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Determination of *Oebalus pugnax* (Hemiptera: Pentatomidae) spatial pattern in rice and development of visual sampling methods and population sampling plans

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Abstract. Commercial rice fields in southeast Texas were sampled during 2003 and 2004 and visual samples compared to sweep net samples. Fields were sampled at different stages of panicle development, times of day, and by different operators. Significant differences were found between perimeter and within field sweep net samples, indicating that samples taken 9 m from the field margin overestimate within field *O. pugnax* populations. Time of day did not significantly affect the number of *O. pugnax* caught with the sweep net; however, there was a trend to capture more insects during morning than afternoon hours. For all sampling methods evaluated during this study, *O. pugnax* was found to have an aggregated spatial pattern at most densities. When comparing sweep net with visual sampling methods, one sweep of the “long stick” and two sweeps of the “sweep stick” correlated well with the sweep net ($r^2 = 0.639$ and $r^2 = 0.815$, respectively). This relationship was not affected by time of day of sampling, stage of panicle development, type of planting or operator. Relative cost-reliability which incorporates probability of adoption indicates the visual methods are more cost-reliable than the sweep net for sampling *O. pugnax*.

Key words: *Oebalus pugnax*, *Oryza sativa*, rice stink bug, visual sampling, sweep net sampling

THE RICE STINK BUG, *Oebalus pugnax* (Fabricius) (Hemiptera: Pentatomidae), is a serious pest of rice, *Oryza sativa* L., in the southern United States (Way 2003) attacking the crop from flowering to grain maturity. This insect is responsible for reductions of rough (unprocessed rice that includes hull and caryopsis) and head (milled kernels at least three-fourths the length of whole kernels) rice yields, and grain quality (Douglas and Tullis 1950, Swanson and Newsom 1962, Bowling 1963, Harper et al. 1993, Tindall et al. 2005, Patel et al. 2006) by feeding on developing kernels, introducing pathogenic microorganisms and causing a discoloration of the grain known as “peck” for which growers are penalized.

To design a sampling program, the determination of the spatial pattern of the insect is essential (Kuno 1991, Wilson 1994). Previously, Foster et al. (1989) reported that the spatial pattern of *O. pugnax* in Florida rice fields was aggregated; however, the sample unit size they employed was different from the sample unit size currently employed in Texas. In the present study, the spatial pattern of *O. pugnax* in Texas rice fields was determined and used to develop population sampling plans for this insect.

Currently, the only recommended method to sample for *O. pugnax* in Texas is the sweep net (Way et al. 2006). Rice fields should be sampled once or twice a week from 50% heading to harvest. A 38 cm diameter net is swept from side to side with each step while walking through the field, making sure the top of the net is flush with the top of the panicles. After 10 consecutive sweeps, the number of adult rice stink bugs is recorded. This constitutes one sample unit. A total of 10 sample units per management area is recommended to arrive at a population estimate. This fixed sample size has been recommended since the 1960s (Bowling 1962, 1969). However, the reliability of this sampling plan or the optimum sample size for *O. pugnax* population sampling has not been determined. Other sampling methodologies have been investigated recently (Rashid

et al. 2006). Visual and sweep net counts in grassy margins and yellow pyramid traps have been used in an effort to predict *O. pugnax* populations in rice fields; however, rice stink bugs were observed or caught only before and after rice panicle development and maturation, limiting the utility of these methodologies.

Many rice producers in Texas have not adopted the sweep net (Harper et al. 1990) and rely on non-standardized, subjective, visual observations of *O. pugnax* populations. Although this “sampling technique” is common, it is not based on scientific criteria. In this study, the performance of the sweep net method was assessed, and visual sampling methods were compared to the sweep net method in an attempt to facilitate *O. pugnax* population estimation in rice fields.

Materials and Methods

Data collection. Data were collected during 2003 and 2004 from commercial rice fields located in Chambers, Colorado, Fort Bend, Jackson and Jefferson Cos., TX. Seven fields were sampled in 2003 and 10 in 2004. Stages of panicle development during sampling were heading, milk and dough. Heading was considered to begin at panicle exertion. Milk was considered to begin when consistency of the caryopsis of at least 50% of the grains on a panicle was milky and panicles began to bend downward due to weight of developing grains. Dough was considered to begin when consistency of the caryopsis of at least 50% of the grains on a panicle was dough (not liquid) and hulls turned from green to tan. A field was considered in heading, milk or dough when at least 75% of the panicles in the field reached one of these stages of development.

