DISPERSION OF THE BAGWORMS *Pteroma pendula* AND *Metisa plana* IN OIL PALM

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ABSTRACT

An attempt was made to determine optimum sampling unit of between-palm and within-palm distribution of bagworms and their interspecific association distribution in oil palm using aggregation indices or distribution models. The within-frond distribution of bagworms varied significantly within the oil palm crown. Peak bagworm density was recorded between frond numbers 9 and 19. Through polynomial regression, standardised residual and relative net precision analyses, frond number 17 was established as the representative sampling unit for experimental work, and frond numbers 10-19 should be used when a greater precision is required as in life-table construction. A lack of interspecific association suggested these sampling units to be applicable for single and mixed infestations. Evaluation of between-palm dispersion revealed that Taylor's Power Law gave a more appropriate fit with highly significant r^2 *values for all categories of assessment. The bagworms were regularly dispersed in oil palm with a general mean-variance relationship of* $\log (s^2) = 1.780 + 0.821 \log (\bar{x})$.

Keywords: bagworms, dispersion, interspecific association, within-palm distribution.

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INTRODUCTION

Elliot (1977) defined the dispersion of an insect population as a description of the pattern of distribution of numbers of the population in space. An understanding of dispersion is important for determining appropriate sampling size, developing sampling programmes, measuring population size and describing its condition (Southwood, 1978). Dispersion of insects in oil palm can be categorised as within- and between-palms dispersion. For the former, Wood (1966; 1968) reported that in severe outbreaks, about 58% of *Metisa plana* larvae were concentrated in the upper fronds. Syed *et al*. (1973) showed that *Mahasena corbetti* larvae preferred the top and middle thirds of the palm canopy, and that more larvae were found in the top third with increasing defoliation. Basri (1993) and Rhainds *et al.* (1998) reported similar heterogenous distributions of *M. plana* within a palm. There was no similar finding for *Pteroma pendula*. The available data for *M. corbetti* and *M. plana* described but did not quantify bagworm distribution within palms.

Ang *et al*. (1997) reported the use of polynomial regression to determine the distribution of single and mixed species infestations of *Darna trima* and *D. bradleyi* in 17-year-old oil palm. Using data from fronds of two out of eight spirals in the canopy, representation of caterpillar numbers of a palm was obtained by sampling frond numbers 15 - 25 for single species, and frond numbers 7 - 11 for mixed species infestations. Similar estimates for bagworms would allow the identification of the optimum sampling unit, both in terms of location and size, and subsequently the establishment of a mathematical model for between-palm distribution. There is, however, to date no information on the quantification of between-palm distribution of bagworms in oil palm. This article attempts to establish the within-palm distribution of single and mixed species infestations of *P. pendula* and *M. plana*, and their interspecific association distribution using aggregation indices or distribution models.

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MATERIALS AND METHODS

Within-palm Distribution

Sampling was conducted from January 1998 to December 1999 at Dusun Durian, North, South, East and West Estates in Selangor. The parameters of measurement for within-palm distribution of single and mixed populations of *P. pendula* and *M. plana* are given in *Table 1*. A total of 150 categories or combinations of palms were assessed randomly as and when they were encountered. For each category, frond numbers 1-40 (*Figure 1*) of 10 palms were enumerated for all life stages of *P. pendula* and *M. plana*. The fronds were examined non-destructively for the short (2- to 5-year-old) palms, while for tall (10- to 15-year-old) palms, the fronds were cut down for ease of counting. Data were kept separately for each third (proximal, middle and distal) section of a frond.

The numbers of bagworms in each section of frond and frond location were compared via a two-factor ANOVA using the module of Statistica® Version 5.0. Analysis was performed on log (1+x) transformed data to stabilise the variance. The demographic structure of bagworm populations in each of the categories was elucidated by plotting the mean number of insects of each stage against frond number. The relationship between larval density and location of frond was determined by polynomial regression using the Multiple Regression Module of Statistica® Version 5.0. From the regression, fronds that possessed peak bagworm density and 95% of this peak were ascertained.

