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Numerical and binomial optimal samplings of arthropods of wet paddy ecosystem in Malaysia

(Pensampelan optimum berangka dan binomial atropod ekosistem sawah padi di Malaysia)

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Key words: insecta, paddy, rice, pest, sampling, OSS, Malaysia

Abstrak

Saiz sampel optimum (SSO) ialah saiz sampel yang paling kecil yang ditetapkan tahap kebolehpercayaan anggarannya. Justeru bagi memastikan kecekapan tugasan, maklumat SSO diperlukan bagi pensampelan berangka dan binomial. Data yang diperoleh daripada penelitian pandang terhadap 204 sampel dengan 40 rumpun padi dalam setiap sampel digunakan untuk menghasilkan lengkung SSO bagi 22 kategori atropod. Untuk menentukan SSO, data bilangan setiap rumpun dianalisis untuk memperoleh varians (s^2) dan min kepadatan ($\bar{x}$) bagi setiap gabungan kategori atropod, tarikh dan masa pensampelan untuk setiap satu daripada 22 kategori atropod (8 perosak dan 14 pemangsa). Pekali Taylor *a* dan *b* telah diperoleh serta digunakan dalam algoritma Wilson dan Room (1983) untuk menjana perkadaran infestasi dan maklumat SSO bagi pensampelan berangka dan binomial bagi setiap kategori artropod. Corak lengkung SSO bagi pensampelan binomial menunjukkan dua kumpulan atropod iaitu kumpulan yang nilai SSO meningkat secara perlahan apabila $\bar{x}$ bertambah dan kumpulan yang menunjukkan peningkatan SSO yang cepat. Kumpulan yang pertama terdiri daripada spesies yang menunjukkan taburan berkelompok manakala kumpulan yang kedua menunjukkan taburan rawak. Kumpulan yang pertama menghasilkan lebih kurang tiga individu serumpun manakala kumpulan yang kedua menghasilkan dua individu serumpun pada saiz sampel yang minimum. Secara umum, pada suatu kepadatan populasi, pensampelan binomial memerlukan lebih banyak sampel daripada pensampelan berangka bagi pencirian optimum. Dalam pensampelan binomial, saiz sampel yang diperlukan menurun mengikut pertambahan kepadatan populasi sehingga suatu takat dan kemudian meningkat berterusan. Dalam pensampelan berangka, saiz sampel yang diperlukan menurun dengan peningkatan kepadatan populasi. Bagi setiap kategori atropod, tiada nilai P(I) (perkadaran infestasi serumpun) di bawah titik SSO minimum pada lengkung SSO binomial. Taburan spatial ditentukan dan didapati berkelompok bagi kebanyakan perosak dan secara rawak bagi kebanyakan pemangsa. Seterusnya bagi pensampelan binomial, pada kepadatan populasi yang serupa, lebih banyak sampel diperlukan untuk menganggarkan kepadatan populasi yang bertaburan secara rawak berbanding dengan yang bertaburan secara berkelompok pada tahap kepadatan populasi yang lebih tinggi.