Planting method (drilled or broadcast seeded) of sampled fields also was recorded. Most fields in Texas are drill seeded with well defined rows. However, occasionally fields are replanted; these fields do not have well defined rows but have the appearance of a broadcast

seeded field. If rows were easily visible and allowed relatively easy movement in the field, the field was considered drill seeded. If rows were not visible, the field was classified broadcast seeded.

Selected fields were divided into parallel transects 18 m apart. Transects were selected and samples taken every 18 m, starting 9 m from the field margin. Number of sampling points in each transect and transects per field varied with field size. At each sampling point, sweep net and visual samples were taken in adjacent areas but spaced enough to avoid interference among methods. Fields were sampled only once during each season, or, if sampled more than once, they were sampled at different stages of panicle development. Sampling was conducted between 1000 – 1200 and 1400 – 1700 h CDT. Sampling before 1000 h CDT was hampered by the presence of dew on foliage, which interfered with sweep net sampling. In 2003, all visual sampling methods were performed by the same operator, while sweep net samples were taken by different operators. In 2004, all sampling methods were performed by each of three operators, and time to complete each sampling method was recorded.

Visual sampling methodologies. Three visual methods were developed and compared to the sweep net. For the first visual method, a “T-tool”, a common device used to sample for the fungal disease sheath blight caused by *Rhizoctonia solani* Kuhn, was evaluated. The T-tool consists of two polyvinyl chloride (PVC) pipes in the form of a T, one a handle (1.25 m long) and the other (0.65 m long) attached perpendicular to the handle. The operator walked 4.5 m in 20 s using the T-tool to lightly push through the panicles to disturb the insects. Adult *O. pugnax* observed on or flying from panicles in the area disturbed by the T-tool were counted. For the second visual method, a “sweep stick” made of a 1 m long PVC pipe (2 cm diameter) was used by the operator to lightly disturb rice panicles, sweeping 180 degrees from one side to the other

with each step. Only adult *O. pugnax* observed on or flying from the panicles in the area determined by the last 0.38 m of the sweep stick were recorded. A total of five consecutive sweeps was performed and the number of *O. pugnax* observed after each sweep was recorded. Number of *O. pugnax* after one, two, three, four and five sweeps of the sweep stick was compared to the number of insects caught with the sweep net. For the third visual method, a “long stick” made of a 1.5 m long PVC pipe (2 cm diameter) was used to gently disturb the rice panicles while sweeping 180 degrees in front of the operator. The number of adult *O. pugnax* observed on or flying from the disturbed panicles along the entire length of the long stick was recorded. Sweep net samples were taken following the procedures described in the 2006 Rice Production Guidelines (Way et al. 2006).

Effect of location of sample and time of day on sweep net sampling. Sweep net samples taken nearest the field margin (9 m) were labeled “perimeter” samples, while all other samples were labeled “within field” samples. For each field, perimeter and within field samples were compared using analysis of variance (ANOVA) with factors being field and location of sample.

For each sampling date, numbers of adult *O. pugnax* caught with the sweep net during morning and afternoon hours were compared using ANOVA with factors being sampling date and time of day. Sampling date was preferred over field as a factor because some fields were sampled during the course of more than one day, and weather conditions sometimes changed drastically during different days. Mean numbers of *O. pugnax* caught at different times of day on each sampling date were compared using Fisher’s Least Significant Difference (LSD) test.

Spatial pattern. Taylor’s model relating variance and mean is one of the best models to describe spatial aggregation (Taylor et al. 1978, 1980, Taylor 1984). The variance corresponding

to different population means can be estimated using the variance-mean relationship developed by Taylor (1961)

$$s^2 = ax^b \quad (1)$$

where s^2 is the sample variance, x is the sample mean, and a and b are Taylor's coefficients. Taylor's coefficients are usually estimated by log-log transformation of equation (1), but this method can overestimate s^2 at low densities. For this reason, coefficients for the sampling methods included in this study were calculated by nonlinear regression of variance versus mean *O. pugnax* aggregated counts (see comparison between sweep net and visual sampling) (Wilson et al. 1983, Binns and Nyrop 1992, Wilson 1994).

