Sampling Adult Beetles (Coleoptera) Associated with Stored Grain: Comparing Detection and Mean Trap Catch Efficiency of Two Types of Probe Traps

BH. SUBRAMANYAM, D. W. HAGSTRUM,[1] AND T. C. SCHENK

Department of Entomology, University of Minnesota,
St. Paul, MN 55108

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ABSTRACT Insect detection and mean trap catch efficiency of two types of commercial probe traps, the Storgard WB Probe II (WB II) and Grain Guard (GG), were compared by sampling live beetles in the top ≤28 cm of shelled corn stored in three round bins and two flat units. Unbaited WB II and GG traps were paired, and number of trap pairs among the five facilities ranged from 8 to 20. Insects were trapped between July and September 1990, and the trapping duration was 7 or 14 d (only in one flat unit). Adults of 13 species were detected by WB II traps, whereas 11 species were detected by GG traps. In general, insect species were more frequently detected and trap catches were higher in WB II traps than in GG traps. However, differences in insect detection and mean trap catch between the trap types were small. A double-logarithmic model satisfactorily described (R^2 = 83%) the nonlinear statistical relationship between proportion of traps with adults and mean trap catches for both trap types. The progressively slower increase in proportion of traps with insects with increasing mean trap catches for both trap types can be explained by a purely probabilistic increase in the chance of a trap having more than one insect. This double-logarithmic model is valuable for predicting mean trap catches, solely based on proportion of traps with insects. When validated with two independent data sets, obtained by sampling insects in shelled corn with WB II traps and in stored barley with GG traps, the predicted mean trap catches explained ≥84% of the variation in observed mean trap catches.

KEY WORDS stored-grain ecosystem, trapping, modeling

DETECTION OR ESTIMATION of live insects associated with bulk-stored grain is important for making pest management decisions (Hagstrum & Flinn 1992). Live insects, especially adults of beetles associated with stored grain, can be detected easily by inserting perforated, cylindrical devices (probe traps) into the grain mass (White et al. 1990). The earlier versions of these devices were made of brass (Loschiavo & Atkinson 1967, Barak & Harein 1982), and the more recent versions are made of polycarbonate (Lexan) or polyethylene plastic (Barak et al. 1990). Unbaited probe traps are useful for surveying or for determining relative abundance of insect species associated with stored grain (Barak & Harein 1982, Subramanyam & Harein 1989, Reed et al. 1991). Probe traps have been used to characterize insect distribution and to determine accuracies and sample sizes needed for estimating mean trap catches (Lippert & Hagstrum 1987, Subramanyam & Harein 1990). Lippert & Hagstrum (1987) related numbers of insects caught in probe traps in stored wheat to numbers in grain samples removed with a deep-bin cup probe.

Probe traps facilitate early detection of insects, and they are effective in detecting insects when grain samples (removed with a grain trier or deep-bin cup probe, or both) fail to reveal any insects (Barak & Harein 1982, Reed et al. 1991). Probe traps also tend to capture more insect species and greater numbers of insects than grain-sampling devices (Barak & Harein 1982, Lippert & Hagstrum 1987, Subramanyam & Harein 1990). Unlike grain-sampling devices, which take an instantaneous grain sample, probe traps can be left in the grain for extended periods. Leaving traps in the grain for extended periods increases the probability of insect detection. White et al. (1990) discuss advantages and disadvantages of probe traps, and Cuperus et al. (1990) discuss factors affecting insect catch in probe traps.

In the United States, currently there are two types of commercial probe traps—the Storgard WB Probe II [WB II] (Trece, Salinas, CA), and the Grain Guard [GG] (Grain Guard, Verona, WI). The WB II trap, made of polyethylene, is 45

[1] U.S. Grain Marketing Research Laboratory, USDA–ARS, Manhattan, KS 66502.

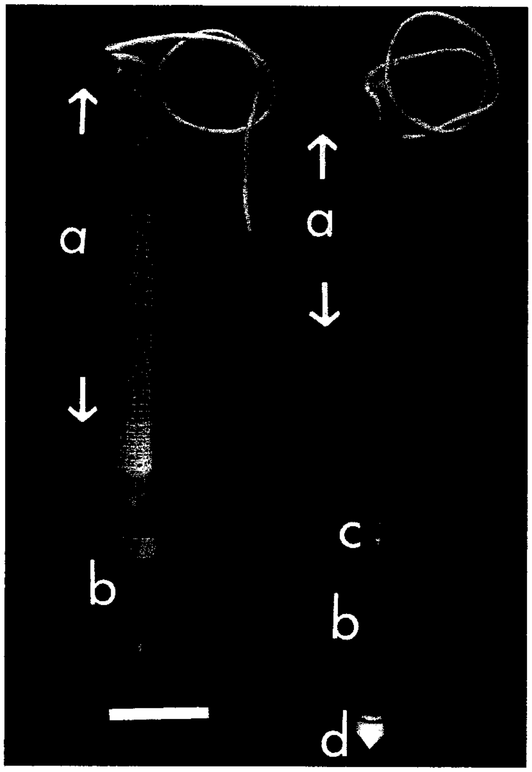

Fig. 1. Disassembled WB II trap (left) and GG trap (right). a, perforated region; b, insect-collecting vial; c, plastic cap that fits on top of the vial; d, snap cap to hold vial in place. Rope attached to top of traps facilitates easy retrieval from the grain. Scale, 1 cm = 3.7 cm.