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Abstract

The optimum sample size (OSS) is the smallest sample size with user-predetermined acceptable reliability of estimation. As such, to ensure efficiency of assignments, OSS information is necessary for both numerical and binomial sampling. Data from visual inspection of 204 samples, with 40 hills of paddy plant per sample, were used to determine the OSS numerical and binomial sampling curves for each of the 22 categories of arthropods. To determine the OSS, the data on counts per hill were analyzed to obtain variance (s^2) and mean density ($\bar{x}$) at each combination of arthropod category, sampling date and sampling time for each of the 22 arthropod categories (8 pests and 14 predators). Taylor's *a* and *b* coefficients were then obtained, and incorporated into Wilson and Room's (1983) algorithms to generate proportions of infestation and OSS information for enumerative and binomial samplings for each arthropod category. The pattern of OSS curves for binomial sampling indicates two groups of arthropods, i.e. those whose OSS increases slowly as $\bar{x}$ increases and those showing a rapid increase in OSS. The first group consists of species having clumped distribution while the second group comprises species showing random distribution. The former group shows approximately three individuals a hill where the minimum sample size occurs, whereas the latter shows approximately two individuals a hill. Generally, at a certain population density, binomial sampling necessitates a larger sample size than numerical sampling for optimal characterization. In binomial sampling, the sample size required decreases with increasing population density up to a point, and then increases. In numerical sampling, the sample size required decreases with increasing population density. For each arthropod category, on the binomial OSS curve, there is no P(I) (proportion of infested hills) value below the minimum OSS point. Their spatial distributions were determined, and found to be clumped (most of the pests) and random (most of the predators). Thus, in binomial sampling at similar population densities, a larger number of samples are required to optimally estimate randomly distributed populations than those showing clumped distribution at higher densities.

Introduction

Accurate assessment and estimation of field population densities are essential in ecologically-based pest management programs. Consequently, sampling plans and their statistical basis have been critically discussed by various workers (e.g. Wilson et al. 1989; Pedigo and Buntin 1994). It is generally agreed that statistically-based schemes should be formulated to minimize the cost of pest monitoring without substantially reducing the reliability of estimates.

Hence, sampling for monitoring pest status necessitates an estimation known as the optimum sample size (OSS). Karandinos (1976) noted that the OSS is the smallest sample size with acceptable reliability of estimation, and grouped the OSS into three categories of reliability with their relevant formulae. Nevertheless, the OSS estimation is not widely used in pest management, except by Tamaki and Weiss (1979) as well as Wright and Cone (1983) on aphids in sugarbeets and asparagus respectively; Thistlewood (1989) on apple arthropods; Wilson and Room (1982, 1983), and Wilson et al. (1983) on cotton arthropods. To date, there is no published information on the OSS estimation in paddy arthropod populations.

Accurate estimation of OSS depends on the reliability of estimates of field population density and its usage increases sampling efficiency, especially at high population density. Furthermore, an OSS estimate is totally based on reliable statistical methods derived from validated functions (Karandinos 1976). Tamaki and Weiss (1979), Wright and Cone (1983) as well as Thistlewood (1989) used only enumerative sampling method to estimate the OSS, whereas Wilson and Room (1983) proposed two different functions, i.e. binomial sampling based on presence-absence and enumerative sampling. Those functions derived by Karandinos (1976) for enumerative sampling were simplified by Wilson and Room (1982, 1983) by incorporating Taylor's Power Law ($s^2 = a.\,\bar{x}^b$) into the variance-mean statement (Taylor 1961, 1971; Taylor et al. 1978) that can be used to estimate OSS, which is suitable for the general, negative binomial and Poisson distributions when the relevant coefficients are known. Wilson (1982) further developed functions based on similar sampling methods to assess cost and reliability of estimates. The presence-absence protocol in binomial sequential sampling is most efficient at high and low population densities (Sterling and Pieters 1979). In binomial sampling, except at very low density, the required sample size increased with increasing density, at a rate greater than the corresponding increase in enumerative sampling. Enumerative sampling is often impractical at higher population densities.

Reliability of estimates should also be defined to relate sample size with accuracy of estimation (Snedecor and Cochran 1980). Subsequently, sampling cost can be optimized by using OSS estimate with a desired specified reliability (Cochran 1977). Different ways of assessing reliabilities have been developed; with some assuring higher precision of estimates (up to 99%) needed for research purposes. In assessing population status for pest management, Kuno (1969) and Iwao (1975) proposed sequential sampling formulae based on mean crowding and mean density relationship, without restriction on distribution patterns. In this method, a regression analysis provides an estimate of density with a fixed coefficient of variation of the mean. However, Pedigo et al. (1972), Bechinski and Pedigo (1981) as well as Bechinski et al. (1983) used relative variation statistic as measurement of the reliability of estimates. Karandinos (1976) proposed three estimates of reliability of OSS, i.e. the coefficient of variability, and two probabilistic statements that include proportion of a relevant parameter and proportion of an arbitrarily chosen fixed positive number. Wilson and Room (1982, 1983) used the proportion (D) of the mean associated with the proportion of infested units [P(I)], whereas Nachman (1984) used the coefficient of variation associated with the proportion of sampling units without individuals.