Comparison between sweep net and visual sampling. Three criteria were used to evaluate the visual methods used in this study. First, a good correlation must exist between sweep net and visual counts. Second, the relationship between sweep net and visual counts should not be affected by planting type, panicle stage, time of day, or operator. Third, the visual methods must optimize cost-reliability. The first two criteria were evaluated by comparing sweep net and visual sample units; relative cost-reliability was determined for the visual methods with respect to the sweep net method.

Sweep net sampling is a relative method which does not yield an absolute population estimate per unit area of habitat (Southwood 1978). The visual sampling methods in the present study also are relative methods. Only Bowling (1969) attempted to determine the absolute number of *O. pugnax* in rice; however, cultivars used at the time and their spatial arrangement in the field (row and plant spacing) have changed considerably, making this determination irrelevant for present conditions. Because of the flooded cultivation of rice, high plant density, closed canopy and high mobility of *O. pugnax*, the determination of the absolute number of *O.*

pungax present under field conditions is difficult. Since no absolute method to sample *O. pungax* populations in rice is available, the visual methods described in this study were calibrated to the sweep net method. To calibrate sampling methods, paired samples should be taken and compared, but achieving a high correlation is difficult when comparing single observations (Todd and Herzog 1980). Because of this, *O. pungax* visual and sweep net counts were aggregated by sampling date, panicle developmental stage (heading, milk or dough), location of sample in the field (perimeter or within field), time of day of sampling (morning or afternoon), and type of planting (drill or broadcast seeded). Analyses were performed on the mean of the aggregated counts.

Correlation between sweep net and visual counts. Linear regression analyses were performed to determine the level of correlation between sweep net and visual counts. Mean sweep net counts were regressed against mean T-tool, long stick and sweep stick counts, and linear regression equations estimated.

Effect of factors on the sweep net and visual methods correlations. Type of planting, stage of panicle development, time of day and operator can influence the relationship between sweep net and visual sampling. The purpose of the present study was to identify a visual method(s) least affected by these factors allowing reliable sampling under a variety of conditions. Number of observed adult *O. pungax* was analyzed using analysis of covariance (ANCOVA) with factors (categorical variables) being planting type, stage of panicle development and time of day. Number of adult *O. pungax* caught with the sweep net served as the covariate (continuous variable). ANCOVA allows comparison of intercepts (main effects) and slopes (interactions) of the regression lines generated between sweep net and visual counts for different factors. For a visual method, if intercepts and slopes for different levels of a factor are not significantly

different, the relationship between sweep net and visual counts is not affected by the factor; however, if intercepts or slopes are significantly different, the relationship between counts changes with changing levels of the significant factor. Only in 2004 were all sampling methods performed by each of the three operators. For that reason, the effect of the operator was determined only with 2004 data. In this case, the number of *O. pugnax* for each visual sampling method was analyzed using ANCOVA, with operator as random factor and number of adult *O. pugnax* caught with the sweep net as covariate.

Cost-reliability. Wilson (1994) defines relative cost-reliability as the ratio of the costs of two sampling methods expressed as:

$$C_v / C_{sn} = n_v (\theta_v + \phi_v) / n_{sn} (\theta_{sn} + \phi_{sn}) \quad (2)$$

where C_v and C_{sn} are the cost per sample in time for a given level of reliability for the visual and sweep net sampling methods, respectively; n_v and n_{sn} are the number of sampling units required for an estimate for a given level of reliability with the corresponding sampling method; θ_v and θ_{sn} are the times required to examine an individual sample unit using the corresponding sampling method; and Φ_v and Φ_{sn} are the times required to move between sample units for the corresponding sampling method.

Equation (2) calculates the relative cost-reliability of a visual method with respect to the sweep net method based on the number of sample units and time required to reach an estimate for a given level of reliability. However, equation (2) does not consider the physical effort necessary for each sampling method to reach an estimate. Scouts may prefer the sampling method that is less physically demanding. An advantage of the visual methods tried in this study is that they are less strenuous than sweeping rice using the sweep net.

