detected in higher densities at one-half the bin radius, while foreign grain beetles were found in approximately the same density by the wall and at one-half the bin radius.

The average density of insects of the five most abundant species varied with depth in the grain mass (F = 6.52; df = 12, 5040; P = 0.0001). The foreign grain beetle and the hairy fungus beetle were found in higher densities on the grain surface (0 cm) (Fig. 8). The density of lesser grain borers increased with increasing depth, having the highest density at 91.4 cm within the grain mass. *Tribolium* spp. had higher densities mainly in samples taken at the

61.0 cm depth and at the surface, while *Cryptolestes* spp. had higher densities in the two intermediate layers (30.5 and 61.0 cm).

Temperature, Moisture Content and Dockage. Grain temperatures did not differ among the five regions (F = 1.62; df = 4, 332; P = 0.1677), with a mean temperature of 31.83 ± 2.53°C. However, mean grain temperatures at each depth were significantly different from one another (F = 195.88; df = 3, 332; P = 0.0001). Grain temperatures were 27.39 ± 4.17, 32.54 ± 1.84, 33.39 ± 2.76 and 34.0 ± 2.89°C at depths 0, 30.5, 61.0 and 91.4 cm, respecively. No significant interaction (F = 0.19; df = 12, 332; P = 0.9983) was found between direction and grain depth.

The mean moisture contents for grain trier and cup probe samples were 10.83 ± 1.0 and 10.70 ± 1.87%, respectively. No significant differences were found among the moisture contents of grain trier samples (F = 0.78; df = 107, 162; P = 0.9176) or cup probe samples (F = 0.75; df = 431, 648; P = 0.9994).

The percentage of dockage at the end of the experiment was higher in the central core than in the cardinal directions. However, no significant differences in dockage between the different grain regions were detected (F = 0.16; df = 8, 18; P = 0.9943).

Efficiencies. Pitfall probe traps were more efficient than the grain trier and cup probe methods in detecting different

insect species in stored wheat. Pitfall probe traps detected foreign grain beetles more often than grain trier and cup probe samples as shown by the frequency of detection ratios (trap:trier, 82.8:1; trap:cup, 151.8:1) (Table 9). The smallest ratios were observed for the lesser grain borer (trap:trier, 1.6:1; trap:cup, 3.0:1) and *Cryptolestes* spp. (trap:trier, 2.0:1; trap:cup, 3.8:1). The five most abundant species were more frequently detected in grain trier samples than in cup probe samples.

Pitfall probe trap catch to estimated insect density ratios were largest for the foreign grain beetle (1,293.0:1 using density estimates from both grain trier and cup probe samples) and *Cryptolestes* spp. (trap:trier, 630.8:1; trap:cup, 655.2:1) (Table 10). The smallest trap catch to estimated density ratios were obtained for the lesser grain borer (trap:trier, 4.9:1; trap:cup, 6.1:1). Intermediate trap catch to density ratios were observed for *Tribolium* spp. and the hairy fungus beetle. The efficiencies of grain trier and cup probe samples in estimating insect densities of the five most abundant species varied according to species. The densities of *Tribolium* spp. and the hairy fungus beetle were higher in cup probe samples than in trier samples, while the density of the lesser grain borer was higher in grain trier samples. Estimated densities for the foreign grain beetle and *Cryptolestes* spp. were the same with these two methods. Data in Tables 9 and 10 indicate

that pitfall probe traps are the least efficient in detecting lesser grain borers as compared with other species.

Correlations for all insects in pitfall probe traps versus all insects in grain trier and cup probe samples were different from zero ($P < 0.05$) (Table 11). Correlation coefficients between the number of insects of a given genus in probe traps and the number of the same genus in grain trier and cup probe samples were >0.5 for *Cryptolestes* spp., *Tribolium* spp. and the lesser grain borer. The correlation coefficient between hairy fungus beetle numbers in pitfall probe traps and grain trier samples was not significantly different from zero ($P > 0.05$). On the other hand, the correlation coefficient for this species in probe traps versus cup probe samples was <0.20, suggesting a small degree of association.

Pitfall Probe Trap Thresholds. A linear relationship was detected between probe trap catches for the lesser grain borer, *Cryptolestes* spp. and *Tribolium* spp. (Figs. 9, 10 and 11) and their estimated densities according to grain trier samples. However, the models explained only 66, 25 and 29%, respectively, of the variability between these two methods. Simple linear regression between numbers of these species in pitfall probe traps and their estimated densities according to cup probe samples also indicated a linear relationship (Figs. 12, 13 and 14). In this case, the models explained

48, 34 and 28% of the variability between estimates of these two methods for the lesser grain borer, *Cryptolestes* spp. and *Tribolium* spp., respectively. Regression coefficients (β_1) for the lesser grain borer and *Cryptolestes* spp. were higher in cup probe samples than in grain trier samples. On the other hand, the regression coefficient for *Tribolium* spp. was higher from grain trier samples than from cup probe samples.

Estimates of treatment thresholds for pitfall probe traps using standard thresholds of two insects per 500 g (USDA 1990) are presented in Table 12. The treatment threshold for the lesser grain borer was 14.4% larger when estimated from insect densities in cup probe samples than from densities in grain trier samples. Treatment thresholds for *Cryptolestes* spp. were 7.7% larger for cup probe sample densities than for grain trier samples, while for *Tribolium* spp. grain trier sample thresholds were 35.3% larger than for cup probe samples. The intercepts in all regressions performed were significant indicating that when no insects of these species are found in grain trier or cup probe samples, pitfall probe trap thresholds correspond to the value of β_0.

Discussion

Totals of 568 and 4 insects (0.03 insects per 500 g) were detected by pitfall probe traps and grain trier samples, respectively, on the first date of collection (July

8). Cup probe samples detected a total of 30 insects (0.05 insects per 500 g) by July 16. The period between grain binning (June 17) and the first date of collection with pitfall probe traps and grain triers could explain the existence of insects in the grain when the first samples were collected.

Insect counts in the three sampling methods indicated that insects tended to accumulate in the center of the bins. Temperature and moisture content are known to play an important role in insect distribution in grain bulks (Surtees 1965) and affect trap and sample catches (Loschiavo 1983, Storey et al. 1983, Loschiavo & Smith 1986, Fargo et al. 1989). Temperature, moisture content and the percentage of dockage in the central core did not statistically differ from other regions in the grain mass in our study. Though, no statistical differences were found, the central core had the highest moisture content, temperature and percentage of fines, which could have biological significance for insects being found in higher numbers in this region.

Samples used to determine the level of dockage in our study, were taken at the end of the sampling period and the percentage of fines was highest in the center. The central core is known to have the highest level of fines in bins where the grain is loaded without a spreader (Noyes et al. 1988). Since the bins studied were loaded without a spreader, we feel confident in assuming that the central

core had highest level of fines throughout the sampling period. Also, species known to accumulate in grain with high percentages of dockage such as *Cryptolestes* spp. and *Tribolium* spp. (McGregor 1964, Tuff & Teleford 1964, Watters 1969) were found in higher numbers in this region. Hagstrum (1987) also found that during the first 12 wk of storage, neither the temperature nor the moisture contents were sufficiently different to explain why insects favor the center of the bins. He concluded that the level of fines in this region might explain the concentration of insects in the center early in the storage period.

As expected, pitfall probe traps captured more insects than grain and cup probe samples as calculated by catch ratios (Tables 9 and 10).

Probe traps also detected more insect species. Grain trier samples did not detect larger black flour beetles and Indianmeal moths, and cup probe samples did not detect larger black flour beetles (Table 1). However, grain trier and cup probe samples were more efficient in detecting species such as *R. dominica*, which represented the second most abundant species in these methods (Table 1). Subramanyam & Harein (1989) also found that probe traps were less likely to capture adults of insect species that are less mobile in grain, form aggregation pheromones such as *R. dominica*, or feed internally on kernels (e.g. - *R. dominica* and *Sitophilus* spp.). Pitfall probe traps, on the other

hand, were more efficient in detecting foreign grain beetles and *Cryptolestes* spp. Greater probe trap efficiencies for these species might result from the fact that they are a more active species (Surtees 1965) or because they form aggregation pheromones (Loschiavo 1974, Barak & Harein 1982, Loschiavo et al. 1986, Chambers 1990). In a laboratory study, Fargo et al. (1993) found that significantly more *C. ferrugineus* were caught in pitfall probe traps than *T. castaneum*, *R. dominica*, and *S. oryzae*.

Correlation coefficients for all genera combined in probe traps and in samples of both grain sampling devices were significantly different from zero (Table 11). However, in both cases, the relationship described only half the variability between methods. Similarly, Reed et al. (1991) found that correlation coefficients described less than half of the relationship between insects in probe traps and grain samples taken with a vacuum probe before November. Correlation coefficients increased after this month because of low insect numbers in both sampling methods. The high correlation coefficients in our study for the lesser grain borer might be explained by the fact that both grain sampling methods were more efficient in detecting this species as compared with other species (Table 10).

Differences in probe trap thresholds obtained from regressions of the number of insects in probe traps and estimated densities from grain trier and cup probe samples

did not differ very much for the lesser grain borer and *Cryptolestes* spp. (Table 12). However, larger differences were found for *Tribolium* spp. These differences may be attributed to differences in the efficiencies of the two grain sampling techniques to detect these species.

The treatment thresholds for pitfall probe traps estimated in this study are expressed as insect numbers not densities. According to Hagstrum et al. (1990b), one of the first considerations in planning a trapping program is the estimation of trap efficiency so that the number of insects caught can be converted to absolute insect densities (trap catch divided by trap efficiency). These same authors define trap efficiency as the portion of the total population per unit volume that is captured during a sampling period. However, the actual volume of grain that a pitfall probe trap 'samples' is not known. Estimates of insect density by standard grain sampling methods can vary according to species, number of samples, position in the grain mass where samples are taken, and grain condition. Nevertheless, these thresholds should be seen with caution since factors that are known to affect trap efficiency such as grain temperature, moisture content, trap placement, and grain condition (Cuperus et al. 1990) were not included in the regression equations.