cm long with an internal diameter of 3 cm (Fig. 1). These traps have 750 rectangular (0.40 by 0.24 cm) perforations; the perforated region is 28 cm long. The GG trap, made of polycarbonate, is 37 cm long with an internal diameter of 2 cm. These traps have 192 round (2.8 mm diameter) downward-sloped perforations in the upper half of the trap; this perforated region is ≈16 cm long (Fig. 1). The GG trap was developed and commercialized around 1984 (White et al. 1990). The WB II trap was developed recently (see Barak et al. 1990) and hence is not as widely used and tested as the GG trap for its effectiveness in sampling insects associated with stored grain. White et al. (1990) provide a comprehensive review of research and tests conducted using GG traps.

The objectives of the present investigation were to determine how frequently WB II and GG traps detect adults of various insect species associated with shelled corn stored on farms in Minnesota, to compare differences in mean numbers of insect species captured between trap types, to model the statistical relationship between proportion of WB II or GG traps with adults and mean trap catch, and to validate the statistical model with independent trap catch data to determine if mean trap catches could be accurately predicted from proportion of traps with insects.

Materials and Methods

Comparing Detection Sensitivity of Trap Types. Three round bins (A, B, and C) and two flat storage units (D and E) holding shelled corn were sampled with WB II and GG traps during 1990. All five facilities were located in Castle Rock, ≈48 km south of the University of Minnesota, St. Paul. The diameter and height (to eaves) of each bin was 10.1 and 7.3 m, respectively. Dimensions of each flat unit were 36.3 by 12.2 by 6.1 m. The grain in all facilities was from the 1986 crop year. Each bin held ≈425 metric tons (16,731 bushels) of grain, whereas each flat unit held 1,399.1 metric tons (49,967 bushels). The grain height in each bin and flat unit was 7.2 and 4.3 m, respectively, and the grain surface in all facilities was leveled.

In all facilities, unbaited WB II and GG traps were paired, and trap pairs were placed along the four cardinal directions. The number of trap pairs in facilities A, B, C, D, and E was 9, 9, 8, 20, and 18, respectively. Distance between the trap types within a pair was 30 cm, and among pairs was ≥90 cm. Trap locations within a pair were chosen at random by a coin toss. In bins A, B, and C, the trapping duration was 7 d (20–27 July). In flat units D and E, the trapping duration was 7 d (30 July–6 Aug.) and 14 d (14–28 Sept.), respectively. Traps were inserted just below the grain surface. Thus, WB II and GG traps sampled insects active in the top 28 and 16 cm of the grain mass, respectively. The top 16–28 cm of the grain mass was sampled because infestation of newly harvested insect-free grain stored in empty, insect-free bin occurs via the grain surface (Hagstrum 1989). In addition, farmers usually check for insect infestations in the surface layers of the grain mass (Harein et al. 1985, Gardner et al. 1988). During the three sampling periods described above, average grain temperature and moisture in the top 28 cm among facilities was 24–27°C and 13–15%, respectively.

Beetle adults captured by each trap type in a pair were identified to genus or species and counted. Each trap type in a pair was scored as 0 if a given species was absent, or as 1 if a given species was present. Thus for each trap pair, there are one of four possible outcomes: (0,0), (1,1), (0,1), or (1,0). For a given species, each trap pair across the facilities (in which that species was detected) was dichotomized in this fashion. For each species, significant differences ($P < 0.05$) in the frequency of detection between trap types were determined by the McNemar test (Conover 1980) as

Table 1. Proportion of WB II and GG traps with adults of insect species associated with shelled corn, and statistical difference in frequency of insect detection between trap types[a]

Insect species	Facilities[b]	N[c]	Proportion of traps with adults		T[d]	P[e]
			WB II	GG		
Ahasverus advena	A, B, C, E	44	0.636	0.477	3.27	0.071
Corticaria spp.	A–E	64	0.094	0.031	2.00	0.157
Cryptolestes ferrugineus	A–E	64	0.500	0.484	0.05	0.827
Cryptolestes pusillus	A–E	64	0.625	0.531	3.60	0.058
Cryptophagus spp.	A, B, C	26	0.269	0.077	5.00	0.025**
Cynaeus angustus	B–E	55	0.145	0.091	0.82	0.366
Lathridius minutus	A–E	64	0.219	0.094	5.33	0.021**
Oryzaephilus surinamensis	C	8	0.250	0.000	2.00	0.157
Sitophilus oryzae	A, E	27	0.222	0.296	0.67	0.414
Tenebroides mauritanicus	E	18	0.167	0.056	1.00	0.317
Tribolium castaneum	A–E	64	0.719	0.750	0.29	0.593
Tribolium confusum	B, E	27	0.111	0.000	3.00	0.083
Typhaea stercorea	A–E	64	0.625	0.484	3.52	0.061

[a] Frequency of insect detection (C_{WB} or C_{GG} [see equation 1]) = proportion * N.
[b] Facilities in which the species was detected in one or more WB II or GG traps.
[c] Total number of trap pairs. Number of trap pairs in facilities A, B, C, D, and E was 9, 9, 8, 20, and 18, respectively.
[d] T is distributed as a χ^2 with 1 df.
[e] **, significant ($P < 0.05$; McNemar test [Conover 1980]).

$$T = \frac{(C_{WB} - C_{GG})^2}{\sum_{i=1}^{r} R_i(2 - R_i)}, \quad (1)$$

where C_{WB} and C_{GG} are column totals (or number of traps with insects) for WB II and GG traps, respectively, and R_i are row totals. T is approximated by a χ^2 distribution with 1 df. For each species, column totals were expressed as proportions by dividing C_{WB} and C_{GG} by the total number of trap pairs (N; see Table 1).