Assuming the probability of adoption of a sampling method is inversely proportional to the physical effort required to sample, the physical effort required to sample an insect population using the i th sampling method, E_i , can be expressed as:

$$E_i = \varepsilon / p_i \quad (3)$$

where p_i is the probability of adoption of the i th sampling method and ε is a constant relating E_i to p_i . Incorporating E_i in equation (2), one obtains:

$$C_v / C_{sn} = n_v (\theta_v + \phi_v) E_v / n_{sn} (\theta_{sn} + \phi_{sn}) E_{sn} \quad (4)$$

and replacing E_i in (4) with (3),

$$C_v / C_{sn} = n_v (\theta_v + \phi_v) p_v^{-1} / n_{sn} (\theta_{sn} + \phi_{sn}) p_{sn}^{-1} \quad (5)$$

where C_v / C_{sn} is the relative cost-reliability that incorporates probability of adoption, p_{sn} is the probability of adoption of the sweep net method and p_v is the probability of adoption of the visual method. Equation (5) can be used to determine the relative cost-reliability of a visual method with respect to the sweep net considering not only sample size and sampling time but also sampling effort. To determine the probability of adoption of the visual methods, 20 potential users of the novel visual methods (growers, Crop Consultants and County Agents) were interviewed. Interviews were conducted by telephone by a person unrelated to the research project who did not know the interviewees. All were asked the same question: “If a visual method to sample the rice stink bug were available, would you use the visual method, given that the visual method is as reliable as the sweep net?” The probability of adoption of the sweep net was obtained from Harper et al. (1990).

During the collection of samples, the time required to count the number of insects caught with the sweep net increased as the number of insects caught increased. To incorporate this time

variation into the cost-reliability analysis, the time needed to examine a sample unit at different mean population densities was estimated by linear regression analysis.

The sample size (n) required to obtain a population estimate with a given level of reliability can be determined using the formula presented by Karandinos (1976) and modified by Wilson and Room (1982)

$$n = t_{\alpha/2}^2 D_x^{-2} s^2 x^{-2} \quad (6)$$

where $t_{\alpha/2}$ is the standard normal variate for a two-tailed confidence interval; D_x is a proportion of the mean equivalent to half the desired confidence interval, a measure of reliability; and x is the mean population density. Substituting s^2 in equation (6) with equation (1), we obtain

$$n = t_{\alpha/2}^2 D_x^{-2} a x^{b-2} \quad (7)$$

Substituting n in equation (5) with equation (7), and including the linear regression equation relating sweep net and visual counts, one obtains:

$$C_v / C_{sn} = a_v (A + Bx)^{(b_v-2)} (\theta_v + \phi_v) p_v^{-1} [(a_{sn} x^{(b_{sn}-2)}) (\theta_{sn} + \phi_{sn}) p_{sn}^{-1}]^{-1} \quad (8)$$

where C_v / C_{sn} is the relative cost-reliability of the visual method with respect to the sweep net method for population sampling; a_v and b_v are Taylor's coefficients for the visual method; a_{sn} and b_{sn} are Taylor's coefficients for the sweep net method; A and B are the intercept and slope, respectively, of the linear regression equation relating visual to sweep net counts; and x is mean population density expressed as numbers of adult *O. pugnax* caught per 10 sweep net sweeps. Equation (8) was used to determine the relative cost-reliability of visual methods compared to the sweep net method for a given level of reliability.

Optimum sample size. Using equation (7), optimum sample sizes for the sweep net and the most appropriate visual methods were calculated to obtain estimates with 90% confidence ($\alpha = 0.1$) within 10, 20 or 30% of the mean ($D_x = 0.1, 0.2$ or 0.3). The reliability of a parameter

estimate for the sweep net method for different insect population densities for the currently recommended sample size ($n = 10$) also was calculated. For all statistical analyses, when assumptions of normality of residuals and constant variances were not met, data were transformed before applying ANOVA or ANCOVA. The Box-Cox procedure was used to determine the best transformation (Kutner et al. 2005). All statistical analyses were performed using the SPSS package (SPSS Inc. 2005) at an α level of 0.05.

Results

Fields sampled were planted to different varieties and planting types, and represented all stages of rice panicle development. Table 1 shows the total number of sample units taken for each sampling method, the average number of adult *O. pugnax* caught or observed and the range of counts. Sampled fields ranged in size from 14 to 50 acres. On average, eight transects and 64 sampling points were taken in each field.

