Pergamon

PII: S0022-474X(97)00057-X

J. stored Prod. Res. Vol. 34, No. 2/3, pp. 129–140, 1998
Published by Elsevier Science Ltd
Printed in Great Britain
0022-474X/98 $19.00 + 0.00

Stored-product Insect Activity Outside of Grain Masses in Commercial Grain Elevators in the Midwestern United States

ALAN K. DOWDY* and W. H. MCGAUGHEY

U.S. Grain Marketing Research Laboratory, USDA, ARS, 1515 College Avenue, Manhattan, KS 66502, U.S.A.

(Accepted 5 November 1997)

Abstract—Knowledge of sources of insect infestation, population dynamics, and movement of pests is needed to effectively target and use both conventional and alternative pest management tactics. This study was conducted to determine the nature and source of insect infestations in commercial elevators with an emphasis on the relative importance of refugial populations in and around commercial facilities. Insect activity was monitored using two types of traps in several areas inside and outside concrete silos. Every area of all of the elevators examined had detectable populations of stored-product insects that could potentially migrate into grain in storage. A total of 13 beetle species and two species of moths were found. Each elevator had different problem areas that demonstrated the structural and management influences on insect movement. Published by Elsevier Science Ltd

Key words—grain storage, population monitoring, refugia, stored products

INTRODUCTION

The development of effective pest management programs requires an understanding of insect behavior and the risks of storing grain in particular locations. Grain managers need the ability to anticipate when, where, and to what extent infestations are likely to develop. However, we have a poor understanding of where insects come from in the environment and when and to what extent they migrate into stored grain. Without this information, we are unable to evaluate the infestation risk for a particular storage facility. Better predictions of pest migration from the outside environment into stored grain will improve our ability to predict when and where to apply control measures in the total marketing system.

Around on-farm storage, adult insects can be detected outside the grain mass with sticky traps and numbers are correlated with the numbers of insects detected within the grain mass (Dowdy and McGaughey, 1994). By examining the seasonal dynamics of insect pests outside grain masses, an assessment can be made of the risk of infestation associated with a particular bin. Corrugated cardboard traps (DeCoursey, 1931) and a variety of sticky traps are effective

*Corresponding author: Tel.: 785-776-2719; Fax: 785-537-5584; *e-mail*: dowdy@usgmrl.ksu.edu.

This article presents the results of research only. Mention of a trade mark or proprietary product does not constitute an endorsement or recommendation by the USDA. All programs and services of the U.S. Department of Agriculture are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, age, marital status, or handicap.

for monitoring stored-product insects in and around grain storage facilities (Cogburn *et al.*, 1984; Soderstrom *et al.*, 1987; Throne and Cline, 1989; Dowdy and McGaughey, 1994; Hagstrum *et al.*, 1994).

Not only may refugial insect pest populations outside of storage facilities be important, but pests residing in grain residue and spillage inside facilities also may infest commodities in storage. Because some stored-product insect species do well on grain containing broken kernels and fine material (McGregor, 1964; Sinha, 1975), it is reasonable to assume that insects also would inhabit this material separated from grain. Insect pests have been collected from grain debris on threshing floors (Khare and Agrawal, 1964) and in flour mills (Girish *et al.*, 1973). These may act as reservoirs of insects to inoculate commodities. Insects also may contaminate a commodity inside grain handling and processing machines if the equipment is not properly cleaned and maintained.

The objective of this research was to determine the nature and sources of insect infestations in selected commercial grain elevators with an emphasis on the relative importance of refugial populations in and around the facilities. This information will provide essential ecological information needed to properly focus insect control tactics within the facilities. This research is among the first of its kind done in commercial concrete storage facilities in the USA.

MATERIALS AND METHODS

This study was conducted over a 2-year period at four commercial grain elevators in north central Kansas. Storage capacity in concrete silos at elevators 1 through 4 was 6.5, 7.4, 17.7, and 20.5 thousand metric tons, respectively. Steel grain bins were present at elevators 1 and 2 but all sampling was done in and around the concrete structures to be consistent with sampling at the other locations. Average annual throughput of grain was about 28 thousand metric tons at all elevators and consisted mostly of hard red winter wheat. The elevators had similar internal distribution systems consisting of a gravity flow dump pit feeding into a bucket-type leg. The leg either feeds directly into storage bins using gravity flow or onto a horizontal drag that delivers the grain to a specified storage bin. Most of the grain was received by truck at the elevators during harvest in the first two weeks of July. Due to the inability to adequately sample grain in concrete storage in a safe manner, as well as the regular movement of grain through the silos to trucks or railway transport, no grain samples were examined for the presence of insects.

Elevators 1 and 2 are much smaller than elevators 3 and 4, resulting in less area requiring sanitation and fewer locations for insect refugia to develop. All elevators aerated grain taken in at harvest for 3–4 days to reduce grain temperature but did not monitor temperatures within the grain mass. Elevator 1 maintained a strict sanitation program including daily sweeping inside the facility, prompt removal of grain spillage inside and out, cleaning and spraying silos with chlorpyrifos-methyl or cyfluthrin prior to filling, and scheduled maintenance on grain conveying equipment. Elevator 2 maintained a poor level of sanitation resulting in grain spillage ranging from a few centimeters accumulation in the bottom areas to drifts up to 1 m deep in the head house. Dust accumulation on horizontal surfaces frequently exceeded 1 cm and broken windows in the head house offered easy access to birds in search of food and roosting sites. The third elevator had a sanitation program consisting of removing grain spills about weekly, the pit area was swept daily and the head house weekly, but the bottom area was cleaned only occasionally. Dust accumulations on horizontal surfaces in the bottom and head house were often greater than 1 cm. Elevator 4 had the poorest sanitation. The pit area, the only area receiving any regular sanitation, was swept daily. All other areas of this facility had heavy accumulations of dust and spilled grain. In 1993, the bottom area around the boot pit accumulated up to 1.5 m of spilled grain and the tunnel under the silos contained from 0 to 10 cm of water standing on the floor. The lower conveyor and all equipment in the tunnel were at least 0.5 m above the floor and never contained standing water. Rodents absconding with cardboard traps further confounded sampling in the bottom area of elevator 4. As at the second elevator, windows in the head house were broken allowing access to birds feeding on spilled grain accumulating up to 0.5 m deep. A personnel change occurred in February, 1994 and sanitation greatly improved.