This report presents graphically, changing estimates of optimum sample sizes with respect to changing mean population densities for each of the 22 categories of paddy arthropods. Proportions of infested hill in relation to mean densities are also given for each arthropod. Their population distribution as determined by Taylor's Power Law is also discussed in relation to sample size pattern with changing density.

Materials and methods

Data collection

Data from 204 sampling occasions (204 samples, each sample contained a minimum of 40 sampling units, i.e. hills of paddy) were used for the analysis. Visual counts of arthropods per hill were recorded from three locations; paddy estate at Bukit Cawi village, Seberang Perak, Perak (4° 7' N, 101° 4' E) (1986), experimental plots at Universiti Pertanian Malaysia, Serdang, Selangor (3° 2' N, 101° 42' E) (1992), and a farmer's plot at Sawah Sempadan, Tanjung Karang, Selangor (3° 20' N, 101° 12' E) (1992). At each site, direct visual counting was done on arthropods within 22 categories; *Nephotettix* spp. (Homoptera: Cicadellidae), *Nilaparvata lugens* (Stal) (Homoptera: Delphacidae), Pyralidae, *Recilia dorsalis* (Motschulsky) (Homoptera: Cicadellidae), *Sogatella furcifera* (Horvath) (Homoptera: Delphacidae), *Pelopidas mathias* (Fabricius) (Lepidoptera: Hesperiidae), *Cyrtorhinus lividipennis* (Reuter) (Heteroptera: Miridae), Diptera, Orthoptera, Odonata, *Casnoidea* spp. (Coleoptera: Carabidae), *Micraspis* spp. (Coleoptera: Coccinellidae), *Paederus fuscipes* (Curtis) (Coleoptera: Staphylinidae); and the spiders Lycosidae, Oxyopidae, Agriopidae, Clubionidae, Thomisidae, Tetragnathidae, Salticidae, spider nymphs of all families and parasitoids. Except the spiders and the parasitoids which are natural enemies, all the other arthropods are important pests of paddy in Malaysia.

Statistical analyses

For each arthropod category, the data on counts per hill were analyzed to obtain variance (s^2) and means ($\bar{x}$) at each sampling date and for each sampling time, using the procedure PROC MEANS in SAS (SAS 1988). Taylor's a and b coefficients were obtained by regressing ln s^2 against ln $\bar{x}$ in the equation:

$$\ln s^2 = \ln a + b \ln \bar{x} \qquad (1)$$

from Taylor's Power Law (Taylor 1961, 1971, 1984)

$$s^2 = a\,\bar{x}^b \qquad (2)$$

Wilson and Room (1983) proposed a binomial sampling procedure to obtain the expected proportion of sampling units [$\hat{P}(I)$] infested based on a negative binomial model which incorporates Taylor's Power Law.

$$\hat{P}(I) = 1 - e^{-\bar{x}[\ln (a\bar{x}^{b-1})\,(a\bar{x}^{b-1} - 1)^{-1}]} \qquad (3)$$