Effect of location of sample and time of day on sweep net sampling. Location main effect was significant ($F = 24.2$; $df = 1, 1002$; $P < 0.001$), indicating a significant difference in the number of *O. pugnax* caught between perimeter and within field samples. Significantly more insects were caught in perimeter samples (6.465 ± 0.274) than in within field samples (5.127 ± 0.147). Field main effect was significant ($F = 50.959$; $df = 16, 1002$; $P < 0.001$), indicating significant differences in number of *O. pugnax* among fields. The interaction between field and location of sample in the field was not significant.

For 17 of 29 sampling dates, samples were taken during both morning and afternoon hours in the same field. ANOVA resulted in a significant interaction between sampling date and time of day ($F = 2.304$; $df = 16, 987$; $P = 0.003$). On four sampling dates, significantly more *O.*

pugnax were caught during morning than afternoon hours, while on two sampling dates significantly more insects were caught in afternoon than morning hours. On the remaining sampling dates, no differences were found between number of insects caught at different times of day; however, numerically more insects were caught during morning hours.

Spatial pattern. Figs. 1 and 2 show how the relationship between variance and mean changes with density. For all sampling methods, the variance is larger than the mean at most densities, suggesting an aggregated spatial pattern (Davis 1994). The figures show differences in the degree of aggregation for different sampling methods. Insects are perceived as more aggregated with the sweep net and five sweep stick sweeps, and less with one sweep stick sweeps and the T-tool.

Comparison between sweep net and visual sampling. All regression analyses associating visual and sweep net counts were significant (Table 2). R-squared values were high and ranged from 0.639 for the long stick to 0.825 for three sweep stick sweeps. Results of ANCOVA for the long stick and two sweep stick sweeps show no significant differences in the intercepts or slopes of the lines (Table 3); therefore, a single line was used to describe the relationship between the sweep net and the visual methods. No differences were found in the intercepts for the rest of the visual methods; however, differences were found in the slopes for time of day of sampling. ANCOVA showed that the relationship between sweep net and visual methods was not affected by the use of different operators. Intercepts and slopes were not significantly different for operators sampling with any of the visual methods ($P > 0.05$).

Cost-reliability. The linear regression between sweep net counts and time (in seconds) required to take and examine a sweep net sample unit was significant ($F = 11.974$, $P = 0.001$, $r^2 = 0.255$, $n = 36$). Intercept and slope for this relationship were 17.370 ± 2.311 and 1.616 ± 0.467 ,

respectively. Linear regression between visual counts and time required to take a visual sample unit was not significant ($P > 0.05$) for any visual methodologies, indicating that time required to take a visual sample unit was not affected by the number of insects observed. Average time, in seconds, required to take a sample unit for each visual method was 33.37 ± 0.93 , long stick; 13.28 ± 0.62 , one sweep stick sweep; 27.32 ± 1.19 , two sweep stick sweeps; 42.02 ± 1.78 , three sweep stick sweeps; 55.79 ± 2.42 , four sweep stick sweeps; and 69.82 ± 3.11 , five sweep stick sweeps. Time required for the T-tool method was always 20 seconds. Time required to move between sample units was 18.72 ± 0.323 seconds, based on samples taken during 2005 throughout the Texas Rice Belt. This time was assumed to be the same for all sampling methodologies. Time for the operator to record data while sampling was not included for any of the methods. Scouts generally do not record data while sampling. Usually, data recording is performed once sampling a management area is completed (M. O. Way, personal communication).

A survey of 20 potential users revealed that 18 of them would adopt a visual sampling method for *O. pugnax*. Adoption probability of the novel visual methods (p_v) was calculated to be 0.9. Harper et al. (1990) conducted mail surveys among Texas rice producers during 1986 and 1987 and calculated the probability of adoption of the sweep net (p_{sn}) to be 0.4.

Relative cost-reliability values for visual sampling methods relative to the sweep net method are shown in Fig. 3. Values larger than one indicate the sweep net method is more cost-reliable than a specific visual method, while values smaller than one indicate the converse. For all visual methods, as insect populations increased, relative cost-reliability decreased. The visual methods were more cost-reliable than the sweep net at most *O. pugnax* densities. The long stick and three sweep stick sweeps were more cost-reliable than the sweep net for densities of two or

more adult *O. pugnax* per 10 sweep net sweeps; the T-tool, for densities of three or more; four sweep stick sweeps, for densities of four or more; two and five sweep stick sweeps, for densities of five or more; and one sweep stick sweep, for densities of six or more.