However, this person left by July and sanitation levels declined but still remained better than the 1993 levels.

Insect activity outside commodities but within the facilities was monitored using unbaited delta 1x sticky traps (Ecogen Inc., Langhorne, PA) and corrugated cardboard traps baited with wheat flour (DeCoursey, 1931). The numbers of traps placed in each area within the elevators are listed in Table 1. The number of traps varied at each elevator because of differences in the layout of the facilities, but we attempted to be as consistent as conditions allowed. Six areas were identified in each elevator for sampling: (1) bottom area consisting of the base of the elevator leg and tunnel containing the grain conveyor running below the silos; (2) pit area consisting of the truck dump pit, driveway, and control rooms at ground level; (3) head house containing the top of the elevator leg, grain distribution system and scale hopper; (4) safety railings located outside around the top of the elevator; (5) silo head spaces above the grain mass; (6) and outside at ground level around the base of the elevator. Cardboard traps were placed on floors or horizontal surfaces of equipment where insects could enter the trap by walking. Delta traps were hung on equipment supports, near windows and in the head space of silos. All traps were removed and replaced weekly. Insect species in each trap were identified and the number collected was recorded. Delta traps (which are more weatherproof) were placed on wooden stakes or tied to equipment supports to detect insects outside around the base of facilities. Data are reported as the number of insects collected per trap per month during the sampling period.

In addition to trapping in the second year of the study, grain dust residue from different areas of the elevators was sampled for the presence of insects. The samples were incubated for 60 days at 25°C (±1°C) and 65% r.h. (±5%) and any insects present were identified to genus or species.

Means and standard errors of means were calculated for the number of insects per trap per month using the TABULATE procedure (SAS, 1995). Analysis of variance and means separation tests were conducted using a $\log_{10}(x + 1)$ transformation on the data to normalize variance using the GLM procedure (SAS, 1995). Correlations among traps in different locations within elevators and different trap types were determined with the CORR procedure (SAS, 1995). Because of the large numbers of correlations involved in this project, only those where $r \geqslant 0.50$ are reported. Correlations with $r < 0.50$ were considered likely to have little or no biological significance.

RESULTS AND DISCUSSION

A total of 13 beetle species and 2 species of moths were collected from the 4 elevators over the 2-year period. All species were detected in all elevators but the relative abundance of each species was not consistent from elevator to elevator. Stored-product insect species collected included foreign grain beetle (*Ahasverus advena* (Waltl)) family Cucujidae, cornsap beetle (*Carpophilus dimidiatus* (F.)) family Nitidulidae, and rice moth (*Corcyra cephalonica* (Stainton)) family Pyralidae, flat and rusty grain beetles (*Cryptolestes* sp.) family Cucujidae, sawtoothed grain beetle (*Oryzaephilus surinamensis* (L.)) family Cucujidae, smalleyed flour beetle (*Palorus ratzeburgi* (Wissmann)) family Tenebrionidae, Indianmeal moth (*Plodia interpunctella* (Hübner)) family Pyralidae, lesser grain borer (*Rhyzopertha dominica* (F.)) family Bostrichidae, rice weevil (*Sitophilus oryzae* (L.)) family Curculionidae, yellow mealworm (*Tenebrio molitor* L.) family Tenebrionidae, cadelle beetle (*Tenebrioides mauritanicus* (L.)) family Trogositidae, red

Table 1. The number of cardboard traps and delta traps placed in different areas of four commercial elevators in north central Kansas

	Cardboard traps			Delta traps					
Site	Bottom area	Pit area	Head house	Outside	Bottom area	Pit area	Head house	Upper railing	Silo
1	7	10	12	6	6	6	6	6	10
2	6	10	9	4	7	6	4	8	8
3	9	8	10	6	12	8	6	17	17
4	10	12	8	6	8	8	5	22	17