Identification of the optimum location of the sampling unit was attempted by using the analytical methods of Buntin and Pedigo (1981) that used standardised residuals to measure the ovipositional preferences of the green cloverworm, *Plathypena scabra* (F.). Standardised residuals (SR)

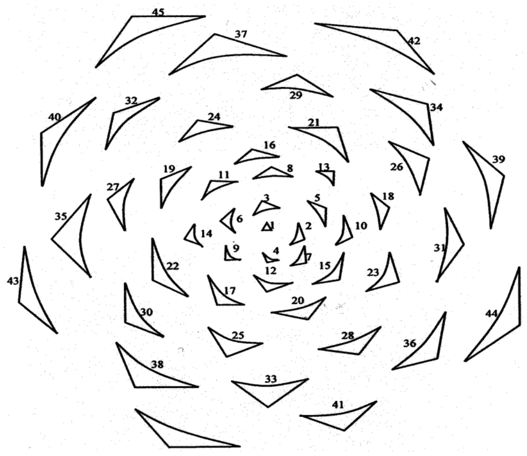

Figure 1. Phyllotaxy of oil palm (Hartley, 1977).

were calculated by:

$$SR = (X_i - \bar{x}) / (\bar{x}^{1/2})$$

where X_i is the actual number of bagworms observed in a frond, and

$\bar{x}$ is the mean bagworm density of the palm (larvae/palm).

Standardised residuals of zero indicate complete agreement between actual and expected counts, while deviations between actual and expected counts produce negative or positive values. SR was calculated for combinations of counts from frond section and palm canopy stratum according to the infestation parameters of infestation type, palm visual damage category, palm height and bagworm life stage. The palm canopy was divided into upper (frond numbers 1-15), mid (frond numbers 16-30) and lower (frond numbers 31-40) strata. The optimum number of fronds per sample unit was determined by comparing cost and variance parameters of four potential sample unit sizes of 1, 2, 5 and 10 fronds per sample. Cost and variance for each couple unit size were compared by calculating

TABLE 1. PARAMETERS FOR MEASUREMENT OF WITHIN-PALM SPATIAL DISTRIBUTIONS OF SINGLE AND MIXED POPULATIONS OF *P. pendula* AND *M. plana*

Species composition	Palm visual damage category[a]	Palm height (years old)	Bagworm stage
P. pendula (single species) *M. plana* (single species)	Slight	Short (2-5)	Early instar[c]
P. pendula (double species)[b] *M. plana* (double species)	Moderate	Tall (10-15)	Late instar[d]
P. pendula + *M. plana* (double species)	Severe	-	Pupa (male) Pupa (female) Pupa (male+female)
	Total 150 categories of palms		

Note: [a] after Basri (1993), *i.e.* slight, moderate and severe.
[b] *P. pendula* sampled from palm infested with both *P. pendula* and *M. plana*.
[c] early instar ≡ L1 – L2 for *P. pendula* and *M. plana*.
[d] late instar ≡ L3 – L4 for *P. pendula*; L3 – L7 for *M. plana*.

the relative net precision (RNP) statistic (Pedigo *et al*., 1972), using the formula:

$RNP = 1/(C_s RV)$
where C_s is the cost required to collect and process one sample, and
RV is the relative variation which is the standard error expressed as a percentage of the mean bagworm density.
C_s was assumed to be RM 0.33 per frond.

SR and RNP values were calculated using the Microsoft Office 2000 Excel spreadsheet program.

Interspecific Association

Thirty plots, each consisting of 100 palms for short and tall palms with mixed *P. pendula* and *M. plana* infestations, were assessed for any interspecific association. The presence or absence of these bagworm species on each palm in the plots was recorded. Data were summarised as follows:

a = number of palms where both species occurred;
b = number of palms where *P. pendula* occurred, but not *M. plana;*
c = number of palms where *M. plana* occurred, but not *P. pendula;*
d = number of palms where neither species were found; and
N = total number of palms (N = a+b+c+d).

From these data, a 2 × 2 table was set up:

		M. plana		
		present	absent	
P. pendula	present	a	b	m = a+b
	absent	c	d	n = c+d
		r=a+c	s=b+d	N = a+b+c+d

The chi-square (χ^2) test for association was obtained by:

$$\chi^2 = \frac{N\,(ad - bc)^2}{mnrs}$$

When the calculated χ^2 was >3.84, the null hypothesis that the co-occurrence of *P. pendula* and *M. plana* is independent was rejected. Measures of association were through the calculation of the Ochiai (OI), Dice (DI) and Jaccard (JI) indices (Janson and Vegelius, 1981; Hubalek, 1982), where:

$OI = a/(\sqrt{a+b}\,\sqrt{a+c})$,
$DI = 2a/(2a+b+c)$, and
$JI = a/(a+b+c)$.

