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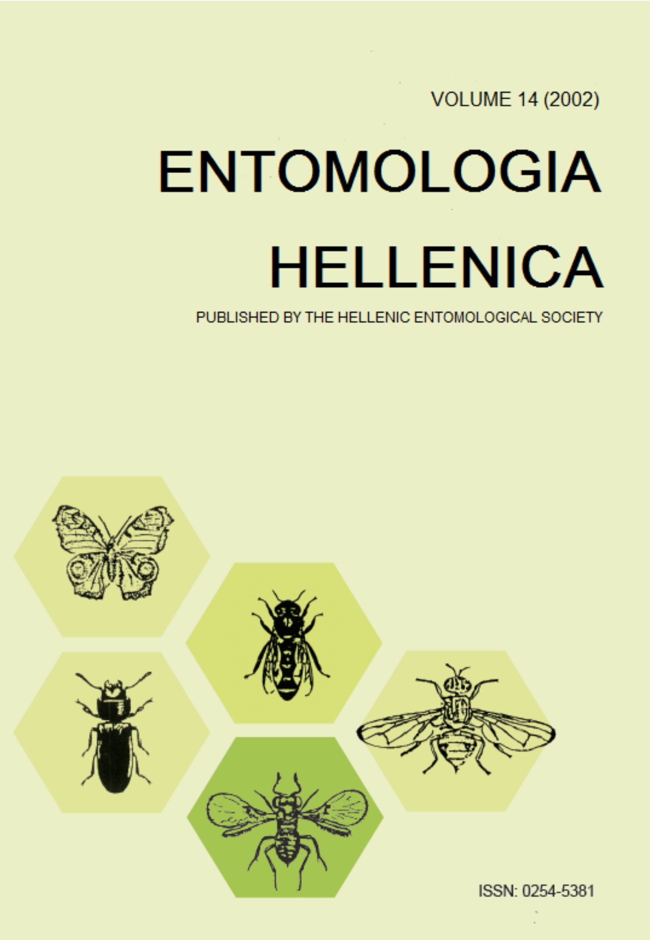

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Prediction of Infestation by Beetles in Stored Wheat Using Two Sampling Methods

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ABSTRACT

Studies were conducted in order to assess the use of binomial sampling for prediction of infestation level in stored wheat. In each of three steel silos with 1500 metric tones of wheat each, located in central Greece, 14 probe traps were placed on 15 June 1997. The traps were checked for adult coleoptera every 15 days, from 30 June until 30 January 1998. On the same dates, 14 wheat samples were taken adjacent to the trap locations, using a grain trier. Most abundant species were found to be *Cryptolestes ferrugineus* and *Tribolium castaneum* in the traps, while *Sitophilus oryzae* in the samples. Regarding all species detected, traps were proved to be more effective as compared to the samples. Taylor's Power Law was used, in order to estimate y-intercept and slope values for each species, The comparison of these parameters indicated that a single (weighted) equation can describe equally well the relation between the mean and the variance, according to Taylor's Power Law, for all adults found, regardless of species. The parameters of this relation were utilized to connect the ratio of sampling units containing one or more adults and the mean number of adults per sampling unit ($\overline{x}$), using Wilson and Room's model. Regarding trap catches, the same model can be used to predict an infestation, with a sufficient precision level, mainly when $\overline{x}<5$; on the contrary, the results were not satisfactory in the case of adult numbers in the samples.

Introduction

The major scope of a sampling program in bulked grain must be early detection of an insect infestation (Wilkin 1990). In the case of stored product beetles, the infestation is manifested from several species at the same time (Madrid et al. 1990, Buchelos and Athanassiou 1993, Subramanyam et al. 1993). This fact influences negatively the effort of detecting the consequent presence of various species with different adult ratios in the same sampling unit.

Standard sampling methods based on several types of sampling devices (grain trier, deep bin cup etc.) consist in removing an amount of the product (sample). These samples must be examined for insect presence in the laboratory; so the possibility of taking immediate decisions is reduced. The small body size of most stored product beetles consists an additional problem, while at the same time only live beetles in the grain samples are counted (Subramanyam et al. 1993, Subramanyam and Hagstrum 1995). To obtain the desirable accuracy level, taking in account the whole quantity of the stored grain, is a target which can't be practically achieved by taking a large number of samples (Hagstrum et al. 1990). Even then, sample size could not be statistically representa-

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tive to insure safe conclusions (White and Loschiavo 1986, Hagstrum et al. 1990, Reed et al. 1991, Wilkin and Van Natto 1997).

The use of perforated trapping devices introduced into the grain bulks (probe traps), has been developed by many researchers as an alternative sampling method. Direct counting and evaluation of the catches combined with increased effectiveness and sensitivity are important advantages of this method, as compared to "absolute" sampling methods. However, the interpretation of probe trap catches is very difficult because catches are influenced by many factors, most of which do not affect the efficiency of standard sampling methods. Those factors can be temperature (Fargo et al. 1989, Hagstrum et al. 1998), the type of product (White et al. 1990), trapping duration (Fargo et al. 1989), population density (Cuperus et al. 1990), developmental stage (White and Loschiavo 1986), insect species (White et al. 1990, Cogan and Wakefield 1994, Pereira et al. 1994, Buchelos and Athanassiou 1999), trap type (Subramanyam et al. 1993, Cogan and Wakefield 1994, Fargo et al. 1994) and trap location (Cuperus et al. 1990, Subramanyam and Harein 1990). As a result, after more than 20 years of experimentation with probe traps, the advantages of their use remain unexploited due to lack of catches' interpretation (Wilkin 1990).

This study aims to: **a)** compare the effectiveness of two sampling methods during a long period of time (180 days), for the detection of coleoptera species and **b)** evaluate the use of the proportion of sampling units containing adults for prediction of infestation level, with emphasis to the differences between the two sampling methods.

Materials and Methods

a. Sampling

Three steel silos, located in Central Greece, were used for experimentation. At the end of May 1997 old product quantities were moved away and careful cleaning took place. The interior walls were then sprayed with pyrimiphos-methyl and fumigated with phosphine. The silos were filled with new product on 15 June. Approximately 1500 metric tones of wheat (harvested in June 1997) were placed in each silo.

On 15 June, 14 perforated probe traps (WBII probe, Trécé Inc, USA) were placed in each silo, just below the grain surface. Traps were checked at 15-day intervals from 30 June to 30 January. On each trap-check date, from each silo, 14 samples of wheat grain were taken adjacent to trap locations, using a non partitioned grain trier (2 m in length, 750 gr capacity, 9 openings). Traps and grain trier samples were checked for coleoptera adults. The adults were collected out of the samples with a fine paintbrush. For statistical analysis only live adults found in grain trier samples were used. No insecticide treatments took place during the experimental period.

