KFRI Research Report 95

DEVELOPMENT OF A MANAGEMENT STRATEGY FOR THE TEAK DEFOLIATOR, HYBLEA PUREA

K.S.S. Nair
K. Mohanadas
V.V. Sudheendrakumar

KERALA FOREST RESEARCH INSTITUTE
PEECHI, THRISSUR

October 1994 Pages: 121

CONTENTS

Section 1

GENERAL INTRODUCTION

K.S.S. Nair

The teak defoliator, *Hyblaea puera* Cramer (Lepidoptera, Hyblaeidae) is recognised as the most serious pest of teak in India. Previous studies in the Kerala Forest Research Institute (Nair et al., 1985) have demonstrated the enormous growth loss caused by this insect in teak plantations. It was shown that in 4-to 8-year old plantations, trees protected from defoliation by *H. puera* put forth an annual increment of 6.7m^3/ha compared to 3.7m^3/ha of unprotected trees. This amounts to a gain of 3m^3/ha/year, which is a substantial gain.

Attempts to develop control measures for teak pests have been made since the 1930s. These attempts fall into two main categories- (1) silvicultural-cum-biological control using insect parasitoids, and (2) chemical control using insecticides.

Based on detailed studies of the insect parasitoids and their ecological interrelationships, a package of silvicultural-cum-biological control has been recommended (Beeson, 1941) which consisted of four major steps:

(1) subdivide the planting area into small blocks of 8-16 ha, leaving strips of pre-existing natural forest in between, to serve as reserves for natural enemies;

(2) improve these reserves by promoting desirable plant species and removing undesirable ones. Desirable plants support the alternative hosts of the parasitoids, and undesirable ones serve as alternative hosts for the teak defoliators;

(3) Encourage the natural growth of desirable plant species, within the teak plantation itself, as an understorey and discourage the undesirable species; and

(4) introduce natural enemies of the teak defoliators where they are deficient.

Although this package of recommendations has been advocated since the 1940's it has never been practised by forest managers, for various reasons. Recent work (Nair and Sudheendrakumar, 1986; Nair, 1987) indicated that the recommended measures may not be effective because outbreak populations of H. *puera* are highly aggregated and mobile, and therefore the effect of a resident population of parasitoids on millions of larvae built up suddenly from immigrant moth populations will be insignificant.

Chemical control by aerial spraying of insecticides has been tested in teak plantations at Konni, Kerala (Basu-Chowdhury, 1971) and Bhopal, Madhya Pradesh (Singh, 1980). Although chemicals may prove effective for immediate knock-down of the insects, there are several well-known problems associated with the use of insecticides in the forest ecosystem and we cannot therefore advocate it.

Development of alternative, ecologically sound, pest management systems is therefore required. An in-depth knowledge of the dynamics of pest populations is necessary to accomplish this. It was towards this end that the present project was initiated.

The original project proposal is reproduced as Appendix 1. The study was organised into four components and the responsibility for detailed study of each component was assigned to individuals, as indicated in the Project Proposal. It was anticipated that collaboration from experts in the fields of insect population dynamics as well as pheromone identification, isolation and synthesis will be available. Proposals were made to obtain funds through the US-India Cooperative Programme, but unfortunately, the collaboration did not materialize. In addition, the project Co-ordinator (Dr. K.S.S. Nair) was inducted to hold additional charge of the Director of the Institute from May 1988 to May 1991. These un-anticipated developments disrupted the smooth progress of the planned research work and some modifications of the research programme became unavoidable. Although not all the anticipated objectives have been accomplished, good progress was made on several aspects. In view of the modifications made, the report is organised in a different manner from what was laid down in the Project Proposal.

Following this General Introduction, Section 2 presents the results of studies on the population dynamics which combines component 1 and part of component 4 of the original Project Proposal. This section which constitutes a major part of the report is based on population sampling carried out at weekly interval in 3 permanent plots and a variable number of 'moving plots', over a 3-year period. Section 3 entitled 'Early events in population outbreaks' covers part of the original component 4 on patterns and causes of outbreak.

Section 4 deals with studies on reproductive behaviour and the role of pheromones (component 2 of the Project Proposal). Although the original intention was to isolate the pheromones and test them in the field for management of teak pests, this part of the work could not be accomplished in the absence of expert collaboration. The studies were therefore limited to reproductive behaviour and preliminary investigations to detect presence of female sex

Section 5 presents the results of field evaluation of phenological resistance for protection of teak against *H. puera*. Earlier investigations (Nair et al., 1989) had indicated that the observed escape of Attack of some trees in plantations is not due to genetic resistance but due to early flushing of these trees. Tho usefulness of this "phenological resistance is examined in this section.

The last section discusses the possible management strategies for the teak defoliator, based on the current knowledge. Areas for future investigations are indicated. Following the leads obtained in this studey, further investigations have been taken up at the Institute on some of the aspects, particularly, the relationship between moth behaviour and spatial dynamics of outbreaks and the use of Nuclear Polyhedrosis Virus and selected parasitoids for biocontrol.

Each eection of the report is authored by the investigators who were responsible for the particular component of the work. Some repetition of facts, particularly in the introduction to each section, could not be avoided since we intended each section to be intelligible by itself.

Section 2

POPULATION STUDIES - 1987 TO 1989

K. Hohanadas and K.S.S. Nair

2.0. Abstract

The population dynamics of *Hyblaea puera* was investigated by sampling immature stages of the pest from 3 permanent plots and a variable number of 'moving plots' within a 1000 ha teak plantation, at weekly intervals, over a 3 year period.

The variance of insect counts was found to depend on the mean. This dependence was removed when the counts were transformed to the power of 0.195, using Taylor's power law. Analysis of transformed data showed that between-shoots variation accounted for 32% of the total variance, between-trees variation for 26%, and interaction between crown-levels and treee for another 26%. Between-plots variation was only l0%, but it differed very substantially between sampling dates, accounting for upto 58% on some dates, indicating that the infestation was not uniform over the entire area on some dates.

Generally, eggs are laid only on tender leaves and the neonate larvae do not survive on older leaves. Based on infestation characteristics, two kinds of populations are recognized - low density populations and high density populations. Low-density populations, with less than 2 insects/shoot, had a mixed age-structure, while high-density populations with upto 14 insects/shoot were characterised by predominance of one developmental stage at any given time. For both kinds of populations, the immature stages follow a negative binomial distribution on shoots, similar to that of many other insects. The sample size required to estimate the population at not more than 10% error worked out to 94 shoots for high-density populations and 566 shoots for low-density populations, or at the rate of 6 shoots per tree, 16 trees for' the former and 94 trees for the latter.

Several distinct phases were recognized in the annual population trend. The first phase, often starting from the 4th week of February, is characterised by small-patch infestations which appear erratically in some areas. This is followed by the next phase which constitutes the main infestation season. In the third phase, the population density declines and infestations again become erratic. Following a lull period, erratic infestations appear again in August, September or October and subside. From then on, until the first phase begins again next year, the population

remains very low, almost undetectable. Depending on some factors, the months in which the above phases appear vary between years.

Because of the shifting foci of infestations resulting from the mobile nature of moth aggregations, parasitoids were not capable of regulating host numbers during outbreaks. A large number of predators were active during outbreaks, but they did not have much impact on the host population because of the sheer host population size. Disease caused by a specific NPV, was prevalent during the later generations and caused heavy mortality of larvae and pupae after the main outbreak phase, often leading to complete collapse of local populations.

There was a time-lag between flushing of teak trees and occurrence of large-scale defoliator outbreaks, indicating the operation of a positive feed-back of tender foliage on build-up of moth populations necessary for outbreak development.

The time of occurrence of the first phase of outbreaks was strongly correlated with the appearance of pre-monsoon showers. Indirect evidences suggest that the weather system causing the rainfall somehow aids aggregation and displacement of moth populations, pointing to the need for further investigations.

It is shown that *H. puera* population outbreak is of the eruptive type, according to Berryman's classification scheme.

2.1. DEVELOPMENT OF A SAMPLING PLAN FOR ESTIMATING POPULATIONS

Previous studies on the seasonal incidence of defoliators in teak plantations (Nair et al., 1985) gave valuable information on the temporal and spatial dynamics of *H. puera* populations. This information was obtained indirectly from the scoring of leaf damage in observation plots during insect outbreaks, supplemented by direct qualitative observations on insect populations. Several important questions on the origin of *H. puera* outbreaks and the mechanisms of their spread remained unanswered. To shed light on these aspects it is necessary to study the changes in the insect population and the mortality factors, not only during outbreaks, but also during the non-outbreak period when damage scoring is insufficient to indicate the status of the population. The studies reported here were therefore undertaken to standardise the methods for estimating *H. puera* populations.

Section 2.1.1 deals with methods used for preliminary sampling, 2.1.2 derives a transformation function for the population counts, 2.1..3 covers analysis of variance of the sample data, 2.1.4 describes the biological characteristics of *H. puera* infestations and lastly Section 2.1.5 arrives at an ideal sampling plan, based on the mathematical distribution of *H. puera* populations.

2.1.1. PRELIMINARY SAMPLING

The study was carried out in teak plantations at Kariem-Muriem beat of Nilambur Forest Range under the Nilambur Forest Division. The study site, located between latitudes 11O22.7-11°25.7N and longitudes 76°16.44'-76^{0}18.47'E, consists of about 1000 ha of young teak plantations. In April 1987, when the study began, the plantations were 6 to 13 years old, and the trees had a top height of 12 to 18 metres. The initial planting was at a spacing of 2m x 2m

The study plots

Three permanent study plots were established in the study area and sampling was carried out at weekly interval. These plots were located 0.5 km to 3 km apart on either side of the forest road within the plantation (Fig. 2.1.1). Each plot consisted of about 192 trees (12 x 16 trees at a spacing of 4m x 2m after the first silvicultural thinning) occupying about 0.15 ha. To establish the plot, the first tree to be sampled was marked at random and a rectangular plot consisting of a vertical row of 12 trees and a horizontal row of 16 trees starting from this first tree was marked out.

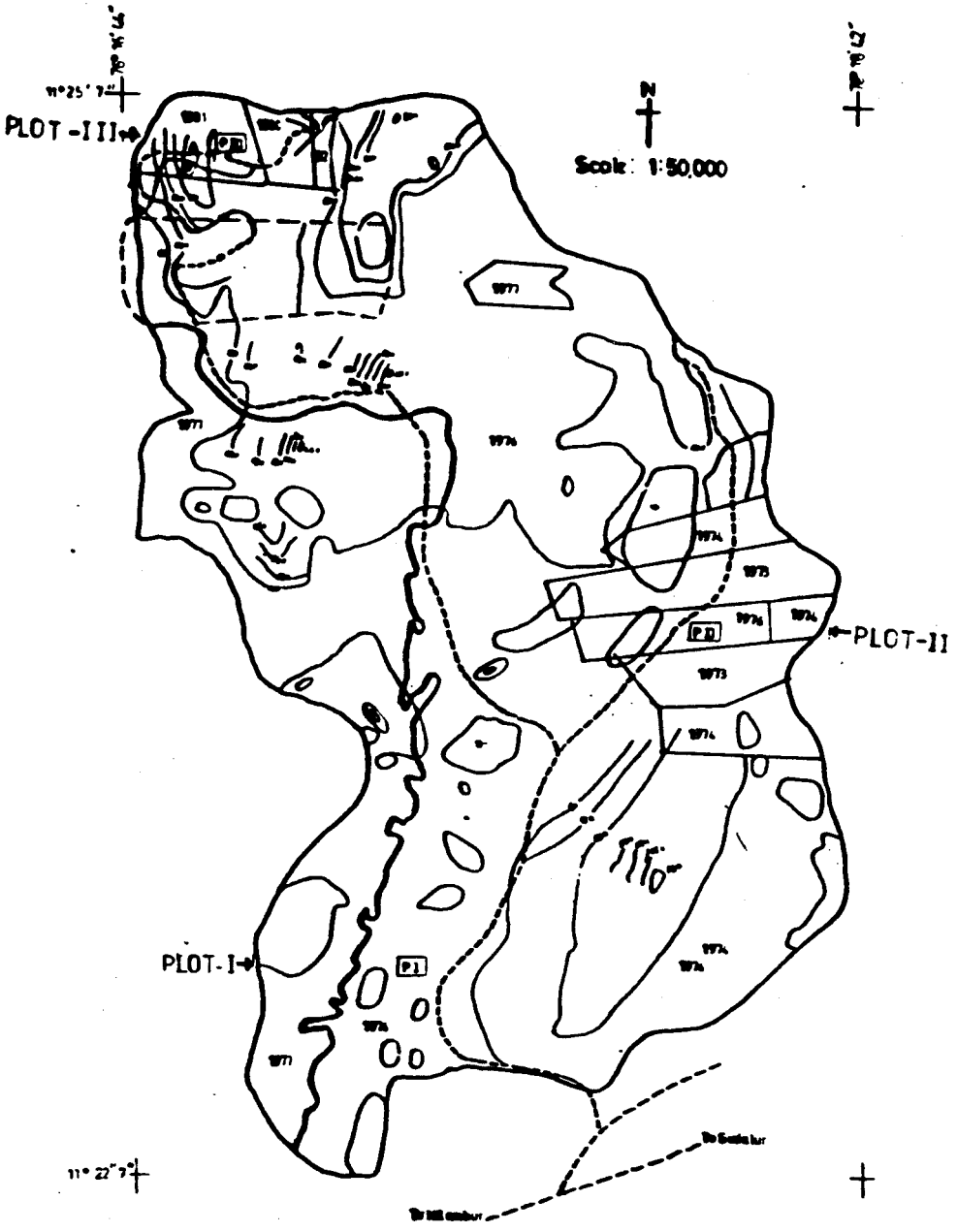


Fig. 2.1.1. Location of the study plots in the Kariem-Muriem teak plantation at Nilambur.