Optimum sample size. The long stick and two sweep stick sweeps correlated well with the sweep net and these correlations are not affected by stage of panicle development, time of day, type of planting, or operator. Fig. 4 shows the number of sample units required to arrive at an estimate with a given level of reliability for different population densities, expressed as number of adult *O. pugnax* per 10 sweep net sweeps, for the sweep net, one long stick sweep and two sweep stick sweeps. For the same density, to obtain an estimate within 10% of the mean ($D_x = 0.1$), the number of sample units required is large (> 100) for all methods, especially at low population levels. To obtain an estimate within 30% of the mean ($D_x = 0.3$), the number of sample units is considerably smaller. The sweep net and long stick methods require a similar number of sample units at populations higher than five adult *O. pugnax* per 10 sweep net sweeps, but at lower populations the long stick method requires more sample units than the sweep net method. At all densities, two sweep stick sweeps requires more sample units than the sweep net or the long stick to reach an estimate with the same level of reliability.

Using equation (4), the reliability of taking 10 sample units with the sweep net method for different insect population densities was calculated (Fig. 5). As population density increases, the reliability of an estimate obtained by taking 10 sample units increases (D_x becomes smaller).

Discussion

Populations sampled included a wide range of insect densities (Table 1). Fifty five percent of the sweep net counts ranged from three to 15 adults. In Texas, damaging populations

are considered to be three to 15 adults per 10 sweep net sweeps (Harper et al. 1993, Way et al. 2006); so, the data include population levels common in Texas.

Results of the current study show that sweep net samples taken 9 m from the field margin caught significantly more *O. pugnax* than sweep net samples taken within the field. To avoid border effects and obtain unbiased estimates of population density, sweep net samples should be taken farther than 9 m from the field border. Past research has found that sweep net samples taken 50 m from field margins provide a good estimate of *O. pugnax* populations (Foster et al. 1989).

Previous research also has found significant effects of time of day in SN catches. Rashid (2006) found that during hot, sunny days in Arkansas, samples taken at 1330 h CDT had fewer *O. pugnax* than earlier or later sampling times. Other workers determined time of day is not a significant factor in the number of *O. pugnax* caught with the SN (Douglas 1939, Cherry and Deren 2000); however, the sample unit size in these experiments was much larger. Results of the present study show that time of day may not affect *O. pugnax* counts. However, numerically, more insects were captured with the SN from 1000 to 1200 than from 1400 to 1700 h CDT.

The variance-mean ratio can be used to classify the spatial pattern of a species as aggregated ($s^2 > x$), random ($s^2 = x$) or uniform ($s^2 < x$) (Davis 1994, Wilson 1994). Results from the current study show the spatial pattern of *O. pugnax* in Texas rice fields was aggregated at most densities for all sampling methods (Figs. 1 and 2). Degree of aggregation varied depending on the sampling method used. *O. pugnax* was perceived as highly aggregated when using the sweep net method, and less so when using visual methods. Likewise, Foster et al. (1989) determined that the spatial pattern of *O. pugnax* in rice fields in Florida was aggregated.

All visual sampling methodologies correlated well with the sweep net method (Table 2) but only the relationships of the long stick and two sweep stick sweeps with the sweep net were unaffected by time of day of sampling (Table 3). The other visual sampling methodologies were significantly affected by time of day of sampling which indicates that a single linear regression equation does not accurately describe the relationship with the sweep net method; thus, two functions are needed, one for morning and another for afternoon.

Previous research reported the physical aspects of sweep net sampling can be a factor discouraging the adoption of this method (Harper et al. 1990). Although a sweep net is relatively inexpensive (\$ 23.50, BioQuip Products Inc., Rancho Dominguez, CA), some farm managers may not possess one when needed. Also, nets frequently need replacing due to the abrasive nature of rice plants. These factors may explain why growers, Crop Consultants and County Agents have a strong preference for visual sampling methods. An advantage of the visual sampling methods evaluated in this study is they require less physical effort than the sweep net. It is difficult to quantify directly the amount of sampling effort required to reach a population estimate. Traditionally, relative cost-reliability only considers the number of sample units needed and time required to sample. By including the probability of adoption of a sampling method (as a measure of sampling effort), relative cost-reliability is broadened and presents a better comparison of sampling methods. However, the probabilities of adoption presented in this paper are only indicative of the potential users' intention to use a sampling method. In order to determine real adoption rates for the sweep net or the visual methods, a more comprehensive study would be necessary.