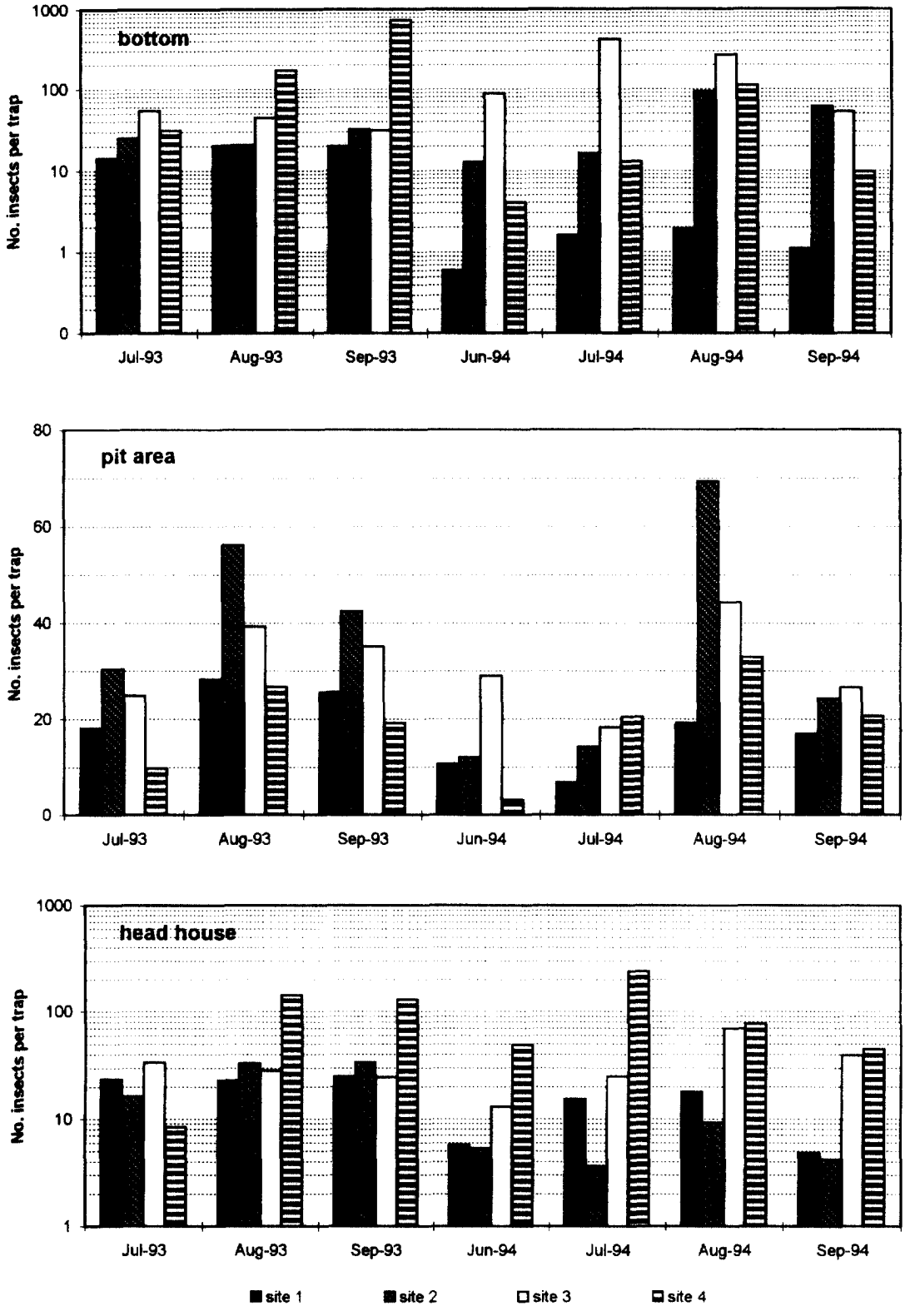

Fig. 1. Insects collected monthly per cardboard trap in different areas of four commercial elevators, 1993–1994.

flour beetle (*Tribolium castaneum* (Herbst)) family Tenebrionidae, dermestid beetles family Dermestidae, and hairy fungus beetle (*Typhaea stercorea* (L.)) family Mycetophagidae. More insects, except for moths, were typically collected in cardboard traps than in delta traps. Compared to the delta traps, the cardboard traps may be easier for beetles to access because because they could be entered by walking whereas the delta traps were hung and required flight for entry. The corn sap beetle was the only species collected in cardboard traps that was not collected in the delta traps. All species detected have the potential to develop into economically important populations if given sufficient time to develop in grain suitable for reproduction.

CARDBOARD TRAPS

Few insects were detected at elevator 1 in 1993 (Fig. 1). The three most abundant species collected in cardboard traps at this elevator were the sawtoothed grain beetle, dermestid beetles and hairy fungus beetle (Fig. 2). In 1993 the population trend was different for each of these species; the numbers of hairy fungus beetles increased, dermestid beetles decreased and sawtoothed grain beetles peaked in August with lower numbers in July and September. In 1994 populations of sawtoothed grain beetles and hairy fungus beetles increased throughout the sampling period while dermestid beetle populations increased during the first 3 months then declined to their lowest levels in September. The total number of insects collected from the bottom area of the elevator was relatively constant the first year. The average number of insects collected from the pit area was larger than in the bottom with peak density occurring in August. The number of insects collected in the head house also was relatively constant during the first