These indices equal zero at 'no association' and one at 'maximum association'.

Between-palm Distribution

Sampling was conducted at Dusun Durian, North, South, East, West and Melentang Estates. The between-palm distribution of *P. pendula* and *M. plana* was assessed in 1080 to 1346 (block numbers) oil palm blocks that were delineated by natural boundaries like roads and drains. The parameters for measurement are shown in *Table 2*. The 64 categories of sampling blocks as defined in *Table 2* were replicated 10 times, the sampling time and location of replications being dependent on the availability of suitable infestations. During each sampling, frond number 17 of each palm of the block was examined intact in the short palms but cut down in tall palms. The total number of larvae and pupae were recorded for calculation of distribution statistics.

The between-palm distribution of bagworms within a block using sampling block data over a series of infestation categories was estimated using

TABLE 2. PARAMETERS FOR MEASUREMENT OF BETWEEN-PALM SPATIAL DISTRIBUTIONS OF SINGLE AND MIXED POPULATIONS OF *P. pendula* AND *M. plana*

Species infestation type	Stage	Palm height (years old)	Visual infestation category[a] of sampling block[b]
P. pendula (single species)	Larva	Short (2-5)	Nil
P. pendula (double species)			Emerging
M. plana (single species)	Pupa	Tall (10-15)	Intermediate
M. plana (double species)			Advanced
Total of 10 replicates of 64 categories of sampling blocks were used			

Note: [a] Nil = all palms of sampling block green or healthy with no noticeable damage from a distance.
Emerging = cut holes or desiccation of frond tips observed on palms from a distance, such palms often occurring unevenly within a sampling block. Infestations are, however, new with little or no severe desiccation of leaflets or fronds arising from the activity of earlier generations of bagworms.
Intermediate = cut holes and desiccated leaflets or fronds of palms readily seen in large pockets of the sampling blocks.
Advanced = severe palm damage with more than 50% defoliation and desiccation readily seen in wide pockets. Damage of various degrees is readily observed in almost all palms between severely infested pockets.
[b] Sampling blocks of 1080 to 1346 oil palms planted in a 9.14 m × 9.14 m equilateral triangular pattern.

Taylor's Power Law (TPL) (Taylor, 1961; 1984) and Iwao's patchiness (Iwao, 1968) regressions. Data from 10 sampling blocks each of nil, emerging, intermediate and advanced visual infestation categories for a bagworm infestation type, life stage and palm height were used for the analyses. TPL related the mean bagworm density of the 40 sampling blocks of 1080 to 1346 palms (as defined in *Table 2*) to the respective variance by:

$$\text{Log}\ (s^2) = \log\ (a) + b \log\ (\bar{x})$$

Parameter *b* (gradient of regression) of TPL was used as the index of aggregation, whereby the population was aggregated (when b>1), random (b=1) or regular (b<1).

Iwao's patchiness regression relates mean crowding, $m^* = [\bar{x} + (s^2/\bar{x}) - 1]$,
to $\bar{x}$ by: $m^* = a + b\bar{x}$, where:

a (intercept) is an index of basic contagion, and
b (slope) has the same interpretation as the b from TPL.

Where appropriate, analysis of covariance (Zar, 1984) was used to obtain a common regression equation from the various linear regressions.

The linear regressions of TPL and Iwao's patchiness regression used the Multiple Regression module of Statistica® Version 5.0. All other calculations were carried out with the Microsoft Office 2000 Excel spreadsheet program.

RESULTS

Within-palm Distribution

A typical 2-factor ANOVA, demographic structure and polynomial regression are depicted in *Figure 2* for early instars of *P. pendula* in single species slightly infested short palms. It may be seen that bagworm number was significantly different between fronds and frond sections, except for frond sections with female and male + female pupae of single species *M. plana* in slightly infested tall palms and female pupae of double species *P. pendula* + *M. plana* infestations in severely infested short palms. The interaction between frond number and frond section was significantly different for all categories of measurements (*Figure 2*). Descriptive statistics of frond numbers with peak bagworm density and ≥95% of this density for 24, 36 and 60 combinations of *P. pendula* and *M. plana* alone, and for 60, 90 and 150 combinations of single and mixed species of the two bagworm species are shown in *Table 3*. Peak bagworm density was recorded between frond numbers 9 and 19. Fronds with ≥95% bagworm number of that peak were detected in three to six fronds by the polynomial regressions, with five fronds being the most frequently recorded. For these five fronds, the mean of the lower and upper ranges of frond number with ≥95% bagworm numbers of the frond with peak density was 14 and 18.

