Monitoring field populations of *Lyctocoris campestris*, a predator of stored-grain insects: assessment of different trap designs

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Abstract

A year-round sampling of field populations of *Lyctocoris campestris* was conducted in Madison, Wisconsin, USA during 1992–93. Three different trapping methods were used to monitor relative populations: pitfall probe, cardboard, and sticky (flight) traps. One absolute sampling technique was also employed by using a 1140 mL cup sampler. Probe traps caught adult bugs throughout the year, but other traps were unable to detect bugs during times of low density. Probe traps caught significantly more bugs than cardboard and flight traps at most times throughout the trapping season. Absolute sampling catches were low, making comparison between absolute and relative sampling difficult. During early summer, flight traps caught more bugs than cardboard traps, while the opposite was true in early fall. The reversed response to cardboard and flight traps through the season might be due largely to environmental factors. Flight activity was higher because of relatively higher temperatures in the storage and surroundings during summer, thus flight trap catches were higher. A lower temperature during fall drove bugs inside the grain mass, increasing cardboard trap catches. Earlier work, based on probe trap catches, reported that *L. campestris* showed a highly female-biased sex ratio in the field as opposed to a 1:1 sex ratio in laboratory colonies. The present study found that the estimate of sex ratios in the field can differ with trapping methods. Examination of environmental factors and behaviour of bugs in the grain suggested that relative sampling methods are unreliable for sex-ratio studies in the field, and an absolute sampling method must be used to detect the true field sex ratio of *L. campestris*. Understanding this type of seasonal pattern across different traps could be valuable in monitoring predator populations during biological control operations.

Introduction

The predacious bug *Lyctocoris campestris* (F.) (Heteroptera: Anthocoridae) is commonly found in stored grains and other stored-product habitats. *L. campestris* is a generalist predator of stored-product insects that has been shown to be a potential biological control agent for these pests (Parajulee and Phillips 1992a, b). Because of the growing interest in using natural enemies in stored-product pest management systems and the realisation of the predatory potential of *L. campestris*, detailed biological studies have been undertaken in recent years. Parajulee and Phillips (1992b) first described the rearing techniques and the laboratory biology of *L. campestris*. Laboratory studies have shown that *L. campestris* can use a wide range of prey species of any stage and size that it can overpower (Parajulee and Phillips 1993). Parajulee et al. (1994) report a detailed account of *L. campestris* predatory response to different prey species and habitat structures. Our earlier work (Parajulee and Phillips 1992b) reported that *L. campestris* prefer mouldy and moist microenvironments over dry, and that the sex ratio is highly female biased in the field.

For the efficient use of natural enemies in pest management programs it is important that a thorough knowledge of the biologies, including distribution, abundance, population structure, and seasonality of both pests and natural enemies be known. Therefore, a two-year trapping study was initiated to document the field ecology of *L. campestris* in flat storages of shelled maize in Wisconsin. Specific objectives of this study were: 1) to monitor the seasonal patterns of *L. campestris* in the field; and 2) to examine the effectiveness of different trapping methods to monitor *L. campestris* population dynamics.

Materials and Methods

Experimental site and duration

A year-round sampling study of *L. campestris* was conducted for two consecutive years in 1992 and 1993 in a privately owned flat storage of shelled maize located 15 km west of the University of Wisconsin, Madison, Wisconsin, USA, hereinafter called Storage I. The sampling study was carried out mainly by trapping, except that there was one form of absolute sampling (see below). Storage I was a metal building (20 m × 40 m) on a cement slab with a buttressed 5 m tall inner wooden wall. Maize was harvested in October and December of 1991 and 1992, respectively, and thermally dried to a moisture content of 12–14% before storage. The surface of the storage was divided into 70 equal plots (2.7 m × 3.7 m) and we sampled alternating plots (up to 35) in a systematic manner. A nine-month (July 1992 to March 1993) sampling study was also conducted in another flat storage of shelled maize owned by the same farmer located 13 km west of Madison campus, hereinafter called Storage II. Storage II was a wooden building, approximately 20 m × 10 m, with maize filled to a height of 3 to 4 m. Storage II contained two to five-year-old maize in the lower layers, but had an approximately 1 m upper layer of maize harvested in 1991.