To describe the relationship between the proportion of sampling units (sampling unit: one trap or one grain trier sample) with one or more adults (p) and the mean number of adults per sampling unit, the equation of Wilson and Room (1983) was used:

$$p = 1 - e^{-\bar{x}[(\ln(A\bar{x}^{b-1})(\frac{1}{A\bar{x}^{b-1}} - 1)]}$$

The parameters A and b were calculated using Taylor's Power Law which describes the linear regression of the variance (s^2) against the mean ($\bar{x}$) following a logarithmic transformation ($s^2 = A\bar{x}^b$, Taylor 1961, Southwood 1978). The similarity of Taylor's regression equations of several species (comparison of y-intercept and slope values) in order to find a weighted equation, was examined using the F-test (Draper and Smith 1981). Finally, in order to compare traps and samples the ratios of adult numbers (traps: trier samples) and the frequency of detection was examined.

b. Model validation

In order to evaluate the provided accuracy in estimating the mean (from the relationship between p and $\bar{x}$) 12 probe traps were placed in each one of 17 silos from June to December 1998. Silos' capacity varied from 500 to 2000 metric tones of wheat. Traps were removed after 15-days, and on the day of the removal 12 grain trier samples were taken adjacent to trap locations. For each silo, mean number of adults per sampling unit (trap or trier sample) was plotted against the predicted value (using the p-$\bar{x}$ model for 12 sampling units) and the correlation coefficient was examined.

Results

a. Population fluctuation-frequency of detection

For most of the species found, high numbers of adults was observed from the fifth up to and including the eleventh sampling date (August-November). Traps contained remarkably higher number of adults compared to samples throughout the whole sampling period, although trap performance was not the same for each species (Fig. 1).

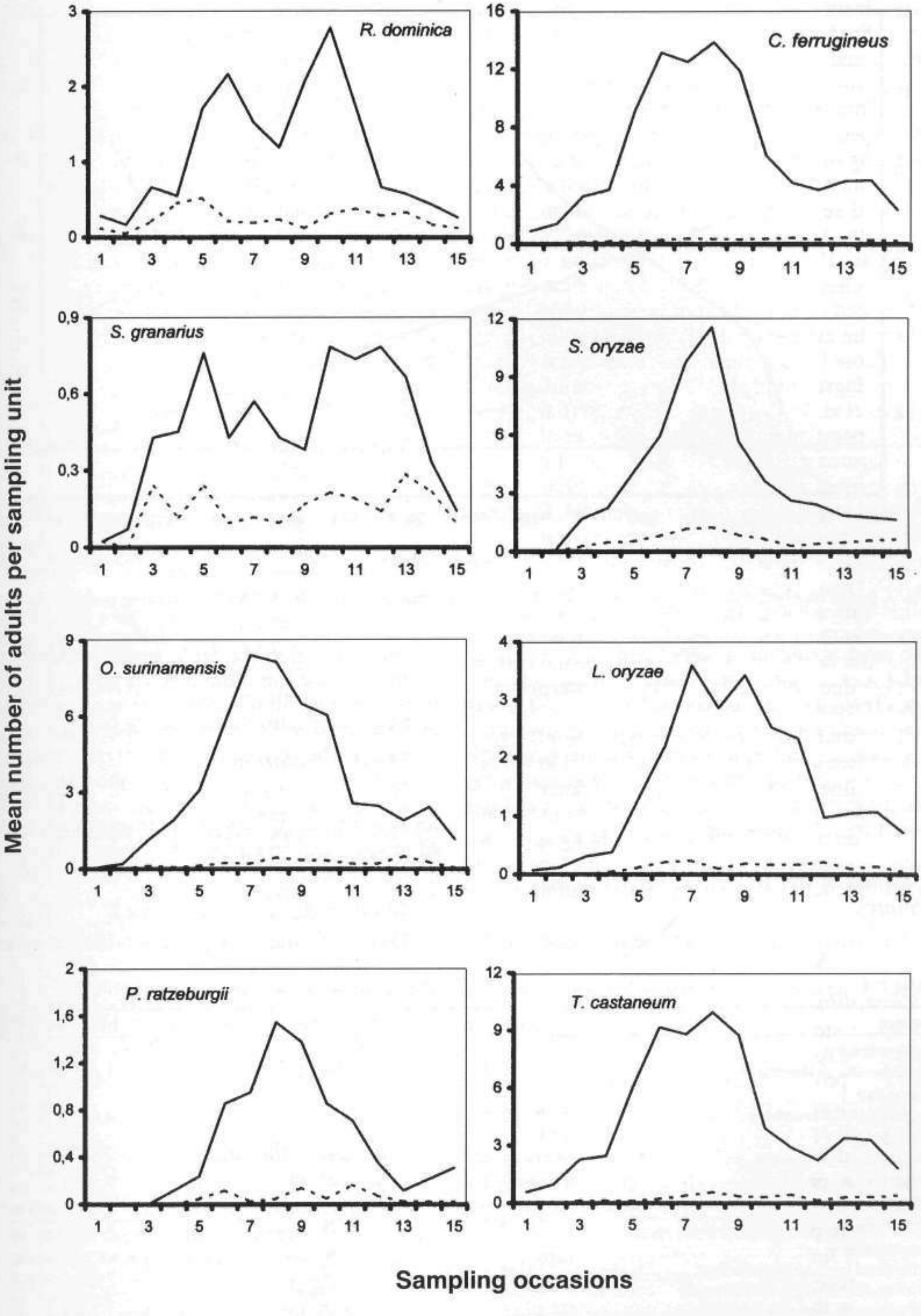

FIG. 1. Mean number of live Coleoptera adults per trap (continuous line) or per sample (dotted line), during the sampling period.