The lowest mean deviation of the standardised residuals from zero of the 60 combinations of *P. pendula* and *M. plana* larvae was encountered 80% of the time in a whole frond in the middle stratum (frond numbers 16-30) of the canopy (*Table 4*). For the 90 combinations of data involving pupae of *P. pendula* and *M. plana*, the lowest mean deviation was recorded 64.4% of the time in a whole frond from the upper stratum (frond numbers 1-15), followed by 22.2% of the time in the distal portion of a frond in the middle stratum of the canopy.

Relative variation within 25% precision was recorded at 80.7, 89.3, 98.7 and 100% for each of the

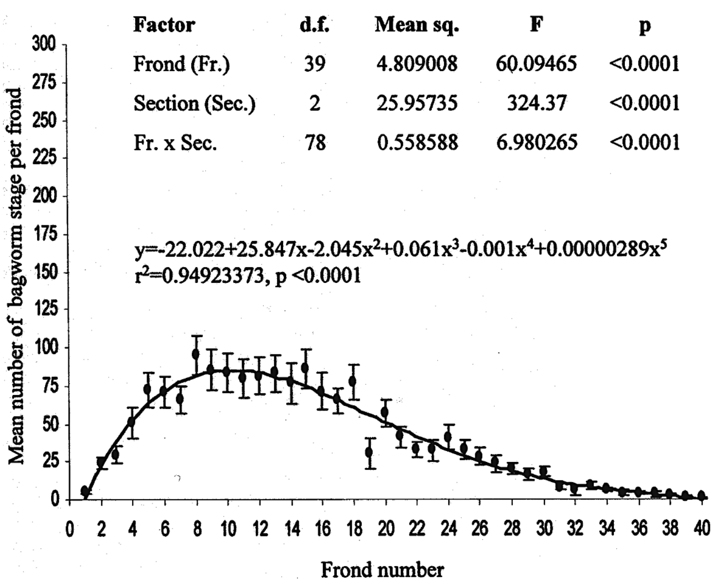

Figure 2. Distribution of early instar P. pendula *against frond number in single species slightly infested short palms.*

TABLE 3. DESCRIPTIVE STATISTICS OF FROND NUMBERS AT ≥95% OF PEAK BAGWORM DENSITY

Palm category	Statistic	Peak bagworm density	Frond number at ≥95% peak bagworm density	
			Lower	Upper
P. pendula	**(24 combinations)**			
Single + double spp.	Average	12	11	14
Slight to severe damage	Median	11	10	13
Short + tall palms	Mode	11	10	12
Early + late instars				
	(36 combinations)			
Single + double spp.	Average	17	16	20
Slight to severe damage	Median	17	16	20
Short + tall palms	Mode	17	16	21
Male, female, male + female pupae				
	(60 combinations)			
Single + double spp.	Average	15	14	18
Slight to severe damage	Median	16	15	19
Short + tall palms	Mode	17	16	21
Early + late instars				
Male, female, male + female pupae				
M. plana	**(24 combinations)**			
Single + double spp.	Average	9	8	12
Light to severe damage	Median	9	8	12
Short + tall palms	Mode	10	9	11
Early + late instars				
	(36 combinations)			
Single + double spp.	Average	19	18	23
Slight to severe damage	Median	18	17	21
Short + tall palms	Mode	18	17	20
Male, female, male + female pupae				
	(60 combinations)			
Single + double spp.	Average	15	14	18
Slight to severe damage	Median	17	16	20
Short + tall palms	Mode	18	17	20
Early + late instars				
Male, female, male + female pupae				
P. pendula + M. plana	**(60 combinations)**			
Single + double spp.	Average	11	10	13
Slight to severe damage	Median	10	9	12
Short + tall palms	Mode	11	10	12
Early + late instars				
	(90 combinations)			
Single + double spp.	Average	18	17	21
Slight to severe damage	Median	18	17	20
Short + tall palms	Mode	18	17	20
Male, female, male + female pupae				
	(150 combinations)			
Single + double spp.	Average	15	14	18
Slight to severe damage	Median	16	15	19
Short + tall palms	Mode	18	17	20
Early + late instars				
Male, female, male + female pupae				

150 categories of recording for sample unit sizes of 1, 2, 5 and 10 fronds, respectively (*Table 5*). At 10% precision, the frequencies were 14.0%, 22.0%, 60.7% and 83.3%. The highest RNP was recorded at 90% of the 150 assessments for the single frond sample unit, and 10% for the sampling unit of two fronds.