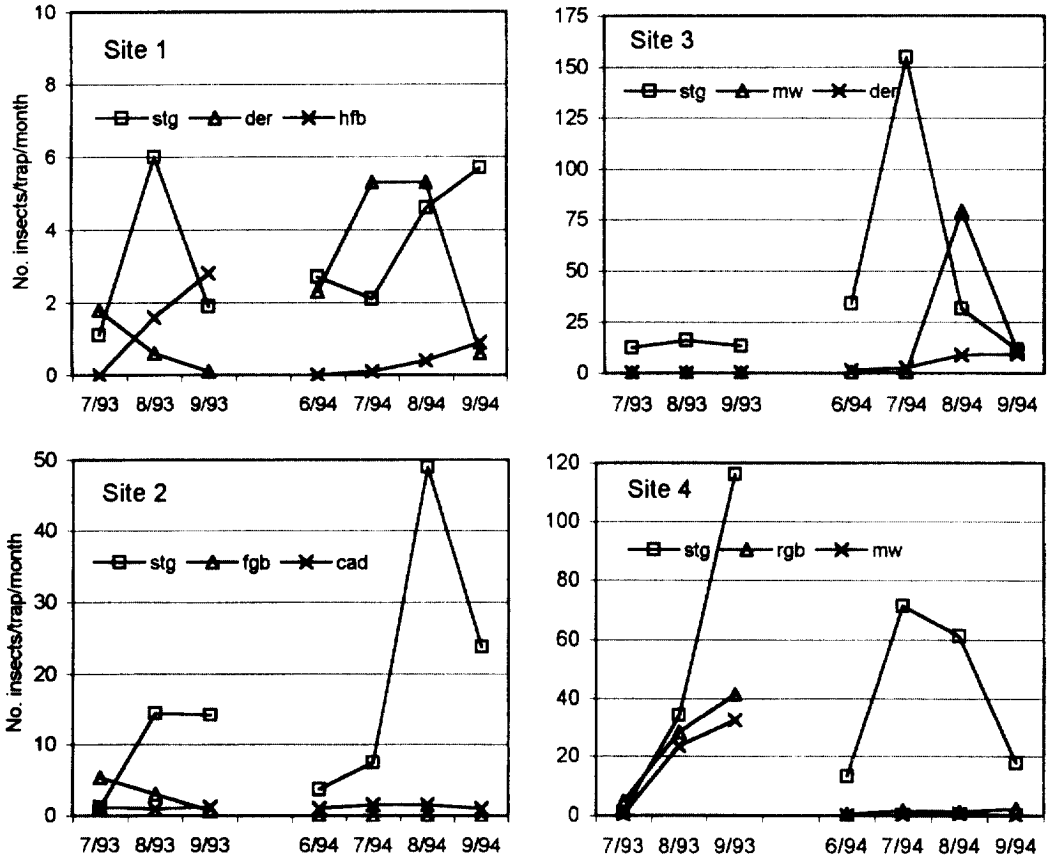

Fig. 2. Population trends for the three most abundant species of stored-product insects collected using cardboard traps in four commercial elevators, 1993–1994: cad = cadelle beetle, der = dermestid beetles, fgb = foreign grain beetle, hfb = hairy fungus beetle, mw = yellow mealworm, rgb = flat/rusty grain beetle, stg = sawtoothed grain beetle.

Table 2. Analysis of variance for insects collected in four commercial grain elevators using corrugated cardboard traps and delta 1x sticky traps

Date	Cardboard traps				Delta 1x sticky traps			
	LSD[a]	*F*	df	*P*	LSD[a]	*F*	df	*P*
				Site 1				
July, 1993	—	0.29	2, 25	0.75	0.015	5.91	5, 34	0.0005
August, 1993	—	0.05	2, 26	0.95	0.013	3.01	5, 34	0.02
September, 1993		0.89	2, 12	0.43	0.004	28.58	5, 12	0.0001
June, 1994	0.382	3.91	2, 26	0.03	0.022	3.14	5, 34	0.019
July, 1994	—	1.51	2, 26	0.24	0.027	2.09	5, 34	0.09
August, 1994	0.574	3.06	2, 26	0.06	0.062	6.19	5, 34	0.0004
September, 1994	0.335	3.81	2, 26	0.04	0.029	2.42	5, 34	0.06
				Site 2				
July, 1993	—	0.86	2, 20	0.44	—	0.18	5, 29	0.97
August, 1993	—	0.92	2, 24	0.41	—	0.07	5, 31	0.99
September, 1993	—	0.03	2, 10	0.98	—	2.31	5, 12	0.11
June, 1994	—	1.28	2, 23	0.30	0.045	4.55	5, 31	0.003
July, 1994	—	1.24	2, 23	0.31	0.025	3.74	5, 32	0.009
August, 1994	1.066	2.83	2, 23	0.08	0.054	3.31	5, 31	0.02
September, 1994	0.644	5.77	2, 23	0.009	0.024	3.08	5, 31	0.02
				Site 3				
July, 1993	—	1.11	2, 22	0.35	—	0.72	5, 56	0.61
August, 1993		0.26	2, 23	0.77	—	0.17	5, 60	0.97
September, 1993	0.201	3.88	2, 12	0.05	—	1.74	5, 23	0.17
June, 1994	0.481	8.80	2, 22	0.002	0.020	11.92	5, 61	0.0001
July, 1994	0.747	16.81	2, 22	0.0001	0.017	15.92	5, 61	0.0001
August, 1994	—	1.72	2, 22	0.20	0.029	4.90	5, 61	0.0008
September, 1994		0.50	2, 22	0.61	0.016	7.80	5, 61	0.0001
				Site 4				
July, 1993	0.094	3.22	2, 25	0.06	0.009	14.21	5, 40	0.0001
August, 1993	—	0.82	2, 25	0.45		1.45	5, 58	0.22
September, 1993	0.260	21.47	2, 21	0.0001	0.017	7.56	5, 26	0.0002
June, 1994	0.285	11.95	2, 27	0.0002	0.037	9.21	5, 61	0.0001
July, 1994	0.421	41.43	2, 27	0.0001	0.038	13.98	5, 61	0.0001
August, 1994	0.761	3.07	2, 27	0.06	0.050	8.21	5, 61	0.0001
September, 1994	0.412	5.21	2, 27	0.01	0.027	7.15	5, 61	0.0001

[a]LSD values based on $\log_{10}$ analysis.

year. There were no significant differences in the number of insects collected per month among the three areas within the elevator (Table 2). In 1994 the average number of insects collected in cardboard traps at elevator 1 tended to be lower in all areas than had been detected in 1993 (Fig. 1). Insect populations in the bottom averaged < 2.0 per trap per month during the sampling period. Significantly more insects were collected in the pit area than in the bottom (Fig. 2). Highest populations in the head house were detected in August.

The average number of insects collected at elevator 2 was greater than at elevator 1 in both years. The three most abundant species of insects at this facility were the sawtoothed grain beetle, foreign grain beetle and cadelle beetle (Fig. 2). The number of sawtoothed grain beetles generally increased through the sampling periods of both years while the populations of the other two species were relatively flat. In 1993 most insects per trap were collected in the bottom area in September, but peak populations occurred during August in the pit area (Fig. 1). The numbers of insects collected among the three areas sampled were not significantly different in 1993 (Table 2). The population trends in 1994 for the bottom and pit areas of elevator 2 were similar to those of 1993 with peak collections occurring in August (Fig. 1). Insect populations in the head house were highest in July during the second year. There were no consistent differences in insect populations among the three areas in June and July but significantly more insects were collected from traps in the bottom area of elevator 2 than in the head house during the last two months of the period.