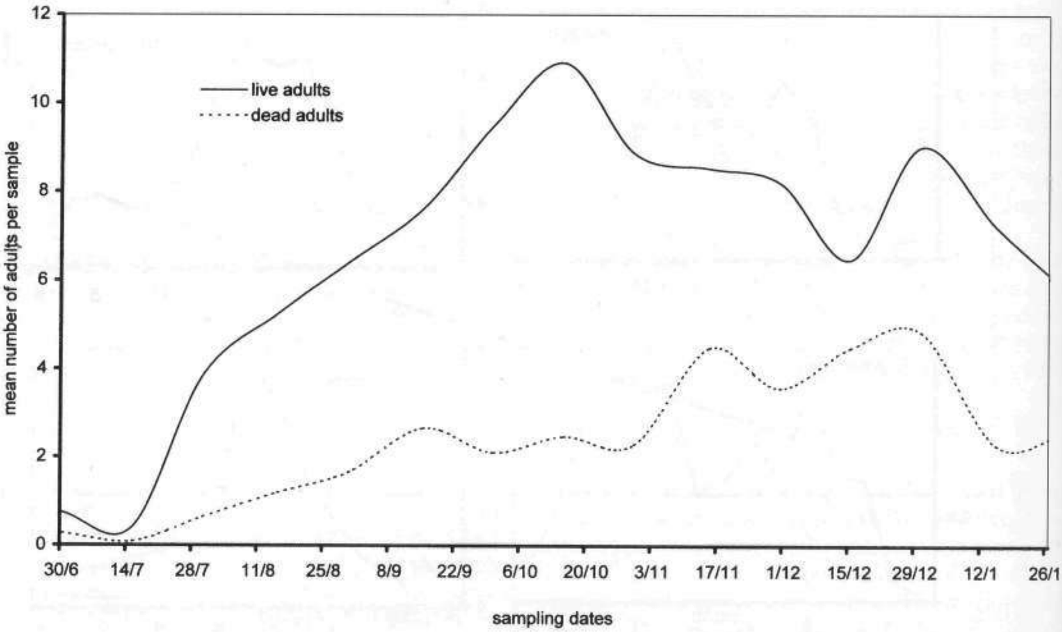

FIG. 2. Mean number of dead and live adults of all species per grain trier sample, during the sampling period.

The most abundant species were *C. ferrugineus* and *T. castaneum* in traps and *S. oryzae* in samples (Table 1). The highest values in adult ratios were found for *C. ferrugineus* and the lowest for *S. granarius* and *R. dominica*. Furthermore, the greatest values in frequency of detection were found for *P. ratzeburgii* and *T. castaneum* and the lowest for *Sitophilus* spp.

b. Ratios of live and dead adults in the samples.

The percentage of dead adults found in the samples was notably high, tending to increase during the last sampling dates (Fig. 2). For most of the species, live adults were more numerous than the dead, with the exception of *P. ratzeburgii* (Table 1). The highest (live: dead) ratio value was noted for *S. oryzae*. Referring to the total number of adults the average ratio value was 3,42: 1. The relationship is described more accurately by an hyperbolic curve (Fig. 3).

c. Relationship between p and $\bar{x}$.

Taylor's Power Law gives a sufficient estima-

TABLE 1. Adult ratios, frequency of detection and live: dead adults per sample, for each species.

Species	Adult ratios[1]	Frequency of detection[2]	Live: dead adults
Bostrychidae			
Rhyzopertha dominica (F.)	4,51: 1	1,92: 1	1,52: 1
Cucujidae			
Cryptolestes ferrugineus (Stephens)	23,12: 1	2,39: 1	4,64: 1
Curculionidae			
Sitophilus granarius (L.)	3,12: 1	1,70: 1	3,35: 1
Sitophilus oryzae (L.)	6,57: 1	1,47: 1	7,16: 1
Silvanidae			
Oryzaephilus surinamensis (L.)	16,50: 1	2,20: 1	4,55: 1
Tenebrionidae			
Latheticus oryzae Waterhouse	13,20: 1	2,55: 1	4,29: 1
Palorus ratzeburgii (Wissmann)	10,38: 1	3,18: 1	0,73: 1
Tribolium castaneum (Herbst)	17,25: 1	3,03: 1	2,34: 1

[1] Number of adults found in traps per 1 adult found in trier samples
[2] Number of traps contained adults per 1 trier sample with adults

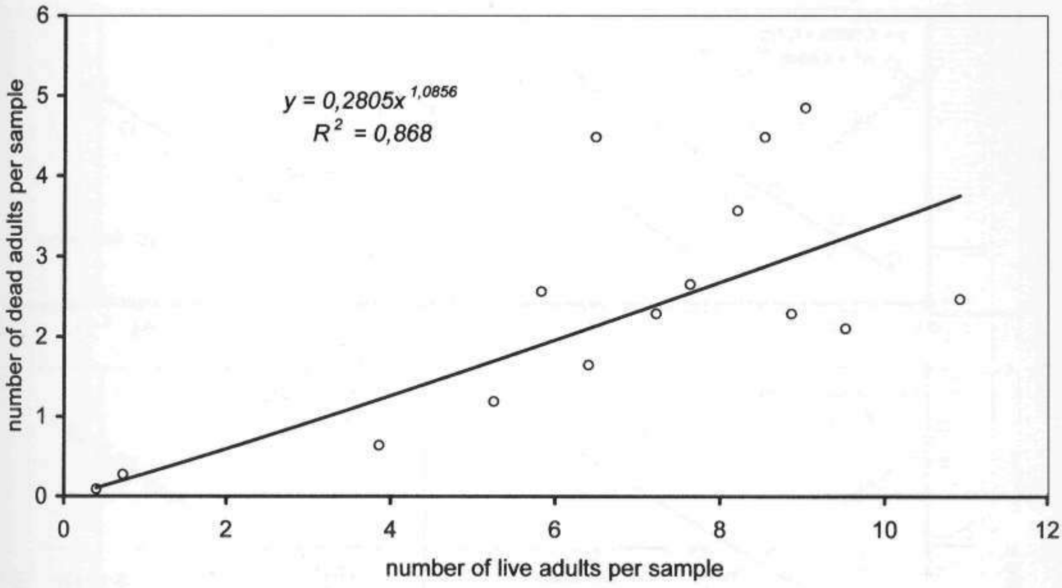

FIG. 3. Relationship between mean number of dead and live adults per grain trier sample.

tion of the relationship between variance and mean for all species found with both sampling methods (Fig. 4 and 5). For each method, the comparison between the regression parameters (*A* and *b*) showed that satisfactory description of the relationship is achieved (Table 2) from a single (weighed) regression equation for all species (Fig. 6 and 7).

As the mean progressively increases, the corresponding value of the variance is higher for the trap catches than for the adults in grain trier samples. Wilson and Room's model gives an accurate estimation for trap catches as shown by *R* values which in all cases were significantly higher than zero (Table 2). The use of the aforementioned model can explain 90% of the variability in the mean-proportion relationship (Fig. 8). According to this equation, when 90% of the traps contains one or more adults then the mean value is 40 adults per trap. By solving this equation it is found that when p values are 0.63, 0.68, 0.72, 0.79, 0.83 and 0.93, $\overline{x}$ value is 0.1, 0.5, 1, 5, 10 and 100 adults per trap, respectively.

On the other hand, Wilson and Room's model can not efficiently describe the p-$\overline{x}$ relationship when calculations are made according to the num-

TABLE 2. Parameters of Wilson and Room's model, for each species, using the two sampling methods.