In conclusion, probe traps are important in detecting insects in the grain mass mainly during the first phase of

insect infestation. Probe traps also detected more insect species than the grain sampling methods used. Probe traps were more sensitive in detecting active species such as *Cryptolestes* spp. and the foreign grain beetle. Trier and cup probe samples were important in detecting insects that are less likely to be trapped by pitfall probe traps, such as the lesser grain borer. A significant association was found for insect numbers in probe traps and estimated densities from both grain trier and cup probe samples. Correlation coefficients for all genera combined and for individual species explained approximately half the variability between pitfall probe traps catches and insect densities for grain trier and cup probe samples. Treatment thresholds for pitfall probe traps obtained from simple linear regressions with insect densities from cup probe samples were 7.7% larger for *Cryptolestes* spp. and 14.4% larger for the lesser grain borer than from thresholds computed from grain trier densities. Thresholds were 35.3% larger for *Tribolium* spp. with grain trier densities than with cup probe densities. Treatment thresholds for probe traps estimated in this study should be seen with caution since factors that are known to affect trap catch were not included in the equations.

References Cited

Barak, A. V. & P. K. Harein. 1982. Trap detection of stored-grain insects in farm-stored, shelled corn. J. Econ. Entomol. 75: 108-111.

Bruce, W. A. 1988. Detection of hidden insect infestations by infrared dioxide gas analysis. *In* Proceedings, 17th Intl. Congress of Entomology. Vancouver, Canada.

Chambers, J. 1990. Overview on stored-product insect pheromones and food attractants. J. Kansas Entomol. Soc. 63: 490-499.

Cuperus, G. W., W. S. Fargo, P. W. Flinn & D. W. Hagstrum. 1990. Variables affecting capture of stored-grain insects in probe traps. J. Kansas Entomol. Soc. 63: 486-489.

Fargo, W. S., D. Epperly, G. W. Cuperus, B. C. Clary & R. Noyes. 1989. Effect of temperature and duration of trapping on four stored grain insect species. J. Econ. Entomol. 82: 970-973.

Fargo, W. S., G. W. Cuperus, E. L. Bonjour, W. E. Burkholder & B. C. Clary. 1993. Influence of probe trap type and attractants on the trap capture of four stored grain insect species. J. stored Prod. Res. (In press).

Faustini, D. L., A. V. Barak, W. E. Burkholder & J. Leos-Martínez. 1990. Combination-type trapping for monitoring stored-product insects - a review. J. Kansas Entomol. Soc. 63: 539-547.

Hagstrum, D. W. 1987. Seasonal variations of stored wheat environment and insect populations. Environ. Entomol. 16: 77-83.

Hagstrum, D. W., G. A. Milliken & M. S. Waddell. 1985. Insect distribution in bulk-stored wheat in relation to detection or estimation of abundance. Environ. Entomol. 14: 655-661.

Hagstrum, D. W., K. W. Vick & J. C. Webb. 1990a. Acoustical monitoring of *Rhyzopertha dominica* (Coleoptera: Bostrichidae) populations in stored wheat. J. Econ. Entomol. 83: 625-628.

Hagstrum, D. W., P. W. Flinn, Bh. Subramanyam, D. W. Keever & G. W. Cuperus. 1990b. Interpretation of trap catch for detection and estimation of stored-product insect populations. J. Kansas Entomol. Soc. 63: 500-505.

Hagstrum, D. W., W. S. Fargo & P. K. Flinn. 1991. How to sample grain. pp. 65-69. *In* Management of grain, bulk commodities, and bagged products. Okla. State Univ. Coop. Ext. Serv. Circ. No. E-912.

Little, T. M. & F. J. Hills. 1978. Transformations (what to do when data break the rules). pp. 139-165. *In* Agricultural experimentation design and analysis. John Wiley & Sons, New York.

Loschiavo, S. R. 1974. Laboratory studies of a device to detect insects in grain, and of the distribution of adults of the rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), in wheat-filled containers. Can. Entomol. 106: 1309-1318.

Loschiavo, S. R. 1983. Distribution of the rusty grain beetle (Coleoptera: Cucujidae) in columns of wheat stored dry or with localized high moisture content. J. Econ. Entomol. 76: 881-884.

Loschiavo, S. R. & J. M. Atkinson. 1973. An improved trap to detect beetles (Coleoptera) in stored grain. Can. Entomol. 105: 437-440.

Loschiavo, S. R. & L. B. Smith. 1986. Population fluctuations of the rusty grain beetle, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), monitored with insect traps in wheat stored in a steel granary. Can. Entomol. 118: 641-647.

Loschiavo, S. R., J. Wong, N. D. G. White, H. D. Pierce, Jr., J. H. Borden & A. C. Oehlschlager. 1986. Field evaluation of a pheromone to detect adult rusty grain beetles, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), in stored grain. Can. Entomol. 118: 1-8.

McGregor, H. E. 1964. Preference of *Tribolium castaneum* for wheat containing various percentages of dockage. J. Econ. Entomol. 57: 511-513.

Noyes, R. T., B. L. Clary & G. W. Cuperus. 1988. Maintaining quality of stored grain by aeration. OSU Extension Facts No. 1100. Cooperative Extension Service, Oklahoma State University.

Reed, C. R., V. F. Wright, T. W. Mize, J. R. Pedersen & J. Brockschmidt Evans. 1991. Pitfall traps and grain samples as indicators of insects in farm-stored wheat. J. Econ. Entomol. 84: 1381-1387.

SAS Institute. 1988. SAS/STAT™ user's guide, release 6.03 ed. SAS Institute, Cary, NC.

Storey, C. L., D. B. Sauer & D. Walker. 1983. Insect populations in wheat, corn, and oats stored on the farm. J. Econ. Entomol. 76: 1323-1330.

Subramanyam, Bh. & P. K. Harein. 1989. Insects infesting barley stored on farms in Minnesota. J. Econ. Entomol. 18: 1817-1824.

Surtees, G. 1965. Ecological significance and practical implications of behaviour patterns determining the spatial structure of insect populations in stored grain. Bull. Entomol. Res. 56: 201-203.

Tuff, D. W. & H. S. Teleford. 1964. Wheat fracturing as affecting infestation by *Cryptolestes ferrugineus*. J. Econ. Entomol. 57: 513-517.

USDA. 1990. Official United States standards for grain. USDA Fed. Grain Insp. Ser. 47 p.

Vick, K. W., J. C. Webb, B. A. Weaver & C. Litzkow. 1988. Sound detection of stored product insects that feed inside kernels of grain. J. Econ. Entomol. 81: 1489-1493.

Watters, F. L. 1969. The locomotor activity of *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) in wheat. Can. J. Zool. 47: 1177-1182.

Webb, J. C., D. C. Slaughter & C. A. Litzkow. 1988. A computerized acoustical detection system for monitoring larvae in grain and other post-harvest commodities. *In* Proceedings, 17th Intl. Congress of Entomology. Vancouver, Canada.

Wilkin, D. R. 1990. Detection of insects in bulk grain. J. Kansas Entomol. Soc. 63: 554-558.

[1]Filled to one-third of its capacity.

[2]Primary insects are insects which penetrate and destroy whole sound kernels (e.g. - lesser grain borer and the rice weevil (Noyes et al. 1988).

Table 1. Mean number of insects in pitfall probe traps and mean insect density in grain trier and cup probe samples

Species	Probe traps	Grain Trier	Cup Probe
Cryptolestes spp.	210.170	0.779	0.509
A. advena	6.814	0.006	0.006
Tribolium spp.	5.542	0.135	0.206
T. stercorea	2.500	0.025	0.049
Corticaria spp.	2.462	0.014	0.004
R. dominica	1.445	0.424	0.307
O. surinamensis	1.360	0.017	0.011
C. angustus	0.035	-	-
S. oryzae	0.004	0.002	0.002
P. interpunctella	0.013	-	0.002
Others[a]	0.069	0.004	0.006
Total[b]:	254,056.0	1,016.89	3,806.88

Means are geometric means (antilog($\log_{10}$X) - 1).

[a]Insects of the families Dermestidae and Anthicidae.

[b]Total in 27 traps, 27 grain trier and 36 cup probe samples taken every 7 d from July 8 to September 27, 1991.

Table 2. Differences in the number of adult insects of the five most abundant species in unbaited pitfall probe traps

Species	Mean no.[a] (n = 270)	SD range[b]
Cryptolestes spp.	210.170a	27.278, 1575.94
A. advena	6.814b	1.559, 22.86
Tribolium spp.	5.542b	-0.099, 46.55
T. stercorea	2.500c	1.559, 22.86
R. dominica	1.445d	-0.393, 8.85
F	342.82	
df	4, 1305	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}$X) - 1).

[b]Lower SD = Antilog($\log_{10}$X - $\log_{10}$SD) - 1. Upper SD = antilog($\log_{10}$X + $\log_{10}$SD) - 1.

Table 3. Distribution of adult insects in the different regions sampled with pitfall probe traps

Trap position	Mean no.[a] (n = 360)	SD range[b]
Center	18.422a	0.326, 283.594
West (wall)	11.451b	0.384, 111.043
North (wall)	9.912bc	0.459, 80.608
South (wall)	8.310bcd	0.023, 83.704
East (wall)	7.594cd	0.342, 70.416
West (1/2 r)	7.460cd	-0.178, 86.100
East (1/2 r)	7.280cd	-0.081, 73.612
North (1/2 r)	6.970cd	-0.131, 72.110
South (1/2 r)	6.359d	-0.213, 67.819
F	5.51	
df	8, 1305	
P	0.0001	

Means with different letters are significantly different ($P = 0.0001$; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}X$) - 1).

[b]Lower SD = Antilog($\log_{10}X - \log_{10}SD$) - 1. Upper SD = antilog($\log_{10}X + \log_{10}SD$) - 1.