The three most abundant species in elevator 3 were the sawtoothed grain beetle, yellow mealworm and dermestid beetles (Fig. 2). Populations of all three species were low and relatively constant during 1993. In 1994 peak populations of the sawtoothed grain beetle occurred in July while yellow mealworm populations peaked in August. Dermestid beetle populations increased

gradually through the second year. In contrast to the other locations in 1993, elevator 3 had its highest populations in July which decreased through August and September in the bottom area and head house (Fig. 1). The population trend in the pit area was similar to that of elevator 1 with highest insect density occurring in August during 1993 (Fig. 1). The number of insects collected in cardboard traps was not significantly different among the three areas sampled (Table 2). In 1994, the number of insects collected in the bottom of elevator 3 was greater than during the previous year (Fig. 1). Additionally, in June and July, there were significantly more insects per trap in the bottom than the pit or head house areas (Table 2). The occurrence of peak populations in the pit area was in August. Head house populations increased to a peak of 69 per trap in August.

Elevator 4 was inaccessible for 3 weeks during 1993 due to flooding. Because of the poor quality of sanitation at this elevator, there were substantially higher insect populations than had been observed at the other elevators. The three most abundant species collected in elevator 4 were the sawtoothed grain beetle, flat/rusty grain beetles and the yellow mealworm (Fig. 2). Populations of all three species increased throughout the sampling period in the first year but were at much lower levels during the second year due to improved sanitation in and around the elevator. The populations in the bottom increased through 1993 with peak densities recorded in September (Fig. 1). The number of insects collected in the pit area remained constant in August and September and at lower densities than in the other two areas. The number of insects collected per trap in 1994 was more in line with insect counts at the other three elevators (Fig. 1). This was probably due to temporarily improved sanitation. The number of insects detected remained relatively low in the bottom area of the elevator during June and July with an increase during August and a decline to previous levels in September. The number of insects collected in the pit area also was similar to the previous year with a peak in population occurring in August. The number of insects collected per trap in the head house was highest in July (Fig. 1). Additionally, significantly more insects were typically collected from the head house than the other two areas (Table 2).

Within each elevator, correlation coefficients calculated for the number of insects collected in cardboard traps in the three areas sampled were all less than $r = 0.50$ and generally close to zero, indicating that the relationship between trap catch in the different areas is weak. The number of insects collected in one area of an elevator was not a good predictor of insect populations in other areas. Sampling each area was necessary to determine the number of insects present and their distribution within the facility due to the high variability in the number of insects collected in different areas throughout the elevator.

DELTA TRAPS

The number of insects collected in delta traps in elevator 1 remained at low levels throughout both years (Fig. 3). The three most abundant stored-product insect species collected were the Indianmeal moth, sawtoothed grain beetle and hairy fungus beetle (Fig. 4). In 1993, significantly fewer insects were collected in traps along the railing on top of the elevator than in the other areas sampled (Table 2). Highest populations were documented in the silo head spaces during August, 1994 with a peak density of 81 per trap. No other traps contained more than 22 insects per month and numbers were generally significantly less than those collected from traps in silo head spaces (Fig. 3).

The three most abundant stored-product insect species collected in delta traps from elevator 2 were dermestid beetles, sawtoothed grain beetle and foreign grain beetle (Fig. 4). Insect activity was low in all areas of elevator 2 in 1993 except for a spike in August in the traps along the railing (Fig. 3). During 1994 the number of insects per trap continued to be low in most areas of elevator 2 (Fig. 3) except for a surge in June in the head house that dropped to lower levels for the rest of the sampling period. The numbers of insects collected in delta traps outside the elevator was generally significantly greater than the other areas sampled during July, August, and September of 1994 (Table 2). However, monthly trap catch was never greater than 12 insects per month outside.

At elevator 3, the three most abundant species of stored-product insects collected were the sawtoothed grain beetle, foreign grain beetle and yellow mealworm (Fig. 4). Populations of all three species were low during the first year but increased abruptly in August of the second year. During the first year, few insects were collected in delta traps at elevator 3 and there were no significant differences in the numbers of insects collected in the six areas sampled (Fig. 3 and Table 2). In 1994 significantly more insects were collected in delta traps at the base of the elevator outside the facility throughout the sampling period than in any other area (Fig. 3 and Table 2). Populations remained low in all other areas of elevator 3 except in August when an average of 70 insects per trap was detected in the bottom area.