Trap types

We used three different relative sampling and one absolute sampling methods to monitor the *L. campestris* population in the field. Both relative and absolute sampling methods were deployed during 1992, while only relative sampling methods were used during 1993 in Storage I. Probe traps only were deployed in Storage II. Traps used in our study are described below.

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Probe traps

We used WB-II pitfall probe traps (Trece Inc., Salinas, CA) in our entire trapping study. Probe traps were 45.0 × 3.3 cm plastic cylinders, of which the top 30 cm was constructed of a mesh (3.5 mm × 2 mm openings) and the bottom 15 cm consisted of a removable, tapered tip that concealed a small inner funnel with a lower opening of 8 mm. Probe traps employ a pitfall design to passively capture insects that move through grain (Barker et al. 1990).

Fight traps

Flight traps were made of 480 mL yellow plastic drinking cups (Fabr-Kal Corp., Kalamazoo, Michigan) the outer surface of which was uniformly covered with the sticky material Tangletrap® (The Tanglefoot Co., Grand Rapids, MI). Cups were then inverted and an S-shaped hook was inserted at the bottom surface of the cup as a hanging device.

Cardboard traps

Cardboard traps were simply single pieces of single-faced corrugated cardboard (18 cm × 13 cm) inserted into a paper envelope (19 cm × 14 cm) with top and bottom ends open. The trap was inserted vertically in the grain mass and insects were able to crawl through either end of the envelope and hide in the corrugations of the trap.

Cup sampler

A 1140 mL cup sampler was used to obtain an absolute sample from each experimental plot. The cup sampler is a cylindrical device (7.5 cm ID × 26 cm height) of which the bottom end is pointed so that the device can be inserted into the grain mass; when the handle is pulled up, the top cover opens and a grain sample falls into the cylinder.

Sampling procedures

Each of 35 experimental plots in Storage I received a probe trap that was inserted vertically into the maize so that the top edge was 1–2 cm above the surface, a pair of flight traps (one 10 cm and the other 1 m above the grain surface) to monitor flying insects, and a cardboard trap inserted just below the grain surface. All these traps were deployed in May of 1992 and checked every week until November of 1993. Samples from probe traps were emptied and the same traps were replaced, but cardboard and flight traps were replaced with new traps every week. *L. campestris* caught in each trap type and plot were sorted by sex and stages and were recorded. The grain temperature at each experimental plot was recorded at 20 cm depth by using a digital thermometer (Fisher Scientific, Pittsburgh, PA). Two grain samples (absolute samples) were taken from each experimental plot each week during 1992 by using a 1140 mL cup sampler. One cup sample was taken as a column of 0–30 cm from the grain surface, and the second sample was drawn as another column of 30–60 cm from the surface, each randomly selected within a plot. Maize samples were returned to the laboratory and all insects were separated from the maize by sifting. Moisture content was also determined for each maize sample every other week by using a Steinlite digital moisture meter (Seedburo Equipment Company, Chicago, IL). *L. campestris* were sorted and identified by sex and stage, and counted as before. Surveying was continued through the winter of 1993, but the frequency of sampling was every two to four weeks. In April 1993, a weekly sampling scheme was resumed and continued through November, 1993 when the owner removed the 1992 crop from the storage and added the 1993 crop. A daily high and low air temperatures and relative humidities (r.h.) were recorded at 1 m above the grain near the centre of the storage building using a mini hygrothermograph (Cole-Parmer Instrument Company, Chicago, Ill), and calculated as mean daily temperatures and relative humidities. We then calculated weekly mean temperatures and relative humidities for each sampling date. Similarly, mean grain temperature and grain moisture for the entire site were calculated for each sampling date. There were only four pitfall probe traps deployed in Storage II throughout the sampling period. *L. campestris* caught in each of four probe traps were sorted by sex and stages and were recorded as before. Grain temperatures were also recorded in Storage II on a weekly basis.