Species	Probe traps			Grain trier samples		
	p_1[a]	x_{90}[b]	R[c]	p_1[a]	x_{90}[b]	R[c]
R. dominica	0,73	15,85	0,819*	0,75	4,74	0,630
C. ferrugineus	0,78	71,43	0,871*	0,78	6,18	0,496
S. granarius	0,73	5,15	0,959*	0,73	3,60	0,244
S. oryzae	0,71	36,25	0,931*	0,73	5,11	0,903*
O. surinamensis	0,71	27,71	0,946*	0,75	3,74	0,869*
L. oryzae	0,72	15,13	0,928*	0,74	3,55	0,146
P. ratzeburgii	0,71	17,11	0,933*	0,72	4,07	0,068
T. castaneum	0,72	112,55	0,909*	0,74	5,10	0,609

[a] Proportion of traps (or samples) with one or more adults corresponding to $\overline{x} = 1$ adult per trap (or per sample) according to the Wilson and Room's model.
[b] Mean number of adults corresponding to $p = 0.90$, according to Wilson and Room's model.
[c] Correlation coefficient for Wilson and Room's model.
* Significantly different from zero ($\alpha = 0.05$, two tailed *t*-test). Slope and y-intercept values for eight species found (from fig. 4 and 5) are not significantly different for probe trap ($F = 6.144$, $df = 7{,}351$; $P<0.05$) and grain trier data ($F = 1.944$, $df = 7{,}236$; $P<0.05$).

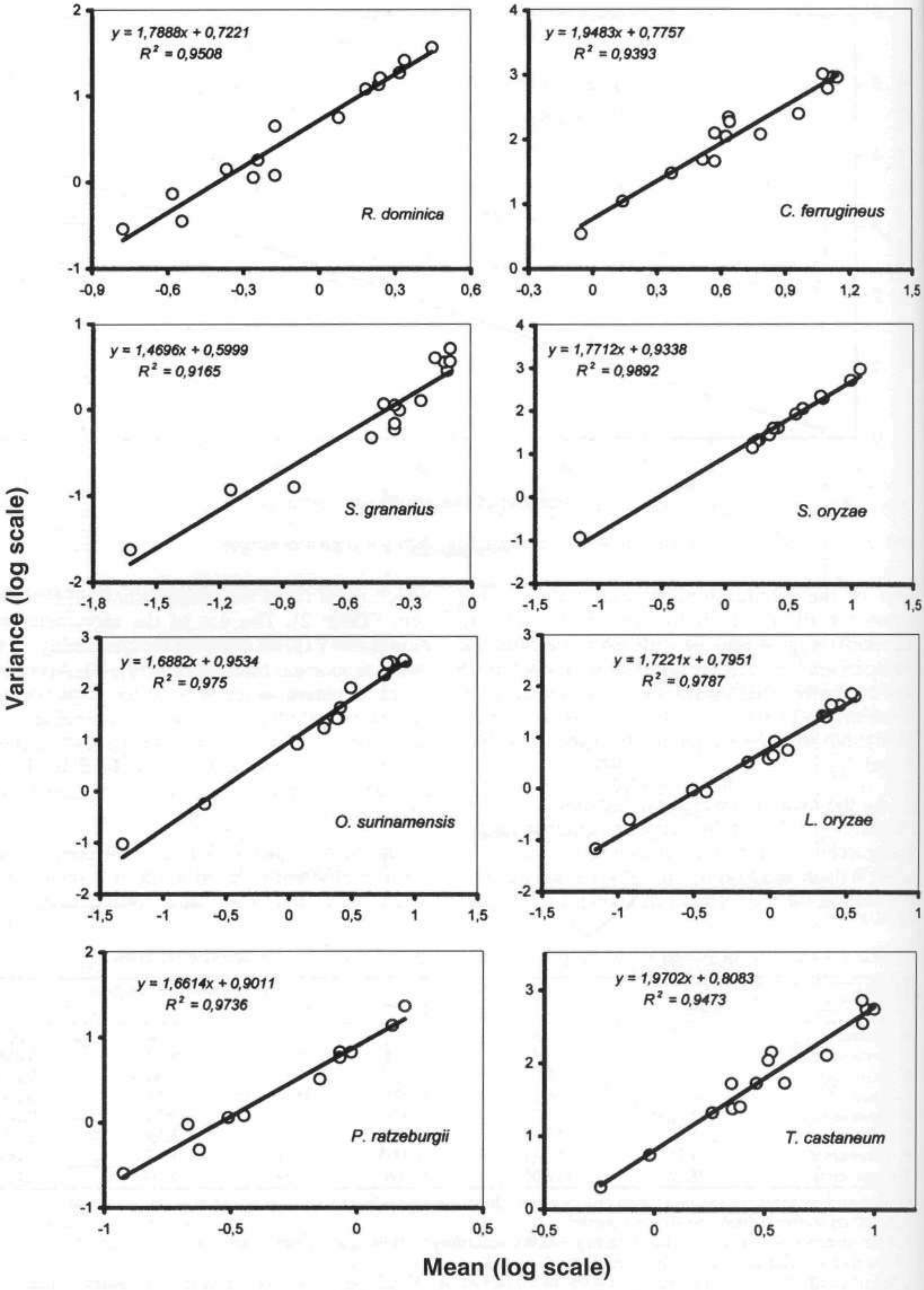

FIG. 4. Taylor's Power Law parameters for probe trap catches, of each species.