Comparing Differences in Trap Catch. In each facility, difference ($P < 0.05$) between trap types in mean catch of a species was determined by a paired t test (SAS Institute 1988). For species captured in only one of the two trap types, a paired t test was used to determine if mean trap catch of that species was significantly different from zero. For species that were detected by both trap types in more than one facility, the difference between trap types in mean catch of each species across facilities was determined by the Fisher combined test (Wolf 1986) as

$$\chi^2 = -2 \Sigma \ln P, \quad (2)$$

where P is one-tailed probability associated with each t test. The χ^2 statistic has a sampling distribution approximated by a χ^2 distribution with $2n$ degrees of freedom, where n is the number of facilities for which data were combined.

Modeling Relationship Between Proportion of Traps with Adults and Mean Trap Catch. For each species captured by WB II or GG traps in each of the facilities, proportion of traps with adults (Y) and mean trap catch ($\bar{x}$) were calculated. The nonlinear statistical relationship between Y and $\bar{x}$ for WB II or GG traps was described by the following double-logarithmic model:

$$Y = 1 - (A*\text{Exp}^{-B\bar{x}} + (1 - A)*\text{Exp}^{-C\bar{x}}) \quad (3)$$

Parameters A, B, and C were estimated by the derivative-free (DUD) regression method of SAS procedure PROC NLIN (SAS Institute 1988). Differences ($P < 0.05$) between WB II and GG trap models were determined by comparing individual models with a pooled model (Draper & Smith 1981). If models were not significantly different from one another, data were pooled and a model was fitted to the pooled data. Equation 3 was fitted to combined species' data, because Hagstrum et al. (1988) have shown that relationship between Y and $\bar{x}$ was similar for several species and stages of stored-grain insects.

Model Validation. To determine if equation 3 could be used to predict accurately mean trap catches from proportion of traps with adults, we compared two independent data sets with model predictions. Independent data were obtained by inserting 10 WB II traps just below the corn grain surface in each of the bins A, B, and C. Trap locations were chosen at random, and the trapping duration was 7 d (24–31 August 1990). Average grain temperature and moisture in the area sampled with traps among bins was 26–31°C and 12–14%, respectively. In each of five bins holding barley, 16 GG traps were inserted just below the grain surface for 2 d (30 July–1 Aug. 1987). In each bin, the grain surface was stratified into four quadrants, and four traps were allocated at random to each quadrant. The diameter among the five bins ranged from 3.0 to 4.1 m, and these bins held about ≈107 to 192 metric tons (5,000–9,000 bushels) of barley harvested in 1985 (four bins) and 1987 (one bin). The grain temperature and moisture near traps among bins averaged 26–28°C and 12–13%, respectively.

Insects caught in traps were segregated by species and counted. For each species captured by 10 WB II or 16 GG traps in each of the facilities, the proportion of traps with adults and mean trap catch were calculated. From the proportion of WB II or GG traps with adults, the mean trap catch was predicted using equation 3 and parameter estimates of equation 3 (see Fig. 3) by DUD least squares method (SAS Institute 1988). The predicted mean catches in WB II or GG traps were then regressed on the corresponding observed mean trap catches. Because residual plots for each of the regressions showed a right-opening megaphone, both predicted and observed trap catches were transformed to logarithmic scale to stabilize variances (Weisberg 1980).

Results

Detection Sensitivity of Trap Types. Across the five facilities sampled, WB II traps detected adults of 13 insect species, whereas GG traps detected 11 species (Table 1). Two additional species detected only by WB II traps were the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Silvanidae) and confused flour beetle, *Tribolium confusum* Jacquelin du Val (Tenebrionidae). *O. surinamensis* and *T. confusum* were detected by WB II traps in one and two facilities, respectively, and the proportion of traps with each of these species was not significantly different from zero ($P \geq 0.083$). The 11 insect species detected by both WB II and GG traps were the foreign grain beetle, *Ahasverus advena* (Waltl) (Cucujidae); *Corticaria* spp. (Lathridiidae); rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Cucujidae); flat grain beetle, *Cryptolestes pusillus* (Schönherr) (Cucujidae); *Cryptophagus* spp. (Cryptophagidae); larger black flour beetle, *Cynaeus angustus* (LeConte) (Tenebrionidae); squarenosed fungus beetle, *Lathridius minutus* (L.) (Lathridiidae); rice weevil, *Sitophilus oryzae* (L.) (Curculionidae); cadelle, *Tenebroides mauritanicus* (L.) (Trogositidae); red flour beetle, *Tribolium castaneum* (Herbst) (Tenebrionidae); and hairy fungus beetle, *Typhaea stercorea* (L.) (Mycetophagidae). *Corticaria* spp., *C. ferrugineus, C. pusillus, L. minutus, T. castaneum,* and *T. stercorea* were present in all five facilities as indicated by their capture in WB II or GG traps (Table 1). The other species were detected in fewer than five facilities. Of the 11 species captured by both WB II and GG traps, a significantly greater proportion of WB II than GG traps ($P < 0.05$) detected adults of only *Cryptophagus* spp. and *L. minutus*. For each of the other 9 species, proportions of WB II and GG traps containing these insects were not significantly different from one another ($P > 0.05$), although adults of *A. advena, Corticaria* spp., *C. ferrugineus, C. pusillus, C. angustus, T. mauritanicus,* and *T. stercorea* were more frequently detected by WB II than GG traps. For example, an additional 7, 4, 1, 6, 3, 1, and 9 WB II traps detected *A. advena, Corticaria* spp., *C. ferrugineus, C. pusillus, C. angustus, T. mauritanicus,* and *T. stercorea*, respectively, when the corresponding GG traps failed to detect these species. Conversely, a slightly greater proportion of GG than WB II traps detected adults of *S. oryzae* and *T. castaneum* (Table 1). Each of these species was detected in 2 additional GG traps when the corresponding WB II traps failed to detect the insects.

