Relationship Between Flight Activity Outside Grain Bins and Probe Trap Catches Inside Grain Bins of *Cryptolestes Ferrugineus*

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ABSTRACT Insect sampling/monitoring inside grain bins is time consuming, cumbersome during the summer heat in the headspace of grain bins, may require investment in costly sampling devices for sampling of grain, and involves a certain risk to employees. Thus, it is important to explore unbaited sticky traps on the outside of grain elevators as decision support tools for improved management of stored grain. In this study, we analyzed seven trap catch data sets of unbaited sticky trap catches on the outside of grain bins and corresponding probe trap catches in the upper level of the grain mass at three farm bins in 1991, with capacities ranging from 68 to 141 metric tons, and at two commercial steel bins in 1993 and 1994, with capacities of 5,400 and 6,800 metric tons. We used response surface regression analysis to analyze standardized trap catches of the rusty grain beetle, *Cryptolestes ferrugineus*, and showed that (1) from late June to late July, catches on unbaited sticky traps placed on the outside of grain bins preceded probe traps inside the bins by ≈3 d, which suggested immigration into bins; and (2) in late August, unbaited sticky trap catches on the outside of bins started to decrease, while probe trap catches inside the bins continued to increase until mid-September. We concluded that, from late June to mid-August, immigration of *C. ferrugineus* individuals into grain bins influences abundance in the upper grain layer, whereas later in the season, the two types of trap catches were only loosely associated. This study is consistent with results published elsewhere that immigration of *C. ferrugineus* into grain bins initiated shortly after wheat was loaded into the bins.

KEY WORDS monitoring, Oklahoma, stored-product beetles, trap catch analysis

THE RUSTY GRAIN BEETLE, *Cryptolestes ferrugineus* Stephens (Coleoptera: Laemophloeidae), is among the most abundant insect pests in stored grain in North America (Barak and Harein 1981, Storey et al. 1983, Cuperus et al. 1986, 1990). Although *C. ferrugineus* only causes minor damage to sound wheat, its presence may trigger price discounts at sale because of the special category "infested" applied during grading when densities of two or more live insect pests per kilogram are found in grading samples (Anonymous 1994). Studies by Hagstrum (1989), Dowdy and McGaughey (1994), and Hagstrum et al. (1998) have shown that wheat is generally uninfested as it goes into storage, and Hagstrum (1989) showed that *C. ferrugineus* predominantly infested the upper grain layer during the first weeks of storage. Thus, infestations by *C. ferrugineus* likely originate from individuals immigrating into grain facilities through ventilation ducts and other openings near the top of the structure shortly after storage and initially infest the upper layer of grain.

It seems reasonable to assume that simultaneous insect monitoring on the outside at roof eaves at the top of sidewalls and in the upper grain layer would reveal a slight time delay between catches at the two locations because it may take some time for the immigrating beetles to establish in the grain. Insect sampling/monitoring inside grain bins is time consuming, is cumbersome during the summer heat in the headspace of grain bins, may require investment in costly sampling devices for sampling of grain (Hagstrum 1989), and involves a certain risk to employees. Therefore, it is of considerable interest to analyze how information about the abundance of stored-product insects obtained from traps placed on the outside of grain bins can be used to make decisions about developing insect infestations inside grain bins.

Unbaited sticky traps perform unbiased/passive sampling of flying insects and therefore give a good indication of their general flight activity. These traps have been used to catch stored-product beetles on the outside (Dowdy and McGaughey 1994, Vela-Coiffier et al. 1997, Dowdy and McGaughey 1998, Nansen et al. 2004) or in the headspace (Hagstrum et al. 1994) of grain storage facilities. In a study of grain samples and unbaited sticky trap catches from 14 experimental

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grain bins, Hagstrum et al. (1994) found that detection of several beetle species in the grain generally coincided with beetle captures in the headspace of the bins. Dowdy and McGaughey (1998) examined the pairwise correlations of catches with cardboard traps and unbaited sticky traps in the head house, pit area, and bottom of four grain bins at a concrete grain elevator, and they found a highly significant correlation for all pairs. There are, to our knowledge, no studies in which the relationship between beetle flight activity on the outside of grain bins and probe trap catches in the upper grain layer has been examined.