$\hat{P}(I)$ and Taylor's coefficients were then used to estimate the OSS (i.e. n as defined below) needed to achieve a specified level of reliability D (proportion of the mean) for each species, for enumerative and for binomial sampling, using the following formulae respectively

$$n = C \,.\, a \,.\, \bar{x}^{b-2} \qquad (4)$$

$$n = C \,.\, q \,.\, p^{-1} \qquad (5)$$

where $C = Z^2_{\alpha/2}.D^{-2}$

$Z^2_{\alpha/2}$ = standard normal deviate

Throughout this paper, D = 0.1 (i.e. a proportion of 10% of the mean density). Moreover, half of the confidence interval is equal to a proportion (D) of the mean, i.e. $D_{\bar{x}}$ for equation (4), or of the proportion (D) of infested units (p), i.e. D_p for equation (5), whereby:

$\bar{x} \pm D_{\bar{x}}$ corresponds with $p \pm D_p$, and
$p = \hat{P}(I) = 1 - q$

Therefore, by substituting $\bar{x} - D_{\bar{x}}$ for $\bar{x}$ in (3) gives an estimate for $p - D_p$. Similarly, substituting $\bar{x} + D_{\bar{x}}$ for $\bar{x}$ gives $p + D_p$. These two estimates were used to calculate the mean D_p for each corresponding $\bar{x}$ values. This procedure was repeated for a range of densities for each arthropod category.

Consequently, a range of OSS for numerical and binomial samplings was generated using equations (4) and (5) respectively.

Results and discussion

Figure 1 and *Figure 2* present the relationship between the proportion of infested hills and mean population density, and the optimum sample size (OSS) required to estimate the density within 10% of the mean, using the enumerative binomial and (presence-absence) sampling models. At low densities, both sample size estimates are quite similar. However, as the mean population density increases, the sample size