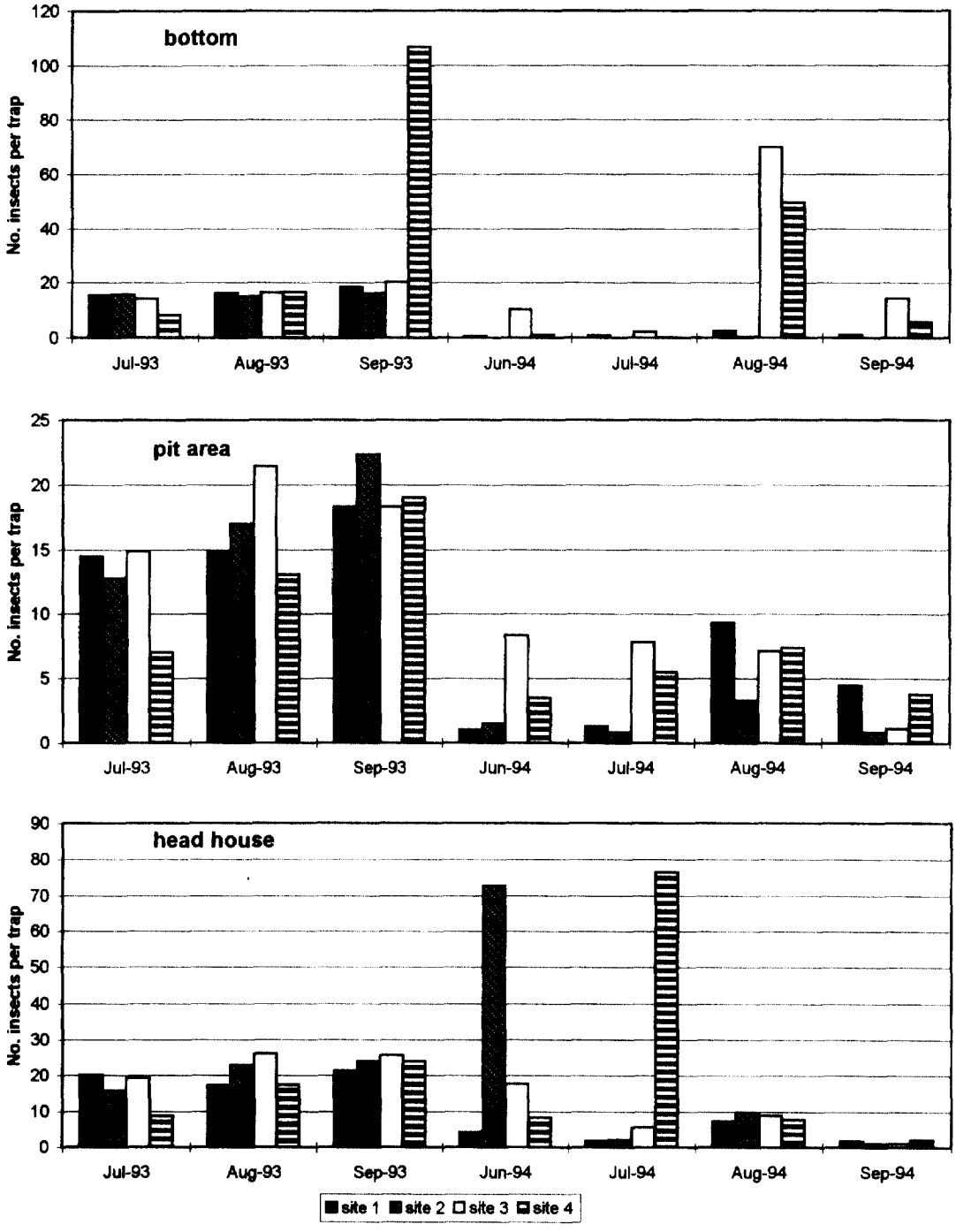

Fig. 3(a). *Caption on facing page.*

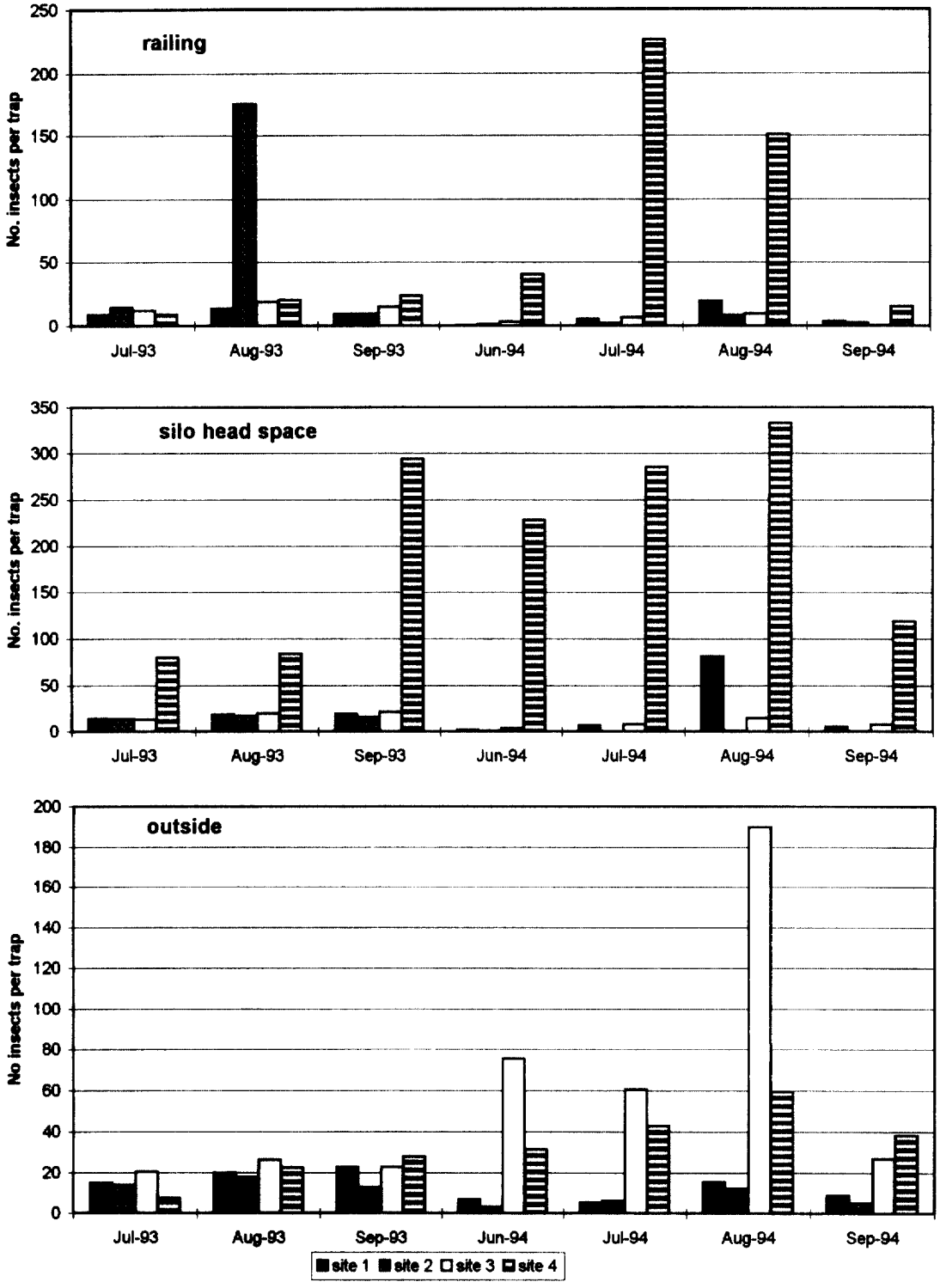

Fig. 3. Insects collected monthly per delta sticky trap in different areas of four commercial elevators, 1993–1994.