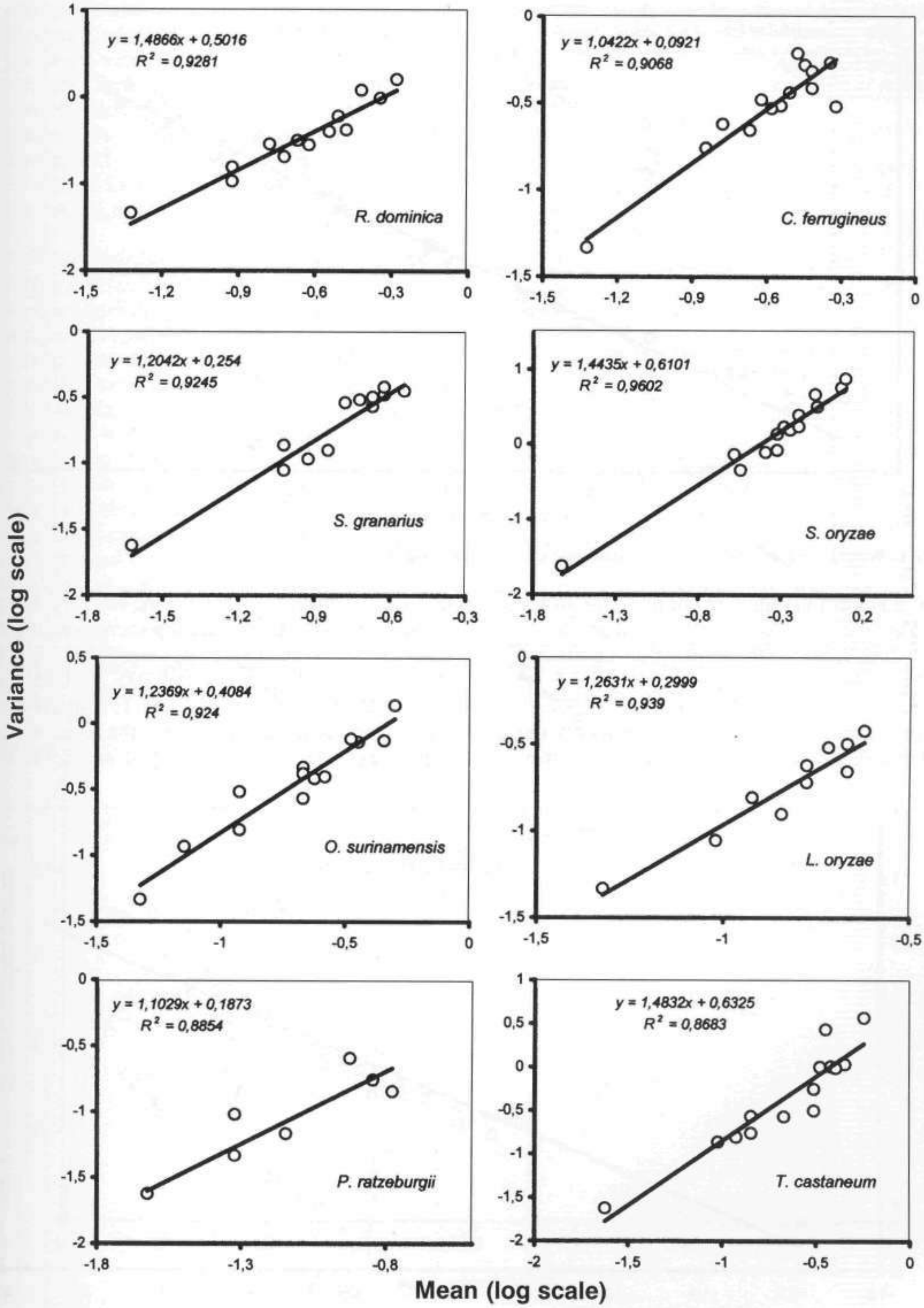

FIG. 5. Taylor's Power Law parameters for adults found in grain trier samples, of each species.

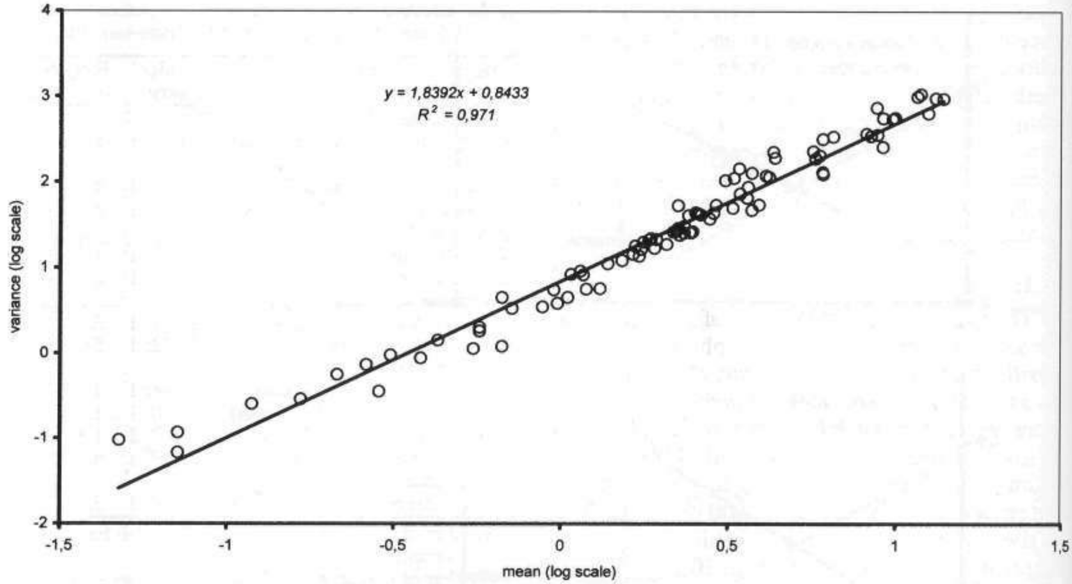

FIG. 6. Weighed regression line for the combined species data of fig. 4.

ber of adults in grain trier samples. For all species in Table 2, R values are lower than the corresponding values in the traps while significant differences from zero were noted only for *S. oryzae* and *O. surinamensis*. As shown in Fig. 9, a hyperbolic curve is describing more accurately the p-$\overline{x}$ relationship. Using the equation of Fig. 9 it comes that $\overline{x} = 6.2$ when $p = 0.90$. On the contrary, using Wilson and Room's model the corresponding $\overline{x}$ value is 5.4. According to this equation, when $\overline{x}$ value is 0.1, 0.5, 1, 5, 10 and 100, p values are 0.63, 0.69, 0.74, 0.91, 0.97 and 1, respectively, while with the hyperbolic curve, the respective p values are 0.09, 0.15, 0.22, 0.79, 1 and 1. For all