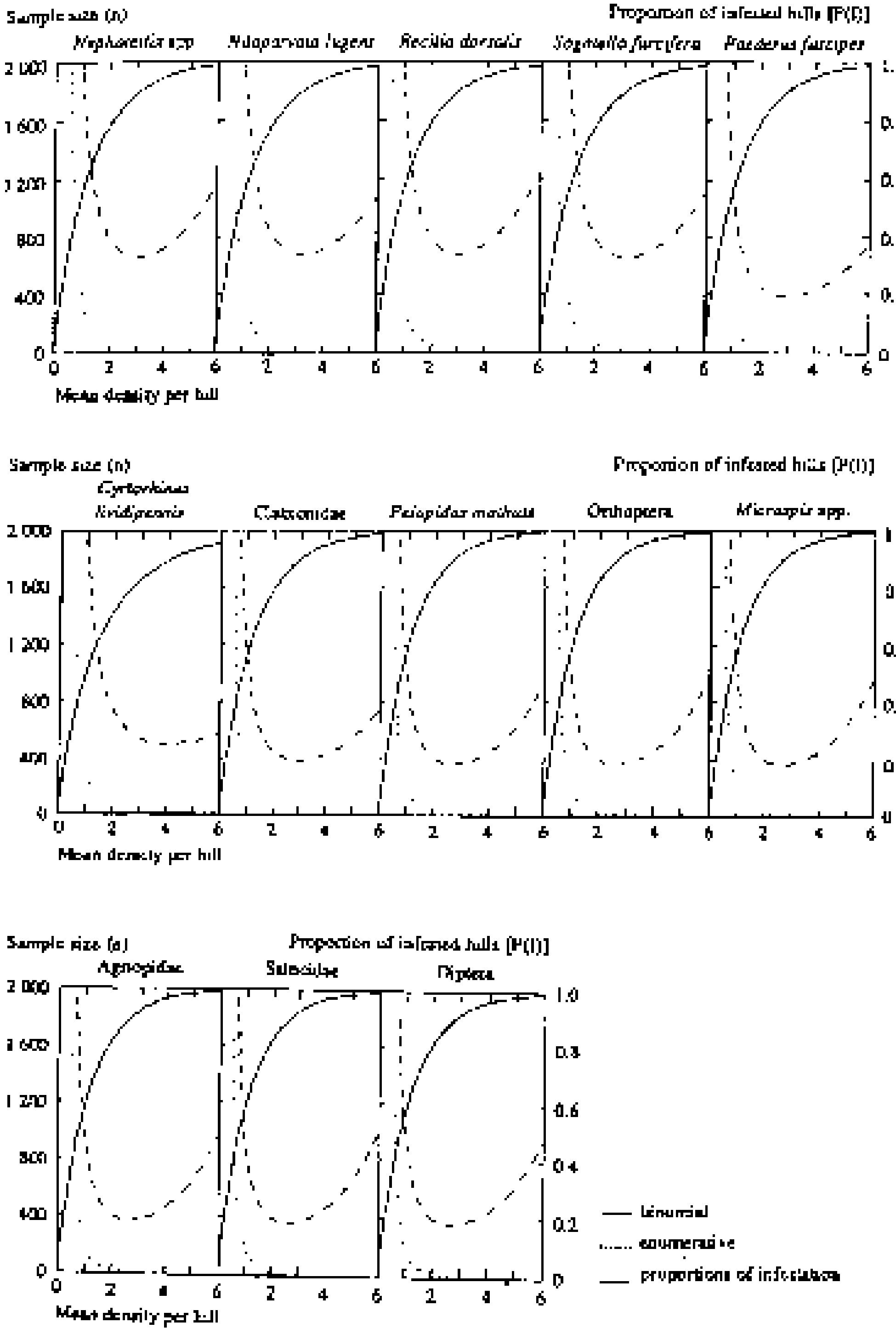

Figure 1. Optimum sample sizes for binomial and enumerative plans, with proportions of infestation [P(I)] at various mean densities of clumped paddy field arthropods