The mean number of bagworm stages per palm with visual damage category and palm height did not show clear trends in terms of consistent significantly increasing gradients of larvae and pupae numbers with slight, moderate and severe visual damage symptoms (*Table 6*).

TABLE 4. DISTRIBUTION OF LOWEST MEAN DEVIATION OF STANDARDISED RESIDUALS FROM ZERO FOR WITHIN-PALM DISTRIBUTION OF *P. pendula* AND *M. plana*

Palm category	Counts from		Frequency	%
	Frond section	Palm canopy stratum		
60 combinations for larvae				
Single and double species,	Distal	Middle	1	1.7
Slight to severe damage,	Mid	Middle	2	3.3
Short and tall palms,	Whole frond	Upper	8	13.3
Early and late instar larvae	Whole frond	Middle	48	80.0
Early and late instar larvae	Whole frond	Lower	1	1.7
90 combinations for pupae				
Single and double species,	Distal	Middle	20	22.2
Slight to severe damage,	Mid	Middle	4	4.6
Short and tall palms,	Whole frond	Upper	58	64.4
Male, female, male + female pupae	Whole frond	Lower	8	8.8

TABLE 5. DISTRIBUTION OF RELATIVE VARIATION (RV) WITHIN 25% AND 10% PRECISION LIMITS AND RELATIVE NET PRECISION (RNP) VALUES WITH SAMPLE UNIT SIZE FOR 150 PALM CATEGORIES

Sample unit size (No. fronds)	RV within 25% precision		RV within 10% precision		Highest RNP	
	Freq.	%[a]	Freq.	%[a]	Freq.	%[b]
1	121	80.7	21	14.0	135	90.0
2	134	89.3	33	22.0	15	10.0
5	148	98.7	91	60.7	0	0
10	150	100.0	125	83.3	0	0

Note: [a] out of 150 cases for each sample unit size.
[b] out of a cumulative 150 cases for all sample unit sizes.

TABLE 6. MEAN NUMBER OF BAGWORM STAGES PER PALM WITH VISUAL DAMAGE CATEGORY AND PALM HEIGHT

Infestation type	Palm height	Life stage	Mean No. bagworms per palm with visual damage category		
			Slight	Moderate	Severe
P. pendula					
Single sp.	Short	Early instar	1 622 b	3 388 a	2 676 a
		Late instar	1 183 b	1 660 b	2 341 a
		Pupa	2 131 b	4 290 a	4 829 a
M. plana					
Single sp.	Short	Early instar	1 613 b	1 874 b	3 172 a
		Late instar	1 493 ns	2 035 ns	1 745 ns
		Pupa	834 c	1 745 b	2 404 a
P. pendula+M. plana					
Double spp.	Short	Early instar	2 653 ns	1 993 ns	2 482 ns
		Late instar	2 378 ns	1 809 ns	1 933 ns
		Pupa	2 941 b	2 648 b	6 356 a
P. pendula					
Single sp.	Tall	Early instar	729 b	2 639 a	3 426 a
		Late instar	2 137 ab	1 325 b	2 537 a
		Pupa	2 544 b	642 c	5 153 a
M. plana					
Single sp.	Tall	Early instar	926 c	1 459 b	2 561 a
		Late instar	379 c	1 282 b	3 096 a
		Pupa	3 301 ns	3 689 ns	3 084 ns
P. pendula+M. plana					
Double spp.	Tall	Early instar	2 519 b	2 491 b	5 723 a
		Late instar	1 718 b	1 750 b	3 435 a
		Pupa	3 602 ns	4 363 ns	4 520 ns

Note: ns = not significant at p=0.05; 1-way ANOVA performed on log (1+x) values.
Means of each species within a row followed by the same letter are not significantly different at p=0.05 according to LSD test.