In a recent study, Nansen et al. (2004) showed that minimum and maximum temperatures and daylength could explain 41% of the variation of *C. ferrugineus* flight activity on the outside of commercial steel bins. Knowledge about environmental conditions that favor high insect flight activity is important because such conditions likely increase the risk of insect immigration into grain bins. Therefore, based on a weather-driven model by Nansen et al. (2004), grain elevator managers may be able to make better decisions on when to fumigate and aerate their grain bins. However, the weather-driven model of *C. ferrugineus* flight activity on the outside of grain bins only becomes meaningful when relationships between outside beetle flight activity and occurrence of the beetles in the grain is understood.

In this study, we analyzed catches of *C. ferrugineus* with unbaited sticky traps on the outside of grain bins and corresponding probe trap catches from the upper grain layer inside the bins to examine the temporal relationship between the two types of trap catches.

Materials and Methods

Grain Bins. The five grain bins included in this study belonged to different grain elevators in northcentral Oklahoma. All grain bins contained hard red winter wheat, *Triticum aestivum* L. In 1991, we collected trapping data from three farm bins with capacities ranging from 68 to 141 metric tons (Vela-Coiffier et al. 1997), and in 1993 and 1994 we collected trapping data from two commercial steel bins with capacities of 5,400 and 6,800 metric tons (Nansen et al. 2004). Although other insects were also caught, this study only concerns catches of *C. ferrugineus.* Before loading the grain, all grain bins were swept clean and fumigated with chloropicrin at recommended rates (Cuperus et al. 2002). The cleaning and fumigation was done to rule out that residual insects from the bins were the source of insects trapped on the outside of bins. In all 3 yr, loading of grain took place in June or July.

Outside Trapping. Unbaited sticky traps (Pherocon II; Trece, Salinas, CA) were attached to ropes on the exterior of the bins in four cardinal directions at either four (1991) or five (1993 and 1994) different heights. In this study, we analyzed weekly mean catches of *C. ferrugineus* with unbaited sticky traps placed on the outside roof eaves at the top of sidewalls in the four cardinal directions ($n = 4$). The traps were placed on ropes that ran through pulleys bolted through the roof eaves for efficient weekly trap replacement, and traps were reused up to three times. In 1991 (Vela-Coiffier et al. 1997), trapping was initiated in May, whereas in 1993 and 1994 (Nansen et al. 2004), trapping was initiated during the second week of June.

Inside Trapping. Plastic probe traps (WB Probe II traps; Trece) were inserted into the grain mass ≈3 cm below the grain surface. In 1991, nine probe traps were placed in each of three farm bins with (1) one probe trap in the center, (2) traps 30.5 cm from the side wall in each of the four cardinal directions (four probe traps), and (3) traps at one-half the bin radius in each of the four cardinal directions (four probe traps) (Vela-Coiffier et al. 1997). In 1993 and 1994, three probe traps were placed in each cardinal direction at 1.5 m from the bin wall, one-half bin radius, and in the center of the bin ($n = 12$). The four center traps formed the corners of a 1.5 by 1.5-m square (Gates 1995). For all 3 yr of trapping, we analyzed the weekly mean probe trap catches.

Regression Analysis. Because of considerable variation among grain bins and years in terms of total trap catches, weekly averages of unbaited sticky traps ($n = 4$) and probe traps (1991, $n = 9$; 1993 and 1994, $n = 12$) were standardized by converting trap catches from each bin into proportion of total for the entire trapping period to allow a single model to be fit the data. The dates of trap catches were converted into day numbers (a discrete number from 1 to 365), and response surface regression (PROC RSREG) in SAS/STAT (SAS 9.0; SAS Institute, Cary, NC) was used to analyze the relationship between standardized trap catches and day number. Further details on the use of this regression procedure are available in Freund and Littell (1991). The coefficients of linear and quadratic responses of *C. ferrugineus* trap catches with either unbaited sticky traps or probe traps to day number were used to develop seasonal response curves.