Table 4. Differences in the number of adult insects of the five most abundant species present in grain trier samples

Species	Mean density[a] (n = 270)	SD range[b]
Cryptolestes spp.	0.780a	-0.106, 2.541
R. dominica	0.424b	-0.366, 2.197
Tribolium spp.	0.136c	-0.183, 0.580
T. stercorea	0.025d	-0.092, 0.158
A. advena	0.006d	-0.053, 0.069
F	66.04	
df	4, 1305	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}$X) - 1).

[b]Lower SD = Antilog($\log_{10}$X - $\log_{10}$SD) - 1. Upper SD = antilog($\log_{10}$X + $\log_{10}$SD) - 1.

Table 5. Distribution of adult insects in the different regions sampled with grain triers

Sample position	Mean density[a] (n = 360)	SD range[b]
Center	0.501a	-0.329, 2.356
East (wall)	0.274b	-0.296, 1.304
West (1/2 r)	0.267b	-0.287, 1.253
North (1/2 r)	0.228b	-0.245, 1.000
East (1/2 r)	0.224b	-0.284, 1.092
North (wall)	0.216b	-0.214, 0.882
West (wall)	0.213b	-0.251, 0.965
South (wall)	0.156b	-0.227, 0.731
South (1/2 r)	0.142b	-0.273, 0.795
F	3.90	
df	8, 1305	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}X$) - 1).

[b]Lower SD = Antilog($\log_{10}X$ - $\log_{10}SD$) - 1. Upper SD = antilog($\log_{10}X$ + $\log_{10}SD$) - 1.

Table 6. Differences in the number of adult insects of the five most abundant species present in cup probe samples

Species	Mean density[a] (n = 1044)	SD range[b]
Cryptolestes spp.	0.509a	-0.292, 2.213
R. dominica	0.307b	-0.398, 1.839
Tribolium spp.	0.206c	-0.278, 1.013
T. stercorea	0.049d	-0.178, 0.337
A. advena	0.006d	-0.075, 0.095
F	100.26	
df	4, 5040	
P	0.0001	

Means with different letters are significantly different ($P = 0.0001$; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}X$) - 1).

[b]Lower SD = Antilog($\log_{10}X$ - $\log_{10}SD$) - 1. Upper SD = antilog($\log_{10}X$ + $\log_{10}SD$) - 1.

Table 7. Distribution of adult insects in the different regions sampled with cup probes

Sample position	Mean density[a] (n = 1392)	SD range[b]
Center	0.441a	-0.379, 2.343
North (wall)	0.244b	-0.306, 1.229
West (1/2 r)	0.217bc	-0.332, 1.216
East (1/2 r)	0.201bc	-0.355, 1.238
West (wall)	0.191bcd	-0.272, 0.950
East (wall)	0.152cd	-0.291, 0.870
South (wall)	0.147cd	-0.276, 0.817
South (1/2 r)	0.129d	-0.261, 0.724
North (1/2 r)	0.125d	-0.273, 0.743
F	11.95	
df	8, 5040	
P	0.0001	

Means with different letters are significantly different (*P* = 0.0001; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}$X) - 1).

[b]Lower SD = Antilog($\log_{10}$X - $\log_{10}$SD) - 1. Upper SD = antilog($\log_{10}$X + $\log_{10}$SD) - 1.

Table 8. Distribution of adult insects in the different depths sampled with cup probes

Depth	Mean density[a] (n = 3132)	SD range[b]
0 cm	0.233a	-0.341, 1.305
30.5 cm	0.225ab	-0.324, 1.220
60.1 cm	0.180bc	-0.274, 0.917
90.4 cm	0.172c	-0.326, 1.037
F	3.06	
df	3, 5040	
P	0.0272	

Means with different letters are significantly different ($P = 0.0001$; Fisher's least significant difference [SAS Institute 1988]).

[a]Means are geometric means (antilog($\log_{10}X$) - 1).

[b]Lower SD = Antilog($\log_{10}X - \log_{10}SD$) - 1. Upper SD = antilog($\log_{10}X + \log_{10}SD$) - 1.

Table 9. Frequency of detection and ratios of the five most abundant species in pitfall probe traps, grain trier and cup probe samples

	Frequency of detection								
	Probe trap[a]			Grain trier[b]			Cup probe[c]		
Species	n	%	Range	n	%	Range	n	%	Range
Cryptolestes spp.	267	82.4	1-10,802	137	42.3	1-16	269	20.8	1-17
A. advena	246	75.9	1-112	3	0.9	1-1	6	0.5	1-1
Tribolium spp.	174	53.7	1-950	42	13.0	1-7	135	10.4	1-7
T. stercorea	168	51.9	1-232	11	3.4	1-2	40	3.1	1-2
R. dominica	107	33.0	1-381	67	20.7	1-166	140	10.8	1-78

Table 9. Continued

Species	Frequency of detection ratios		
	Trap:trier	Trap:cup	Trier:cup
Cryptolestes spp.	1.9:1	4.0:1	2.0:1
A. advena	84.3:1	151.8:1	1.8:1
Tribolium spp.	4.1:1	5.2:1	1.3:1
T. stercorea	15.3:1	16.7:1	1.1:1
R. dominica	1.6:1	3.1:1	1.9:1

[a]Frequencies in nine probe trap sampling points in each of three bins from July 8 to September 27, 1991.

[b]Frequencies in nine sampling points in each of three bins from July 8 to September 27, 1991.

[c]Frequencies in 36 sampling points in each of three bins from July 8 to September 27, 1991.

Table 10. Estimated insect density (per 500 g) and ratios based on grain trier and cup probe samples and mean trap catch

Species	Trap (n = 270)	Trier (n = 270)	Cup (n = 261)	Trap: trier	Trap: cup	Trier: cup
Cryptolestes spp.	845.26	1.34	1.29	630.8:1	655.2:1	1.0:1
A. advena	12.93	0.01	0.01	1,293.0:1	1,293.0:1	1.0:1
Tribolium spp.	43.15	0.23	0.49	187.6:1	88.1:1	0.5:1
T. stercorea	10.26	0.03	0.10	342.0:1	102.6:1	0.3:1
R. dominica	10.37	2.10	1.71	4.9:1	6.1:1	1.2:1

Table 11. Correlation coefficients of the relationship between the number of insects found in pitfall probe traps and grain trier and cup probe samples for all insects and for the five most abundant species from July 8 to September 27, 1991

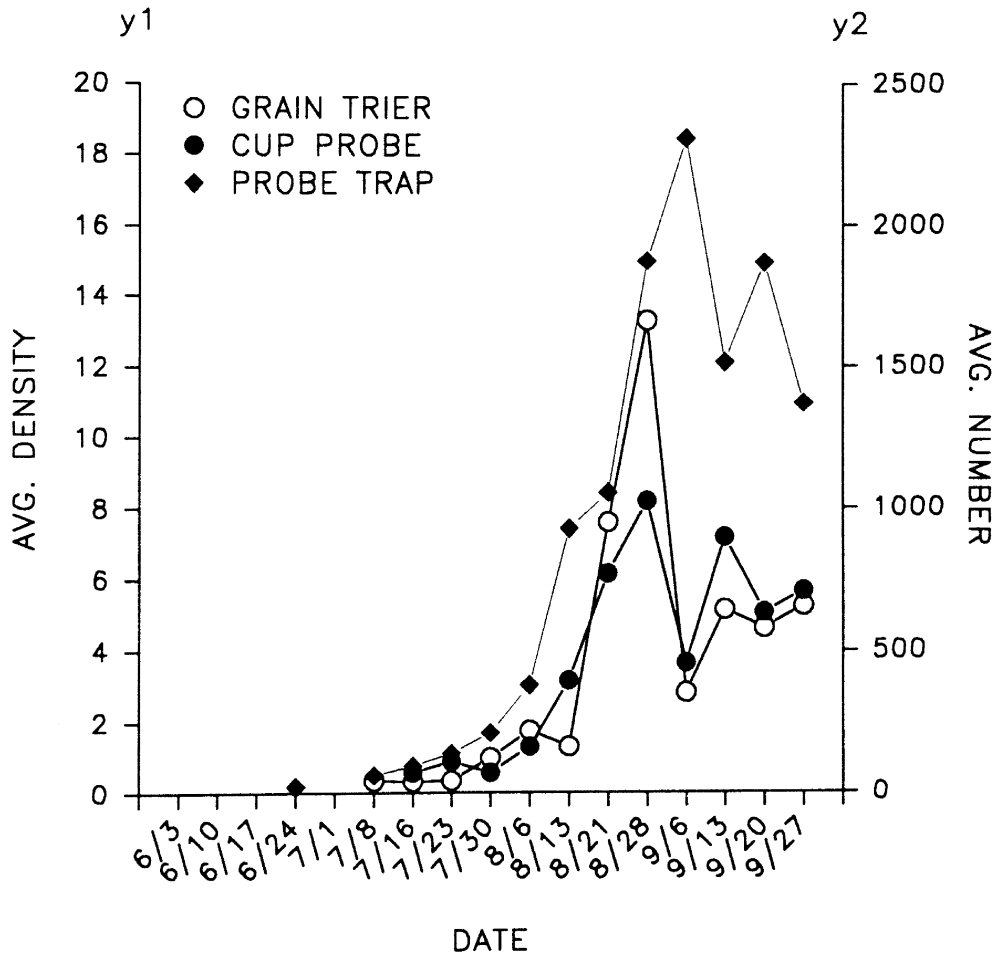
Species	Correlation coefficients[a]	
	Probe trap versus grain trier	Probe trap versus cup probe
All insects	0.53	0.53
Cryptolestes spp.	0.56	0.56
A. advena	ns	ns
Tribolium spp.	0.50	0.63
T. stercorea	ns	0.18
R. dominica	0.76	0.71

[a]ns, correlation coefficient not significantly greater than zero ($P > 0.05$).