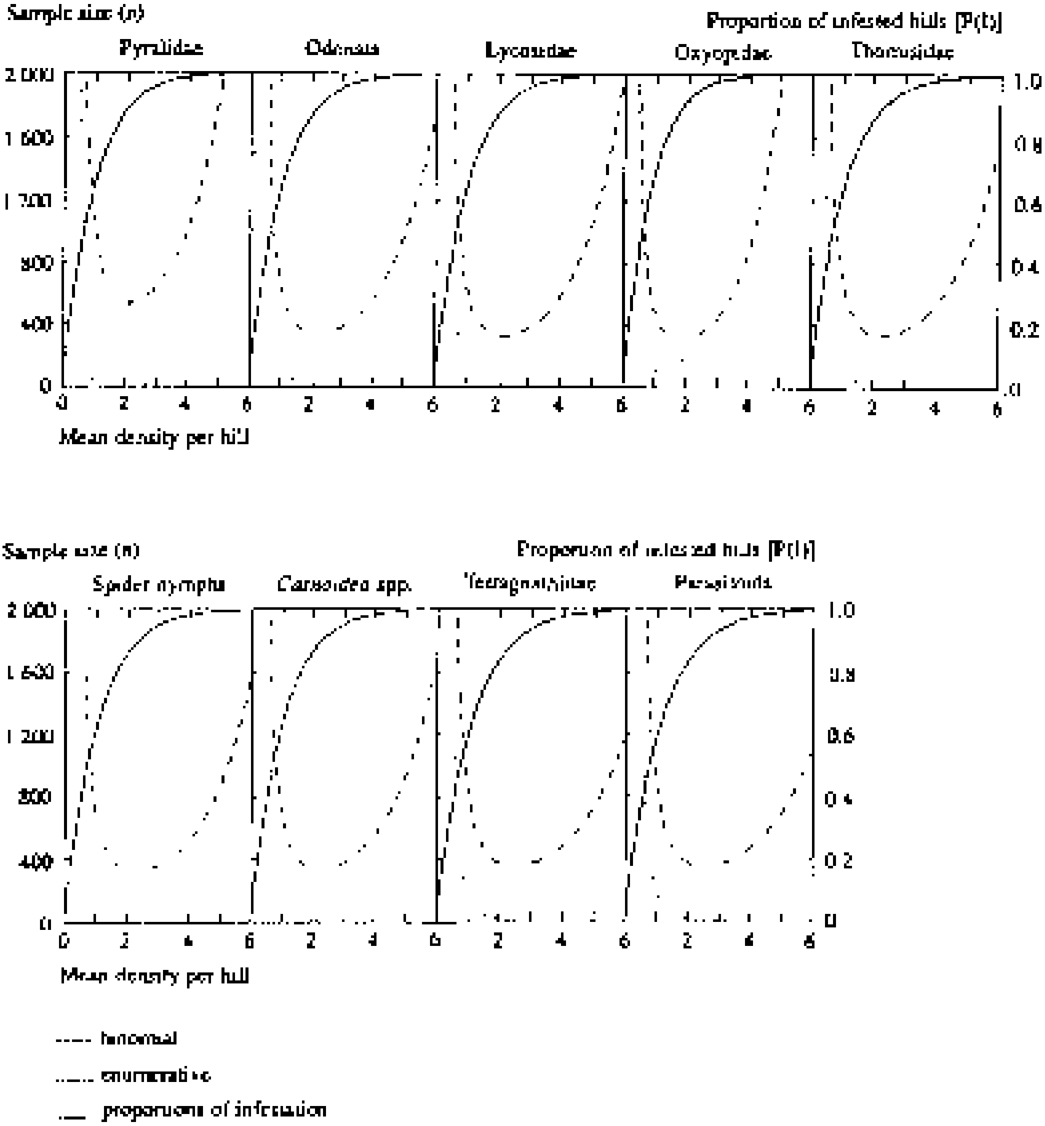

Figure 2. Optimum sample sizes for binomial and enumerative plans, with proportions of infestation [P(I)] at various mean densities of randomly distributed paddy field arthropods

of the binomial sampling increases whilst that of the enumerative sampling decreases though at a sequentially decreasing rate.

This study indicates that the species studied can be grouped into two, i.e. those having the presence-absence sample size estimates increasing slowly as density increases, and those increase rapidly in sample size as density increases. The first group consists of species having clumped distribution such as *Nephotettix* spp., *Nilaparvata lugens*, *Recilia dorsalis*, *Sogatella furcifera*, *Paederus* sp., *Cyrtorhinus* spp., Clubionidae, Lepidoptera, Orthoptera, *Micraspis*, Agriopidae, Salticidae and Diptera *(Figure 1)*. In each of these species, the minimum sample size occurs at a mean population density of approximately three individuals per hill. Species showing random distribution such as Pyralidae, Odonata, Lycosidae, Oxyopidae, Thomisidae, spider nymphs, *Casnoidea* spp., Tetragnathidae and parasitoids *(Figure 2)* comprised the second group. In each of these species, the minimum sample size occurs at a mean population density of approximately two individuals per hill. Interestingly, similar respective values can be obtained for arthropod categories on cotton (Wilson and Room 1983). The optimum sample sizes seem generally high *(Figure 1* and *Figure 2)*. This is expected since a reliability estimate (D) of 10% of the mean was used in the calculations. Increasing the values of D would certainly reduce the sample sizes correspondingly. It is noteworthy that the point of lowest OSS on the binomial curve coincides with the point of inflexion on the proportion of infestation curve, where slope of the curve starts to decrease sharply.