Table 2. Sensitivity of WB II and GG traps in detecting adults of seven insect species associated with shelled corn

Insect species	Facilities in which the species was detected in	
	WB II but not GG	GG but not WB II[b]
Corticaria spp.	A (1)[a], B (1), C (3)	E (1)
Cryptolestes pusillus	B (3)	—[b]
Cryptophagus spp.	C (2)	—
Cynaeus angustus	B (2)	—
Lathridius minutus	D (3), E (1)	—
Oryzaephilus surinamensis	C (2)	—
Sitophilus oryzae	A (1)	—
Tribolium confusum	B (1), E (2)	—

[a] Number of traps in which adults were detected is indicated in parenthesis.
[b] —, adults not detected in GG trap(s).

In certain facilities, WB II traps in one to three pairs detected adults of eight insect species when all the corresponding GG traps failed to detect these species in that facility (Table 2). In one facility, a GG trap in a pair detected *Corticaria* spp. when all the corresponding WB II traps failed to detect this species.

Differences in Mean Trap Catch. Mean trap catches of insect species varied among facilities and between trap types (Fig. 2). *Corticaria* spp., *S. oryzae*, and *T. mauritanicus* were captured by both WB II and GG traps in only one facility, and mean catches of these species were <1.2 adults per trap. Numbers of these three species caught in WB II traps were equal to or 1.2–2.8 times higher than numbers caught in GG traps. However, mean trap catches of each species between trap types were not significantly different from one another ($P = 0.33$–1.00). Fig. 2 also shows the facilities in which insect species were captured by WB II and not GG traps and vice versa. These species include *Corticaria* spp. in facilities A, B, C, and E; *Cryptophagus* spp. in facility C; *C. angustus* in facility B; *L. minutus* in facilities D and E; *C. pusillus* in facility B; and *S. oryzae* in facility A. *Corticaria* spp. in facility E was captured only in GG traps (Fig. 2). All other species, including *Corticaria* spp. in facilities A,