Larval sampling

On the first day of sampling, every 4th tree on the selected vertical and horizontal rows, as shown in Fig. 2.1.2 were sampled. On the next sampling date the next trees in the same vertical rows were sampled. When all the trees in these vertical rows were sampled in this manner in 4 weeks' time, sampling was shifted to the next vertical rows to the right. Thus it was possible to sample 12 previously unsampled trees every week for a period of 4 months, when the cycle was restarted.

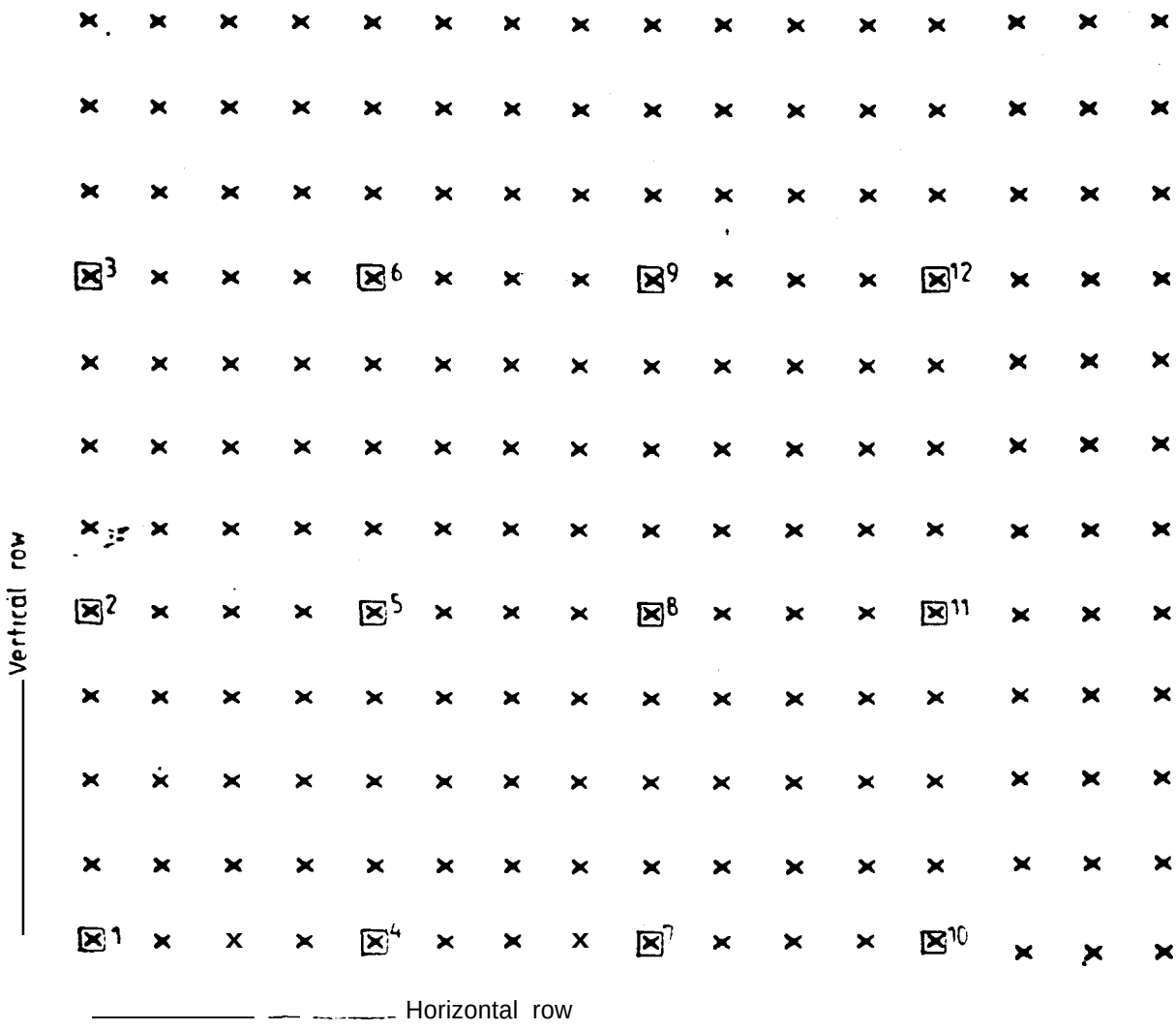


Fig. 2.1.2. Distribution of the trees (Nos. 1 to 12) sampled from a plot of 192 trees (marked 'x') on the first day of sampling.

In each vertical row, trees not suitable for sampling, €or reasons such as very small size or 'top broken' conditions were excluded in the very beginning and the particular row extended outside the rectangular boundary, as necessary.

In addition to weekly sampling in the three permanent plots, to detect the appearance of outbreaks the entire area was kept under constant survey. Whenever outbreaks appeared outside the three permanent plots, and not in any one of them, "moving plots" were established at the place where the outbreak occurred. The moving plot was similar to the permanent plot, except that sampling was carried out only for the duration of a particular outbreak generation. This facilitated sampling of populations when outbreaks occurred outside the permanent study plots.

Generally only one plot was sampled on a particular day. Thus the 3 plots were covered over 3 days of a week, and this was repeated every week. On each sampling day, 12 trees were sampled from a plot, except on rare occasions when only a smaller number (usually not less than 10) could be sampled for unavoidable reasons.

Shoots formed the basic sampling unit. Each shoot normally consist of 1 to 6 pairs of leaves depending on the season. Six shoots were sampled from each tree. Each tree was visually divided into three levels – bottom, middle and top and two shoots were collected from each level.

A twig cutter mounted on a bamboo pole and operated with a hanging rope was used to collect the shoots. The trees were climbed part-way to collect the shoots from the middle and top levels.

Each shoot was examined in the field soon after collection and the insect stages present recorded on a score-sheet. In addition, information was also recorded on the number of tender and total leaves per shoot, approximate number of shoots per branch and number of branches per tree.

On each sampling day, a sub-sample of insect stages was brought to the laboratory and sorted out stage-wise. They were kept separately in sterilized glass tubes containing artificial diet or fresh teak leaves. Larvae were kept individually. These samples were observed for a week and the fate of each larva recorded to gather information on larval parasitoids.

Pupal sampling

Once the leaf-feeding larval period is completed the mature larvae descend to the ground for pupation. Pupation usually takes place under loose surface soil, either between dry leaf litter or between leaf litter and surface soil. If the ground surface around the infested tree is not suitable for pupation the larvae move away in search of a suitable pupation site. In the

rainy season the larvae were found to pupate within folds made in leaves of the ground vegetation (with a few on the lower branches of the teak tree itself).

Pupae were sampled for 6 to 9 trees selected at random within the plot. The ground area covered by the canopy area of each tree was searched for pupae. Based on experience gained in the first and second years of sampling, an improvement in the sampling method was made in the third year. Before pupation started, a trench 30cm wide and 30cm deep was made in a square area surrounding the trees selected for sampling. Leaving a 30cm gap, another similar trench was made outside the above trench. The soil inside the trench was loosened with a spade and a layer of leaf litter was provided at the bottom of the trench.

The larvae were found to pupate inside the trench. The area within the inner trench was cleared of leaf litter to encourage movement of larvae towards the trench. The outer trench prevented the larvae descending from surrounding trees from reaching the inner trench for pupation. Thus the pupae found inside the inner trench gave a good estimate of the number of larvae pupating per the sampled tree.

Pupal sampling was usually done 3 to 4 days after pupation began. This gave sufficient time for the parasites to act upon the pupae.

Pupae collected from each plot were kept separately in the laboratory. They were observed till the adult emergence was over. The sex ratio of the emerged moths, the species and number of parasitoids emerged, and unemerged pupae were recorded.

2.1.2. THE RELATIONSHIP BETWEEN MEAN AND VARIANCE AND DERIVATION OF A TRANSFORMATION FUNCTION

A large number of studies on insect populations have shown that the dispersion of insects in space seldom approaches the normal statistical distribution. In normal distribution, the variance is independent of the mean, and its components are additive, a property which is a pre-requisite for application of several statistical methods of comparison. Since this property is not satisfied in other distributions, the raw data are generally transformed to normalise the data, or stabilise the variance. The need for such transformation was examined in this study by analysing the relationship between mean and variance of counts of immature stages of H. *puera* on trees. Based on this relationship an appropriate transformation was determined.

MATERIALS AND METHODS

Data gathered in the year 1987 (May to December) from the 3 permanent plots and the moving plots were pooled for this analysis. The mean and variance of insect counts (immature stages including eggs and the five larval instars) were calculated separately for (i) the 6 shoots sampled per tree, and (ii) the 10-12 trees sampled per plot on each sampling date. There were 581 shoot means and variances, representing that many trees (ie. within tree, between shoots variances) and 60 per-tree shoot means and variances representing that many sampling dates (ie. within plot, between trees variances). The values of means and variances were plotted on a log/log scale and the regression of variance on mean was calculated, using the plot procedure of the SPSS Statistical Software. The value for transformation (p) was calculated using Taylor's power law (Southwood, 1978).

RESULTS AND DISCUSSION

Mean-variance relationship

Counts of insects per shoot, within trees

In infested trees, the mean number of insects per shoot ranged from 0.17 to 425.5 over the year with an overall mean of 5.5. However, out of the 581 means, except for 5 values between 124 and 426, all were below 54.

The variance ranged from 0.17 to 388,768.7; but except for 6 values all were below 2898. The variance increased as the mean increased (Fig. 2.1.3). It was strongly correlated with the mean as reflected by a high R^2 value (0.948)

Mean counts of insects per shoot among trees, within plote

When averaged over all the trees in the plot for 60 sampling dates, over the year, the mean number of insects per shoot per tree ranged from 0.01 to 12.31, with an overall mean of 2.5. The shoot mean per plot was smaller than the shoot mean per tree discussed above, because the plot contained some uninfested trees. The variance ranged from 0.002 to 143.9 with one exceptional value of 1249.58. The variance increased as the mean increased. The variance was correlated with the mean with an R2 of 0.291. When the exceptional variance of 1249.58 and its corresponding mean of 12.31 were omitted, the R2 increased to 0.651 (Fig. 2.1.4).

Transformation

Variance much larger than the mean and its dependence on the mean indicates clumping or aggregation of the population, described by a contagious distribution (Southwood, 1978). It is therefore necessary to transform the actual numbers appropriately to normalise the data for statistical analysis.

Taylor's power law which has been shown to apply widely in the case of contagious populations was therefore used to arrive at an appropriate transformation. According to this law,

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

Where s^2 = variance, $\bar{x}$ = mean; and 'a' and 'b' are constants, 'a' being largely a sampling factor and 'b' an index of aggregation characteristic of the species (Southwood, 1978).

The appropriate transformation is to be arrived at using the formula $z = xp$,

Where x = the original value
z = the transformed value, and
p = 1-1/2b

Calculation of 'p' using counts per shoot within trees

Based on the above procedure, the following values of 'a' and 'b' were obtained by plotting *In* variance with *In* mean, using the SPSS regression procedure.

a = 6.525
b = 1.61016
p was therefore calculated as 0.19492

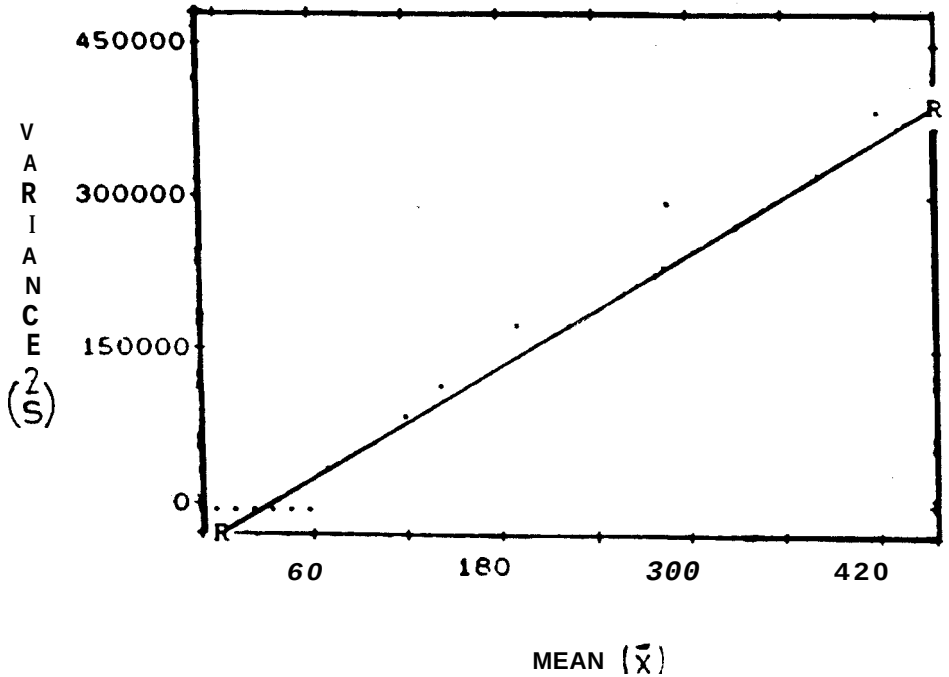


Fig. 2.1.3. Mean-variance relationship of counts of insects per shoot within trees- actual counts

Foot note: Based on 576 cases. Five extreme values of means between 124 and 426, and their corresponding variances between 88,000 and 3,89,000 have been left out from the plot.