Table 12. Estimates of treatment thresholds for pitfall probe traps according to simple linear regression between probe trap catches and insect densities obtained from grain trier and cup probe samples

Species	Threshold (x)[a]	Pitfall probe trap thresholds (y)	
		Grain trier	Cup probe
R. dominica	2	10.1	11.8
Cryptolestes spp.	2	1,084.1	1,174.8
Tribolium spp.	2	176.5	114.2

[a]Standard treatment threshold for primary insects and secondary insects in stored wheat (2 insects per 500 g) (USDA 1990).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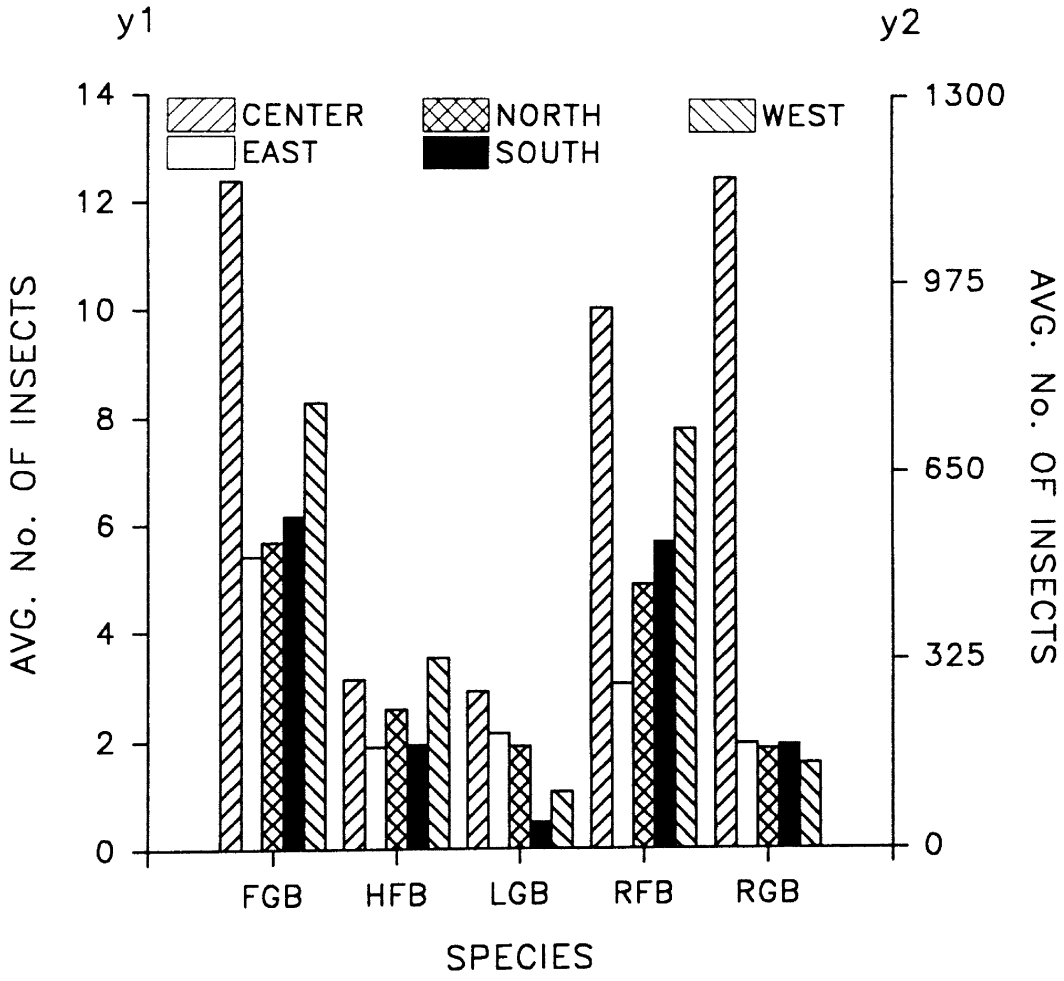