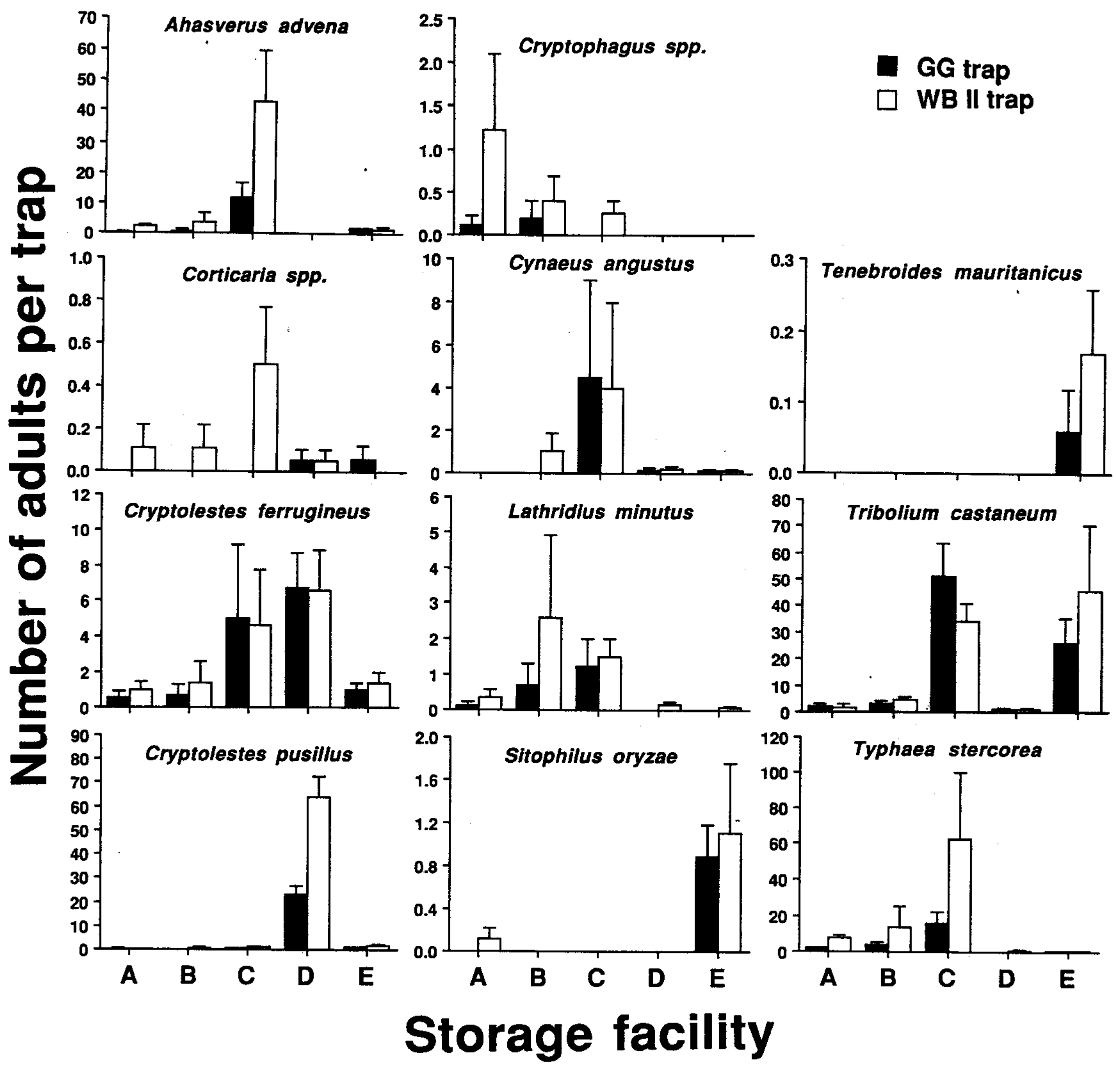

Fig. 2. Trap catches (mean ± SEM) of insect species in WB II and GG traps in each of the five facilities holding shelled corn. Number of trap pairs in facilities A, B, C, D, and E was 9, 9, 8, 20, and 18, respectively. *C. pusillus* adults were captured by both trap types in facility A (mean ± SEM = 0.11 ± 0.11 per WB II trap; 0.22 ± 0.15 per GG trap), and by only WB II traps in facility B (mean ± SEM = 0.80 ± 0.50 per trap). *T. stercorea* adults were captured by both trap types in facilities D (mean ± SEM = 1.00 ± 0.25 per WB II trap; 0.10 ± 0.07 per GG trap), and E (mean ± SEM = 0.44 ± 0.20 per WB II trap; 0.67 ± 0.30 per GG trap). Note: The Y axis scale is different for different species.

B, and C, were captured only in WB II traps. Mean trap catch of each of these species was very low (range among species, 0.06–1.00 adult per trap) and was not significantly different from zero (P = 0.083–0.347). Adults of *O. surinamensis* were captured only in WB II traps in facility C; *T. confusum* adults were captured only in WB II traps in facilities B and E (Table 1). The catch (mean ± SEM) of *O. surinamensis* was 0.25 ± 1.6 adults per trap, and catch of *T. confusum* in facilities B and E was 0.22 ± 0.22 and 0.11 ± 0.08 adult per trap, respectively (data not shown in Fig. 2). Mean trap catch of each of these species also was not significantly different from zero (P = 0.163–0.347).

Adults of *A. advena, C. ferrugineus, C. pusillus, Cryptophagus* spp., *C. angustus, L. minutus, T. castaneum,* and *T. stercorea* were captured by both trap types in 4, 5, 4, 2, 3, 3, 5, and 5 facilities, respectively. The catch ratios (WBII/GG) varied greatly among facilities, but across facilities, WB II traps captured 1.1–6.7 times more adults of these eight species when compared with GG traps (Table 3). However, mean catches of only *A. advena, C. pusillus, T. castaneum,* and *T. stercorea* adults were significantly higher in WB II

Table 3. Fisher combined test results, and insect catch in WB II traps relative to catch in GG traps

Insect species	χ^2 (df)[a]	P	Catch ratio (WB II/GG)	
			Mean[b]	Range[c]
Ahasverus advena	30.86 (8)	<0.001**	5.30	0.96–10.60
Cryptolestes ferrugineus	13.71 (10)	0.186	1.42	0.90– 2.00
Cryptolestes pusillus	33.57 (8)	<0.001**	1.83	0.50– 2.30
Cryptophagus spp.	9.19 (4)	0.056	6.65	2.00–11.10
Cynaeus angustus	6.77 (6)	0.342	1.06	0.90– 1.30
Lathridius minutus	8.82 (6)	0.184	2.63	1.20– 3.70
Tribolium castaneum	18.93 (10)	0.041**	1.20	0.80– 1.50
Typhaea stercorea	36.88 (10)	<0.001**	4.40	0.66–10.00

[a] Fisher combined test results (see equation 2) and catch ratios were based on two or more facilities in which a species was captured by both trap types.
[b] Mean ratio is based on mean trap catches from individual facilities (see Fig. 2).
[c] Range of mean catch ratios among facilities.
** Significant ($P < 0.05$).

traps than in GG traps ($P < 0.05$; Fisher combined test). For the other four species, mean trap catches between WB II and GG traps were not significantly different from one another.