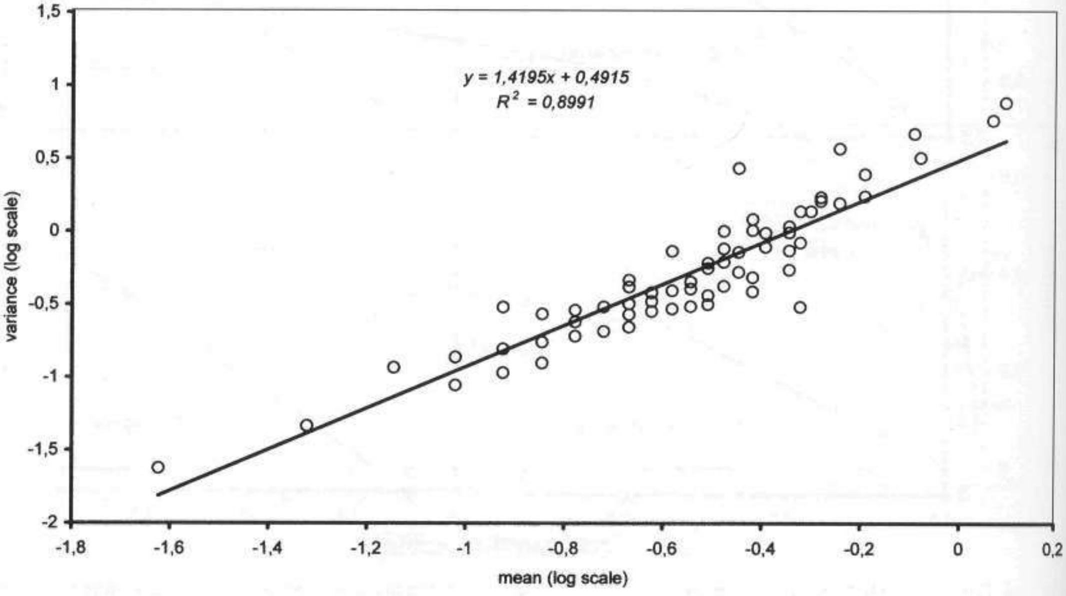

FIG. 7. Weighed regression line for the combined species data of fig. 5.

species p_I values are higher in the traps, with the exception of *C. ferrugineus* and *S. granarius* whose p_I values are similar in both sampling methods (Table 2). The ratio of x_{90} values (traps: samples) differs significantly according to the species. Thus, the lowest values were noted for *R. dominica* (3,3: 1) and *S. granarius* (1,4: 1) while the highest for *C. ferrugineus* (11,5: 1) and *T. castaneum* (22,1: 1).

d. Model validation.

The species found at this part of the study were the same with the previous ones plus *Cryptolestes pusillus*, *Oryzaephilus mercator*, *Palorus subdepressus* and *Tenebroides mauritanicus*. Traps were also more efficient than samples (Table 3). Traps detected beetle adults in all of the 17 silos examined, while samples only in 12. The use of the equation in Fig. 10 can explain more than 75% of the variability in the relationship between predicted and observed values (Fig. 10). On the contrary, in the case of samples the equation in Fig. 9 can't be used for prediction of the mean number of adults per grain trier sample (Fig. 11).

TABLE 3. Adult ratios and frequency of detection for each species found, during the model validation-sampling.

Species	Adult ratios[1]	Frequency of detection[2]
Bostrychidae		
Rhyzopertha dominica (F.)	3,50: 1	1,51: 1
Cucujidae		
Cryptolestes ferrugineus (Stephens)	41,11: 1	4,43: 1
Cryptolestes pusillus (Schönherr)	29,22: 1	3,25: 1
Curculionidae		
Sitophilus granarius (L.)	7,06: 1	1,28: 1
Sitophilus oryzae (L.)	8,80: 1	2,05: 1
Silvanidae		
Oryzaephilus mercator (Fauvel)	24,01: 1	3,65: 1
Oryzaephilus surinamensis (L.)	49.52: 1	5,08: 1
Tenebrionidae		
Latheticus oryzae Waterhouse	13,24: 1	4,12: 1
Palorus ratzeburgii (Wissmann)	4,80: 1	1,30: 1
Palorus subdepressus (Wollaston)	6,17: 1	1,87: 1
Tribolium castaneum (Herbst)	30,12: 1	4,29: 1
Trogositidae		
Tenebroides mauritanicus (L.)	29,90: 1	3,88: 1

[1] Number of adults found in traps per 1 adult found in trier samples

[2] Number of traps contained adults per 1 trier sample with adults

Discussion

High temperatures prevailing during wheat harvest and storage periods in Greece, increase the possibilities for insect infestation in the stores. Some species, such as *C. ferrugineus* and *T. castaneum*, were found in considerable numbers even from the first sampling date (30 June). Moreover, significant numbers of most species' adults ap-

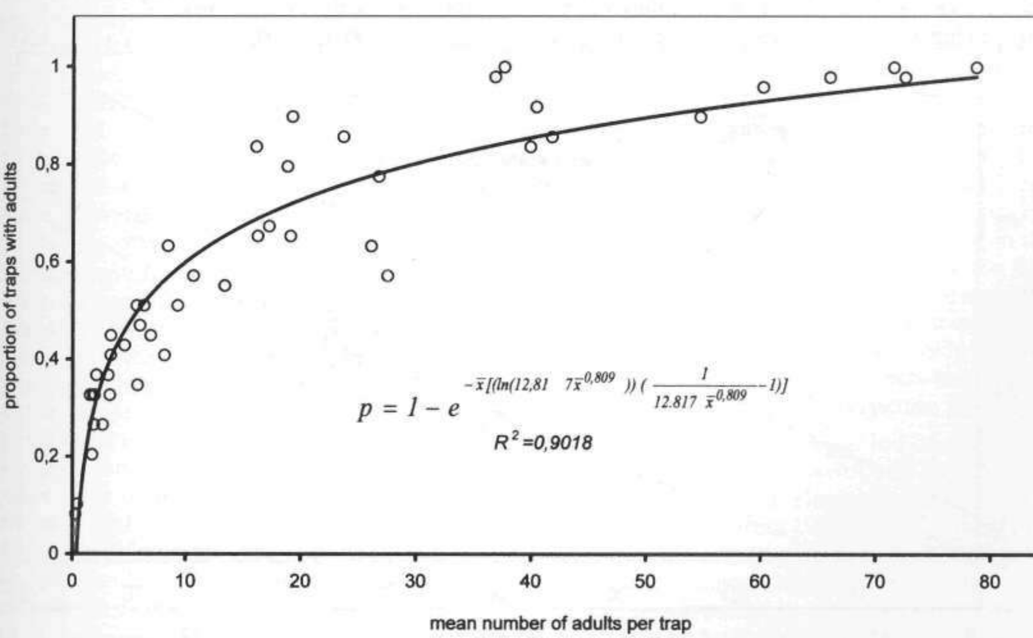

FIG. 8. Relationship between proportion of traps with adults and the mean number of adults per trap, according to Wilson and Room model.