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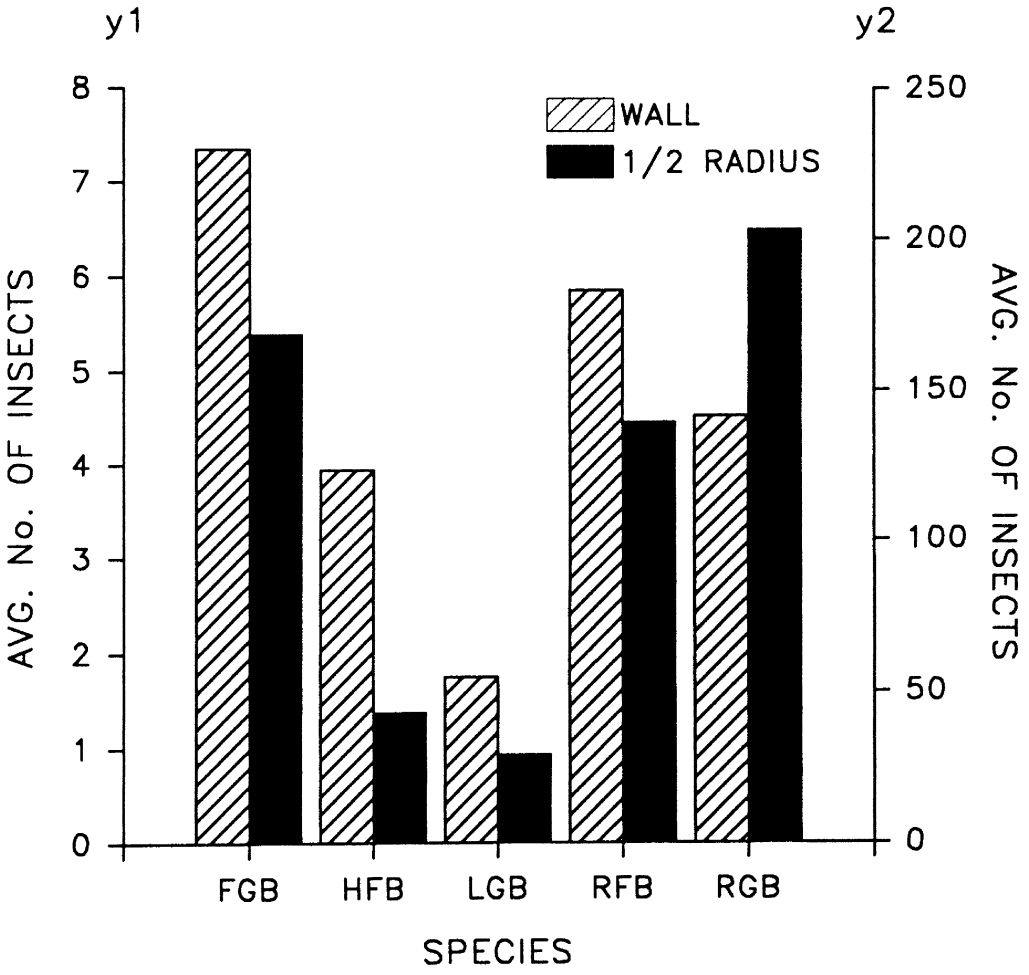
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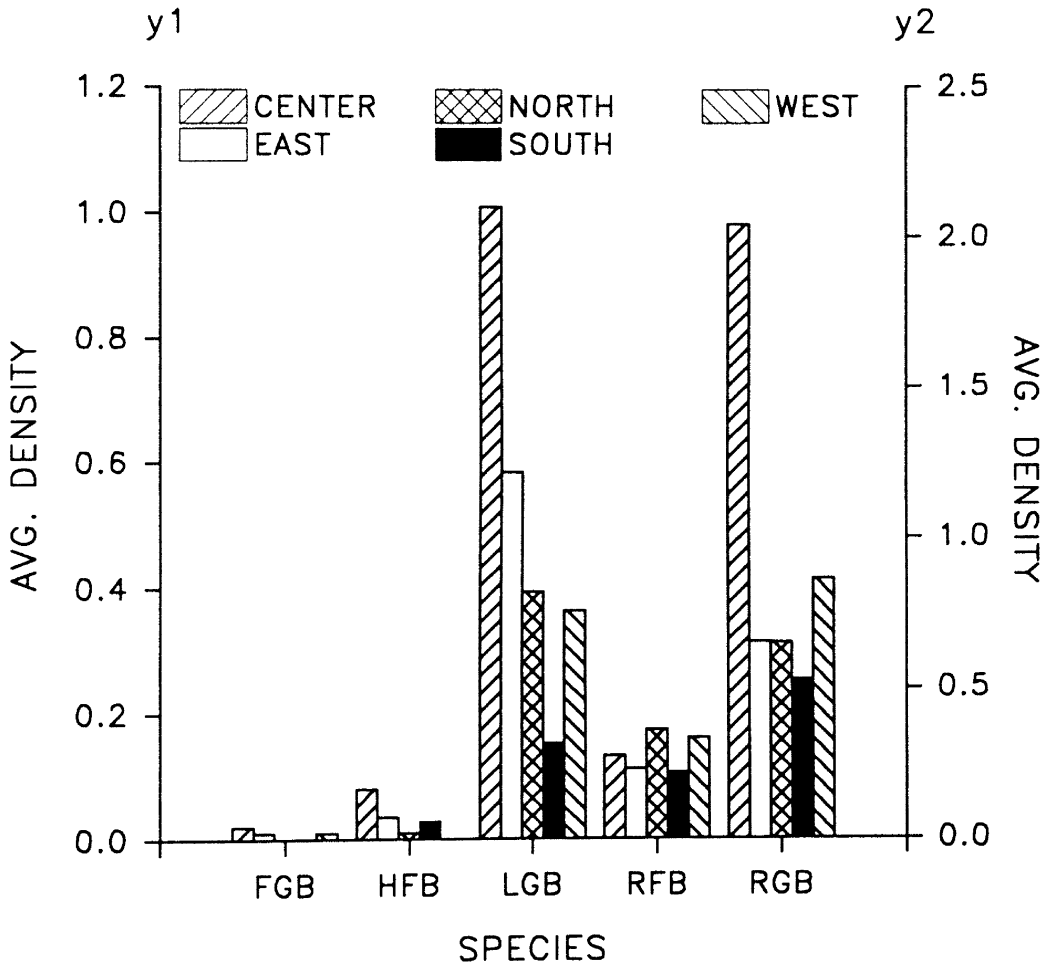
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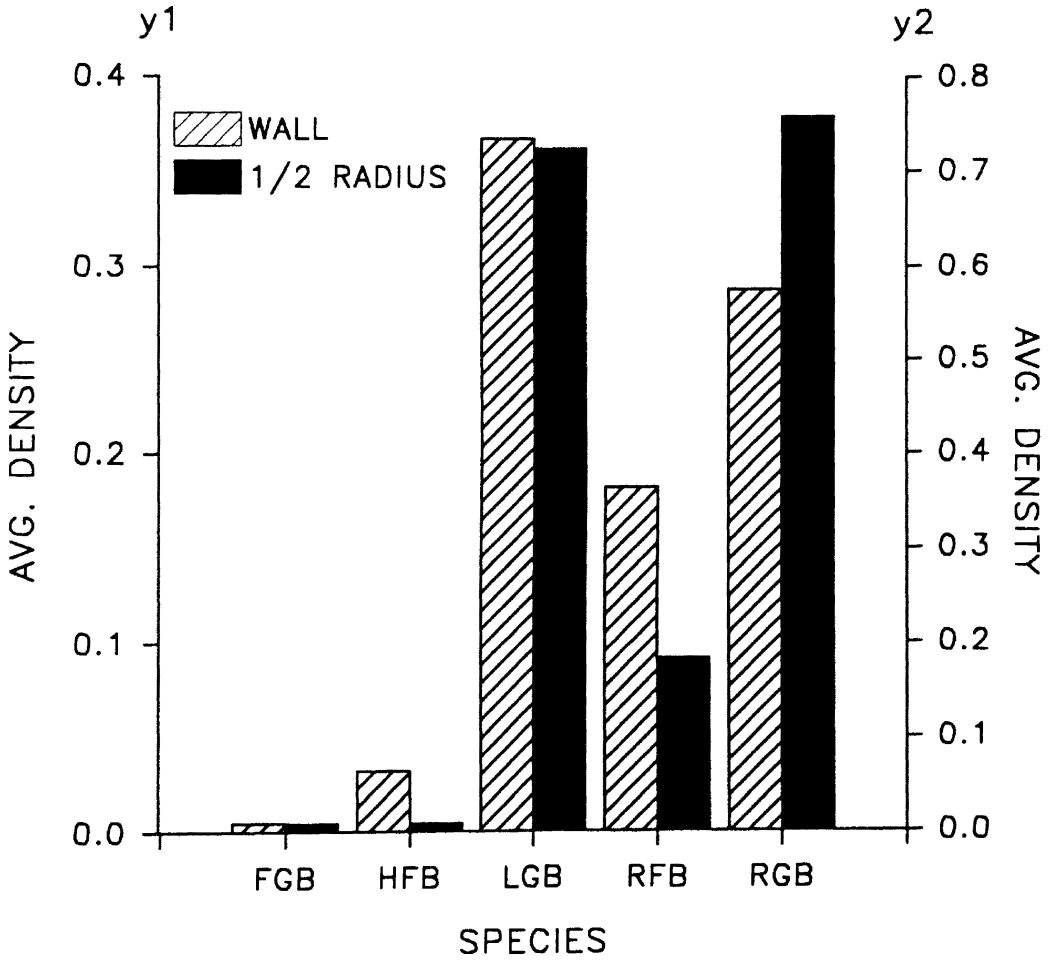
RGB
SPECIES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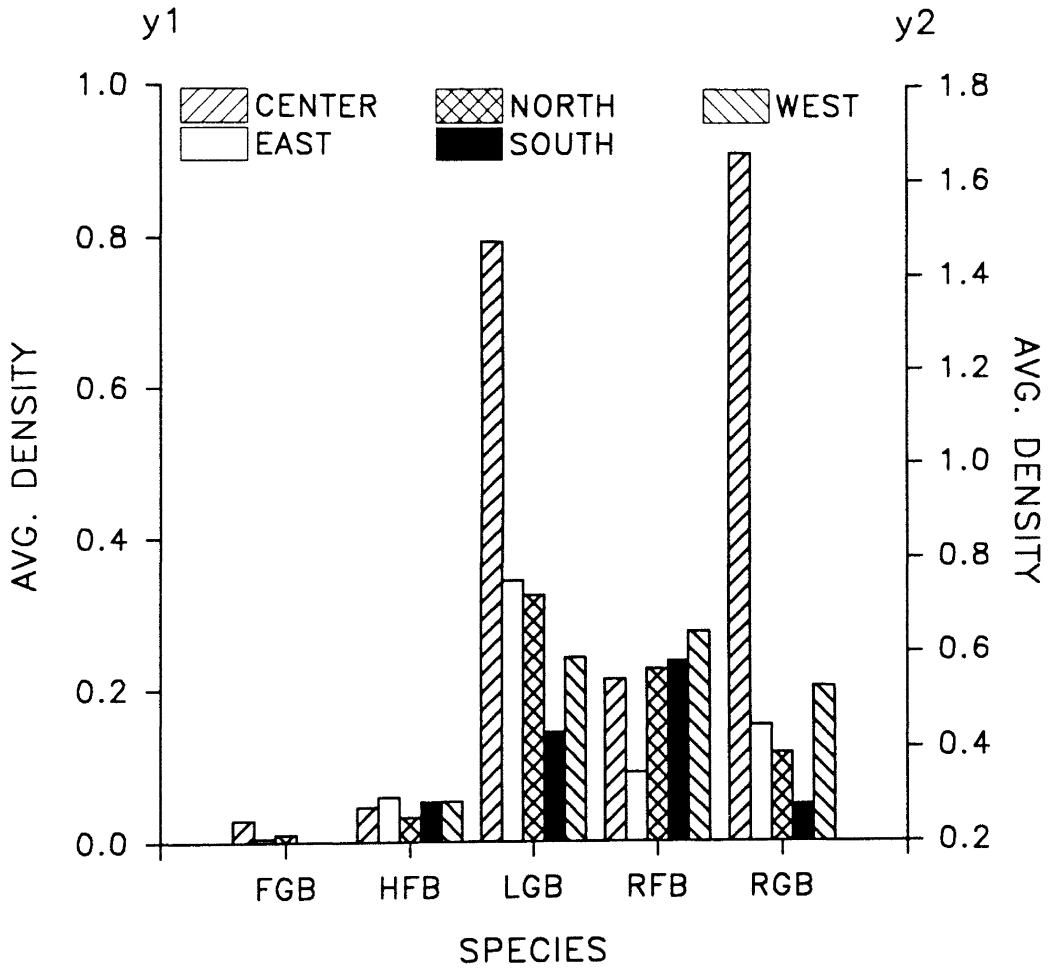
0.3
0.2
0.1
0.0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
WALL
1/2 RADIUS
AVG. DENSITY
AVG. DENSITY
FGB
HFB
LGB
RFB
RGB
SPECIES