Relationship Between Proportion of Traps with Adults and Mean Trap Catch. Equation 3 satisfactorily described the nonlinear relationship between proportion of traps with adults and mean trap catch for data based on WB II traps ($F = 165.78$; df = 3, 44; $P < 0.001$; $R^2 = 0.775$) or GG traps ($F = 224.47$; df = 3, 44; $P < 0.001$; $R^2 = 0.885$). However, models fitted to WB II and GG trap data were not significantly different from one another ($F = 1.07$; df = 3, 88; $P = 0.366$). Therefore, data were pooled and a model was fitted to the pooled data ($F = 373.39$; df = 3, 91; $P < 0.001$; $R^2 = 0.832$) (Fig. 3). The estimated means, asymptotic standard errors, and asymptotic 95% CIs for equation 3 parameters A, B, and C were 0.411 ± 0.088 (0.237–0.585), 1.881 ± 0.706 (0.479–3.284), and 0.112 ± 0.038 (0.037–0.186), respectively.

There was progressively slower increase in proportion of traps with insects as mean trap catches increased from 0.05 to 5 adults per trap (Fig. 3). At mean catches of >5 adults per trap, there was a much slower increase in the proportion of traps with adults. About 0.9 (90%) traps contained adults when the mean trap catch was ≈16 adults per trap. There was negligible increase in proportion of traps with insects at trap catches above 16 adults per trap.

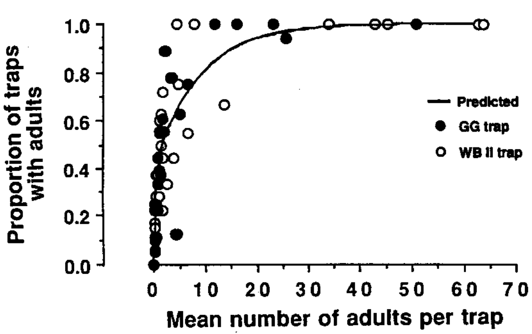

Fig. 3. Observed and predicted relationship between proportion of WB II and GG traps with adults and mean trap catch. Predicted proportion of traps with insects, $Y = 1 - [0.411*\mathrm{Exp}^{-1.881x} + (1 - 0.411)*\mathrm{Exp}^{-0.112x}]$ $n = 94$; $R^2 = 0.832$.

Model Validation. Independent data obtained by capturing insects in WB II traps in shelled corn in facilities A, B, and C were based on the same species as shown in Fig. 2, except for *T. mauritanicus* which was not captured in traps. Data obtained using GG traps in barley included the following species: *A. advena*, *C. ferrugineus*, *C. pusillus*, *O. surinamensis*, *S. oryzae*, *T. castaneum*, and *T. stercorea*. Equation 3 accurately predicted mean trap catches based on proportion of traps with adults (Fig. 4). About 84 and 90% of the variation in observed mean trap catches of insects in corn and barley, respectively, was explained by predicted mean trap catches.

Discussion

WB II and GG traps were equally efficient in detecting adults of nine insect species (Table 1) that are commonly associated with shelled corn stored on farms in Minnesota (Barak & Harein 1981, 1982). Significantly more WB II than GG traps detected adults of two species, *Cryptophagus* spp. and *L. minutus*, which have not been previously reported associated with stored corn in Minnesota. In addition, WB II traps detected *O. surinamensis* and *T. confusum* adults when GG traps failed to detect these species. Detection of eight insect species by WB II traps (Table 2) when GG traps failed to detect them in certain facilities was common; the converse rarely occurred. Mean trap catches of insect species also were generally higher in WB II traps than in GG traps, although catches of majority of species between both trap types were not significantly different from one another. In certain facilities,

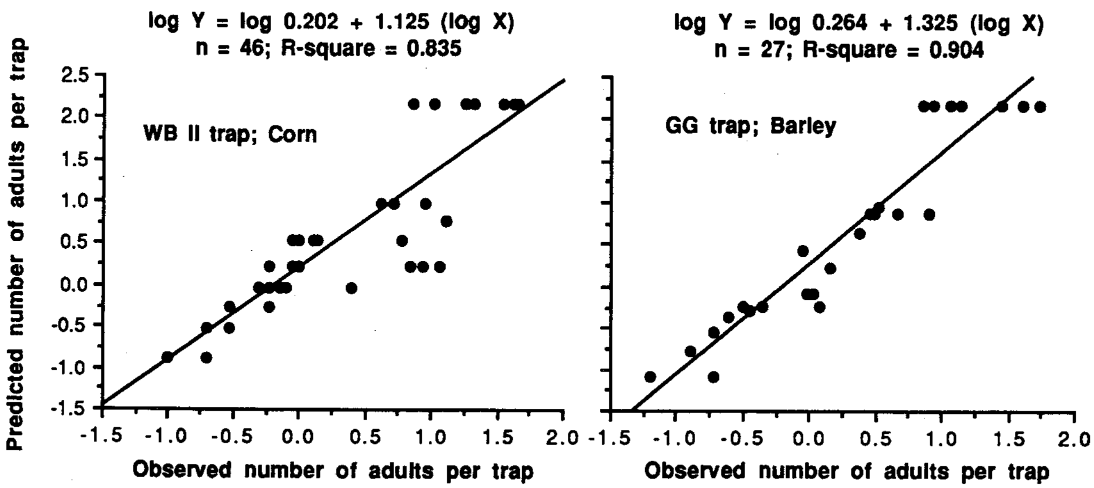

Fig. 4. Linear regressions showing the relationship between predicted and observed mean trap catches of adults sampled with WB II traps in stored corn (left), and with GG traps in stored barley (right). Both the predicted and observed mean trap catches are on a logarithmic scale.