Among the visual methods evaluated in the present study, the long stick and two sweep stick sweeps appear to be the most appropriate for field use. Both methods correlate well with

the sweep net and are not affected by stage of panicle development, time of day of sampling, type of planting or operator. The number of insects observed with these visual methods can be converted into sweep net counts using the equations $LS = -0.156 + 0.675 SN$ and $SS2 = 0.407 + 0.396 SN$, where SN is the number of adult *O. pugnax* caught with 10 sweep net sweeps, LS is the number of adults *O. pugnax* observed per one long stick sweep and $SS2$ is the number of adults *O. pugnax* observed per two sweep stick sweeps (Table 2).

In Texas, 10 sample units are recommended to estimate *O. pugnax* density using the sweep net. Considering a minimum level of reliability of 30%, for a sample size of $n = 10$, the reliability of the sweep net method at densities lower than six *O. pugnax* is poor (Fig. 5). For a population estimate to be within 30% of the mean when populations are as low as one insect per 10 sweeps, a sample size of $n = 27$ is required (Fig. 4). This indicates that the number of sample units needed to arrive at a population estimate using the sweep net should be increased when populations are low. If the desired level of reliability is higher, a greater number of sample units is needed.

Results of the present studies may be used by researchers, County Extension Agents, Crop Consultants and farm managers to facilitate sampling and improve reliability of *O. pugnax* estimates for research purposes.

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Table 1. Total number of sample units taken by sampling method, mean number of adult *O. pugnax* caught or observed \pm SEM, and range of counts, southeast TX, 2003 and 2004

Sampling method ^a	Sample units	Mean <i>O. pugnax</i> caught or observed	Range
SN	1033	5.3 \pm 0.2	0 – 48
TT	919	2.9 \pm 0.1	0 – 23
LS	645	2.9 \pm 0.1	0 – 13
SS1	1025	1.1 \pm 1.0	0 – 10
SS2	1025	2.3 \pm 0.9	0 – 20
SS3	1025	3.5 \pm 0.1	0 – 27
SS4	1025	4.7 \pm 1.8	0 – 35
SS5	1025	5.8 \pm 0.2	0 – 42

^a SN, 10 sweep net sweeps; TT, one T-tool pass (4.5 m in 20 s); LS, one long stick sweep; SS1, one sweep stick sweep; SS2, two sweep stick sweeps; SS3, three sweep stick sweeps; SS4, four sweep stick sweeps; SS5, five sweep stick sweeps.

Table 2. Parameter estimates \pm SEM of linear regression analyses between 10 sweep net sweeps and visual adult *O. pugnax* counts, southeast TX, 2003 and 2004

Sampling method ^a	Intercept	Slope	<i>F</i>	<i>P</i>	<i>r</i> ²	n
TT	0.098 \pm 0.212	0.475 \pm 0.029	270.364	< 0.001	0.818	62
LS	-0.156 \pm 0.358	0.675 \pm 0.074	83.343	< 0.001	0.639	49
SS1	0.279 \pm 0.094	0.184 \pm 0.013	190.923	< 0.001	0.740	69
SS2	0.407 \pm 0.163	0.396 \pm 0.023	294.314	< 0.001	0.815	69
SS3	0.541 \pm 0.242	0.611 \pm 0.034	316.901	< 0.001	0.825	69
SS4	0.754 \pm 0.322	0.786 \pm 0.046	696.575	< 0.001	0.816	69
SS5	0.972 \pm 0.399	0.956 \pm 0.057	285.642	< 0.001	0.810	69

^aTT, one T-tool pass (4.5 m in 20 s); LS, one long stick sweep; SS1, one sweep stick sweep; SS2, two sweep stick sweeps; SS3, three sweep stick sweeps; SS4, four sweep stick sweeps; SS5, five sweep stick sweeps.