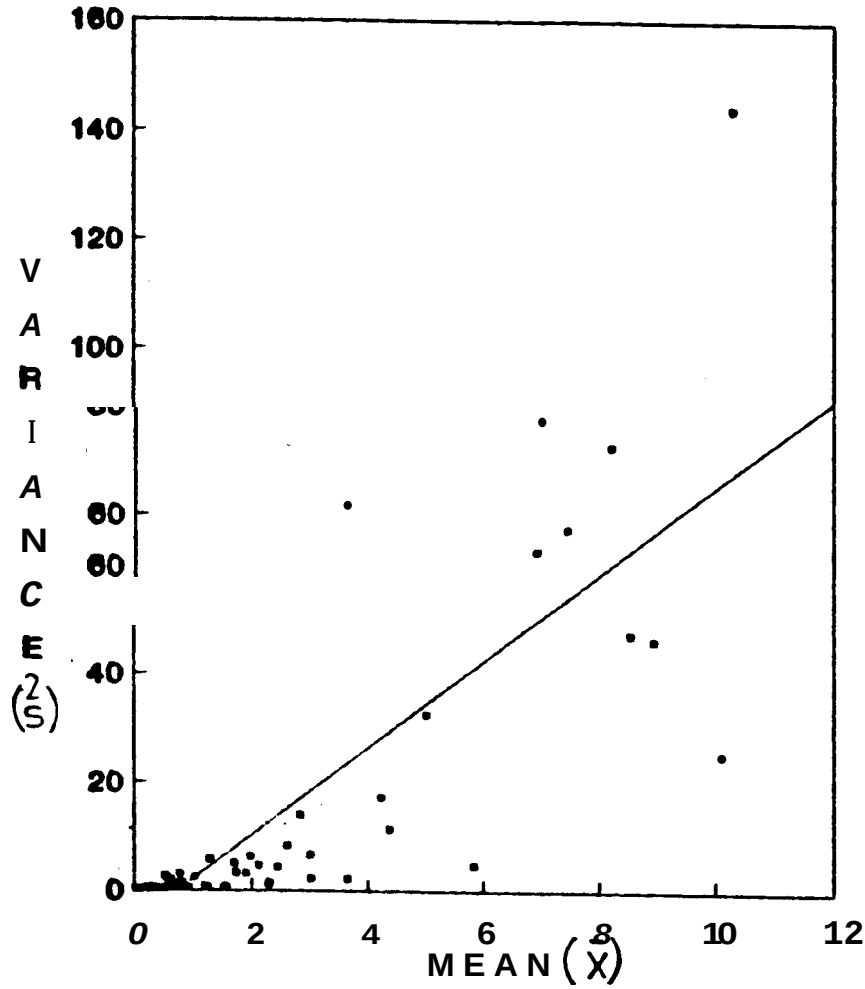


Fig 2.1.4. Mean-variance relationship of counts of insects per shoot among trees- actual counts.

Foot note: Based on 59 cases. One extreme value of mean (12.31) and its variance (1249.5) was left out from the plot.

Calculation of 'p' using counts per shoot among trees

By the same procedure, the constants were calculated as follows for counts of insects among trees.

a = 2.098
b = 1.60978
p = 0.19511

It may be seen that the p value was almost the same by both the methods, i.e., when the means and variances came from counts of insects within shoots per tree or within trees per plot (date).

Effect of transformation

To examine the effect of transformation, the original counts were transformed to the power of p (p=O.19492) and the dependence of variance on the mean re-examined. Figs. **2.1.5** and 2.1.6 show the results. It is clear that the dependence of variance on the mean was removed by the transformation. When transformed, the $\mathbf{R^2}$ for correlation between the mean and variance were reduced to 0.0037 in the case of counts per shoot within trees and 0.0176 in the case of counts per shoot among trees.

CONCLUSIONS

The study showed that the variance of insect counts was much greater than and dependent on the mean. This dependence was removed when the original counts were transformed using Taylor's power law.

It is concluded that transformation using Taylor's power law is adequate for statistical analysis of H. puera population data. A 'p' value of 0.195 is adopted for transformation.

The parameter 'b' of Taylor's power law is considered to be a measure of the aggregation, characteristic of, and constant for the species (Southwood, 1978). It is interesting to note that 'b' worked out to 1.61 for both within-tree and within-plot mean-variance relationship. However, 'a' was different- 6.525 for within-tree counts and 2.098 for between-tree counts.

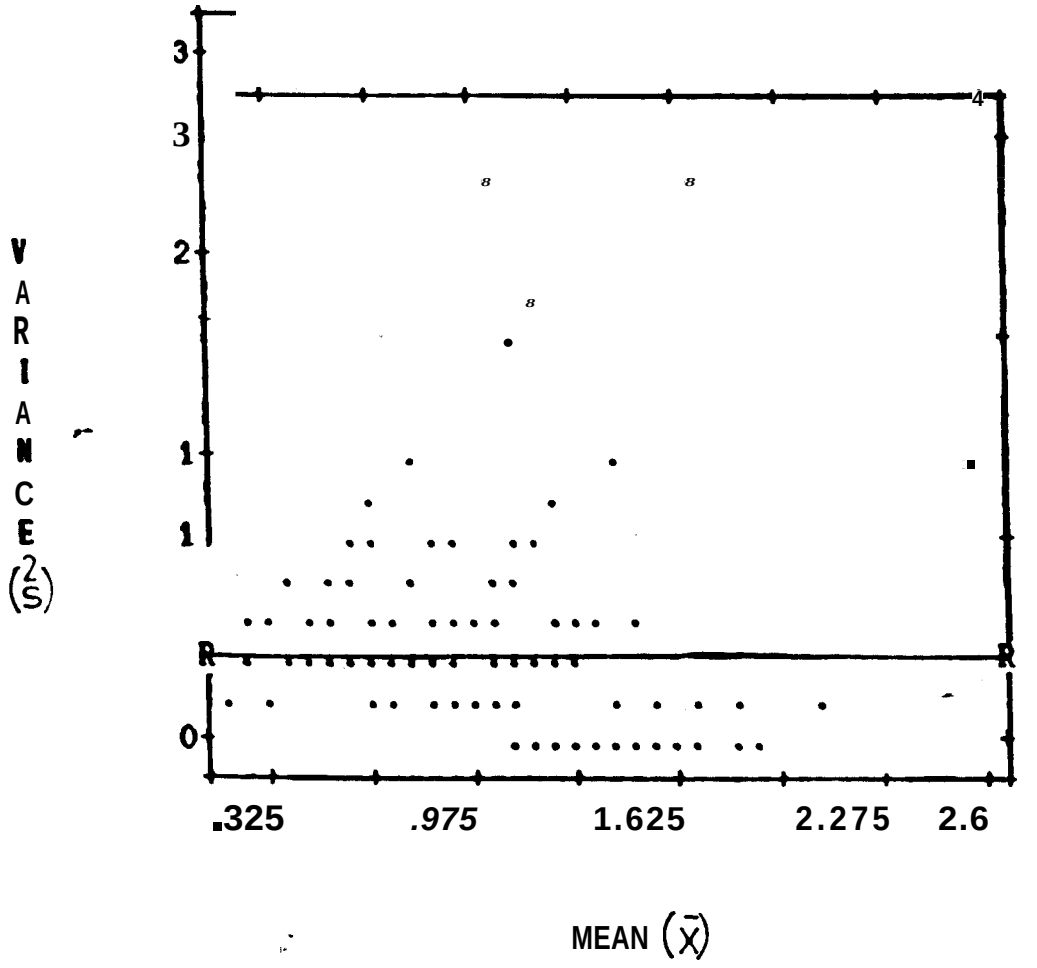


Fig 2.1.5. Mean-variance relationship of counts of insects per shoot within trees- after transforming the original counts to the power of p = 0.19492, Compare with Fig. 2.1.3 and note the lack of correlation between mean and variance.

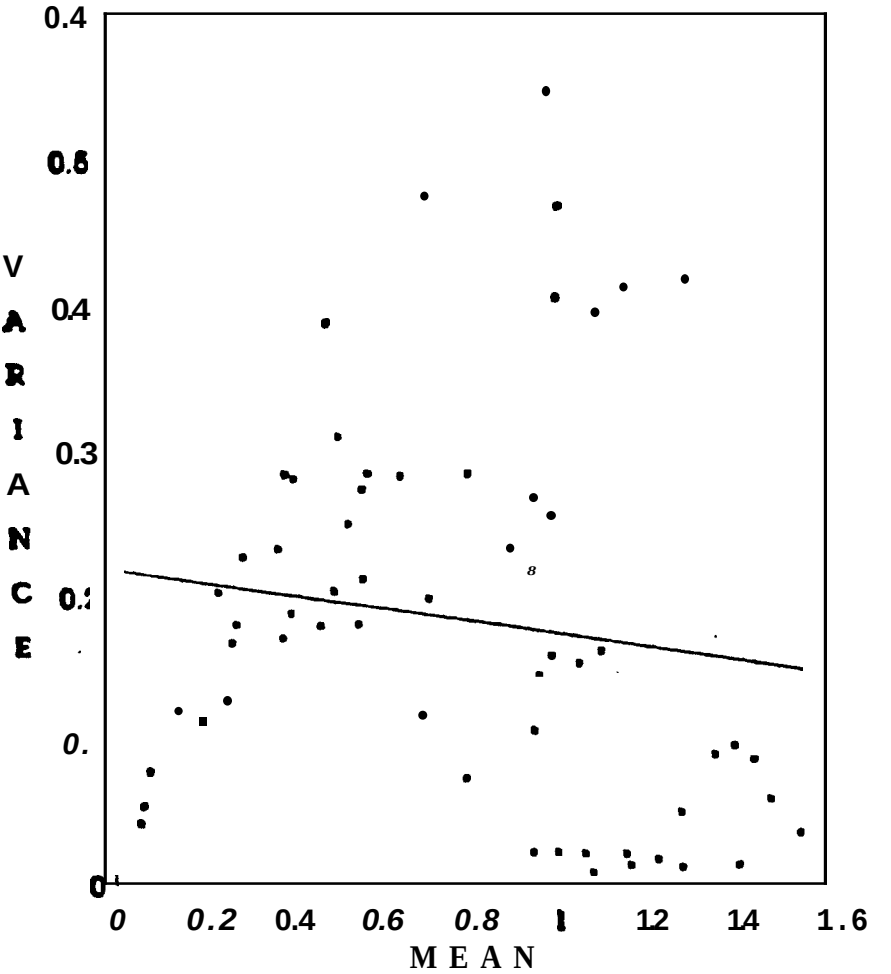


Fig 2.1.6. Mean-variance relationship of counts of insects per shoot among trees- after transforming the original counts to the power of p = 0.19492. Compare with Fig. 3 and note the lack of correlation between mean and variance.

2.1.3. ANALYSIS OF VARIANCE IN TYPICAL DATA SETS

Analysis of variance was carried out in typical, data sets from the different plots to assess main sources of variation and their significance.

MATERIALS AND METHODS

As noted in Section 2.1.1, weekly samples were taken from three plots at Kariem-Muriem during the years 1987 to 1989. Generally, twelve trees were sampled from each plot and immature stages were counted from six shoots per tree- two each from top, middle and bottom levels of the crown. Analysis of variance was carried out independently in nine data sets representing four time periods in 1987 and five time periods in 1988. Each data set consisted of samples taken from three plots on three adjacent dates in a month. The model used was nested ANOVA, and the analysis was carried out using the MANOVA procedure of SPSS. The data were transformed to the power of 0.195 (Taylor's 'p') before analysis.

RESULTS

Table 2.1.1 shows a typical data set (for May 1987).

Table 2.1.1. Spatial distribution of insects in different crown levels within tree - a typical set of raw data

	Mean number[1] of insects per shoot											
	Plot No.1				Plot No. 2				Plot No.3			
Tree No.	Bottom	Middle	Top	Whole tree	Bottom	Middle	Top	Whole tree	Bottom	Middle	Top	Whole tree
1	5.5	16.5	10.5	10.8	2.0	12.5	16.5	10.3	0.0	4.0	13.0	5.7
2	9.0	8.5	5.5	7.7	8.5	14.5	14.0	12.3	7.0	5.0	9.0	7.0
3	0.5	9.5	7.5	5.8	22.5	42.5	13.0	26.0	0.5	6.5	3.5	4.0
4	6.5	9.5	11.5	9.2	4.5	7.0	7.5	6.3	15.0	2.5	3.5	7.0
5	12.0	12.5	5.5	10.0	11.5	10.5	14.0	12.0	3.5	17.0	3.0	7.8
6	4.0	34.5	22.0	20.2	3.5	0.0	0.0	1.2	2.0	6.0	18.5	8.8
7	2.5	8.0	11.5	7.3	1.5	10.5	10.0	7.3	6.0	8.5	2.0	5.5
8	1.5	1.5	1.0	1.3	6.0	23.5	13.5	14.3	11.0	3.5	10.0	8.2
9	15.5	2.5	11.0	9.7	2.5	10.0	4.0	5.5	3.0	2.5	2.0	2.5
10	19.0	12.0	14.5	15.2	2.0	1.5	2.0	1.8	1.0	3.5	4.0	2.8
11	18.0	21.5	8.0	15.8	5.0	1.5	4.0	3.5	2.5	6.0	6.0	4.8
12	4.0	7.5	12.5	8.0	7.0	10.0	3.0	6.7	2.5	5.5	6.0	4.7
Mean (X)	8.2	12.0	10.1	10.1	6.3	12.0	8.5	8.9	4.5	5.9	6.8	5.7

[1] Each value represents the mean number of insects per shoot based on two shoots sampled at that level.