Data analysis

Storage I

Because of low bug counts early and late in each year, we used data from 15 consecutive weeks, July 1 to October 14, 1992 and June 30 to October 13, 1993, for analysis. Absolute grain sampling data from 1992 only were used for the sex ratio analysis. During 1992 there were 19 experimental plots that remained in the storage throughout our 15-week experimental period. However, the number of plots in the storage were variable during 1993 because of the continuous removal of maize by the owner.

Storage II

Probe trap data from the entire nine-month trapping period were used for the analysis of sex ratio and seasonal trend.

Seasonal patterns of *L. campestris* adults were shown by plotting observed counts against sampling dates. The efficiency of cardboard, probe and flight traps in catching insects was examined by comparing the proportion of each trap type catching bugs for each sampling date during 1992 (protected Fisher's exact test; SAS Institute 1989).

Sex ratios (percentage of males) of adult *L. campestris* from Storage I were calculated for each sampling date and trap type across all the experimental plots. Significant departures from a sex ratio of 0.5 were then calculated for each sampling date and trap type (G-test; Sokal and Rohlf 1981). Because of very low counts in cardboard and flight traps during 1993, sex ratios were calculated and compared by summing counts across 15 weeks for these two trap types. Similarly, probe trap bug counts from Storage II were also summed across nine months for sex ratio analysis.

Results

Seasonal patterns

Adult *L. campestris* were first trapped in Storage I during second week of May in both 1992 and 1993 sampling years. However, total counts in all trap types were very low, with no bugs in cardboard traps, < 0.2 bugs/trap/week in probe traps, and < 0.009 bugs/plot/week in flight traps until June 30. Hence, we report statistical inferences based on 15-week sampling periods for both sampling years in Storage I. During 1992 more bugs were caught on the flight traps early in the season (June–July) and low numbers were caught in the cardboard traps. As the season progressed, numbers of bugs caught in the cardboard traps increased while the opposite was true for the flight traps (Fig. 1). Overall, probe traps caught more bugs on most sampling dates than the other two trap types (G-test; $P<0.001$; Sokal and Rohlf 1981), but the seasonal trend was two directional as opposed to the trends depicted by flight and cardboard traps. Probe traps caught low numbers in July and increased steadily for almost half of the sampling season during 1992, then showed a maximum abundance of 154 bugs on August 12, and finally declined steadily as the season pro-

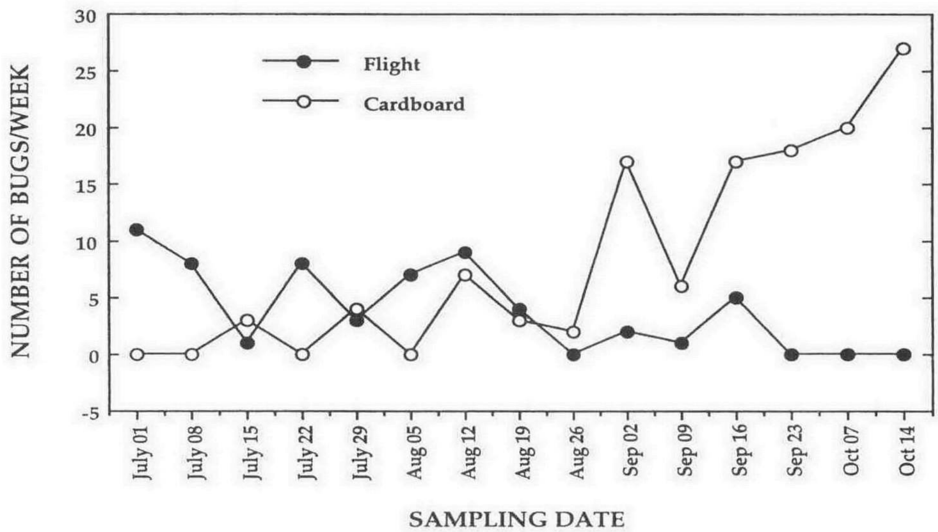

Fig. 1. Seasonal abundance of *L. campestris* monitored by flight and cardboard traps in Storage I of shelled maize from July 1 to October 14, 1992.