The three most abundant stored-product insect species collected at elevator 4 were the saw-toothed grain beetle, Indianmeal moth and flat/rusty grain beetles (Fig. 4). Higher populations were detected at this elevators than at the other three elevators combined. In 1993, most insects were detected in the silo head spaces, significantly more than the other areas in July and

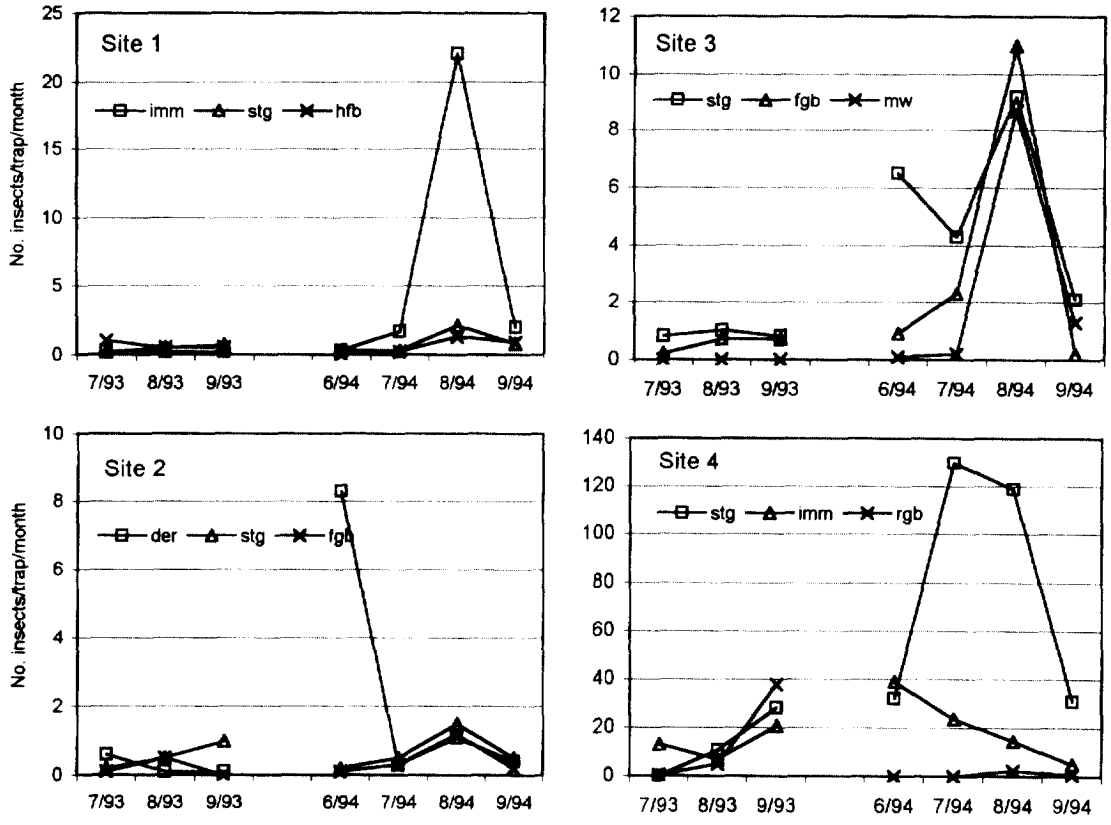

Fig. 4. Population trends for the three most abundant species of stored-product insects collected using delta traps in four commercial elevators, 1993–1994; fgb = foreign grain beetle, hfb = hairy fungus beetle, imm = Indianmeal moth, mw = yellow mealworm, stg = sawtoothed grain beetle.

September (Table 2). More insects were collected from all areas in September, 1993 than in the previous two months. Of all four elevators, this site had the greatest number of insects collected in the silo head spaces. In 1993, populations in silo head spaces averaged 80 insects per trap in

Table 3. Correlation between the numbers of insects collected in cardboard and delta traps

Date	Trap pair	r	P	n
		Site 1		
July, 1993	Head house	0.60	0.0001	107
		Site 2		
September, 1993	Pit area	0.79	0.0001	51
		Site 3		
August, 1993	Pit area	0.72	0.0001	120
	Head house	0.67	0.0001	115
September, 1993	Bottom	0.70	0.0001	57
	Head house	0.63	0.0001	56
July, 1994	Pit area	0.63	0.0001	111
	Head house	0.50	0.0001	109
August, 1994	Bottom	0.68	0.0001	140
September, 1994	Pit area	0.50	0.0001	110
		Site 4		
August, 1993	Bottom	0.88	0.0001	85
	Head house	0.66	0.0001	90
September, 1993	Bottom	0.88	0.0001	58
	Pit area	0.54	0.0001	57
	Head house	0.78	0.0001	59
June, 1994	Head house	0.54	0.0001	149
August, 1994	Bottom	0.70	0.0001	150

July when new-crop wheat went into storage, and increased to 294 per trap by September. Though at lower levels, all other areas of elevator 4 had higher populations in September, 1993 than in previous months. In 1994, the number of insects collected per delta trap at elevator 4 continued to be greatest in the silo head spaces (Table 2) with the highest population being detected in August (Fig. 3). Peak densities occurred during July in the head house and along the railing at densities greater than reported during the first year. Insect populations in the bottom and pit areas remained low throughout the sampling period.

It is difficult to draw general conclusions about the activity of stored-product insects in and around grain elevators because of the variability in the number of insects collected in the different areas of the elevators as well as the variability in seasonal trends within and among the elevators. Each elevator possesses an unique set of circumstances that results in problem areas specific to that elevator. Adequate sampling throughout a facility is necessary to best detect the presence of insects and evaluate the effectiveness of management practices and the risk of infestation.