y1
y2
CENTER
NORTH
WEST
EAST
SOUTH
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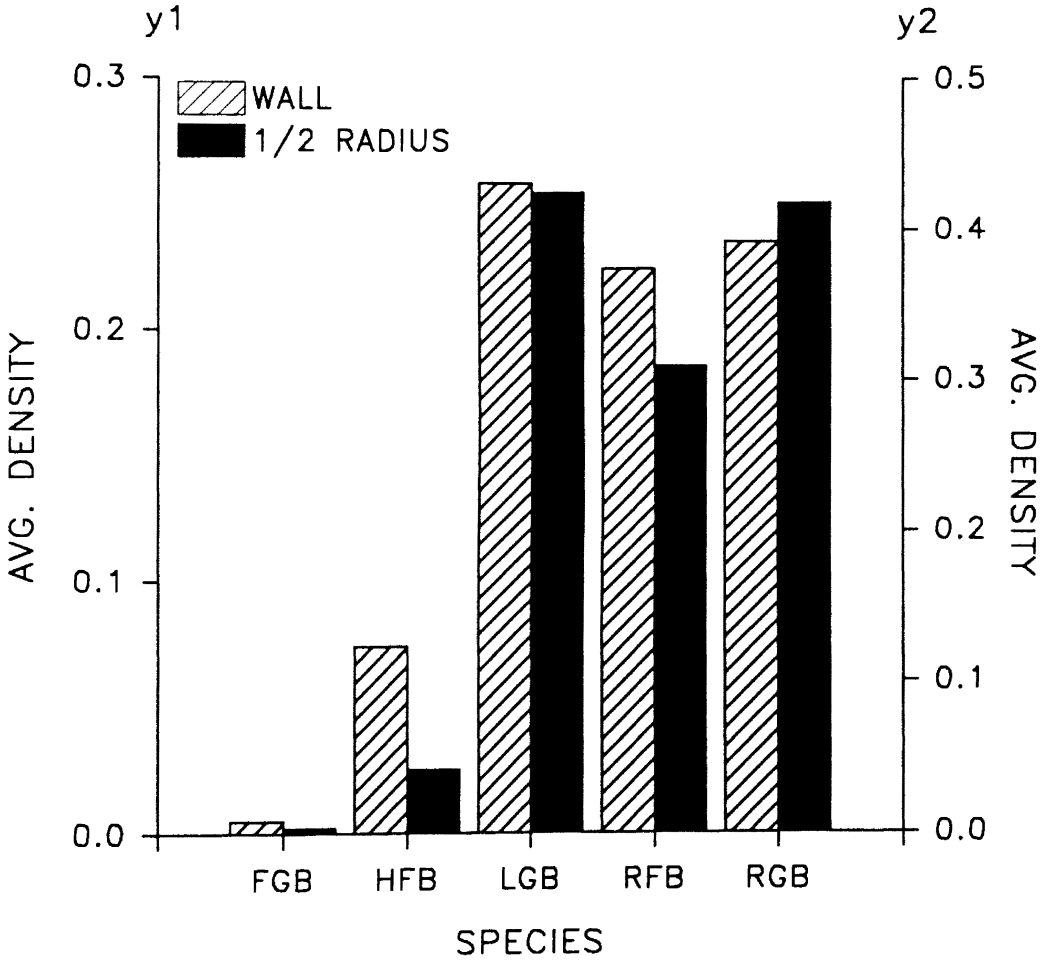
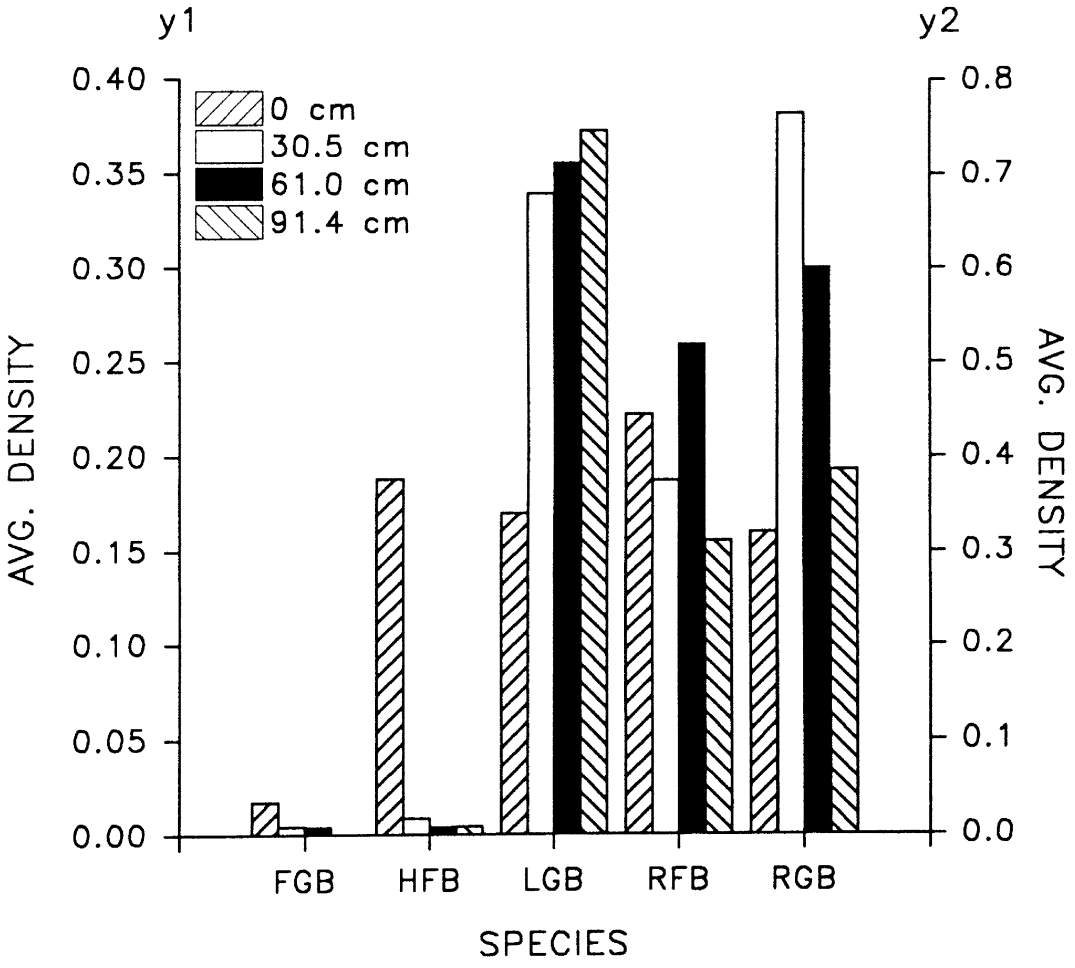
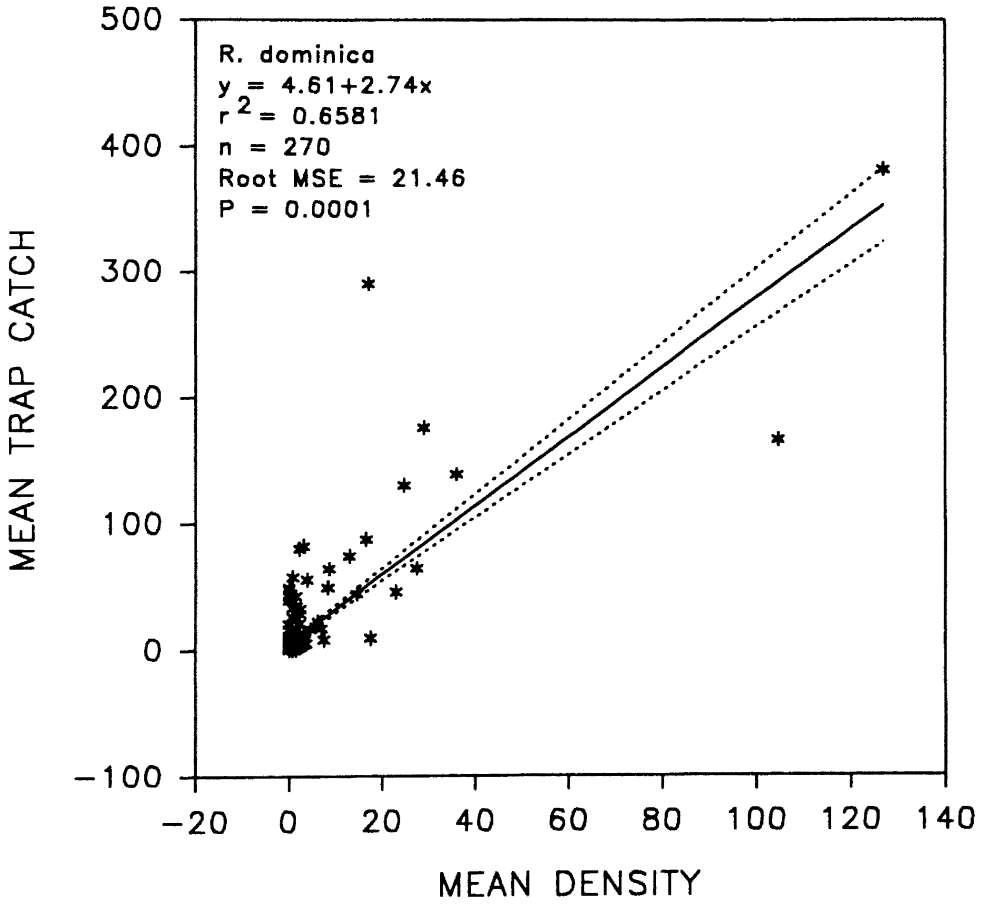
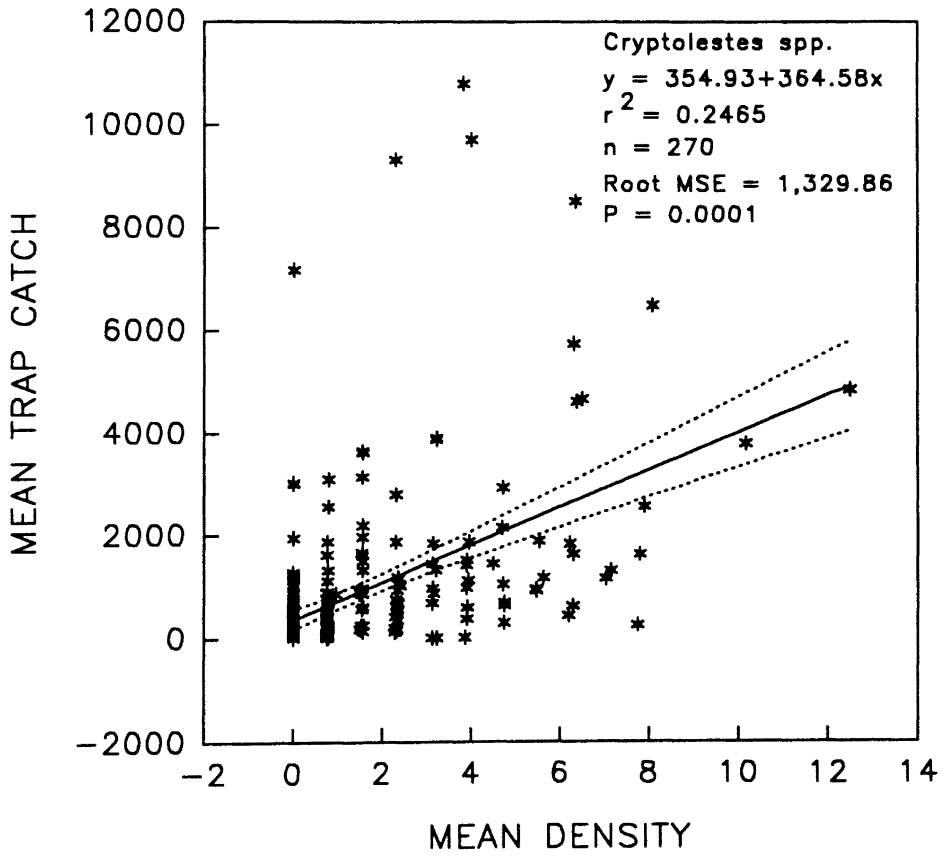
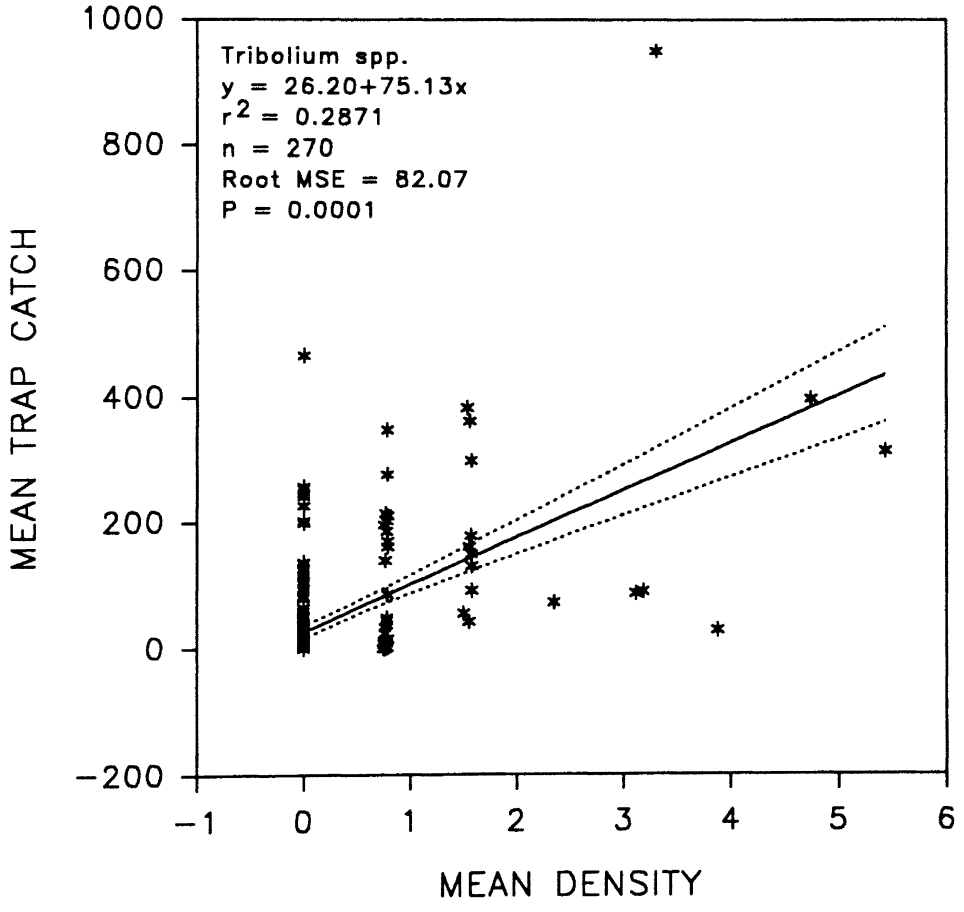
0.8
0.6
0.4
0.2
0.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
AVG. DENSITY
AVG. DENSITY
FGB
HFB
LGB
RFB
RGB
SPECIES