mean trap catches of species that were captured in only one of the two trap types were not significantly different from zero. Because the numbers of insects caught in traps is dependent on the density of insects in grain (Wright & Mills 1984), these insects probably were present in very low numbers in the grain. Across facilities, mean trap catches of only *A. advena*, *C. pusillus*, *T. castaneum*, and *T. stercorea* were significantly higher in WB II traps than in GG traps (Table 3). Because proportions of WB II and GG traps with each of these species were not significantly different from one another, the higher catch in WB II traps is a result of additional adults being captured in traps already containing insects. In the laboratory, WB II traps also captured 2.3 and 1.2 times more adults of the granary weevil, *Sitophilus granarius* L. and *T. castaneum*, respectively, when compared with GG traps (Barak et al. 1990, 479). The WB II trap has 3.9 times more perforations than the GG trap. Also, the capture (perforated) area of WB II trap (75.0 cm^2) is 3.1 times greater than the GG trap (24.1 cm^2). Differences in these trap characteristics may explain the greater detection sensitivity and higher catches of insect species in WB II traps than in GG traps.

The perforated areas of WB II and GG traps are 28 and 16 cm long, respectively (Fig. 1), and these traps, when placed vertically just below the grain surface, tend to capture live insects in the top 28 cm or less of the grain mass. However, the small differences observed between trap types in proportion of traps containing insects, and in mean trap catches except for four species, may suggest that insects are active mainly in the top 16 cm of the grain mass. The fact that a single model (Fig. 3) described the nonlinear relationship between the proportion of traps with insects and mean trap catches for both trap types also indicates that differences between trap types were small. The progressively slower increase in proportion of traps with insects with an increase in mean trap catches for both trap types can be explained by a purely probabilistic increase in the chance of additional insects being captured in traps already containing adults. Equation 3 mechanistically explains the capture of insects in traps in two steps (Hagstrum et al. 1988). The first step is a logarithmic increase in the number of traps occupied with increasing density of insects in the grain. The second step is a logarithmic increase in the number of traps with more than one adult with an increase in absolute insect density. The behavior of insects, and influence of grain temperature and moisture on insect behavior, can affect trap catch (Cuperus et al. 1990, White et al. 1990). However, predicted mean trap catches failed to explain only 16.5 and 9.6% of the variation in observed mean trap catches in shelled corn and barley, respectively. This unexplained variation includes the effects of biological and environmental variables on trap catch. As quantitative information on influence of environment on trap catch becomes available, the double-logarithmic model predictions can be improved by correcting trap catch for these environmental effects.

It is important to note that data fitted to equation 3 and the two validation data sets were all based on different trapping designs. Therefore, distribution of traps in the top 28 cm or less of the grain mass had little effect on mean trap catch predictions. Subramanyam & Harein (1990) have shown that the variation in catch of insect species among traps, in the top 16 cm of stored barley, was least for traps placed farther apart and greatest for traps placed close together.