The result of Taylor's Power Law analysis (Taylor 1961, 1971, 1984) for each species studied is presented in *Table 1.* Other distribution tests have also been done on these species (Hassan 1996). After the minimum OSS point, the increase in sample size required at higher densities for species with clumped distributions is related to their respective proportion of infestations [P(I)]. For these species, the slow increase in P(I) with respect to mean density leads to a corresponding slow increase in sample size for binomial sampling. In contrast, a randomly distributed species shows a rapid increase in P(I) with respect to mean density, leading to a corresponding rapid increase in sample size for binomial sampling. In developing a sampling program, the difference in sample size estimates between various distribution patterns is important particularly for the species with clumping patterns (Wilson and Room 1983). Generally at a certain population density, binomial sampling necessitates a larger sample size than numerical sampling for optimal characterization. In binomial sampling, the sample size required decreases with increasing population density until the minimum OSS, and then increases, due to a small D_p corresponding with a bigger $D_{\bar{x}}$ as p values approach unity (Wilson et al. 1989; Wilson 1994). In contrast, the sample size required in numerical sampling decreases with increasing population density corresponding with $D_{\bar{x}}$ increases. It is noteworthy that for each arthropod category, on the binomial SS curve, there is no maximum P(I) value below the P(I) which corresponds with the minimum OSS point.

In practice, since the OSS function relates density to sample size, knowing one variable would enable calculation of the

Table 1. Taylor's Power Law analysis of 22 categories of wet paddy arthropods, 1986 and 1992

Species category	*n*	Slope *b*
Nephotettix spp.	125	1.16**
Nilaparvata lugens	138	1.17**
Pyralidae	70	0.96
Recilia dorsalis	130	1.18**
Sogatella furcifera	101	1.14**
Pelopidas mathias	49	1.07*
Cyrtorhinus lividipennis	124	1.30**
Diptera	116	1.06**
Orthoptera	94	1.07**
Odonata	85	0.99
Casnoidea spp.	67	0.99
Micraspis spp.	87	1.07*
Paederus fuscipes	95	1.12**
Lycosidae	95	0.96
Oxyopidae	40	0.88
Agriopidae	70	1.08**
Clubionidae	71	1.12**
Thomisidae	45	1.00
Tetragnathidae	90	1.04
Salticidae	41	1.06*
Spider nymphs	136	0.96
Parasitoids	98	1.04

n = no. of data points in regression (each *n* based on 40 samples)
**b* significantly greater than 1 at $p < 0.05$
***b* significantly greater than 1 at $p < 0.01$
($b = 1$, random; $b > 1$, aggregated)

other provided that Taylor's coefficients for the particular species are known. In this study, we have not analyzed the cost of sampling. Hence, the actual cost efficiency of binomial and enumerative samplings cannot be compared. The major rice pests such as *Nephotettix* spp., *Nilaparvata lugens, R. dorsalis* and *S. furcifera* as well as some major predators such as *Cyrtorhinus* spp., Orthoptera and *Paederus* sp. showed clumped distribution. The binomial sample size estimate showed that generally a larger number of samples are required to estimate randomly distributed populations relative to those showing clumped distribution at higher densities. An increase in sample size usually leads to an increase in the reliability of estimates. However, sampling cost often limits sample size. Hence, the OSS information optimizes the sample size required. For field implementation, it is necessary to initiate a preliminary survey to determine the mean population density ($\overline{x}$) of the species concerned. This information can be translated to sample size required using *Figure 1* and *Figure 2*. However, it is clear that for D = 0.1, even the minimum *n* is still relatively substantial for binomial, and still large for numerical sampling at $\overline{x}$ below 1; the OSS generated is perhaps most suitable in intensive sampling for research purposes or for parameter estimation (Southwood 1978). Moreover, enumerative sampling (fixed-sample size) which is based on actual counting of individual insect is often laborious, hence cost prohibitive, especially at very low population densities *(Figure 1* and *Figure 2)*. Furthermore, fixed-sample size procedure often provides inadequate precision at low densities (Nyrop and Simmons 1984). Consequently, sequential sampling schemes based on the presence or absence of insects can minimize the cost of pest monitoring, yet provide the accuracy desired for pest management purposes. Well established sequential plans are available for cotton crop (Sterling 1976; Rothrock and Sterling 1982) and prototype plans for a few paddy arthropods are available (Shepard et al. 1986, Hassan and Rashid 1997).

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