The mean number of insects per shoot ranged from zero to 42.5, with the shoot average for tree ranging from 1.2 to 26.

The sample sets of data for 1987 and 1988 are summarised in Tables 2.1.2 and 2.1.3. It may be seen that the overall shoot mean per plot (ie., the mean number of insects per shoot per tree per plot) ranged from 0.09 (November 1988) to 8.2 (May 1987). Based on the overall shoot mean, two situations can be distinguished- (i) when the population density was high (7.0 to 8.2 insects/shoot) as in May 87, April 88 and May 88 and (ii) when it was low (0.09 to 1.6 insects/shoot) as in the rest of the year. The high-density populations occurred during the main flushing season, and low-density populations, at other times. It is therefore instructive to examine the data in relation to the population density.

The results of the analysis of variance are given in Tables 2.1.4 and 2.1.5 and the levels of significance of various sources of variation ar'e summarised in Table 2.1.6. The following conclusions can be drawn from the results.

1. There was significant interaction between trees and crown levels, except on some occasions (Table 2.1.6). This was not related to the density of the population.

2. Irrespective of the population density, there was a significant difference in the number of insects between levels on most occasions. However, the difference was not consistent- on some dates the top level contained the highest number and on other dates other levels contained the highest number (Tables 2.1.2 and 2.1.3). In view of the interaction between tree and crown levels, the lack of a significant difference between levels on some occasions needs to be interpreted with caution (see below).

3. The differences in the number of insects between trees was highly significant when the population density was high and significant to not significant when the population density was low (Table 2.1.6).

4. There was significant to highly significant difference in the number of insects between plots in some months (e.g., April 1988. See Table 2.1.3) but not in others (Table 2.1.6), irrespective of the population density.

Table 2.1.2. *H. puera* **population estimates on specified dates in 1987**

Sampling date	Plot No.	Mean No. of insects per shoot			
		Bottom	Middle	Top	Whole tree
31 May 87	1	8.2± 1.6	12.0± 8.6	10.1± 5.1	10.1± 4.8
30 May 87	2	6.3± 5.6	12.0± 11.1	8.5± 5.5	8.9± 6.5
28 May 87	3	4.5± 4.4	5.9± 3.8	6.8± 4.9	5.7± 2.0
	Mean	6.3± 1.5	10.0± 2.9	8.5± 1.4	8.2± 1.9
25 June 87	1	1.3± 1.6	1.3± 0.9	1.1± 1.4	1.2± 0.7
24 June 87	2	1.8± 1.1	1.6± 1.2	1.2± 0.6	1.5± 8.1
23 June 87	3	0.8± 4.4	0.7± 0.7	1.1± 1.1	0.9± 1.3
	Mean	1.3± 0.4	1.2± 0.4	1.1± 0.1	1.2± 0.2
29 Oct. 87	1	0.6± 0.8	1.0± 1.8	0.8± 1.6	0.8± 1.1
28 Oct. 87	2	0.1± 0.3	2.3± 5.0	8.5± 19.6	3.5± 8.1
27 Oct. 87	3	1.0± 1.7	0.7± 2.2	0.1± 0.4	0.6± 1.3
	Mean	0.6± 0.4	1.3± 0.7	3.1± 3.8	1.6± 1.3
21 Nov. 87	1	0.9 ± 2.6	0.6 ± 1.1	0.8 ± 1.5	0.8± 1.1
1987	2	0.04± 0.1	0.04± 0.1	0.08± 0.2	0.6± 0.1
	3	0.3 ± 0.8	0.4 ± 0.5	4.4 ± 6.3	1.7± 2.1
	Mean	0.4 ± 0.4	0.4 ± 0.2	1.8 ± 1.9	1.0± 0.5

± indicates standard deviation

Table 2.1.3. *H. puera* **population estimates on specified data. in 1988**

Period	Plot No.	Mean No. of insects per shoot			
		Bottom	Middle	Top	Whole tree
19 April 88	1	12.2± 9.1	8.9± 4.9	7.1± 6.4	9.4± 4.7
20 April 88	2	11.3± 6.9	10.6± 11.7	9.8± 7.6	10.5± 7.6
21 April 88	3	0.9± 1.4	1.5± 2.2	1.2± 1.8	1.2± 1.7
	Mean	8.1± 5.1	7.0± 4.0	6.0± 3.6	7.0± 4.2
3 May 88	1	1.9± 1.7	4.2± 3.9	6.3± 5.6	4.1± 2.7
4 May 88	2	4.3± 4.5	5.2± 5.1	9.7± 10.3	6.4± 6.2
5 May 88	3	6.8± 6.1	12.6± 6.9	18.4± 9.6	13.1± 5.2
	Mean	4.3± 2.0	7.3± 3.8	11.5± 5.1	7.9± 3.8
30 August 88	4*	0.25± 0.6	0.2 ± 1.9	0.21± 0.3	0.22± 0.3
31August88	2	0	0.04± 0.1	0.42± 0.7	0.16± 0.2
2 Sept. 88	3	0	0	0.04± 0.1	0.01± 0.1
	Mean	0.08± 0.2	0.08± 0.2	0.22± 0.2	0.135 0.1
28 Sept. 88	4	0.54± 1.8	0.42± 1.8	1.71± 2.3	0.89± 1.2
29 Sept. 88	2	0	0.04± 0.3	0.08± 0.2	0.04± 0.1
30 Sept. 88	3	0.04± 0.1	0	0	0.01± 0.1
	Mean	0.19± 0.3	0.15± 0.2	0.6± 0.8	0.31± 0.4
4 November 88	4	0.04± 0.1	0	0.04± 0.1	0.03± 0.1
2 November 88	2	0	0	0.67± 2.8	0.02± 0.7
3 November 88	3	0	0	0.63± 1.2	0.21± 0.4
	Mean	0.01± 0.02	0	0.45± 0.3	0.09± 0.1

± indicates standard deviation

* Plot No. 4 represents a "moving plot" taken outside the three permanent plots

Table 2.1.4. Analysis of variance, 1987 data

Source of variation	DF	May 1987 (8.2[1] insects/ shoot)		June 1987 (1.2 insects/ shoot)		October 1987 (1.6 insects/ shoot)		November 1987 (1.0 insect/ shoot)	
		MSS	F	MSS	F	MSS	F	MSS	F
Plot	2	0.74	1.32	0.99	2.07	0.20	0.34	1.55	4.13*
Tree	33	0.56	2.78**	0.48	1.30	0.60	1.88*	0.37	1.67*
Level	2	0.84	4.20*	0.02	0.06	1.19	3.73*	0.85	3.78*
Tree x level	66	0.20	1.29	0.37	1.44*	0.32	1.82**	0.22	1.32
Error	112	0.16		0.26	-	0.17		0.17	

F values followed by one star are significant at 5% level, and by two stars at 1% level of significance; others are non-significant.

[1]Indicates the overall shoot mean (number of insects per shoot, per tree, per plot) during the sampling period.

Table 2.1.5. Analysis of variance, 1988 data

Source of variation	DF	April 1988 (7.04[1] insects/ shoot)		DF	May 1988 (7.9 insects/ shoot)		August 1988 (-13 insects/ shoot)		September 1988 (0.32 insects/ shoot)		November 1988 (0.09 insects/ shoot)	
		MSS	Fvalue		MSS	Fvalue	MSS	Fvalue	MSS	Fvalue	MSS	Fvalue
Plot	2	22.16	28.68**	2	6.79	10.07**	0.39	3.57*	1.15	5.65*	0.03	0.44
Tree	27	0.77	8.60**	33	0.67	2.90**	0.11	1.54	0.20	1.78*	0.07	0.98
Level	2	0.11	1.17	2	2.46	10.57**	0.19	2.77	0.27	2.40	0.41	5.67**
Tree x Level	54	0.09	1.61*	66	0.23	1.67*	0.07	0.84	0.11	1.64*	0.07	1.62**
Error	94	0.06	-	112	0.14	-	0.08	-	0.07		0.04	

F values followed by one star are significant at 5% level and by two stars at 1% level of significance; Others are non significant.

[1]Indicates the overall shoot mean (number of insects per shoot, per tree, per plot) during the period.

Table 2.1.6. Levels of significance of various sources of variation

Source of Variation	High Density Population			Lou Density Population					
	May 87 (8.2)[1]	April 88 (7.0)	May 88 (7.9)	June 87 (1.2)	Oct. 87 (1.6)	No~. 87 (0.9)	Aug. 88 (0.13)	Sept 88 (0.32)	Nov 88 (0.09)
Plots	ns[2]	**	**	ns	ns	*	*	*	ns
Trees	**	**	**	ns	*	*	ns	*	ns
Levels	*	ns	**	ns	•	*	ns	ns	**
Trees x levels	ns	*	•	*	**	ns	ns	*	*

1 The figures in parentheses shou the mean number of insects per shoot

2 ns, denotes not significant; * significant at 5% level; ** significant at 1% level.

Table 2.1.7. Partitioning of the total variation

Source of variation	DF	% distribution of sum of squares									
		May 87	June 87	Oct 87	Nov 87	Apr 88	May 88	Aug 88	Sept 88	Nov 88	Mean
Plots	2	2.8	2.7	<O.l	<0.1	58.4	19.0	4.2	9.4	0.5	10.8
Trees	33	35.0	22.2	31.6	24.1	27.4	30.9	19.8	26.9	18.8	26.3
Levels	2	3.2	<0.1	3.8	3.4	<0.1	6.9	2.1	2.2	6.7	3.1
TreexLevel	66	25.0	34.2	33.7	28.7	<0.l	21.2	25.1	29.6	37.6	26.1
Error (shoots)	112	34.0	40.8	30.3	37.7	7.4	21.9	48.8	31.9	36.5	32.1

DISCUSSION

At first sight, the above results may suggest that there was no consistency in the results- either in the interaction between crown levels and trees, or in the significance of differences between levels, between trees, and between plots. However, the apparent inconsistencies can be explained in the light of two factors - (i) Teak is a deciduous tree, and during the early flushing period, there occur conspicuous differences between trees in the time of appearance of new flush, (ii) Under natural conditions, *H.* puera moths lay eggs'preferentially on tender leaves.

First, let us consider the differences in the number of insects between trees. This difference was highly significant in all the high-density populations, in the months of April and May (Table 2.1.6). This is understandable as April-May represent the early flushing period when notable differences between trees occur in flushing intensity. During other months, differences between trees were either significant or not significant. This may arise due to existence or non-existence of flushing differences between trees due to various factors. These factors may include (a) site differences between trees at the microlevel, which promote differences in flushing level, (b) Onset of rainfall which trigger uniformity in flushing, (c) genetic differences between trees which promote differences in flushing, (d) insect attack in patches resulting in new flushing in patches, etc. It thus appears that the differences in insect population between trees can be attributed largely to differences in the flushing behaviour of trees.

The interaction between trees and levels (Table 2.1.6) shows that differences in insect numbers between levels was dependent on the tree. This may be related to differences in the flushing pattern. When the population density was low, generally, the top level contained the highest number of insects (Tables 2.1.2 and 2.1.3), although the difference was not always prominent (Table 2.1.6). Low population density generally occurred when the rate of new flushing was low and the few new leaves were generally at the top of the crown, which explains the higher number of insects at the top level. When the population density was high, which coincided with high rate of new flushing, the results were variable. Either there was no significant difference between levels (April 1988) or a significantly higher number of insects was present at the middle or top (May 1988 and May 1987, respectively). These differences may be related to the tree-specific distribution of tender leaves.

The differences between plots were significant on some dates, but not on others. The plots were separated by a minimum distance of about half a kilometre and the results indicate that the infestations were not always uniform over the entire plantation. This has been repeatedly confirmed by general observations. Sometimes, noticeable infestation occurred only outside the three permanent plots.

The above results show that the variance in the number of immature stages of *H. puera* sampled is attributable to differences between crown levels, between trees, between plots and between different time periods. Table 2.1.7 shows the partitioning of the total variation into its various components. Between-shoots variation accounted for about 32% of the total variance, between-trees variation for 26%, and interaction between crown levels and trees for another 26%. Between-plots variation was only 10% but it differed very substantially between sampling dates, indicating that on some dates the infestation was not uniform over the entire area.

This analysis of variance sets the background for designing a sampling plan for studying *H. puera* populations, discussed in Section 2.1.4.

2.1.4. BIOLOGICAL CHARACTERISTICS OF *H. PUERA* INFESTATIONS WITHIN THE TREE CROWN

In Section 2.1.3, we analyued the dispersion of immature stages of *H.* puera in teak plantations. Some additional characteristics of infeetation within the tree crown are examined here. These include (i) the within-shoot dispersion of eggs and larvae (ii) age structure of populations of immature utages, and (iii) the instar-wise dietribution within the tree crown.

WITHIN-SHOOT DISPERSION OF EGGS AND LARVAE

It is generally known that young larvae *of H. puera* prefer tender leaves of teak and that trees without tender leaves are seldom infested. However, when the infestation is heavy, even older leaves are consumed, particularly by older larvae. To gather detailed information, the distribution of immature stages among the leaf pairs within shoots was analysed.

Sample data from some generations in 1987, 1988 and 1992 were used for the analysis. In 1992, 15 trees were sampled at 2-day intervals during one generation. The tree crown was divided visually into 2 levels- top and bottom, and 4 shoots were collected randomly from each level.