gressed (Fig. 2). The probe catch abundance during 1993 was much lower and more fluctuating than in 1992 (Fig. 3). A continuous habitat disturbance during 1993 was probably the cause for low counts of bugs in both flight and cardboard traps and no apparent seasonal trend was detected. The seasonal trend found in Storage II (Fig. 4) was similar to the trend found in Storage I in 1992 (Fig. 2), particularly during July to October. Bug abundance peaked in about mid to late August (Fig. 4) in Storage II. Despite a very low sample size (only two probe traps in 1993) we collected *L. campestris* adults from Storage II during most of the winter of 1993 until we terminated the trapping study in that storage in March, 1993. Since absolute sampling during 1992 in Storage I found low counts (mean of 3.33 bugs/week) of *L. campestris*, a seasonal pattern was not apparent. Low counts in grain samples also made comparison between absolute and relative sampling difficult.

Effectiveness of traps

The probe trap was the most effective design in capturing *L. campestris* on most sampling dates (Table 1). Proportions of traps that contain bugs are in agreement with the seasonal pattern we observed before. For instance, the proportion of flight traps containing bugs declined considerably as the season progressed and no flight trap detected any bugs after mid-September. Similarly, the proportion of cardboard traps containing bugs consistently increased throughout the sampling season as the grain temperature declined (Table 1, Fig. 5). Except in a few cases, the proportion of probe traps containing bugs were >0.5 and the efficiency of traps did not vary much with the sampling season. As late as mid-October, 60% of the probe traps captured bugs. It is interesting to note that during and after mid-September the proportion of probe traps containing bugs did not differ from that of cardboard traps.

Table 1. Proportions of traps that captured bugs per sampling date for each of three relative sampling methods in Storage I, 1992 (N= 19 traps).

Sampling date	Cardboard	Probe	Flight
July 1	0.105a	0.474b	0.368ab
July 8	0a	0.737c	0.316b
July 15	0.158a	0.632b	0.053a
July 22	0a	0.632b	0.053a
July 29	0.211a	0.632b	0.053a
Aug 5	0.053a	0.632b	0.158a
Aug 12	0.263a	0.737b	0.158a
Aug 19	0.158a	0.579b	0.158a
Aug 26	0.158a	0.684b	0a
Sep 2	0.316a	0.737c	0.053b
Sep 9	0.263a	0.579b	0.053a
Sep 16	0.474a	0.579a	0.053b
Sep 23	0.474a	0.474a	0b
Oct 7	0.571a	0.214ab	0b
Oct 14	0.500a	0.643a	0b

Proportions with different letters in each row are significantly different (protected Fisher's Exact Test; SAS Institute 1989).

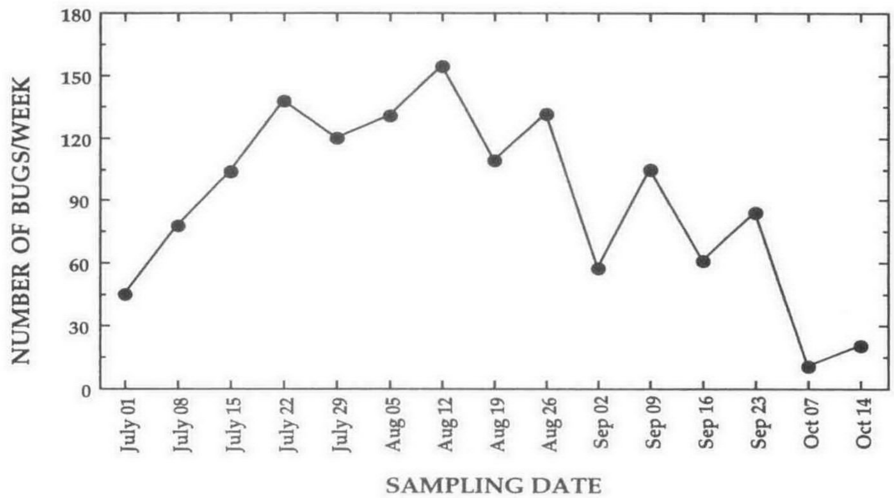

Fig. 2. Total number of *L. campestris* caught per week in probe traps in Storage I of shelled maize from July 1 to October 14, 1992