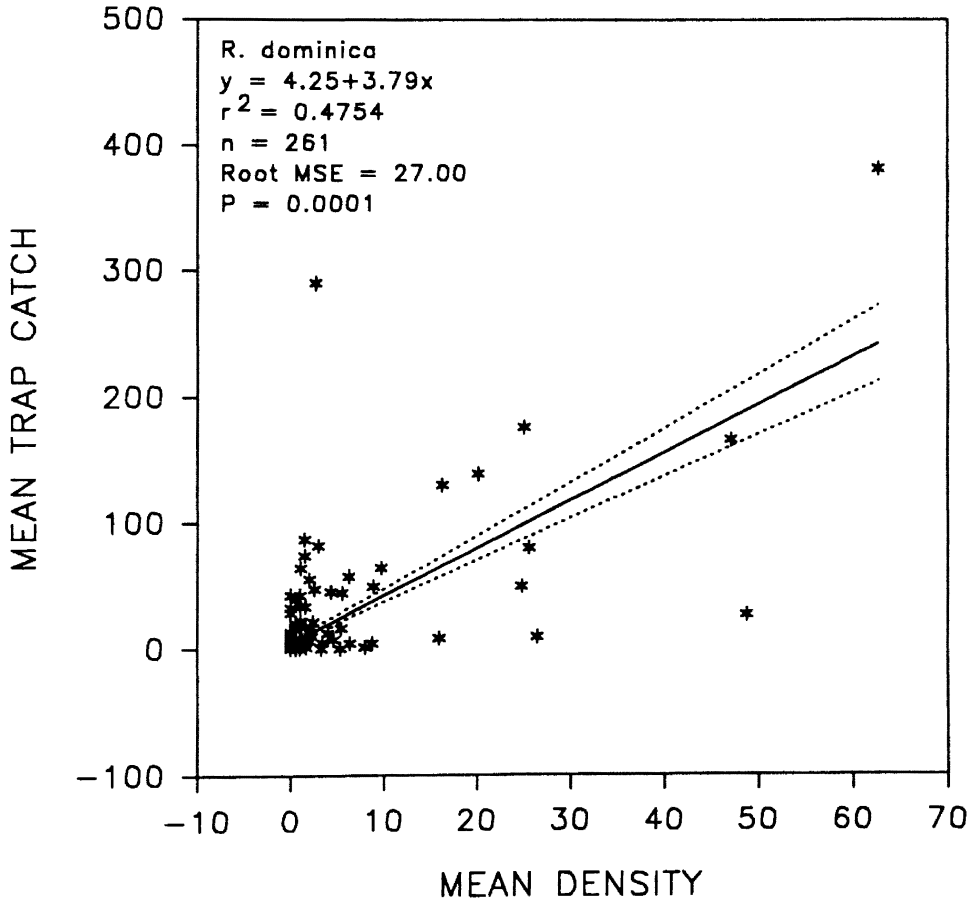

y1
y2
0.3
0.2
0.1
0.0
0.5
0.4
0.3
0.2
0.1
0.0
WALL
1/2 RADIUS
AVG. DENSITY
AVG. DENSITY
FGB
HFB
LGB
RFB
RGB
SPECIES

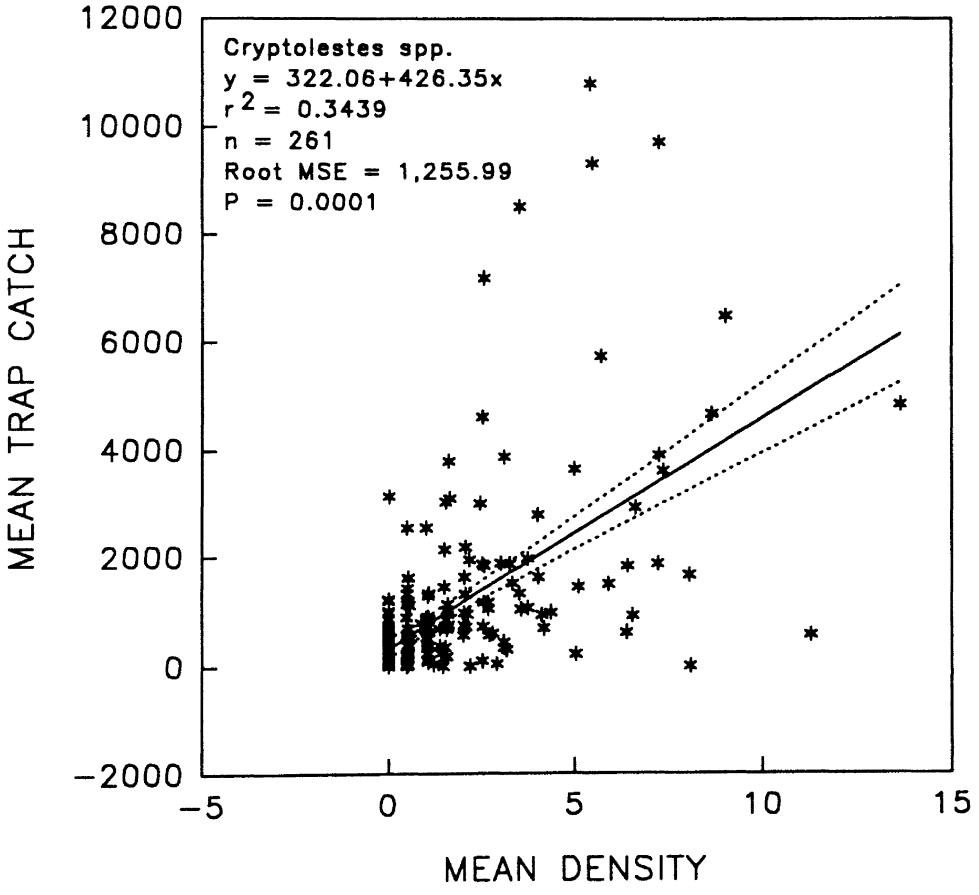

y1
y2
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 cm
30.5 cm
61.0 cm
91.4 cm
AVG. DENSITY
AVG. DENSITY
FGB
HFB
LGB
RFB
RGB
SPECIES

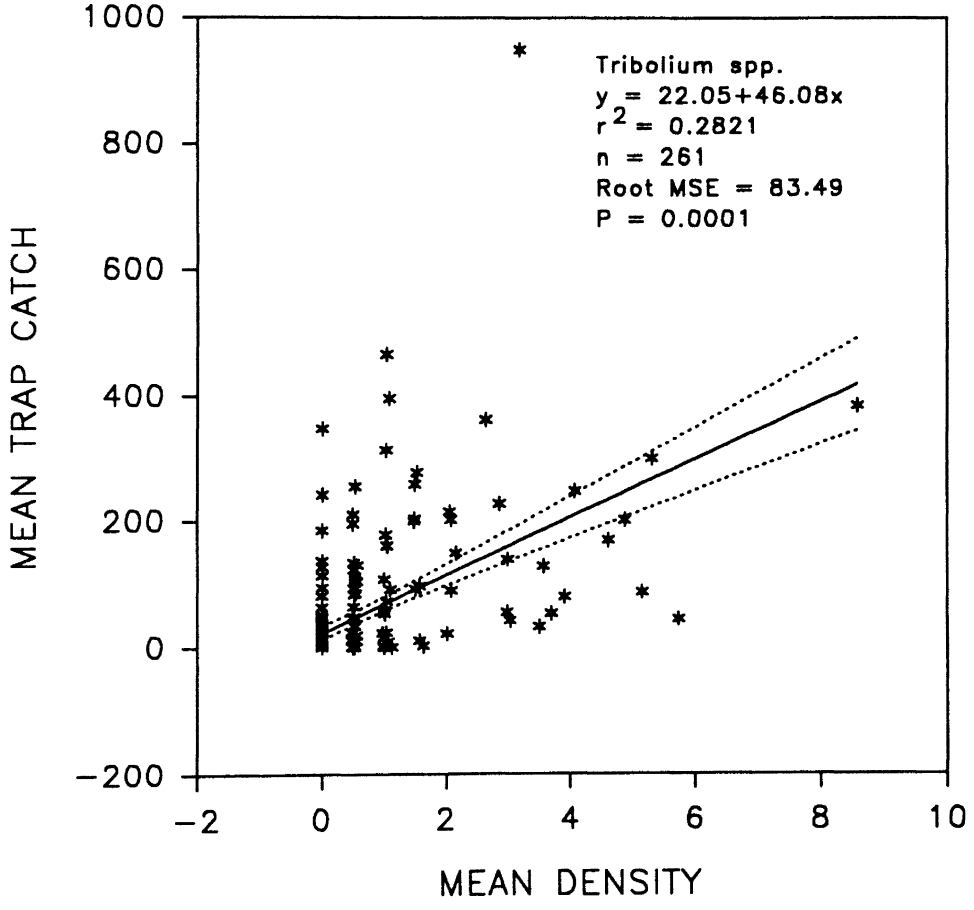

R. dominica
y = 4.61+2.74x
r 2 = 0.6581
n = 270
Root MSE = 21.46
P = 0.0001
MEAN TRAP CATCH
MEAN DENSITY
500
400
300
200
100
0
−100
−20
0
20
40
60
80
100
120
140