Data for 1992 are examined first. Table 2.1.8 shows the number of each instar recorded on each leaf pair during one generation of the insect from 15 to 30 June. Out of the total of 7326 insects. 6689 (91.39) were found on the 1st pair of leaves and 543 (7.4%) on the 2nd pair. Only the remaining 1.3% were found on the 3rd to 5th pairs. This table also shows the instar-wise distribution. It may be seen that all instars preferred the 1st pair of leaves followed by the 2nd pair. Only in the case of the 5th instar were noticeable numbers present on the 3rd and 4th pair of leaves.

Table 2.1.9 shows the within-shoot dispersion of eggs and larvae for the period, 30 May to 24 July 1987. Out of a total of 1676 insects, about 66% were on the 1st pair, 23.4% on the 2nd pair and 7.3% on the 3rd pair. In general, the results were similar to 1992, except that greater proportion of larvae were found on the 2nd and 3rd pair of leaves. In the case of 5th instar, the 2nd and 3rd pair contained a greater proportion than the 1st pair (46% and 28%, respectively, compared to 14%).

Table 2.1.10 presents similar data for the period, 19 July to 4 October 1988. Here again most insects (95%) were found on the 1st pair, with some on the 2nd and 3rd pair; 4th to 7th pair were practically free of insects.

Table 2.1.8. Dispersion of eggs and larvae within shoot - 15 to 30 June 1992

Leaf pair no. from top	No.of pairs	No. of insects recorded on each pair with % of total In parentheses						
		Eggs	Instar 1	Instrr 2	Instrr 3	Instar 4	Instar 5	Total
1	573	63 (84.0)	2847 (99.5)	1984 (81.9)	912 (98.1)	613 (97.1)	270 (66.3)	6689 (91.3)
2	572	10 (13.0)	10 (0.4)	407 (16.8)	14 (1.5)	18 (2.9)	84 (20.6)	543 (7.4)
3	571	2 (3.0)	1	14 (0.6)	4 (0.4)	0	44 (10.8)	65 (0.9)
4	367	0	1	8 (0.3)	0	0	9 (2.2)	18 (0.3)
5	73	0	1	10 (0.4)	0	0	0	11 (0.2)
6	10	0	0	0	0	0	0	0
Total	2166	75	2860	2423	930	631	407	7326

Table 2.1.9. Dispersion of eggs and larvae within shoot - 30 May to 24 July 1987

Leaf pair No. from top	No.of pairs	No. of insects recorded on each pair with % of total in parentheses						
		Eggs	Inster 1	Instar 2	Instar 3	Inster 4	Instar 5	Total
1	530	92 (93.9)	247 (81.0)	278 (76.4)	323 (72.4)	129 (70.1)	40 (14.3)	1109 (66.2)
2	509	5 (5.1)	41 (13.4)	59 (16.2)	110 (24.7)	48 (26.1)	129 (46.2)	392 (23.4)
3	273	0	13 (4.3)	19 (5.2)	7 (1.6)	5 (2.7)	79 (28.3)	123 (7.3)
4	92	1 (1.0)	4 (1.3)	6 (1.6)	5 (1.1)	2 (1.1)	31 (11.1)	49 (2.9)
5	29	0	0	2 (0.5)	1 (0.2)	0	0	3
6	14	0	0	0	0	0	0	0
Total	1447	98	305	364	446	184	279	1676

Table 2.1.10. **Dispersion of eggs and larvae within shoot** - 19 **July to** *4* **October** 1988

Leaf pair No. from top	No.of pairs	No. recorded on each pair with *X* of total in parentheses						
		Eggs	Instar 1	Instar 2	Instar 3	Instar *4*	Instar 5	Total
1	816	151 (100.0)	160 (94.7)	425 (89.3)	815 (99.5)	***464*** (92.6)	131 (91.0)	2146 (95.0)
2	812	**0**	9 (5.3)	45 (9.5)	3 (0.4)	36 (7.2)	9 (6.3)	102 (4.5)
3	781	**0**	**0**	6 (1.3)	**0**	1 (0.2)	4 (2.8)	11
4	460	**0**	**0**	**0**	1 (0.1)	**0**	**0**	1
5	148	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6	44	**0**	**0**	*0*	**0**	**0**	**0**	**0**
7	5	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total	3066	151	169	476	819	501	144	2260

Usually the insect population reaches a very low level by the and of August and remains so until March-April next year. However, in 1987, unusually large numbers of insects were recorded on two subsequent datee- 13 October and 10 November. Counte of insects on these datee and the immediately succeeding dates (of sampling) are given in Tables 2.1.11 and 2.1.12. It may be noted that on these dates, large numbers of eggs were laid indiscriminately on the let to 9th leaf pairs. On 10 November, the largest number of eggs were found on the 4th pair, followed by the 3rd. However, the larvae were mostly confined to 1st to 3rd pairs, as on other dates. It is obvioue that the neonate larvae did not survive on older leaves.

Further analysis of egg laying on these dates showed that the greater part of the eggs was deposited on a few trees (Table 2.1.13).

The data clearly show that in general, eggs are laid only on t-ender leaves and that the larvae feed preferentially on tender leaves (1st to 3rd pair). Older leaves do not support the survival of neonate larvae.

AGE STRUCTURE OF POPULATIONS OF IMMATURE STAGES

The age structure is examined separately for high-density and low density populations based on the same data sets used in Section 2.1.3 for analysis of dispersion.

High-Density Populations

28-31 May 1987

The age structure of the populations in 3 plots on three successive days, viz. 28, 30 and 31 May are shown in Fig. 2.1.7. Let us first consider Plots 2 and 1 sampled on 30th and 31st May, respectively. On both dates, all the immature stages, including eggs, were present but one stage was dominant- 3rd instar on 30th (accounting for 61% of the total) and 4th instar on 31st (accounting for 62% of the total). It is obvious that the same population was represented in both the plots; 3rd instar larvae of 30th had developed into 4th instar on 31st. In Plot 3, sampled on 28 May, 45% of the population was 5th instar, closely followed by 2nd instar, representing 30% of the population. This indicates the presence of two distinct populations of larvae in Plot 3, the 2nd instar population being apparently the same as that in plots 1 and 2.

19-21 April 1988

Fig. 2.1.8 shows the age structure of populations in 3 plots during 19-21 April 00. On 19th, in Plot No. 2, all stages were present, with 4th instar dominating (49%), followed by 3rd instar (21%). On 2Oth, in Plot No. 1, 5th instar was dominant (51%), closely followed by 4th instar (46%). In Plot No. 3, on 21st, most larvae (96%) were in the 5th instar, although the number was

Table 2.1.11. Dispersion of eggs and larvae within shoot on 13 October(A) and 21 October(B) 1987

Leaf pair No. from top	No. recorded on each pair on two Consecutive sampling dates													
	eggs		instar 1		Instrr 2		Instrr 3		Instrr 4		instar 5		Total	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1	910	0	715	76	0	57	0	20	0	3	0	0	1625	0
2	890	0	27	7	11	13	2	15	1	12	0	3	931	156
3	527	0	0	3	15	4	0	5	0	0	0	0	542	50
4	221	0	0	0	0	0	0	0	0	0	0	0	221	12
5	148	0	0	0	0	0	0	0	0	0	0	0	148	0
6	20	0	0	0	0	0	0	0	0	0	0	0	20	0
Total	2716	0	742	86	26	74	2	40	1	15	0	3	3487	218

Table 2.1.12. Dispersion of eggs and larvae within shoot on 10 November(A) and 21 November(B), 1987

Leaf pair No. from top	No. recorded on each pair on two consecutive sampling dates													
	Eggs		Instar 1		Instar 2		Instar 3		Instar 4		Instar 5		Total	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1	399	0	21	0	8	3	1	0	1	1	0	0	430	4
2	553	0	13	0	0	0	3	0	3	0	0	0	572	0
3	812	0	0	0	0	0	0	0	0	0	0	0	812	0
4	876	0	0	0	0	0	0	0	0	0	0	0	876	0
5	145	0	0	0	0	0	0	0	0	0	0	0	145	0
6	245	0	0	0	0	0	0	0	0	0	0	0	245	0
7	140	0	0	0	0	0	0	0	0	0	0	0	140	0
8	76	0	0	0	0	0	0	0	0	0	0	0	76	0
9	69	0	0	0	0	0	0	0	0	0	0	0	69	0
	3315	0	34	0	8	3	4	0	4	1	0	0	3365	4

Table 2.1.13. Dispersion of eggs and larvae on individual trees on specified dates of sampling

Date of sampling	Sl.No. of trees	Number of Eggs	Inst 1	Inst 2	Inst 3	Inst 4	Inst 5	Total
13 Oct. 1987	1	14	7	0	0	0	0	21
	2	821	29	4	0	0	0	854
	3	14	33	8	2	1	0	58
	4	1867	673	14	0	0	0	2541
10 Nov. 1987	1	186	2	0	0	0	0	188
	2	1717	0	0	3	0	0	1720
	3	0	0	0	0	0	0	0
	4	0	0	2	0	3	0	5
	5	0	17	0	0	0	0	17
	6	0	0	0	0	0	0	0
	7	0	0	6	0	0	0	6
	8	1133	15	0	0	0	0	1148

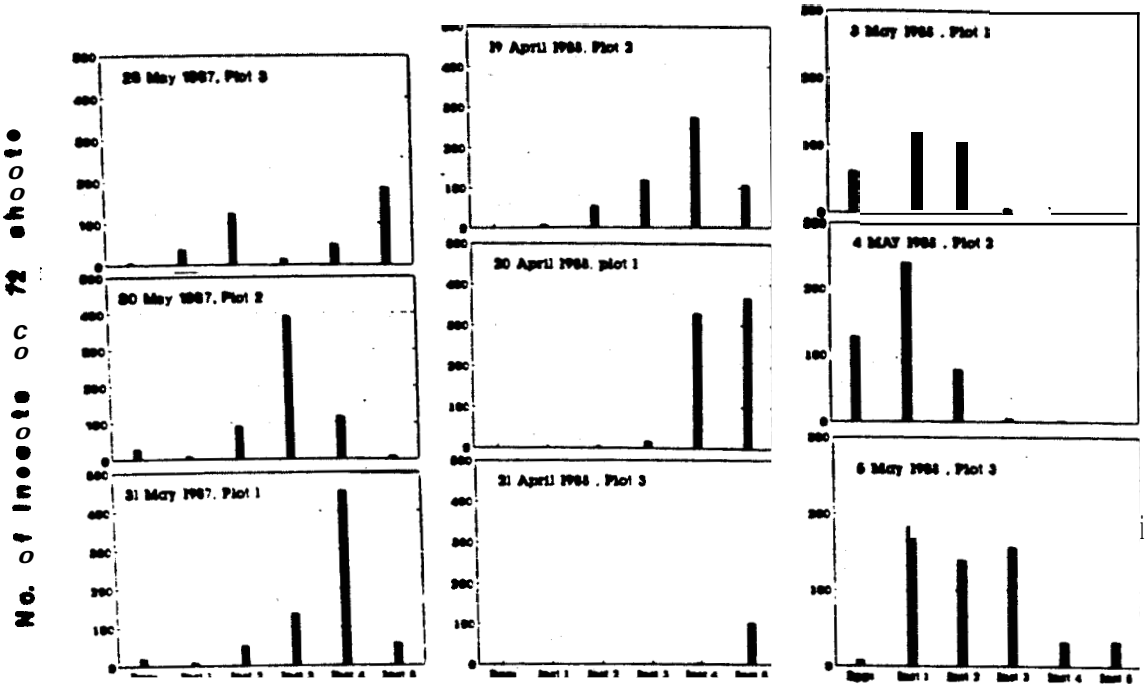


Fig. 2.1.7 Fig,. 2.1.8 Fig,. 2.1.9

Fig. 2.1.7., Fig 2.1.8., Fig. 2.1.9. Age structure of population, on 28-31 May 1987, 19-21 April 1988 and 3-5 May 1988 respectively.

small. It appears that the same population was present in all the three plots during this period.

3-5 May 1988

Fig. 2.1.9 shows the age structure of populations in the 3 plots on three consecutive days starting 3rd May. On 3rd, in Plot No.1, the main stages present were eggs, 1st instar and 2nd instar, with the 1st instar slightly predominating (41%). On the next day, in Plot No.2, the 1st instar was dominant *(58%)*, followed by eggs (28%). On the following day, in Plot No. 3, 1st to 3rd instars were present more or less in equal proportion, with small proportions of other instars.

In summary, high-density populations were generally characterised by a high preponderance of one developmental stage constituting the peak of a bell-shaped distribution curve of the stages. Generally, the stage immediately below and immediately above were also present in smaller numbers.

Low-Density Populations

The age structure of low-density populations, sampled on 18 occasions were analysed. In general, the low-density populations had a mixed age structure consisting of eggs to 5th instar larvae, although on rare occasions when the population size was comparatively larger, dominance of one developmental stage was noticed. Typical examples are shown in Figs. 2.1.10 to 2.1.12.

INSTAR-WISE DISPERSION OF IMMATURE STAGES WITHIN THE TREE CROWN

Differences between crown levels (bottom, middle and top) in the dispersion of immature stages was examined in Section 2.1.3. It was seen that differences existed but were not consistent. In the case of high density populations, highest numbers were noticed at different levels on different dates. To examine whether this was related to the stage of development of larvae at the time of sampling, instar-wise distribution of the immature stages at the three crown levels was analysed.

Figs. 2.1.13 and 2.1.14 show the instar-wise distribution at bottom, middle and top levels of the crown on six sampling dates when the population density was high. The data clearly show that all instars were present at all the three crown levels. Although more insects were present at the top and middle levels compared to the bottom, on some dates (e.g., Fig. 2.1.13), this trend was not consistent (e.g., Fig. 2.1.14). All instars were present at all the three levels and there were no level preferences for instars.