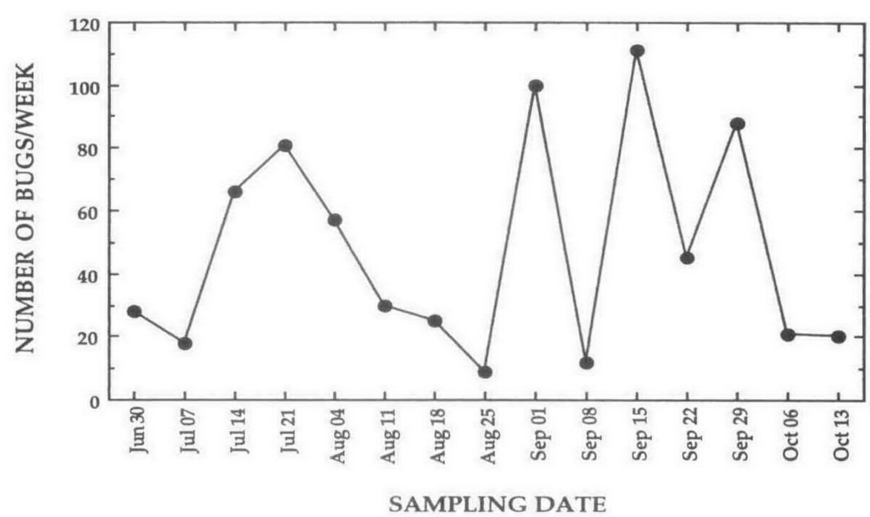

Fig. 3. Total number of *L. campestris* caught per week in probe traps in Storage I of shelled maize from June 30 to October 13, 1993.

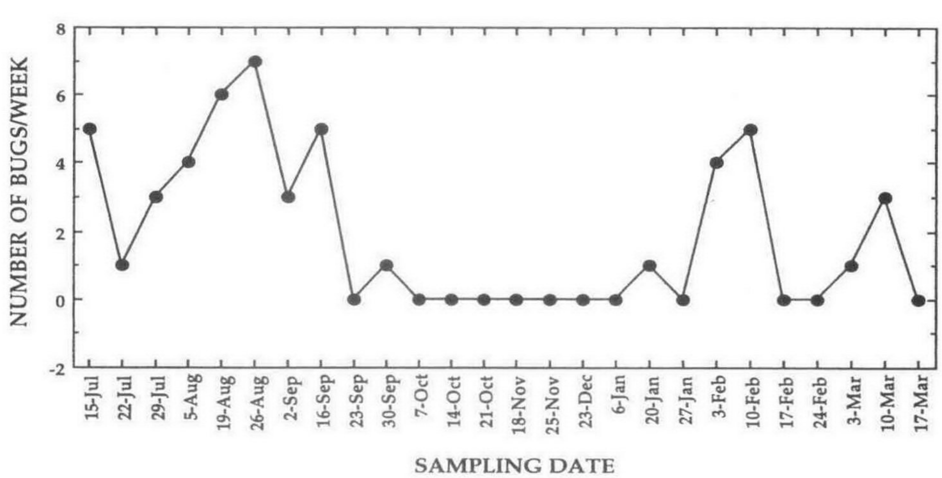

Fig. 4. Total number of *L. campestris* caught per week in probe traps in Storage II of shelled maize from July 15, 1992 to March 17, 1993