Results and Discussion

Trap Catches in 1991. No *C. ferrugineus* individuals were caught on the outside of farm bins before grain was loaded into the three farm bins, and the highest *C. ferrugineus* trap catches were obtained in late August and early September (Fig. 1a). The *C. ferrugineus* flight activity on the outside of grain bins approached zero by the end of September. Although numbers of *C. ferrugineus* individuals in probe traps were several magnitudes lower in the first weekly samples compared with later in the storage season, the beetles were detected 1–4 wk after loading of the grain into the farm bins (Fig. 1b). In late August and early September, the weekly mean probe trap catches exceeded 1,000 *C. ferrugineus* individuals in all three farm bins. While the highest unbaited sticky trap catches were found on the outside of farm bin 1, the highest probe trap catches were obtained from farm bin 3. Thus, the absolute magnitude of *C. ferrugineus* flight activity on the outside of grain bins is not necessarily a strong indicator of the probe trap catches in the top grain layer inside the bins. This is consistent with Cuperus

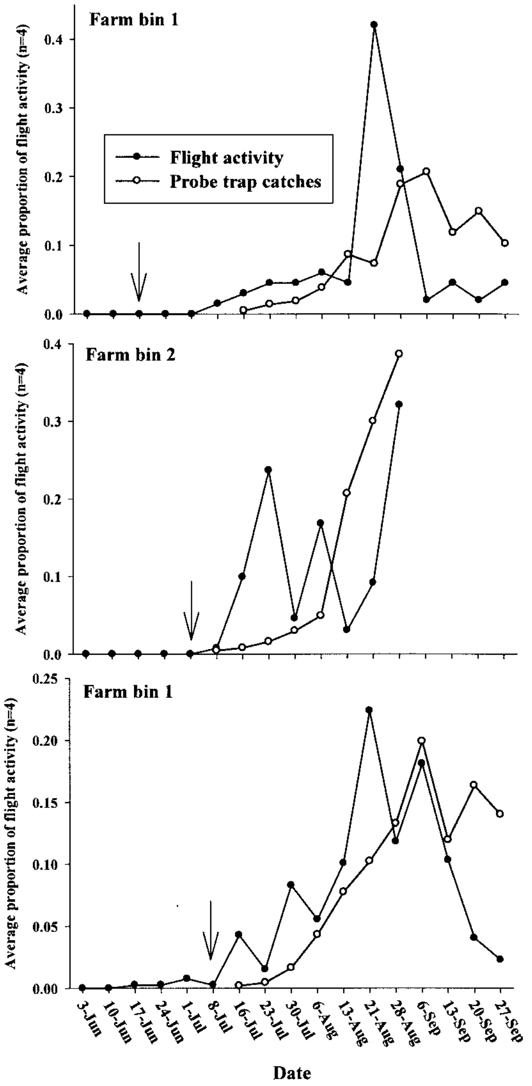

Fig. 1. *Cryptolestes ferrugineus* flight activity on the outside of three farm bins at the eaves and corresponding probe trap catches inside the same bins during 17 consecutive wk in 1991. Weekly mean *C. ferrugineus* flight activity corresponded to trap catches in the four cardinal directions, whereas mean probe trap catches corresponded to catches from one probe trap in the center, traps 30.5 cm from the side wall in each of the four cardinal directions (four probe traps), and traps at one-half the bin radius in each of the four cardinal directions (four probe traps). Arrows indicate dates the grain was loaded into the grain bins.

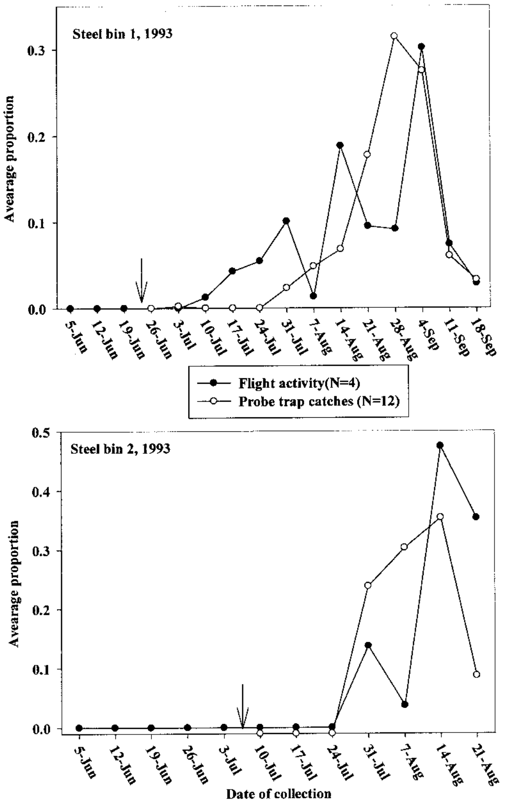

Fig. 2. *Cryptolestes ferrugineus* flight activity on the outside of two commercial steel bins at the eaves and corresponding probe trap catches inside the same bins in 1993. Weekly mean *C. ferrugineus* flight activity corresponded to trap catches in the four cardinal directions, whereas mean probe trap catches corresponded to catches from three probe traps placed in each cardinal direction at 1.5 m from the bin wall, one-half bin radius, and in the center of the bin ($n = 12$). Arrows indicate dates the grain was loaded into the grain bins.

et al. (1991), who listed several factors that affect the performance of probe traps, including grain temperature, grain type, and grain condition, and these variables were not accounted for in this study.