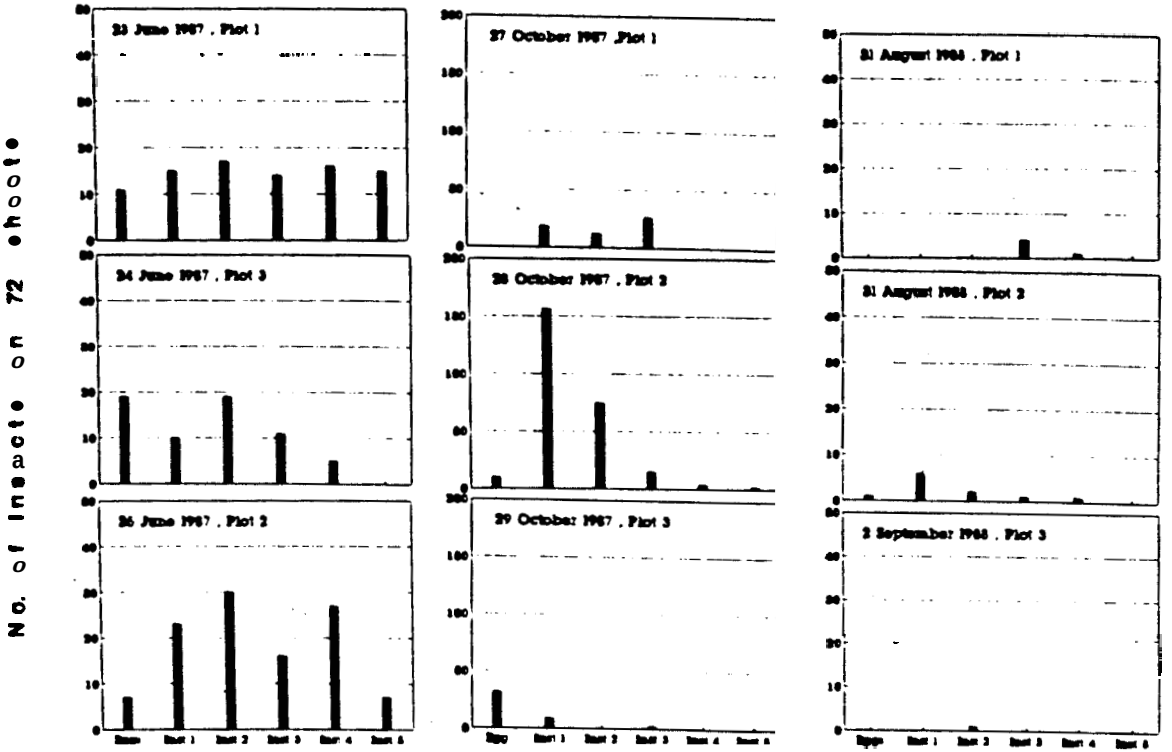


Fig. 2.1.10 Fig.. 2.1.11 Fig.. 2.1.12

Fig. 2.1.10.,Fig. 2.1.11. and Fig. 2.1.12. Age structure of population, on 23-25 June 1987., 27-29 October 1987 and 31 August to 2 Sept 1988 respectively.

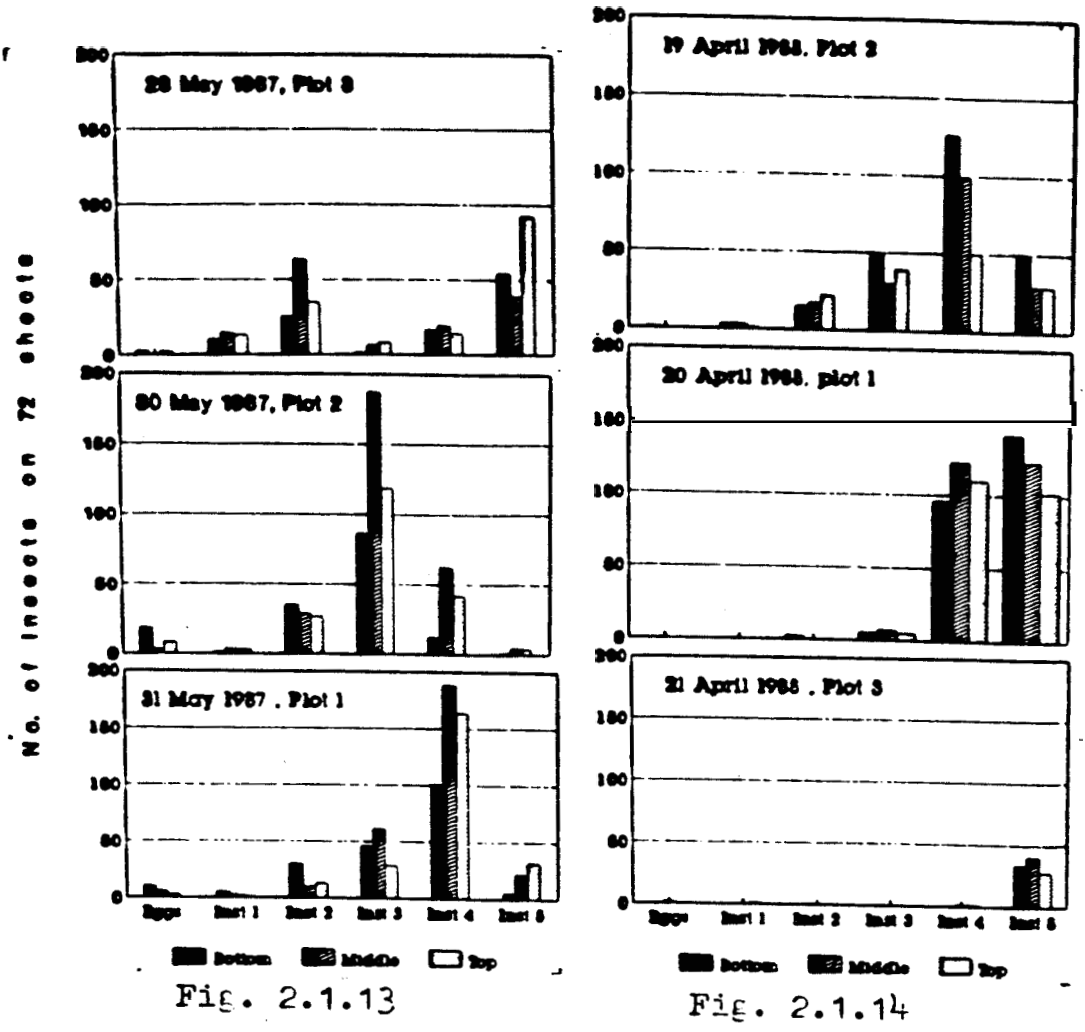


Fig. 2.1.13

Fig. 2.1.14

Fig. 2.1.13., Fig. 2.1.14. Instar-wise distribution of immature stages at bottom, middle and top crown levels on 3 sampling dates in 1987 and 1988 respectively.

GENERAL CONCLUSIONS

The results reported in this Section show the following.

1. In general, eggs are laid only on tender leaves and the larvae feed preferentially on the 1st to 3rd pair of leaves. Neonate larvae do not survive on older leaves.

2. High-density infestations are characterised by the predominance of one developmental stage at any given time and there is no overlap of generations. However, low-density populations have a mixed age structure.

3. Although it was suspected that early instars may concentrate at top level and late instars at bottom level, no level preferences were noticed for instars, all instars being present at all levels of the crown.

2.1.5. THE MATHEMATICAL DISTRIBUTION OF H. *PUERA* POPULATIONS (IMMATURE STAGES) *AND AN* IDEAL SAMPLING PLAN

In this section, we shall examine the variation in the number of insects among shoots within a plot, to test whether it agrees with any of the theoretical mathematical distributions. For the purpose of this analysis, each plot is assumed to be made up of a population of shoots, although the shoots were collected from different trees and different levels. Based on the distribution of insects, we will then work out the sample size needed to estimate the population within an acceptable level of error.

METHODS

Data over 27 sampling dates, used for the analysis of variance described in Section 2.1.3, were used. Insect counts for 72 shoots per plot were available for most dates except for 3 dates on which only 60 shoots were sampled. Since the variance/mean ratio was generally much higher than 1, the fit of the negative binomial distribution was tested. To calculate the expected frequencies, 'k' of the negative binomial was computed by the iterative process using the third and more accurate method suggested by Southwood (1978), by the formula,

$$N \log_e \left(1 + \frac{x}{k}\right) = \frac{Ax}{k+x}$$

For each mean, the expected negative binomial frequencies for 72 shoots with the corresponding mean were computed and the agreement between the expected and observed frequencies was tested by the Chi-square test.

For calculating the common 'k'(kC), the regression method as suggested by Southwood(l978) was used. Two statistics, x1 and y1 were first calculated using the formulae,

$$X^1 = x^2 - \frac{s^2}{N}$$

$$Y^1 = s^2 - x$$

where x = the mean, s2 = variance and N = number of individual counts on which x is based. Then yl was plotted against x^1 and an approximate estimate of common k(kc) was obtained using the equation,

$$\frac{1}{kc} \quad \frac{Y1}{X1}$$

The number of samples to be taken for estimating the population at an acceptable error of l0%, was determined by the formula,

$$N = \frac{1/x + 1/k_c}{E^2}$$

where E = acceptable standard error as a decimal of the mean (0.01).

RESULTS

The mean, variance and variance/mean ratio of the counts of insects (all the immature stages) per shoot in the 27 samples which formed the data set are given in Table 2.1.14. In general, the variance/mean ratio was much higher than 1, indicating a contagious distribution (Southwood, 1978). Test of fit of the negative binomial distribution (by comparing the expected and observed frequencies of copnts for each mean) showed that among the 27 means, 20 agreed with the negative binomial ($P<0.05$) (Table 2.1.14). In the remaining cases, no insects were present in most of the shoots; so no meaningful theoretical distribution can be arrived at. They represented instances when only 1 or 2 insects were present in 1 to 4 shoots out of 72. Thus it can be concluded that all populations sampled conformed to the negative binomial distribution.

Since the means fell within two distinct groups – the high-density and low-density groups, and generally the 'k' value increased as the mean increased (Table 2.1.14), a common 'k' was calculated separately for high-density and low-density populations as described under 'Methods'.

The plots of y1 against x1 for the high density populations and the low-density populations are shown in Figs. 2.1.15 and 2.1.16, respectiveiy. In each group, the scatter of the points around the trend line indicates that calculation of a common k is justified for each group. The kc values worked out to 1.22 for high-density populations and 0.226 for low-density populations. (In the high-density group, one set with a mean number of 3.62 insects per shoot had an exceptionally high variance of 275.1. This represented samples taken on 28 October, when the population density is generally low. In this set, 58 out of 72 shoots (>80%) had no insects, 13 shoots had 1 to 24 insects, and 1 shoot had 137 insects (Instar 1). In reality it was a low-density population, although a single shoot harbouring 137 insects enhanced the mean. But for this single shoot, the mean would have been 1.75, similar to that of low-density populations. Therefore for the purpose of calculating the common 'k' for the high density group, this set was excluded).

Table 2.1.14. Mean and Variance of counts of insects per shoot in 27 samples, and the fit of theoretical distribution

Mean $(\bar{x})$	Variance (S2)	Variance/ mean ratio	Negative binomial distribution K	X2	Remarks
13.34	117.41	8.80	1.817769	13.75	High-
10.53	93.03	8.84	1.585653	23.35	density
10.09	76.70	7.61	1.41519	11.00	
9.38	73.09	7.79	1.75642	29.58	
8.94	104.76	11.71	1.054189	26.29	
6.24	75.50	12.11	0.766604	19.59	
5.74	28.31	4.94	1.410774	13.37	
4.11	23.71	5.77	0.719255	7.70	
3.63	275.08	75.99	0.051598	1.54	
1.68	22.36	13.31	0.100228	5.48	Low-
1.53	2.70	1.76	1.7937	6.69	density
1.23	5.64	4.59	0.230339	1.70	
1.22	2.80	2.29	0.799686	5.93	
0.92	5.58	6.07	0.091744	2.04	
0.89	6.24	7.01	0.092223	0.07	
0.89	1.65	1.85	1.044638	3.02	
0.76	3.79	4.99	0.152554	1.67	
0.60	4.10	6.83	0.090072	0.19	
0.21	0.31	1.48	0.386554	0.07	
0.15	0.44	2.93	0.083044	0.26	
0.22	1.89	8.53	NA1		
0.21	1.13	5.41	NA		
0.06	0.05	0.95	NA		
0.04	0.04	0.95	NA		
0.03	0.03	0.96	NA		
0.01	0.01	1.00	NA		
0.01	0.01	1.00	NA		

1, Not applicable, no insects in 68 to 71 out of 72 shoots.

The homogeneity of k was further tested graphically by plotting l/k against the mean for each group (Southwood, 1978). In the high-density group (Fig. 2.1.17) although there was a trend, the R2 was low (0.5895), suggesting that calculation of a common k is justified. In the low-density group (Fig. 2.1.18) , the R^2 was very low, again suggesting that calculation of common k is justified.

The sample size required to estimate the population at not more than 10% error worked out to 94 shoots for high-density populations, and 566 shoots for low-density populations. At the rate of 6 shoots per tree, this represents 16 trees for high-density- and 94 trees for low-density populations.