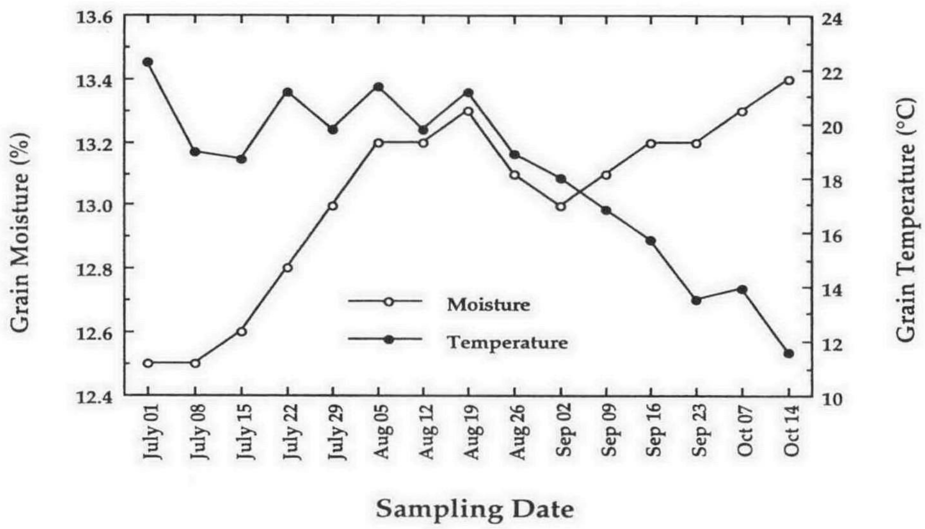

Fig. 5. Weekly record of mean grain moisture content (%) and mean grain temperature (°C) across all plots in Storage I of shelled maize from July 1 to October 14, 1992.

Hence, late in the season both probe and cardboard traps were equally efficient in detecting *L. campestris*. However, the number of bugs caught in cardboard traps was much lower than the bugs captured in probe traps.

Sex ratio

Earlier field work with *L. campestris* (Parajulee and Phillips 1992b) and the present study found a highly female-biased sex ratio in probe traps, but these data may not reflect the true population sex ratio. For both sampling years, probe traps caught significantly more females than males (G-test; $P<0.05$; Sokal and Rohlf 1981) in Storage I, with sex ratios of O. 18 and 0.21 during 1992 and 1993, respectively. Probe traps also showed a highly female-biased sex ratio (0.20) in Storage II (G-test; $P<0.05$; Sokal and Rohlf 1981). Flight traps showed the sex ratios of 0.36 and 0.27 during 1992 and 1993, respectively, but these sex ratios showed no deviation from 0.5 (G-test; $P>0.05$; Sokal and Rohlf 1981). Similarly, cardboard traps showed no deviation in the sex ratios from 0.5 during 1992 (0.46), but showed a female-biased sex ratio (0.13) during 1993. Absolute sampling of grain during 1992 also showed an essentially equal sex ratio (0.52), and no seasonal variation was detected in the sex ratio by absolute sampling (P>O. 10, G -test for 18 individual sampling dates, June 24 to October 21).

Discussion

Seasonal patterns

The estimates of population abundance of *L. campestris* during 1992 from all three trap types were influenced by one or more environmental factors. Correlation analysis (Table 2) showed that all the environmental factors monitored in our study, except relative humidity, were strongly correlated with sampling dates. Similarly, all three trap types showed a significant correlation between sampling dates and trap catches, indicating a seasonal effect on observed *L. campestris* abundance. Correlation analysis (Table 2) showed that grain and air temperatures and grain moistures were important factors affecting bug abundance in cardboard traps. A high correlation between cardboard trap catches and temperatures (Table 2) suggests that temperature is very important in determining bug abundance in cardboard traps. The lower temperatures (both air and grain) might have led the bugs to move into the grain subsurface to seek refuge in the cardboard traps. Similarly, a moist environment, associated with cooler temperatures, could be favourable for *L. campestris* survival as well as oviposition. On the other hand, at higher temperatures (in early and mid-season sampling) bugs may have experienced higher surface mobility and increased flight

Table 2 Correlation coefficients among trap types and environmental variables for 1992 in Storage I.