Trap Catches in 1993. We observed no *C. ferrugineus* flight activity on the outside of the two commercial steel bins before loading of the grain (Fig. 2). In steel bin 1, very few *C. ferrugineus* individuals were caught in probe traps within 5 wk after loading the grain, whereas in the same time period, there was a clear and steady increase in flight activity on the outside of the same grain bin. The peaks of flight activity and probe trap catches coincided in both steel bins in the last part of August.

Trap Catches in 1994. At two commercial steel bins, especially the mean flight activity of *C. ferrugineus,* but also the corresponding probe trap catches were considerably lower in 1994 (Fig. 3) compared with 1993 (Fig. 2). Despite the overall lower catches of *C. ferrugineus* with both unbaited sticky traps and probe traps, the seasonal patterns in 1994 were similar to those of the previous year.

Seasonal Trap Catch Response Curves. We used 71 paired observations of catches of *C. ferrugineus* with unbaited sticky traps and probe traps using day num-

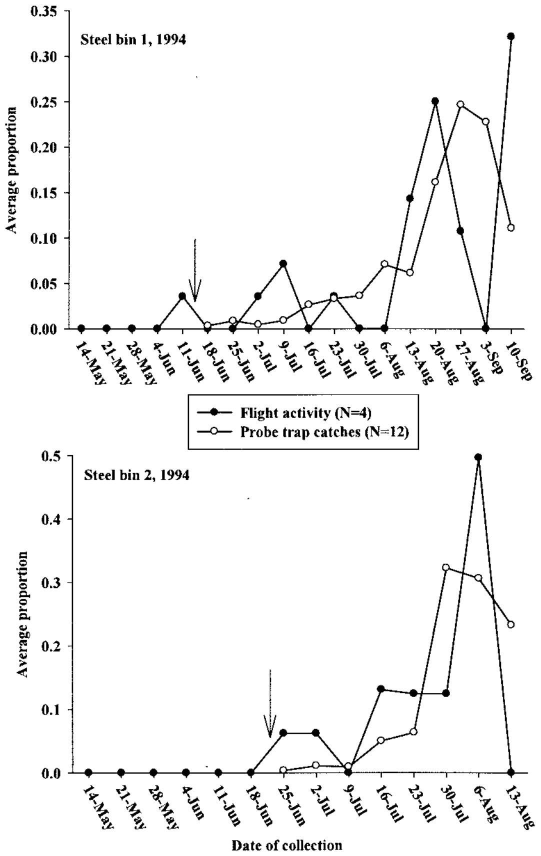

Fig. 3. *Cryptolestes ferrugineus* flight activity on the outside of two commercial steel bins at the eaves and corresponding probe trap catches inside the same bins in 1994. Weekly mean *C. ferrugineus* flight activity corresponded to trap catches in the four cardinal directions, whereas mean probe trap catches corresponded to catches from three probe traps placed in each cardinal direction at 1.5 m from the bin wall, one-half bin radius, and in the center of the bin ($n = 12$). Arrows indicate dates the grain was loaded into the grain bins.

Table 1. Linear and quadratic responses of standardized *C. ferrugineus* trap catches to day number

Response	Type 1 SS	R^2	*F* value	*P* value
Unbaited sticky trap catches				
Linear	0.134	0.140	11.880	0.001
Quadratic	0.056	0.059	4.990	0.029
Total	0.190	0.199	8.430	0.001
Probe trap catches				
Linear	0.268	0.335	36.790	<0.0001
Quadratic	0.037	0.046	5.020	0.028
Total	0.304	0.381	20.910	<0.0001

Response surface regression analysis was conducted for unbaited sticky traps on the outside of bins and probe traps in the upper grain layer, and the relative contribution of linear and quadratic responses are presented. Type 1 SS, type 1 sum of squares; R^2, coefficient of determination; *F* value and *P* value, levels of significance of the regression analyses.