Interspecific Association

The chi-square tests of association showed that all, except three samples in the short palms and one sample in the tall, were not significantly different from the null hypothesis that *P. pendula* and *M. plana* in mixed infestations are independent of each other (*Table 7*); frond numbers 14-18 were the best location for sampling with frond number 17 as the representative sampling unit. Association indices of these significant samples were close to 1. However, such indices varied from near 0 (reflecting 'no association') to 1 (reflecting 'maximum association') even in the non-significant samples.

Between-palm Distribution

The between-palm distribution of bagworms using sampling block data over a series of infestation categories showed TPL to be a more appropriate fit than Iwao's patchiness regression (*Table 8*). Highly significant, near unity r^2 values and gradients of regression for all 16 categories of assessment were obtained. In contrast, r^2 values were either well below unity and/or non-significant with a similar variability in significance of the gradients for the Iwao's patchiness regressions. The TPL results however show the gradient to be consistently below 1, indicating significantly regular distribution of bagworms. Analysis of covariance for the TPL regressions for *P. pendula* and *M. plana* showed slopes and intercepts that were not significantly different (*Table 9*). The common regression equation of $\log(s^2) = 1.782 + 0.820 \log(\bar{x})$ obtained was very close to the pooled regression equation for the 640 data sets of *P. pendula* and *M. plana*, *viz.* $\log(s^2) = 1.780 + 0.821 \log(\bar{x})$.

TABLE 7. INTERSPECIFIC ASSOCIATION TEST STATISTICS AND INDICES BETWEEN *P. pendula* AND *M. plana* IN SHORT AND TALL OIL PALMS

Sample No.	χ^2 test of association	Association indices			χ^2 test of association	Association indices		
		Ochiai	Dice	Jaccard		Ochiai	Dice	Jaccard
	Short palms				Tall palms			
1	0.010 ns	0.101	0.020	0.010	0.174 ns	0.204	0.080	0.042
2	0.010 ns	0.101	0.020	0.010	0.021 ns	0.142	0.040	0.020
3	0.010 ns	0.101	0.020	0.010	0.129 ns	0.177	0.061	0.031
4	0.010 ns	0.101	0.020	0.010	0.042 ns	0.143	0.040	0.020
5	0.010 ns	0.101	0.020	0.010	0.031 ns	0.174	0.059	0.030
6	0.076 ns	0.266	0.132	0.071	17.166 *	0.917	0.914	0.842
7	0.053 ns	0.225	0.096	0.051	0.042 ns	0.143	0.040	0.020
8	0.021 ns	0.143	0.040	0.020	0.306 ns	0.305	0.170	0.093
9	0.010 ns	0.101	0.020	0.010	0.130 ns	0.247	0.115	0.061
10	0.164 ns	0.376	0.248	0.141	0.174 ns	0.204	0.080	0.042
11	0.192 ns	0.402	0.278	0.162	0.021 ns	0.142	0.040	0.020
12	0.164 ns	0.376	0.248	0.141	2.955 ns	0.329	0.220	0.124
13	0.064 ns	0.246	0.114	0.061	0.063 ns	0.974	0.974	0.950
14	0.360 ns	0.391	0.265	0.153	0.305 ns	0.364	0.234	0.133
15	0.112 ns	0.318	0.183	0.101	0.735 ns	0.395	0.270	0.156
16	0.269 ns	0.461	0.350	0.212	1.636 ns	0.253	0.135	0.072
17	0.192 ns	0.402	0.278	0.162	0.853 ns	0.421	0.301	0.177
18	0.448 ns	0.429	0.310	0.184	0.651 ns	0.340	0.208	0.116
19	0.192 ns	0.402	0.278	0.162	0.408 ns	0.805	0.795	0.660
20	3.800 ns	0.893	0.888	0.798	1.484 ns	0.481	0.376	0.232
21	0.010 ns	0.990	0.990	0.980	0.558 ns	0.395	0.270	0.156
22	18.947 *	0.923	0.920	0.853	0.202 ns	0.942	0.943	0.890
23	0.151 ns	0.927	0.925	0.860	0.065 ns	0.434	0.328	0.196
24	0.031 ns	0.980	0.980	0.960	0.314 ns	0.942	0.942	0.890
25	2.456 ns	0.840	0.831	0.711	0.589 ns	0.406	0.283	0.165
26	11.569 *	0.948	0.947	0.899	1.207 ns	0.894	0.893	0.806
27	0.010 ns	0.996	0.990	0.980	0.043 ns	0.979	0.979	0.959
28	42.918 *	0.967	0.967	0.936	0.419 ns	0.913	0.912	0.838
29	0.112 ns	0.943	0.942	0.890	0.129 ns	0.964	0.964	0.930
30	0.270 ns	0.462	0.349	0.312	2.236 ns	0.947	0.947	0.899

Note: ns = not significant ; * denotes significance at 5% probability level.