	Week	Moisture	Grain temperature	Air temperature	r.h.	Cardboard trap	Flight trap
Grain moisture	O. 84						
Grain temperature	−0.85	−0.56					
Air temperature	−0.77	−0.48	0.87				
Relative humidity	0.05[a]	−0.31[a]	−0.22[a]	−0.02[a]			
Cardboard trap	0.86	0.62	−0.89	−0.89	0.06[a]		
Flight trap	−0.69	−0.47	0.70	0.60	−0.02	−0.59	
Probe trap	−0.44	−0.07[a]	0.62	0.80	−0.38[a]	−0.69	0.31[a]

[a]Correlation coefficients are not significantly different from zero (PROC CORR; SAS Institute, 1989; N = 15C).

activity, thus leading to a decrease in cardboard trap catches and an increase in the flight trap catches (Fig. 1, Table 2). The negative correlation between flight trap and cardboard trap catches is reflected in the opposite trends of these two traps in correlations with all environmental factors (Table 2). Bug abundance in probe traps also was influenced by both grain and air temperatures. The higher temperature might have enhanced the mobility of bugs in the grain leading to more bugs falling into the probes. Although grain moisture was not correlated with probe trap catches in this study, in earlier work we found that *L. campestris* was caught in probe traps in high moisture mouldy areas of the grain compared to drier areas (Parajulee and Phillips 1992b). High moisture in 'hot spots' is a direct result of zones of fungal activity that harbour many prey species. Overall, grain moisture in the current study increased through the season as grain temperature decreased. Thus, increased grain moisture may be a consequence of fungal activity in certain areas or simply from a decrease in temperature throughout a grain mass, and bug activity (measured by flight and probe traps) is more directly related to temperature.

Effectiveness of traps

A suitable sampling method must be devised to accurately predict predator population levels before augmentation for a cost-effective biological control program (e.g. Shipp et al. 1992). Flight traps appear to be effective in early season and cardboard traps in late season in monitoring *L. campestris* field populations. Probe traps seem to be most effective in detecting *L. campestris* population throughout the sampling season. Absolute sampling was labour intensive, yet it could not detect low populations of *L. campestris*. Hence, we recommend using probe traps in monitoring *L. campestris* field populations. Performance of relative sampling methods is influenced by the behaviour of insects being sampled, habitat structure, environmental factors, and the effectiveness of traps in catching insects. Thus, the results based on relative sampling must be interpreted with caution. The timing and duration of the activity period of insects depend on the life history characteristics of the species in question (Wolda 1988). Hence, we would typically expect the same seasonal pattern if all the traps had a similar performance. Thus, differences in trap performance could lead to misinterpretation of seasonal pattern of the species if only one type of trap were used.

Sex ratio

Seasonal activity patterns and differences in sex ratios may reflect different behavioural responses of bugs to trap designs. Probe traps consistently showed a female-biased sex ratio of *L. campestris* field populations for the entire sampling studies. If only probe traps were used in field sampling, one might consider an apparent female-biased sex ratio. However, the other two relative sampling methods, flight traps and cardboard traps, showed essentially equal sex ratios. No deviation in the sex ratios in flight traps suggests that both sexes are similar in flight activity. Cardboard traps caught bugs mostly during the second half of the sampling season during periods of higher grain moisture and lower air and grain temperatures, which may have caused L. *campestris* to seek refuge. Once *L. campestris* find refuge, they hide until they have to leave to search for prey. We have observed in the field that one of the prey of *L. campestris*, the Indianmeal moth larvae, tend to seek such refuge as cardboard traps for pupation. Hence, *L. campestris* may not have to leave cardboard traps if they encounter their prey in the trap. The equal sex ratio revealed by cardboard traps must be attributed to the similar behaviour of both male and female *L. campestris* in seeking refuge. Laboratory studies have consistently shown equal sex ratios under various rearing conditions (Parajulee and Phillips 1992, 1993). More importantly, absolute sampling of grain during 1992 in Storage I showed an essentially equal sex ratio (0.52), and no seasonal variation was detected in the sex ratio by absolute sampling. Absolute samplings were independent of insect mobility or any environmental factor because the samples were taken instantly along with their habitat substrate. An equal sex ratio in these grain samples confirmed that males and females exist in equal numbers in the field. Therefore, the trap type and the time of sampling can affect the sample count and consequently the sex ratio.

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