ber as the sole explanatory variable, and we obtained significant curve fits to both unbaited sticky trap catches (intercept = −2.00584, linear = 0.01710, quadratic = −0.00003) and probe traps (intercept = −2.22913, linear = 0.01987, quadratic = −0.00004; Table 1). For both trap catch data sets, the partitioned R^2 values in Table 1 suggested that the standardized *C. ferrugineus* response was predominantly linear, but Fig. 4 clearly shows quadratic responses with peak values in late August (unbaited sticky trap catches) and mid-September (probe trap catches). *C. ferrugineus* individuals are believed to immigrate into the grain bins and initially infest the upper grain layer (Hagstrum 1989), and this is consistent with the 2- to 3-d time delay between unbaited sticky trap catches outside bins and probe trap catches inside bins in the time period from late June to beginning of August. Unbaited sticky trap catches continued to increase until mid-August, whereas probe trap catches increased until mid-September. From late June to early August, the strong correlation between predicted unbaited sticky trap catches outside bins and predicted probe trap catches inside bins suggested that outside trapping may be used as an indicator of the rate of increase of the *C. ferrugineus* population density in the upper grain layer inside bins. The continuous increase in predicted probe trap catches from early August to mid-September did not seem to elicit noticable migration, as predicted unbaited sticky trap catches showed a gradual decline within the same time period.

Conclusions. This study was based on trap catch data collected from grain bins with a considerable range of grain capacities and from 3 different yr with varying occurrence of *C. ferrugineus* in both unbaited sticky traps and probe traps. Although one grain bin (steel bin 2 in 1993) was only sampled with probe traps for 7 consecutive wk, most of the data sets represented >10 wk of sampling. In addition, individual grain elevators are often considered to be unique because of differences in management practices. Despite the variation among grain bins, we found a significant seasonal trend in catches with both unbaited sticky traps and probe traps, and this trend is consistent with results from seasonal analyses of stored product beetle flight activity (Nansen et al. 2001, 2004). With addition of this analysis, it may be possible in the future to develop a single model that uses ambient weather conditions to describe dynamics of probe trap catches inside the bins. The results from this study emphasize early-season immigration is likely the main source of *C. ferrugineus* infestations in grain bins. This study also showed that a time delay probably has to be taken into account when comparing insect catches inside and outside grain bins and that more research is needed to fully explore unbaited sticky traps on the outside of grain elevators as decision support tools for improved management of stored grain.

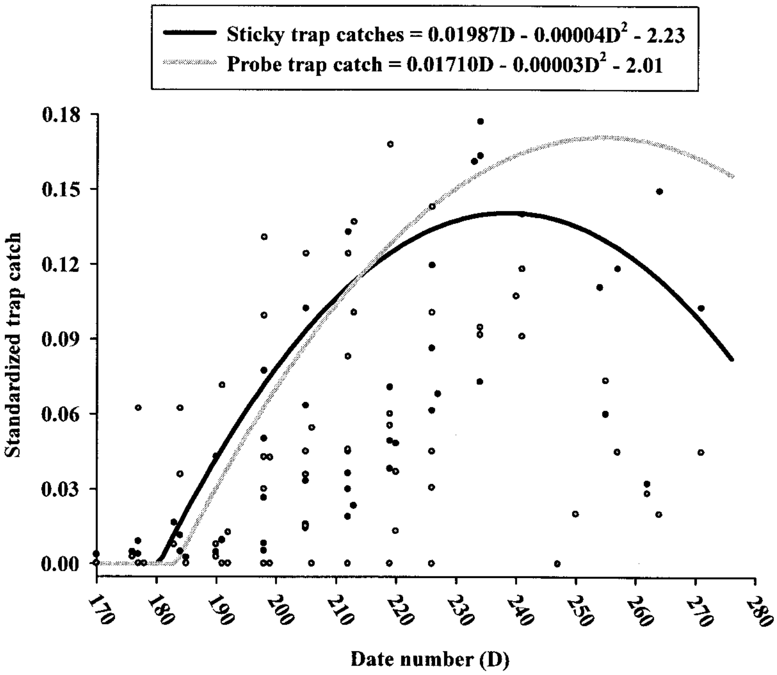

Fig. 4. Predicted and observed proportional catches of *C. ferrugineus* from unbaited sticky traps placed on the outside of storage bins and from probe traps inside storage bins. The model predictions were based on day numbers (D), which were discrete numbers from 1 to 365, and the model included linear and quadratic responses. Observed trap catches from each grain bin were converted into proportion of total per trapping period.

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