The correlation coefficients calculated for the numbers of insects collected among the delta traps in the six areas within each elevator were negative and close to zero. Although there were some significant correlations, all values were small, indicating weak relationships and are of little biological importance. As with the cardboard traps, estimates of insect numbers present in delta traps in one area of this elevator cannot accurately be made based on the number of insects collected in another area of the elevator.

Correlation coefficients were calculated between the number of insects collected in cardboard traps and delta traps in the areas within elevators where both trap types were present (bottom, pit area and head house). Although there were significant correlations between the trap types

Table 4. Analysis of residual material collected from different locations within commercial grain elevators

Location	Grains present	Insects present 60 days after collection
	Site 1	
Bottom	Corn, milo, wheat	None
Pit area	Soybean, wheat	Dermestid larvae
Pit area	Wheat	None
Top of manlift	Milo, wheat	Dermestid larvae
Headhouse	Milo, wheat	Dermestid larvae
Headhouse	Milo, wheat	Dermestid larvae, pseudoscorpion
Silo wall	None	None
Silo wall	None	None
	Site 2	
Bottom	Milo	Foreign grain beetle (dead at time of collection)
Bottom	None	Dermestid larvae
Top of manlift	None	None
Headhouse	Milo	Dermestid larvae
Headhouse	Milo	None
Silo wall	None	None
Silo wall	None	None
	Site 3	
Bottom	Wheat	None
Bottom	Wheat	Cockroach (dead at time of collection)
Pit area	Wheat	Cadelle adult, dermestid larvae
Pit area	Corn, milo, soybean, wheat	Dermestid larvae, yellow mealworm
Top of manlift	Corn, milo, soybean, wheat	Dermestid larvae
Headhouse	Milo, soybean	Dermestid larvae
Headhouse	None	Dermestid larvae
Silo wall	Milo	None
	Site 4	
Bottom	Corn, milo, soybean	None
Pit area	None	None
Top of manlift	Corn milo, soybean, wheat	None
Headhouse	Soybean	Dermestid larvae, yellow mealworm
Silo wall	None	None

Collected June 22, 1994.

during the study, there was no consistency in significance within an area from month to month. Additionally, the r values were small, indicative of weak relationships with little biological importance and only those significant correlations where $r \geqslant 0.50$ are reported (Table 3). Therefore, the numbers of insects collected in one trap type was not a good indicator of the numbers of insects collected in the other trap type. Delta traps were more effective at detecting the presence of moths, but cardboard traps were more effective at detecting the presence of beetle species, especially when densities were low, probably because the beetles were able to more readily walk into cardboard traps whereas delta traps were more accessible to flying insects.

RESIDUAL MATERIAL

Residual material was sampled from several locations inside each of the four elevators. All residual material contained grain dust (Martin, 1981) and some contained small amounts of whole- and broken-grain kernels or soybeans ($< 5\%$) (Table 4). No insects were detected in the material upon initial examination but insects developed in several samples after the 60-day incubation period. These insects, predominantly dermestid larvae, may have survived because of tolerance to insecticide residue that might have been present or the ability to use decaying organic matter in the material. The residual grain material may have been more suitable if it contained a larger portion of whole or broken grain kernels.

In conclusion, stored-product insects were detected in all areas of each elevator studied and could migrate into uninfested commodities. Within elevators, insect population levels were erratic and variable from area to area and the relationship between insect populations in different areas of an elevator is not well correlated. Thus, extensive sampling throughout a facility is necessary to adequately detect insect activity. Each elevator had different problem areas and general statements about where most insects were located within a facility must be considered with caution. Few insects were detected in grain dust residue located throughout each elevator, but this material is a potential habitat for maintaining refugial populations that can infest grain.

Acknowledgements—We thank Rich Hammel, Warren Blodgett, and Leon Hendricks for assistance in the field and Joel Perez, Mary Alice Schrick and Sandy Steele for assistance in the laboratory.

REFERENCES

Cogburn R. R., Burkholder W. E. and Williams H. J. (1984) Field tests with the aggregation pheromone of the lesser grain borer (Coleoptera: Bostrichidae). *Environmental Entomology* **13**, 162–166.

DeCoursey J. D. (1931) A method of trapping the confused flour beetle, *Tribolium confusum* Duval. *Journal of Economic Entomology* **24**, 1079–1081.

Dowdy A. K. and McGaughey W. H. (1994) Seasonal activity of stored-product insects in and around farm-stored wheat. *Journal of Economic Entomology* **87**, 1351–1358.

Girish G. K., Goyal R. K. and Krishnamurthy K. (1973) Faunistic studies on stored grain insect pests in roller flour mills in India. *Bulletin of Grain Technology* **11**, 193–195.

Hagstrum D. W., Dowdy A. K. and Lippert G. E. (1994) Early detection of insects in stored wheat using sticky traps in bin head space and prediction of infestation level. *Environmental Entomology* **23**, 1241–1244.

Khare B. P. and Agrawal N. S. (1964) Rodent and ant burrows as sources of insect inoculum in the threshing floors. *India Journal of Entomology* **26**, 97–102.

Martin C. R. (1981) Characterization of grain dust properties. *Transactions of the American Society of Agricultural Engineers* **24**, 738–742.

McGregor H. E. (1964) Preference of *Tribolium castaneum* for wheat containing various percentages of dockage. *Journal of Economic Entomology* **57**, 511–513.

SAS Institute (1995) *SAS User's Guide: Statistics*. SAS Institute, Cary, NC.

Sinha R. N. (1975) Effect of dockage in the infestation of wheat by some stored-product insects. *Journal of Economic Entomology* **68**, 699–703.

Soderstrom E. L., Hinsch R. T., Bongers A. J., Brandl D. G. and Hoogendorn H. (1987) Detecting adult Phycitinae infestations in a raisin-marketing channel. *Journal of Economic Entomology* **80**, 1229–1232.

Throne J. E. and Cline L. D. (1989) Seasonal flight activity of the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), and the rice weevil, *S. oryzae* (L.), in South Carolina. *Journal of Agricultural Research* **6**, 183–192.