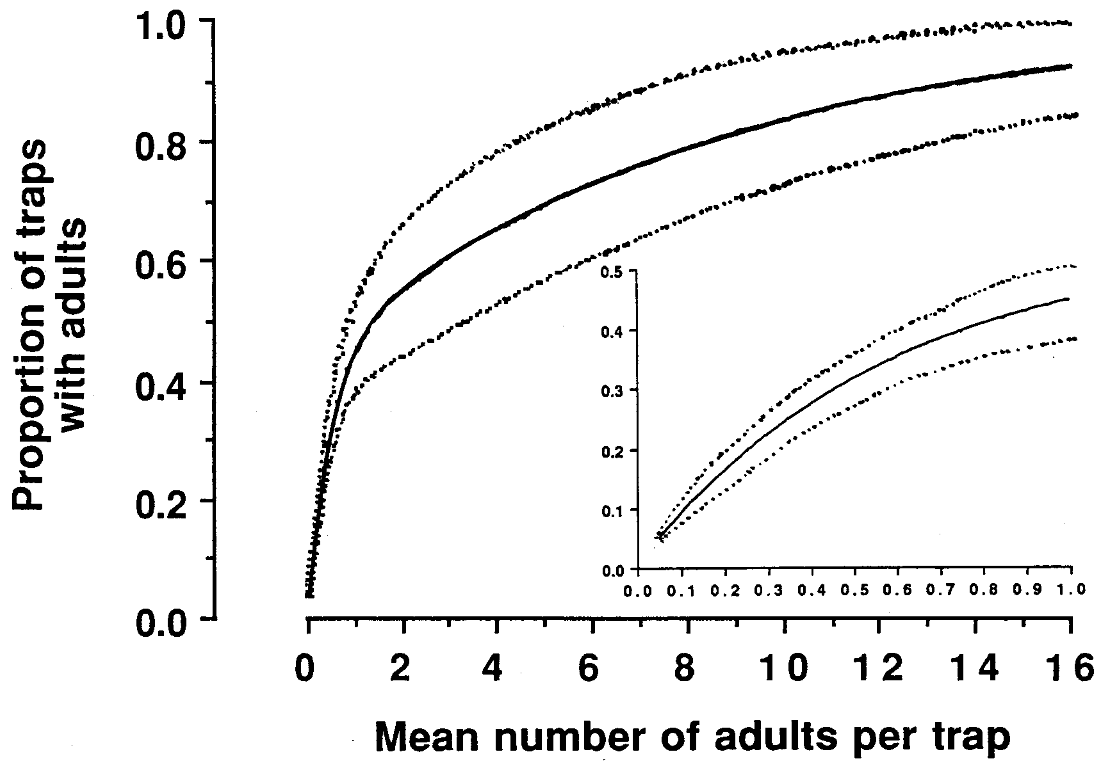

Fig. 5. Plots showing the predicted relationship between proportion of traps with adults and mean trap catch. These plots can be used for estimating mean trap catches from fraction of traps with insects. The dotted lines are asymptotic 95% CIs. Plots were generated by fitting equation 3 to combined data sets presented in Figs. 3 and 4.

Because ≥84% of the variation in observed mean trap catches was explained by model predictions, we combined the validation data (n = 73) with data originally fitted to equation 3 (n = 94) to reestimate parameters A, B, and C of equation 3. The DUD least-squares method of SAS procedure PROC NLIN (SAS Institute 1988) was used to fit equation 3 to the combined data set. Equation 3 satisfactorily described the combined data ($F = 947.41$; df = 3, 164; $P < 0.001$; $R^2 = 0.855$). The reestimated means, asymptotic standard errors, and asymptotic 95% CIs for parameters A, B, and C were 0.433 ± 0.055 (0.325–0.542), 2.126 ± 0.493 (1.153–3.099), and 0.12 ± 0.023 (0.076–0.168), respectively. Each of these reestimated parameter means are not significantly different ($P > 0.05$) from corresponding parameter means originally estimated (see above) because of overlapping asymptotic 95% CIs. Hagstrum et al. (1988, 379) have presented estimates of parameters A, B, and C for several species and stages of stored-product insects sampled with various devices in different grain types. Our reestimated means for parameters A and B were similar to those reported by Hagstrum et al. (1988), because the point estimates for A and B given by Hagstrum et al. (1988) were included within our estimated asymptotic 95% CIs for the parameter means. However, our reestimated mean for parameter C was lower than those presented by Hagstrum et al. (1988), except in one instance. Only parameter means for insects sampled with probe traps and deep-bin cup probes in stored wheat were similar to our reestimated means.

Data originally fitted to equation 3 (Fig. 3) and the validation data sets (Fig. 4) were collected during the months of July, August, and September. In Minnesota, stored-grain insects are active between April and November (Bh. S., unpublished data). A preliminary analysis of unpublished data (Bh. S.) collected during the months of April through November 1990 in nine facilities holding shelled corn in Minnesota, with nine GG traps per facility, showed that the range of proportion of traps with insects and mean trap catches observed between April and November were similar to ranges observed in this study. Therefore, equation 3 can be used to predict mean trap catches from proportion of traps with insects for months other than July, August, and September.

Fig. 5 was generated by fitting equation 3 to pooled original and validation data sets (n = 167); it shows the predicted relationship between proportion of traps over a limited range of mean trap catches. At mean trap catches of 0.05–1.0 insect per trap, ≈0.05–0.4 (5–40%) traps contained insects (Fig. 5, see inset). More than 90% of traps contained insects at trap catches of >16 adults per trap. The accuracy in predicting mean trap catches from proportion of traps with insects greatly decreases at trap catches of >16 adults per trap, because the proportion of traps with insects increases very little for a unit increase in mean trap catch. Therefore, it is better to predict mean trap catches when ≤90% of traps contain insects. Detection of insects at low densities is important so that management strategies (aeration, grain turning, or fumigation) can be used to suppress insect populations before they build up within the grain mass.

Our results suggest that either the WB II or GG traps would be effective in detecting insects associated with stored corn in Minnesota. With these two trap types, similar insect detection efficiency may be expected in other stored commodities, because the same insect species found in corn are commonly associated with stored wheat and barley (Barak & Harein 1981, Subramanyam & Harein 1990). Stored-grain insects are small, and a majority of species are difficult to identify without the aid of a microscope. In addition, separating and counting insects captured in traps takes a considerable amount of time, and the trap processing time depends on number of insects and amount of grain debris present in traps (see Subramanyam et al. 1989). With the double-logarithmic model (equation 3 and reestimated parameters of equation 3), mean trap catches of insects associated with stored corn and barley in Minnesota can be accurately predicted from proportion of traps with insects. Therefore, this model can save time and effort by eliminating the need for counting insects captured in traps. The double-logarithmic model or Fig. 5 is useful for predicting mean trap catches based on proportion of WB II or GG traps with insects, when 8–20 traps per bin (facility) are used in barley for 2 d or in shelled corn for 7 or 14 d. We do not recommend using >20 traps per bin, because the incremental improvement in probability of insect detection is extremely small when >20 traps are used (see Lippert & Hagstrum 1987). Quantitative information obtained by using the labor-saving model presented here should encourage grain managers to use WB II or GG traps for making insect management decisions.

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