Table 3. Results from ANCOVA for number of adult *O. pugnax* observed with different visual methods, southeast TX, 2003 and 2004

Factors ^a	Sampling method ^b											
	TT			LS			SS1			SS2		
	<i>F</i>	df	<i>P</i>	<i>F</i>	df	<i>P</i>	<i>F</i>	df	<i>P</i>	<i>F</i>	df	<i>P</i>
S	0.524	2, 52	0.595	0.130	2, 39	0.879	1.892	2, 59	0.160	1.178	2, 59	0.315
D	1.369	1, 52	0.247	0.234	1, 39	0.631	0.837	1, 59	0.364	0.0003	1, 59	0.985
PT	0.103	1, 52	0.750	1.231	1, 39	0.274	0.838	1, 59	0.364	0.776	1, 59	0.382
SN	25.371	1, 52	< 0.001	63.523	1, 39	< 0.001	77.455	1, 59	< 0.001	67.224	1, 59	< 0.001
S x SN	0.034	2, 52	0.967	1.304	2, 39	0.283	1.863	2, 59	0.164	0.323	2, 59	0.725
D x SN	5.410	1, 52	0.024	1.405	1, 39	0.243	7.216	1, 59	0.009	3.179	1, 59	0.080
PT x SN	0.078	1, 52	0.782	1.977	1, 39	0.168	0.517	1, 59	0.475	0.523	1, 59	0.472

Table 3. Continued

Factors ^a	Sampling method ^b								
	SS3			SS4			SS5		
	<i>F</i>	df	<i>P</i>	<i>F</i>	df	<i>P</i>	<i>F</i>	df	<i>P</i>
S	0.798	2, 59	0.455	0.694	2, 59	0.503	1.072	2, 59	0.349
D	0.188	1, 59	0.666	0.700	1, 59	0.406	1.418	1, 59	0.238
PT	0.562	1, 59	0.457	0.292	1, 59	0.591	0.341	1, 59	0.562
SN	74.376	1, 59	< 0.001	71.504	1, 59	< 0.001	74.729	1, 59	< 0.001
S x SN	0.128	2, 59	0.880	0.076	2, 59	0.927	0.273	2, 59	0.762
D x SN	5.968	1, 59	0.018	9.359	1, 59	0.003	12.676	1, 59	0.001
PT x SN	0.514	1, 59	0.476	0.508	1, 59	0.479	0.829	1, 59	0.366

^aS, panicle stage; D, time of day of sampling; PT, planting type; SN, 10 sweep net sweeps counts.

^bTT, one T-tool pass (4.5 m in 20 s); LS, one long stick sweep; SS1, one sweep stick sweep; SS2, two sweep stick sweeps; SS3, three sweep stick sweeps; SS4, four sweep stick sweeps; SS5, five sweep stick sweeps.

Fig. 1. Taylor's variance–mean relationships ($s^2 = a x^b$) for *O. pugnax* when sampling using 10 sweep net sweeps (SN), one long stick sweep (LS), one T-tool pass (TT) and one sweep stick sweep (SS1), southeast Texas rice fields, 2003 and 2004.

Fig. 2. Taylor's variance–mean relationships ($s^2 = a x^b$) for *O. pugnax* when sampling using two (SS2), three (SS3), four (SS4) and five (SS5) sweep stick sweeps, southeast TX rice fields, 2003 and 2004.

Fig. 3. Relative cost-reliability for the T-tool (TT), long stick (LS), one (SS1), two (SS2), three (SS3), four (SS4) and five (SS5) sweep stick sweeps with respect to the sweep net (SN). Mean population density is expressed in number of adult *O. pugnax* per 10 sweep net sweeps. The dashed straight line represents a value of one, meaning the sweep net and visual methods have the same cost-reliability. For values above this line, the sweep net is more cost-reliable, and below it, the visual methods are.

Fig. 4. Optimum sample size required to obtain a population estimate within 10, 20 and 30% of the mean for the sweep net (SN), long stick (LS) and two sweep stick sweeps (SS2) for *O. pugnax* in rice. Mean population density is expressed as number of adult *O. pugnax* per 10 sweep net sweeps.

Fig. 5. Level of reliability, expressed as a proportion of the mean (D_x), of using a fixed sample size of $n = 10$ for population sampling of *O. pugnax* in rice using the sweep net (SN) at different population densities. Mean population density is expressed as number of adult *O. pugnax* per 10 sweep net sweeps.