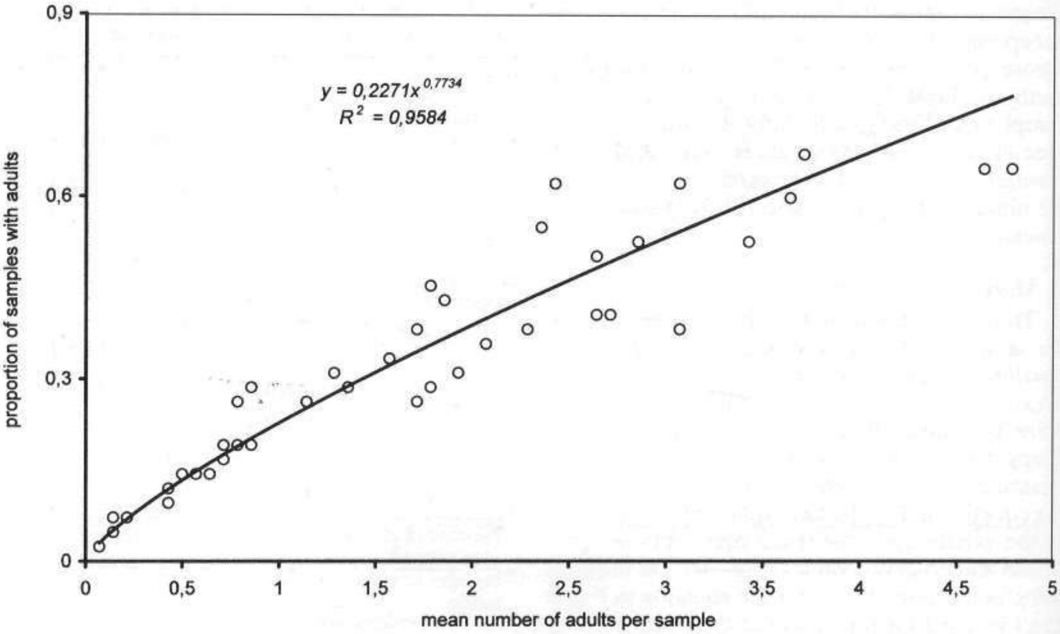

FIG. 9. Relationship between proportion of grain trier samples with adults and the mean number of adults per sample.

pear, mainly in the traps, from the fourth sampling (14 August) and on (Fig. 1). Hagstrum (1989) stated that considerable numbers of *C. ferrugineus* adults were observed 30 to 60 days after the storage date, that is to say after the insect had completed one or two generations. Similar results have been reported by Vela-Coiffier et al. (1997). Lower numbers of adults, occurring in trap catch-

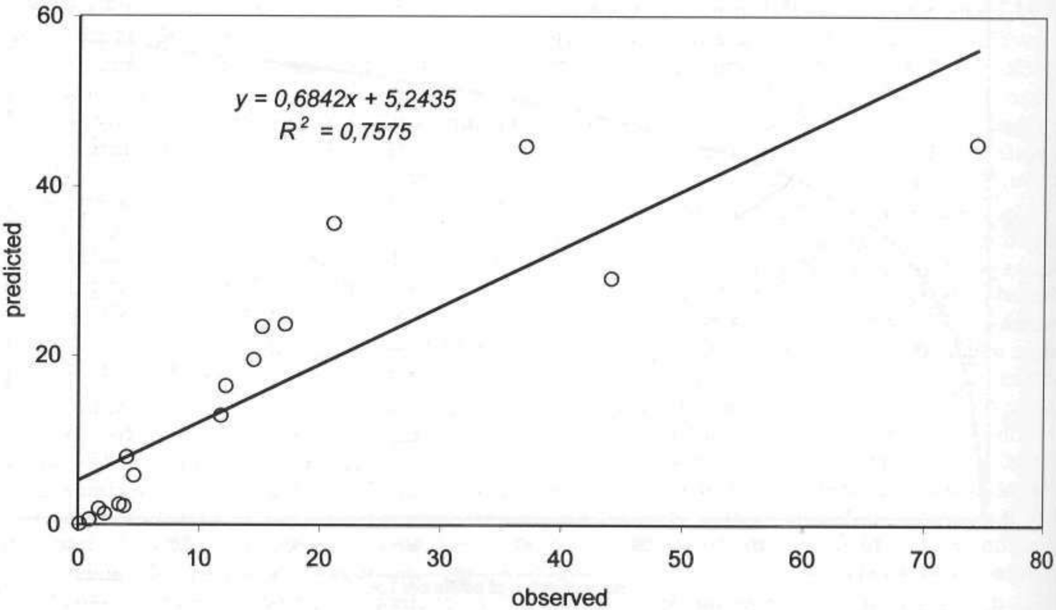

FIG. 10. Relationship between the predicted and the observed values for probe trap data (linear regression), using the equation of fig. 8 (each point represents a silo on which beetle adults were detected by traps).

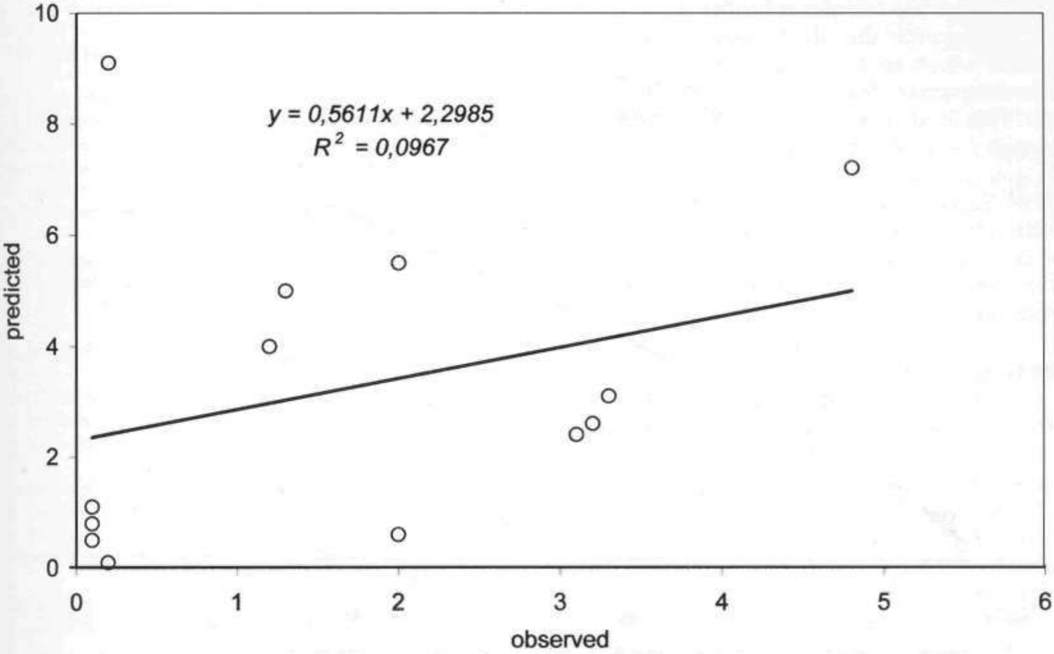

FIG. 11. Relationship between the predicted and the observed values for grain trier data (linear regression), using the equation of fig. 9 (each point represents a silo on which beetle adults were detected by trier samples).

es during the cold months, are surely due to the insects' reduced mobility because of the prevailing low temperatures (Cuperus et al. 1990, Fields 1992, Hagstrum et al. 1998); even then, traps are proved more efficient than samples concerning all species found (Fig. 1). Performing laboratory tests Fargo et al. (1989) found that at low temperatures traps caught fewer *C. ferrugineus* adults, while no significant influence was observed for *T. castaneum*, *S. oryzae* and *R. dominica*.