Cryptolestes spp.
y = 354.93+364.58x
r 2 = 0.2465
n = 270
Root MSE = 1,329.86
P = 0.0001
MEAN TRAP CATCH
MEAN DENSITY
12000
10000
8000
6000
4000
2000
0
−2000
−2
0
2
4
6
8
10
12
14


Tribolium spp.
y = 26.20+75.13x
r2 = 0.2871
n = 270
Root MSE = 82.07
P = 0.0001
MEAN TRAP CATCH
MEAN DENSITY
1000
800
600
400
200
0
−200
−1
0
1
2
3
4
5
6


R. dominica
y = 4.25+3.79x
r 2 = 0.4754
n = 261
Root MSE = 27.00
P = 0.0001
MEAN TRAP CATCH
MEAN DENSITY
500
400
300
200
100
0
−100
−10
0
10
20
30
40
50
60
70


Cryptolestes spp.
y = 322.06+426.35x
r 2 = 0.3439
n = 261
Root MSE = 1,255.99
P = 0.0001
MEAN TRAP CATCH
MEAN DENSITY
12000
10000
8000
6000
4000
2000
0
−2000
−5
0
5
10
15


Tribolium spp.
y = 22.05+46.08x
r 2 = 0.2821
n = 261
Root MSE = 83.49
P = 0.0001
MEAN TRAP CATCH
MEAN DENSITY
1000
800
600
400
200
0
−200
−2
0
2
4
6
8
10

APPENDIX

ANALYSIS OF VARIANCE TABLES

Table 1. Analysis of variance for flight traps

Source	df	Type III SS[a]	MS	*F*	*P* > *F*
Direction	3	6.65	2.22	32.93	0.0001
Height	4	6.60	1.65	24.50	0.0001
Direction*Height	12	2.11	0.18	2.61	0.0018
Species	5	61.10	12.22	181.47	0.0001
Direction*Species	15	5.92	0.39	5.87	0.0001
Height*Species	20	7.01	0.35	5.21	0.0001
Direction*Height*Species	60	2.35	0.03	0.58	0.9959
Error	4,752	319.97	0.07		
Corrected total	4,871	414.30			
Contrasts:					
Inside vs outside	1	1.65	1.65	24.45	0.0001
Eaves (out) vs eaves (in)	1	0.02	0.02	0.28	0.5942

[a]Because of unbalance data, type III SS were used (Proc GLM, SAS Institute 1988).

Table 2. Analysis of variance for pitfall probe traps

Source	df	SS	MS	*F*	*P* > *F*
Position	8	20.69	2.59	5.51	0.0001
Species	4	643.09	160.77	342.82	0.0001
Position*Species	32	27.01	0.84	1.80	0.0042
Error	1305	612.01	0.47		
Corrected total	1349	1302.80			
Contrasts					
East vs North	1	0.28	0.28	0.61	0.4359
East vs South	1	0.01	0.01	0.02	0.8832
East vs West	1	1.09	1.09	2.32	0.1279
North vs South	1	0.40	0.40	0.86	0.3545
North vs West	1	0.26	0.26	0.55	0.4569
South vs West	1	1.31	1.31	2.79	0.0951
Wall vs ½ radius	1	3.35	3.34	7.14	0.0076
Center vs all positions	1	14.70	14.70	31.35	0.0001

Table 3. Analysis of variance for grain trier samples

Source	df	SS	MS	*F*	*P* > *F*
Position	8	1.43	0.18	3.90	0.0001
Species	4	12.08	3.02	66.04	0.0001
Position*Species	32	2.57	0.08	1.76	0.0059
Error	1305	59.66	0.05		
Corrected total	1349	75.74			
Contrasts					
East vs North	1	0.01	0.01	0.29	0.5902
East vs South	1	0.19	0.19	4.25	0.0393
East vs West	1	0.002	0.002	0.03	0.8551
North vs South	1	0.11	0.11	2.32	0.1277
North vs West	1	0.01	0.01	0.13	0.7219
South vs West	1	0.16	0.16	3.53	0.0603
Wall vs ½ radius	1	0.0	0.0	0.0	0.9920
Center vs all positions	1	1.13	1.13	24.76	0.0001

Table 4. Analysis of variance for cup probe samples

Source	df	SS	MS	*F*	*P* > *F*
Position	8	5.11	0.64	11.95	0.0001
Depth	3	0.49	0.16	3.06	0.0272
Position*Depth	24	1.45	0.06	1.13	0.2994
Species	4	21.44	5.36	100.26	0.0001
Position*Species	32	9.63	0.30	5.63	0.0001
Depth*Species	12	4.18	0.35	6.52	0.0001
Position*Depth*Species	96	5.12	0.05	1.00	0.4869
Error	5040	269.41	0.05		
Corrected total	5219	316.83			
Contrasts					
East vs North	1	0.004	0.004	0.07	0.7921
East vs South	1	0.12	0.12	2.27	0.1324
East vs West	1	0.06	0.06	1.13	0.2878
North vs South	1	0.17	0.17	3.13	0.0770
North vs West	1	0.03	0.03	0.64	0.4241
South vs West	1	0.35	0.35	6.60	0.0103
Wall vs ½ radius	1	0.04	0.04	0.69	0.4067
Center vs all positions	1	4.06	4.06	75.97	0.0001

Table 5. Analysis of variance for grain temperature

Source	df	Type III SS[a]	MS	*F*	*P* > *F*
Date	11	871.39	79.22	12.34	0.0001
Position	4	34.24	8.56	1.33	0.1677
Date*Position	39	106.00	2.72	0.42	0.9992
Depth	3	3412.42	1137.47	177.18	0.0001
Date*Depth	33	1679.06	50.88	7.93	0.0001
Position*Depth	12	14.74	1.23	0.19	0.9983
Date*Position*Depth	117	177.03	1.51	0.24	1.0000
Error	332	2131.40			
Corrected total	551	8810.58			

[a]Because of unbalance data, type III SS were used (Proc GLM, SAS Institute 1988).

Table 6. Analysis of variance for moisture contents of grain trier samples

Source	df	Type III SS[a]	MS	*F*	*P* > *F*
Date	11	56.25	5.11	5.16	0.0001
Position	8	6.22	0.78	0.79	0.4558
Date*Position	88	18.57	0.21	0.21	1.0000
Error	162	160.47	0.99		
Corrected total	269	243.03			
Contrasts					
East vs North	1	0.60	0.60	0.61	0.4368
East vs South	1	0.02	0.02	0.02	0.8849
East vs West	1	0.02	0.02	0.02	0.8849
North vs South	1	0.85	0.85	0.85	0.3566
North vs West	1	0.85	0.85	0.85	0.3566
South vs West	1	0.0	0.0	0.0	1.0000
Wall vs ½ radius	1	0.24	0.24	0.24	0.6214
Center vs all positions	1	3.49	3.49	3.53	0.0622

[a]Because of unbalance data, type III SS were used (Proc GLM, SAS Institute 1988).

Table 7. Analysis of variance for moisture contents in cup probe samples

Source	df	Type III SS[a]	MS	*F*	*P* > *F*
Date	11	37.09	3.37	0.97	0.4746
Position	8	31.73	3.97	1.14	0.3352
Date*Position	88	202.64	2.30	0.66	0.9918
Depth	3	119.82	39.94	11.46	0.0001
Date*Depth	33	55.02	1.67	0.48	0.9945
Position*Depth	24	121.97	5.08	1.46	0.0734
Date*Position*Depth	264	494.44	1.87	0.54	1.0000
Error	648	2257.55	3.48		
Corrected total	1079	3384.71			
Contrasts					
East vs North	1	4.59	4.59	1.32	0.2512
East vs South	1	0.01	0.01	0.0	0.9568
East vs West	1	2.27	2.27	0.65	0.4199
North vs South	1	4.17	4.17	1.20	0.2743
North vs West	1	0.41	0.41	0.12	0.7330
South vs West	1	1.98	1.98	0.57	0.4517
Wall vs ½ radius	1	8.59	8.59	2.46	0.1169
Center vs all positions	1	11.16	11.16	3.20	0.0739

[a]Because of unbalance data, type III SS were used (Proc GLM, SAS Institute 1988).

Table 8. Analysis of variance for the level of fines

Source	df	SS	MS	*F*	*P* > *F*
Position	8	0.020	0.002	0.16	0.9943
Error	18	0.285	0.016		
Corrected total	26	0.305			

VITA

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Candidate for the Degree of

Master of Science

Thesis: RELATIONSHIPS AMONG FLIGHT TRAP, PITFALL PROBE TRAP, GRAIN TRIER AND DEEP CUP PROBE METHODS IN SAMPLING STORED WHEAT INSECTS

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