TABLE 8. TAYLOR'S POWER LAW AND IWAO'S PATCHINESS REGRESSIONS FOR 40[a] OIL PALM SAMPLING BLOCKS OF BAGWORMS *P. pendula* AND *M. plana*, LIFE STAGES, INFESTATION TYPES AND PALM HEIGHT

Species (infestation type)	Stage	Taylor's Power Law			Iwao's patchiness		
		Equation[b]	Significance[c]		Equation[b]	Significance[c]	
			t	p		t	p
P. pendula		**Short palms**					
Single sp.	Larva	y=1.964+0.634x (r^2=0.928, p= **)	22.132	**	y=67.528+0.277x (r2=0.153, p=0.127)	2.615	0.013
″	Pupa	y=1.515+0.923x (r^2=0.921, p= **)	21.019	**	y=34.61+0.884x (r2=0.684, p=**)	9.067	**
Double spp.	Larva	y=2.006+0.69x (r^2=0.928, p= **)	22.182	**	y=87.22+0.061x (r2=0.014, p=0.472)	0.727	0.472
″	Pupa	y=1.95+0.665x (r^2=0.973, p= **)	37.001	**	y=69.158+0.24x (r2=0.373, p=**)	4.750	**
		Tall palms					
Single sp.	Larva	y=2.328+0.78x (r^2=0.922, p= **)	21.163	**	y=182.098+0.193x (r2=0.094, p=0.053)	1.994	0.053
″	Pupa	y=2.44+0.709x (r^2=0.963, p= **)	46.239	**	y=180.471+0.05x (r2=0.028, p=0.306)	1.038	0.306
Double spp.	Larva	y=2.12+0.709x (r^2=0.953, p= **)	27.909	**	y=93.329+0.361x (r2=0.362, p=**)	4.652	**
″	Pupa	y=1.586+0.623x (r^2=0.973, p= **)	37.062	**	y=40.163+0.056x (r2=0.154, p=0.012)	2.627	0.012
M. plana		**Short palms**					
Single sp.	Larva	y=1.927+0.587x (r^2=0.972, p= **)	36.216	**	y=70.492+0.09x (r2=0.096, p=0.052)	2.010	0.052
″	Pupa	y=1.334+0.566x (r^2=0.973, p= **)	37.574	**	y=25.489+0.125x (r2=0.381, p=**)	4.837	**
Double spp.	Larva	y=2.086+0.593x (r^2=0.960, p= **)	30.236	**	y=91.688+0.002x (r2=0.0002, p=0.933)	0.084	0.933
″	Pupa	y=1.761+0.65x (r^2=0.918, p= **)	20.691	**	y=50.696+0.206x (r2=0.299, p=0.0003)	4.027	0.0003
		Tall palms					
Single sp.	Larva	y=1.958+0.62x (r^2=0.969, p= **)	34.373	**	y=70.524+0.231x (r2=0.397, p=**)	5.002	**
″	Pupa	y=2.513+0.633 (r^2=0.984, p= **)	48.531	**	y=196.446+0.023x (r2=0.11, p=0.524)	0.664	0.524
Double spp.	Larva	y=2.14+0.708x (r^2=0.934, p= **)	23.293	**	y=103.252+0.333x (r2=0.245, p=0.001)	3.515	0.001
″	Pupa	y=2.312+0.654x (r^2=0.931, p= **)	22.597	**	y=141.357+0.034x (r2=0.007, p=0.584)	0.551	0.585

Note: [a] 10 sampling blocks each of nil, emerging, intermediate and advanced visual infestation categories.
[b] $y = \log(s^2)$, intercept = log (a), gradient = b; $x = \log(\bar{x})$ of $\log(s^2) = \log(a) + b \log(\bar{x})$.
[c] for H_o : gradient = 1; df = 38; ** = <0.0001.
[d] $y = m^* = [(\bar{x} + (s^2/\bar{x}) - 1]$, intercept = a, gradient = b of $m^* = a + b\bar{x}$.