The use of Wilson and Room's model gave satisfactory results in predicting the mean number of adults per trap. In Fig. 8 the increase of p is manifested in two phases: in the first, there is a steep increase of the proportion of traps with one or more adults, in a relatively narrow range of mean values, while in the second a logarithmic increase of the mean is observed. In general, a gradual limitation of the increase rate of p when $\bar{x}>5$ is taking place. This limitation is a direct consequence of the increased mean values, because in high population densities additional adults are found in sampling units already containing adults (Subramanyam et al. 1993).

In the present study, p-$\bar{x}$ relation can be used to predict a future infestation, especially in low population densities, because the accuracy in prediction is reduced with the increase of the mean value. In $\bar{x}$ values more than 40 adults per trap, the accuracy in estimating mean is reduced, as p very slightly follows the increase for every $\bar{x}$ unit. Fig. 8 makes clear the limited accuracy in predicting high mean values; it is generally preferable to use the p-$\bar{x}$ relation when $p<0.90$, as this is the primary aim of a sampling plan. Subramanyam et al. (1993) using the double logarithmic model to predict probe trap catches, with trapping duration 7 days, stated that when $p = 0.90$, $\bar{x} = 16$. In our case, the higher number of $\bar{x}$ value for $p = 0.90$ can be explained from the longer trapping duration which positively affects probe trap catches (Fargo et al. 1989, Cuperus et al. 1990), but also from the differences observed between several models (Subramanyam and Hagstrum 1995).

The high accuracy level in low mean values, renders trapping a very useful tool for decision-making (Lippert and Hagstrum 1987, Subramanyam and Hagstrum 1995). On the other hand, separation and counting of adults found, takes the more time the more samples and adults involved. Another disadvantage in the use of standard sampling methods is the presence in the samples of dead adults, compared to traps in which all adults are (or considered to be) alive. Thus, a visual examination of the samples is further required in order to separate the alive ones, especially for species which are not very active or develop inside the grain such as *R. dominica* and *Sitophilus* spp. This kind of procedure is not practically fast enough for immediate decision-making, but consists a more laborious method (Hagstrum et al. 1990, Subramanyam et al. 1993, Wilkin and Van Natto 1997). It is also noticeable that the number of dead adults is analogous to the number of the live ones observed and also to longer storage periods, due to the continuously increasing number of adults belonging to previous generations, during recent samplings (Fig. 2 and 3).

Concerning the traps, the use of Wilson and Room's model has proved that gives satisfactory results, due to small difference between observed and predicted values. It is also important the fact that this model was proved accurate although **a)** different storage rooms (facilities) were used **b)** other beetle species also existed and **c)** 12 instead of 14 traps were used in order to calculate the mean and the variance. It is concluded that Wilson and Room's model can be used for a broad spectrum of cases. On the contrary, the equation of Fig. 9 concerning the samples seems to correspond exclusively to these data.

The inability of the same model to sufficiently describe two sampling methods applied in the same storage facilities during the same period of time, indicates the qualitative difference between the two methods (Buchelos and Athanassiou 1999). The effort to correlate trap catches with population density is a very complex procedure and demands further experimentation (Lippert and Hagstrum 1987, Reed et al. 1991, Vela-Coiffier et al. 1997, Hagstrum et al. 1998). Using binomial methods (adults present or not) the population density can be estimated with a simple inspection of the traps, without counting or identifying the adults caught.

Acknowledgements

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KEY WORDS: Coleoptera, stored wheat, sampling, probe traps, grain trier, binomial methods.

Πρόβλεψη της Προσβολής από Κολεόπτερα σε Αποθηκευμένο Σιτάρι με τη Χρήση δύο Μεθόδων Δειγματοληψίας

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ΠΕΡΙΛΗΨΗ

Σε κάθε ένα από τρία μεταλλικά silos με σκληρό σιτάρι, που βρίσκονταν στην Κεντρική Ελλάδα, τοποθετήθηκαν 14 παγίδες τύπου probe, στις 15 Ιουνίου 1997. Οι παγίδες ελέγχονταν για ακμαία κολεόπτερα κάθε 15 ημέρες από τις 30 Ιουνίου μέχρι και τις 30 Ιανουαρίου 1998. Κατά τις ημερομηνίες ελέγχου των παγίδων, 14 δείγματα λαμβάνονταν με έναν δειγματολήπτη τύπου σόντας ακριβώς δίπλα στις θέσεις παγίδευσης. Πολυπληθέστερα είδη στις παγίδες βρέθηκαν να είναι τα *Cryptolestes ferrugineus* και *Tribolium castaneum* ενώ στα δείγματα το *Sitophilus oryzae*. Για όλα τα ευρεθέντα είδη οι παγίδες ήσαν αποτελεσματικότερες σε σύγκριση με τα δείγματα στην ανίχνευση των ακμαίων. Η γενική δοκιμασία του *F* έδειξε ότι μια σταθμική εξίσωση μπορεί να περιγράψει εξίσου ικανοποιητικά τη σχέση του μέσου και της διασποράς σύμφωνα με τον νόμο της δύναμης του Taylor, για όλα ευρεθέντα ακμαία, ανεξαρτήτως είδους. Οι παράμετροι της σχέσης αυτής χρησιμοποιήθηκαν, με βάση το πρότυπο των Wilson και Room, για την σύνδεση της αναλογίας των δειγματοληπτικών μονάδων με ακμαία (p) και του μέσου αριθμού ακμαίων ανά δειγματοληπτική μονάδα ($\bar{x}$). Με βάση τις συλλήψεις των παγίδων, το παραπάνω πρότυπο μπορεί να χρησιμοποιηθεί για πρόβλεψη με ικανοποιητικό επίπεδο ακρίβειας, ιδιαίτερα όταν $\bar{x} < 5$. Αντίθετα, η χρήση του μοντέλου των Wilson και Room δεν έδωσε ικανοποιητικά αποτελέσματα όταν εξετάστηκε με βάση τους αριθμούς ακμαίων στα δείγματα.