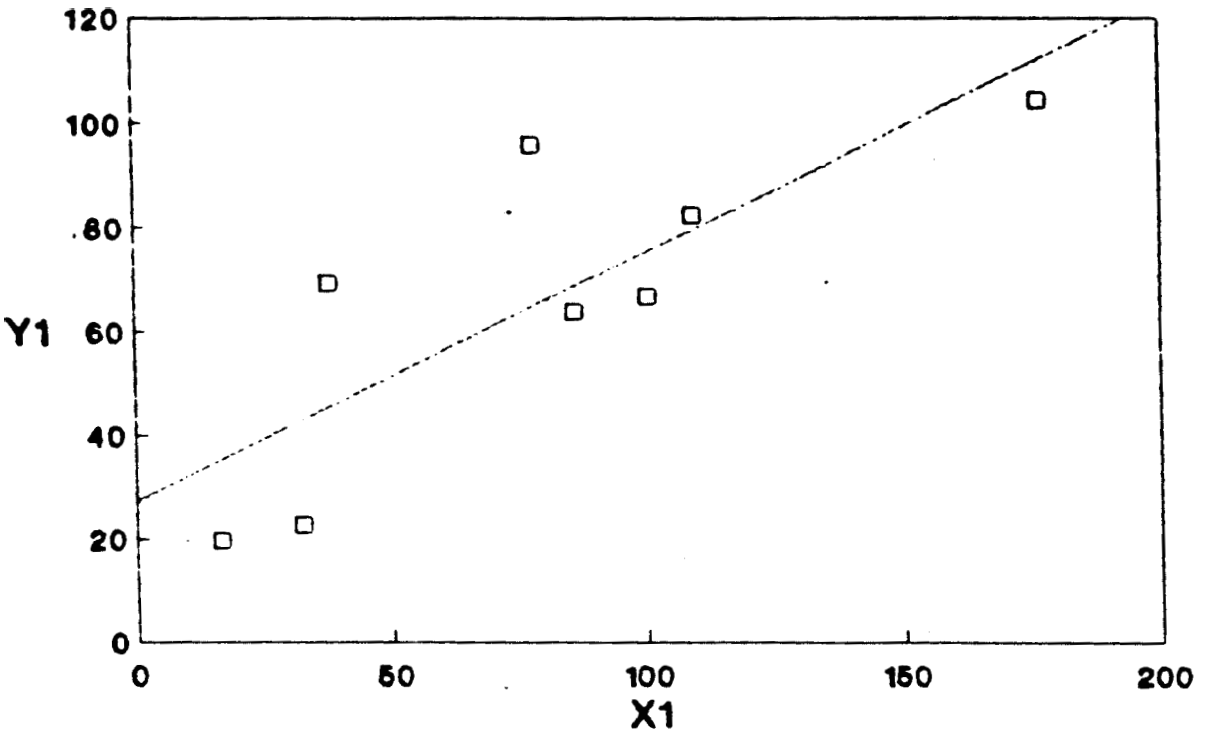


Fig. 2.1.15. Plot *of* y1 against x1 for high-density populations. One set of values with an exceptionally high value of 271.5 for y1 (X1 = 9.3) was excluded from the graph. R2 = 0.6468.

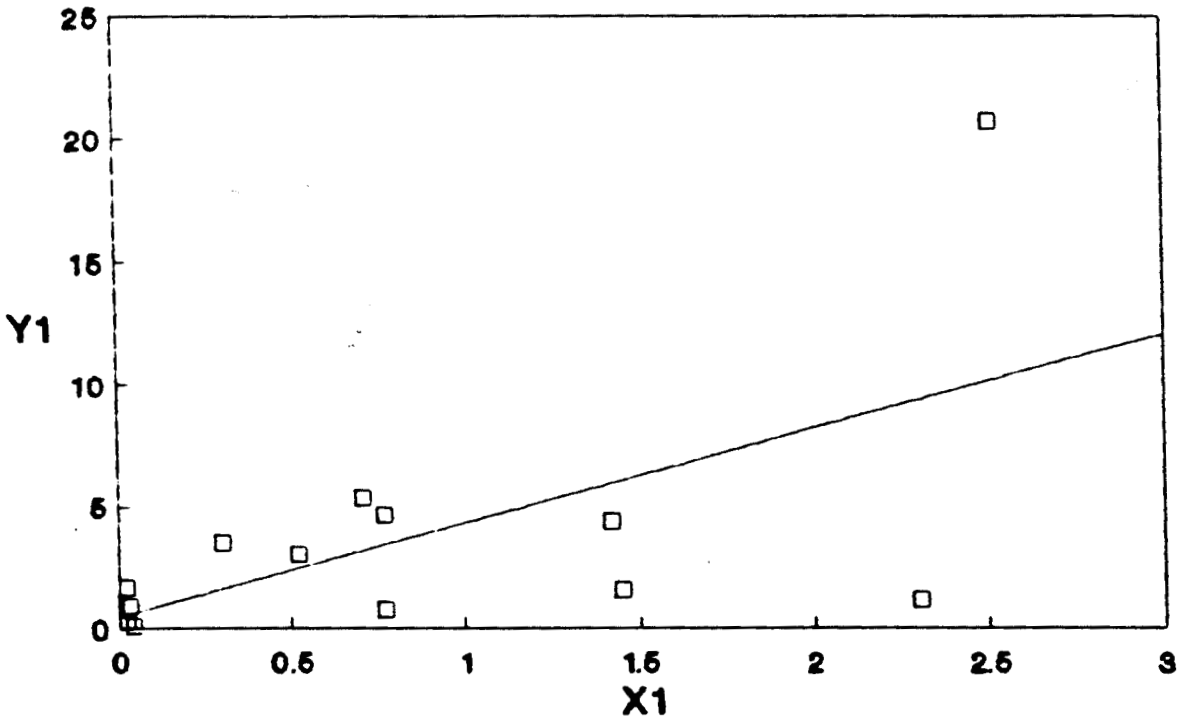


Fig. 2.1.16. Plot of yl against x1 for low-density populations.

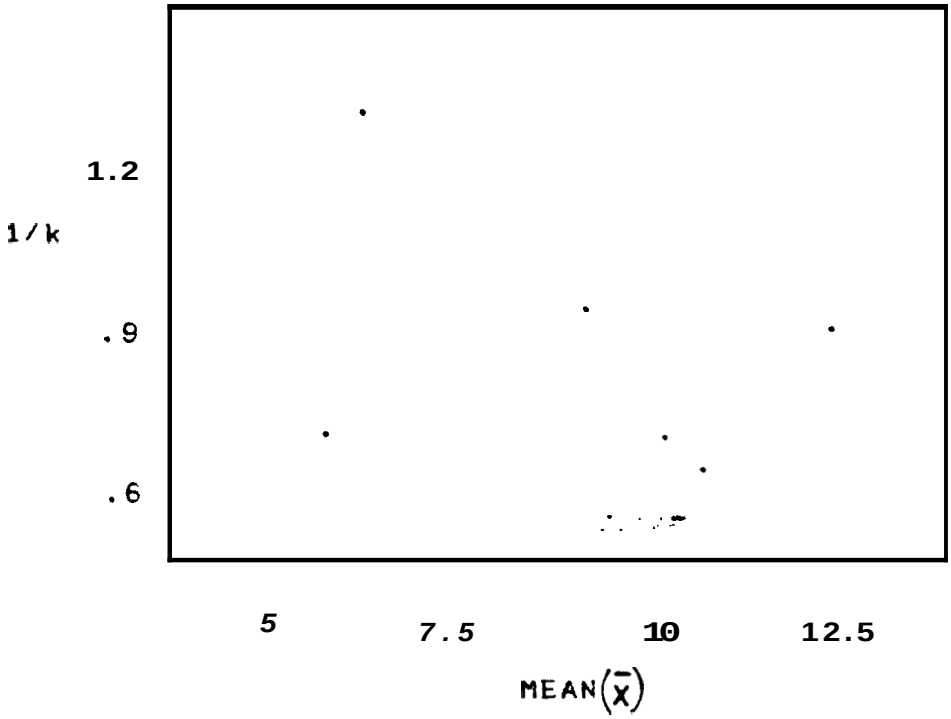


Fig. 2.1.17. The relation of l/k to the mean, for high-density populations. R2 = 0.5895.

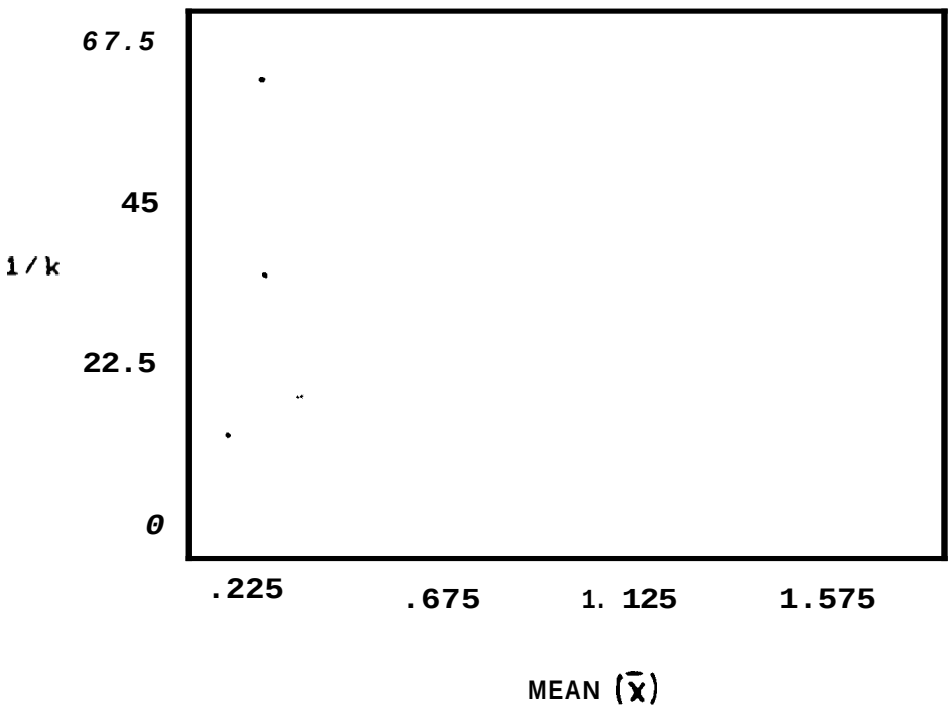


Fig. 2.1.18. The relation of l/k to the mean for low-density populations. R2 0.2782.

DISCUSSION

Many insect populations that have been studied have been found to follow a contagious distribution, more particularly, negative binomial. *H. puera* is no exception. The biological meaning of this distribution is that the presence of one individual in a unit increases the chance that another will occur there also (Southwood, 1978). This is understandable as the distribution of immature stages is primarily determined by the egg-laying behaviour of the moths.

The value of k (1.22 for high-density and 0.226 for low-density population) gives a measure of dispersion; the smaller the value of k, the greater the extent of aggregation.

According to Southwood (1978) the aggregation recognized by the negative binomial may be due either to active aggregation by the insects or to some heterogeneity of the environment. The mean number of individuals in the aggregation calculated as suggested by Southwood (1978) using the k values, worked out to 6.5 for high-density- and 0.82 for low-density populations. A mean clump size of less than 2 suggests that the aggregation may be due to some environmental effect, and not to an active process, whereas aggregations of 2 or more could be caused by either factor (Southwood, 1978).

The sample size arrived here for estimating the population at 10% error is 94 shoots for high-density, and 566 shoots for low-density populations, or at the rate of 6 shoots per tree, 16 trees for the former and 94 trees for the latter.

Generally, sampling 6 shoots from a teak tree, 10-20 m tall, required about 30 minutes for two persons, one of them an expert tree climber. The tree was climbed part-way and the shoot samples from middle and top levels were cut using a twig cutter. On an average, shoot collection required about 15 min and recording of observations about 20 min, per tree (6 shoots). Sampling of 16 trees will thus require about 8 hrs of work for a team of 2 persons, after reaching the sampling site.

Sampling of 94 trees for estimating low-density populations is not feasible, because of the time and effort required (although recording of observations will require less time for low-density populations). The present discussion pertains to estimating the *H. puera* population in a small plot of teak plantation at a given point of time. Based on the results, it is concluded that a sample of 94 shoots (taken without reference to crown level) will give a reasonable estimate, when the population density is not too low. When the population density is low, ie., below 2 insects per shoot, it is not feasible to get a reliable estimate.

2.2. POPULATION TRENDS OF *H. PUERA* IN TEAK PLANTATIONS AT KARIEM-MURIEM, NILAMBUR

As described in Section 2.1.1, immature stages of *H. puera* were sampled at weekly interval from the three permanent plots as well as from temporarily established moving plots within a large plantation area covering about 1,000 ha at Kariem-Muriem. The population trends over the 3-year study period are examined here.

METHODS

As a routine, 12 trees were sampled from each plot every week (Section 2.1.1), except on rare occasions when only a smaller number of trees could be sampled due to heavy workload. It may be recalled that the sample size arrived at for estimating the population at not more than 10% error is 16 trees for high-density populations and 94 trees for low-density populations (Section 2.1.5). The sample size of 12 trees used in this study is a close approximation of the sample size required for high-density populations, although it is inadequate for low-density populations. Sampling started in April 1987. Based on general observations it is known, that in 1987, no major infestation occurred in the study area prior to this sampling. The sampling continued almost uninterruptedly at weekly interval over 3 years, ending in the last week of March 1990.