DISCUSSION

The within-frond distribution of bagworms varied within the palm crown. A similar trend was reported for first instar larvae of *Oiketikus kirbyi* on oil palm in Costa Rica (Rhainds *et al.*, 1996). The present study shows this to be applicable to the larval and pupal stages of single and mixed infestations of *P. pendula* and *M. plana* in short and tall oil palms. The interaction further suggests that whole fronds would be a more consistent sampling unit than sections of them, this being supported by a consistent and significant polynomial relationship between bagworm density and frond number.

The lowest mean deviation of the standardised residuals from zero reflects the optimum location

TABLE 9. TEST OF DIFFERENCE BETWEEN TAYLOR'S POWER LAW LINEAR REGRESSIONS FOR POOLED *P. pendula* AND *M. plana* DATA

Regression	$\sum x^2$	$\sum xy$	$\sum y^2$	x	b	Residual sum of squares	Residual df	a
P. pendula	155.83	131.74	145.11	320	0.845	33.136	318	1.799
M. plana	157.52	125.27	140.72	320	0.795	41.103	318	1.763

Test for difference between slope = $H_o : b_1 = b_2$

$t_{(calc.)} = 1.294$ $t_{0.05, 636} = 1.964$, thus accept H_o

Test for difference between intercepts; $H_o = a_1 = a$

$t_{(calc.)} = 0.929$ $t_{0.05, 636} = 1.964$, thus accept H_o

Common regression coefficient (b_c) = 0.820

Common intercept (a_c) = 1.782

Common regression equation: y = 1.782 + 0.820x

Pooled regression equation for *P. pendula* and *M. plana* using 640 data sets: y = 1.780 + 0.821x

Note: [a] $y = \log(s^2)$, intercept = log(a), gradient = b and $x = \log(\bar{x})$ of $\log(s^2) = \log(a) + b \log(\bar{x})$.

of the sampling unit being in the middle stratum consisting of whole frond numbers 16-30 for larvae, and in the upper stratum consisting of whole frond numbers 1-15 for pupae. As the polynomial regressions indicate, each of frond numbers 14 to 18 represents ≥95% of the peak frond density, and these fronds are at the interface of the upper and middle strata of the palm crown; hence, a frond within frond numbers 14 to18 could be taken as the best location of the sampling unit. The highest RNP being recorded for 90% of the single frond samples further suggests that a single frond is the most efficient sampling unit. This unit is also 80.7% of the time within Southwood's (1978) criterion of 25% precision for pest management surveys. Frond number 17 could be used as the sampling unit in a small area, as Hartley (1977) also used frond number 17 as the standard unit for foliar analysis of oil palm. However, sampling from frond numbers 10 to19 would be more suitable when greater precision is required. Southwood (1978) further indicated that for life-table studies, a higher level of accuracy set at 10% is necessary on natural populations. The highest frequency of samples (83.3%) in the present study met this criterion for the sample unit size of 10 fronds. The sampling of 10 fronds within this range of frond numbers thus has a high probability (>80%) of representing 90% of the bagworm number on a palm. This is followed by 60.7% for five fronds (frond numbers 14 to 18); however, the probability is lower, at approximately 60% only.

The variable indices of association and the general non-significance of the chi-square tests indicate that *P. pendula* and *M. plana* exist independently of each other in a mixed infestation situation. This being the case, mixed species samples can be pooled with that of single species infestations for the fitting of models of dispersion.

For the evaluation of between-palm dispersion, TPL produced consistent highly significant near unity r^2 values and gradients of regressions. As the estates in this study covered the major bagworm infestation areas of Peninsular Malaysia, there is a possibility for the development of a general bagworm sequential sampling plan for TPL analyses based on the mean-variance relationship of $\log(s^2) = 1.780 + 0.821 \log(\bar{x})$. The TPL results derived from sampling over a large area of oil palm show that the populations of both the bagworm species sampled follow a consistent significantly regular distribution (gradient <1). Rhainds (1999) reported that density-dependent dispersal of bagworms could simultaneously stabilise the populations in heavily infested palms and redistribute the larvae onto lightly infested ones, hence encouraging a regular or more uniform distribution of the population.

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