The larval stages of *H. puera* last about 12 to 14 days in total, including 1.5-2 days each for egg, instar 1, instar 2 and instar 3; and 2-3 days each €or instar 4 and instar 5. As the sampling was carried out at weekly interval, there is a chance of one stage or the other not getting fully represented in the sampling. Therefore, the immature stages were pooled into (i) Stage 1, represeqting eggs, 1st instar and 2nd instar; (ii) Stage 2, representing 3rd, 4th and 5th instar; and (iii) pupae. Estimates for the adult are based on successful emergents in the laboratory from the sampled pupae.

To study the general population trend, Stage 2 was plotted in all the graphs. Data gathered for Stage 1 and pupae were used for shedding light on certain aspects.

Usually the three plots were sampled on three consecutive days. The data are plotted on the basis of week numbers (week of the year). For some weeks when sampling was missed for unavoidable reasons, the number of insects present was estimated by extrapolation from the previous week's sampling, using the survival rate for each instar estimated in a separate study on life table (unpublished).

Year 1987

The population trend in the study area in 1987 is shown in Fig. 2.2.1. The first population peak appeared in week No. 18 (mid-date 3 May) in one of the permanent plots (Plot 3, Fig. 2.2.1). It may be noted that only Stage 2 is represented in the graphs; since it takes 5-6 days from egg-laying to reach the 3rd instar, the peak egg laying may be considered to have occurred about a week earlier. Simultaneously, a similar infestation was noticed in a location about 400 m away from Plot 3. A moving plot was established in this location for sampling. At both locations the infestation was patchy, but the population density was high (6 to 7 insects per shoot, see Fig. 2.2.1). This population did not appear in Plots 1 and 2. A second peak appeared in week No. 22 (mid-date 31 May) simultaneously in all the permanent plots, and the population density was high (4-9 insects per shoot). These two populations caused almost total defoliation in the affected area.

A third major peak appeared in week No. 33 (mid-date 16 August). This peak appeared in Plot 3 as well as in an area between Plots 1 and 2, where another moving plot was established for sampling. The population density ranged from about 3 to 6 insects per shoot. This peak was not noticed in Plots 1 and 2, although smaller peaks appeared in these plots earlier or later (in week No. 32 in Plot 1 and week No. 34 in Plot 2). Subsequent peaks were smaller; with a maximum number of 1.9 insects/shoot in week No. 39 (mid-date 27 Sept.) in Plot 2 (Fig. 2.2.1).

Fig.2.2.2 summarises the overall population trend in the study area, irrespective of the plot locations. The following general conclusions can be drawn based on Stage 2 trends. During 1987, considering the entire observation area, there were four noticeable population peaks. The most dominant was the 2nd peak, which appeared at the end of May. It was widespread and was recorded in all the 3 permanent sample plots. The next dominant was the 1st peak, which appeared in the first week of May. But it was restricted to some patches. The last two peaks were much smaller and occurred during July and August.

Fig. 2.2.2 also shows the overall population trend for the early instars. In general, it reflects the population trends recorded for Stage 2, except that the population size was bigger. In addition, the high population peaks on week No. 41 and 45 (mide-date 10 Oct. and 8 Nov.), mainly contributed by the presence of unusually large numbers of eggs in a few trees, was not reflected in Stage 2. This is due to their poor survival beyond the 2nd instar (see Section 2.3.4).

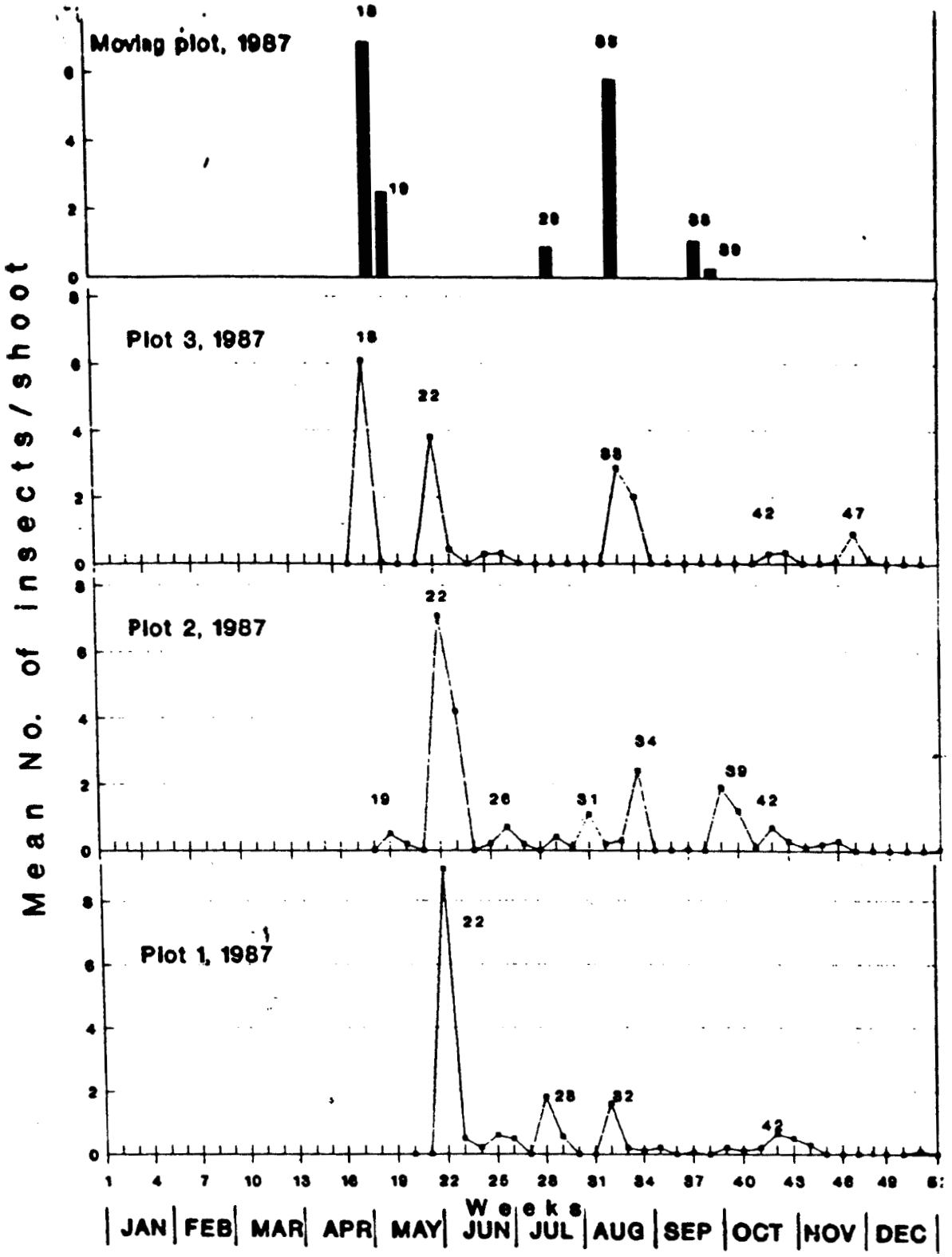


Fig. 2.2.1. Population trend of *H. puera* in permanent plots and the moving plots in 1987. Moving plots were sampled only on the weeks shown. Week number is indicated for each major peak.

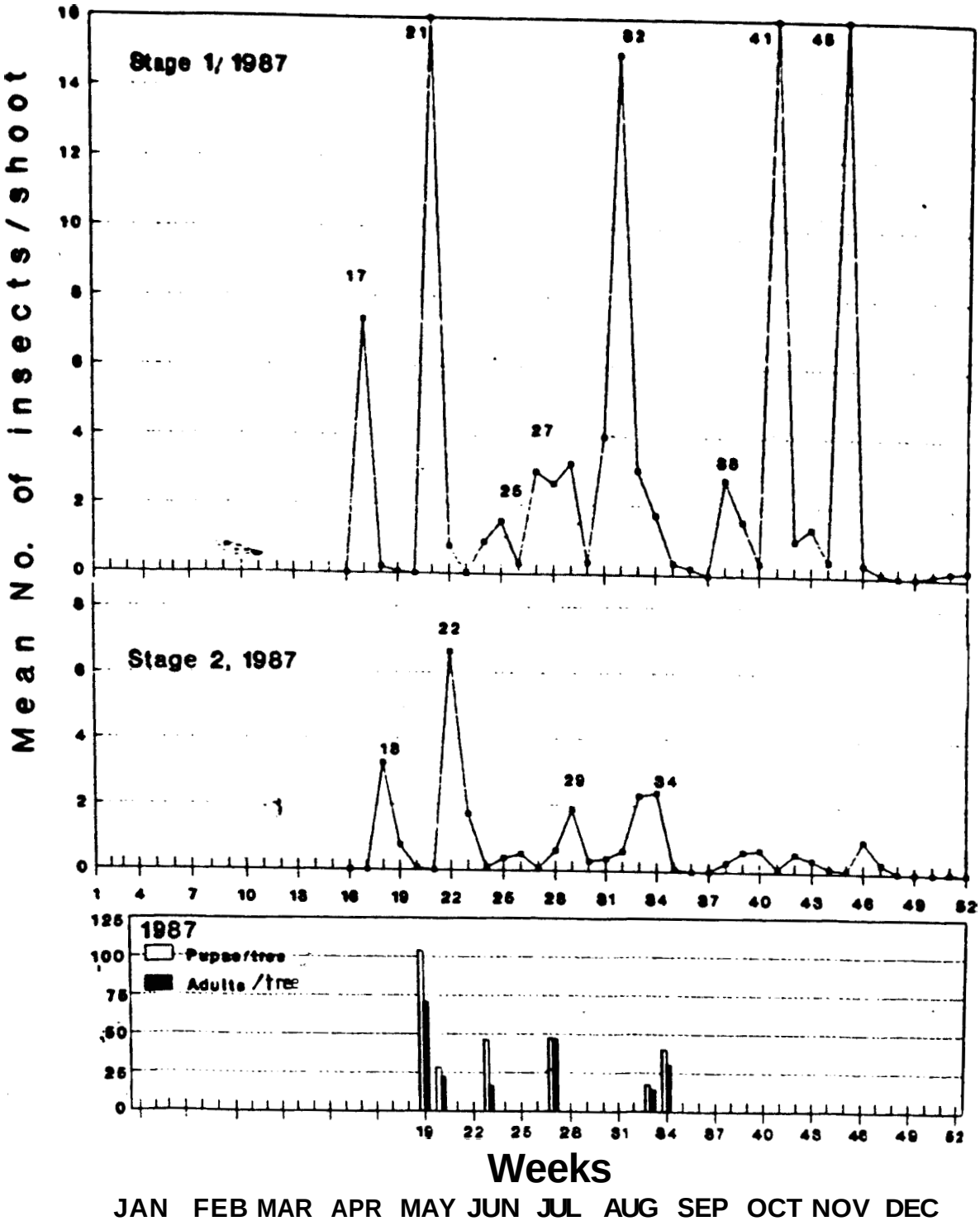


Fig. 2.2.2. Overall population trend in the study area in 1987 for Stage 1, Stage 2, pupae and adults.

Pupal sampling revealed 4 distinct peaks in week Nos. 19-20, 23, 27 and 33-34 (Fig. 2.2.2). Survival of pupae to the adult stage is also shown in the figure by solid bare. The pupal trend is in general agreement with the Stage 2 trends, but it may be noted that the smaller peaks of larvae, particularly during the later part of the year were not represented by pupae. This is due to (1) poor survival to the pupal stage, and (2) sampling inefficiency at low population densities. In addition, it may be noted that the Stage 1 larvae of week Nos. 27-29 leading to Stage 2 larvae of Week No. 29 did not lead to a pupal peak. This was the time when the highest NPV disease incidence was recorded in that year (Section 2.3 - Fig. 2.3.7). It is evident that this generation was practically eliminated by NPV disease.

Year 1988

Population trends in the different plots in 1988 are shown in Fig. 2.2.3. Although smaller number of larvae were recorded in some plots during January and the second half of February, the first population outbreak appeared in week No. 10 (mid-date 7 March). This outbreak was confined to plots 1 and 2. A second peak appeared in week NO. 13 (mid-date 28 March), but this was confined to plot 1, although smaller number of instects were present in other plots. A third major peak appeared in all the plots between 14-19 April (week No. 15-16) (This peak was recorded in plot 1 in the sampling carried out on 14 April, and in plot 3 in the sampling carried out on 15 April. Although the gap between these observations was only 1 day, these peaks fell on two different weeks in the graph depicted in Fig. 2.2.3. because the dividing line between the two weeks fell between these dates). This was followed by the 4th high peak in week No. 18 (mid-date 5 May) in plot No. 3 and corresponding smaller peaks in other plots. A 5th high peak appeared on 2 June in plot 1 and on 3 June in plot 3 (week No. 22-23). A 6th high peak was recorded on 19-23 July (week No. 29-30) in the moving plot, with corresponding smaller peaks in plots 2 and 3, but not in plot 1. A 7th high peak appeared again in week No. 33 in the same moving plot location, but not in other plots. This was followed by a smaller peak in the same location on 13 September (week No. 37).

Fig. 2.2.4 summarises the overall population trends in the study area irrespective of the plot locations. The following general conclusions can be drawn based on stage 2 trends. During 1988, considering the entire observation area, there were three noticeable population peaks. The first of these appeared in the 2nd week of March (week No. 10) and was restricted to some patches, including Plots 1 and 2 (Fig. 2.2.3). The second major peak which appeared in the 3rd week of April (week No. 16) was widespread and was recorded in all the 3 permanent sample plots. The third dominant peak occurred in the 2nd week of May (week No. 19). This peak was also widespread and occurred in all the permanent sample plots, although the population size was small in Plots 1 and 2. Apart from these, there were two moderate peaks

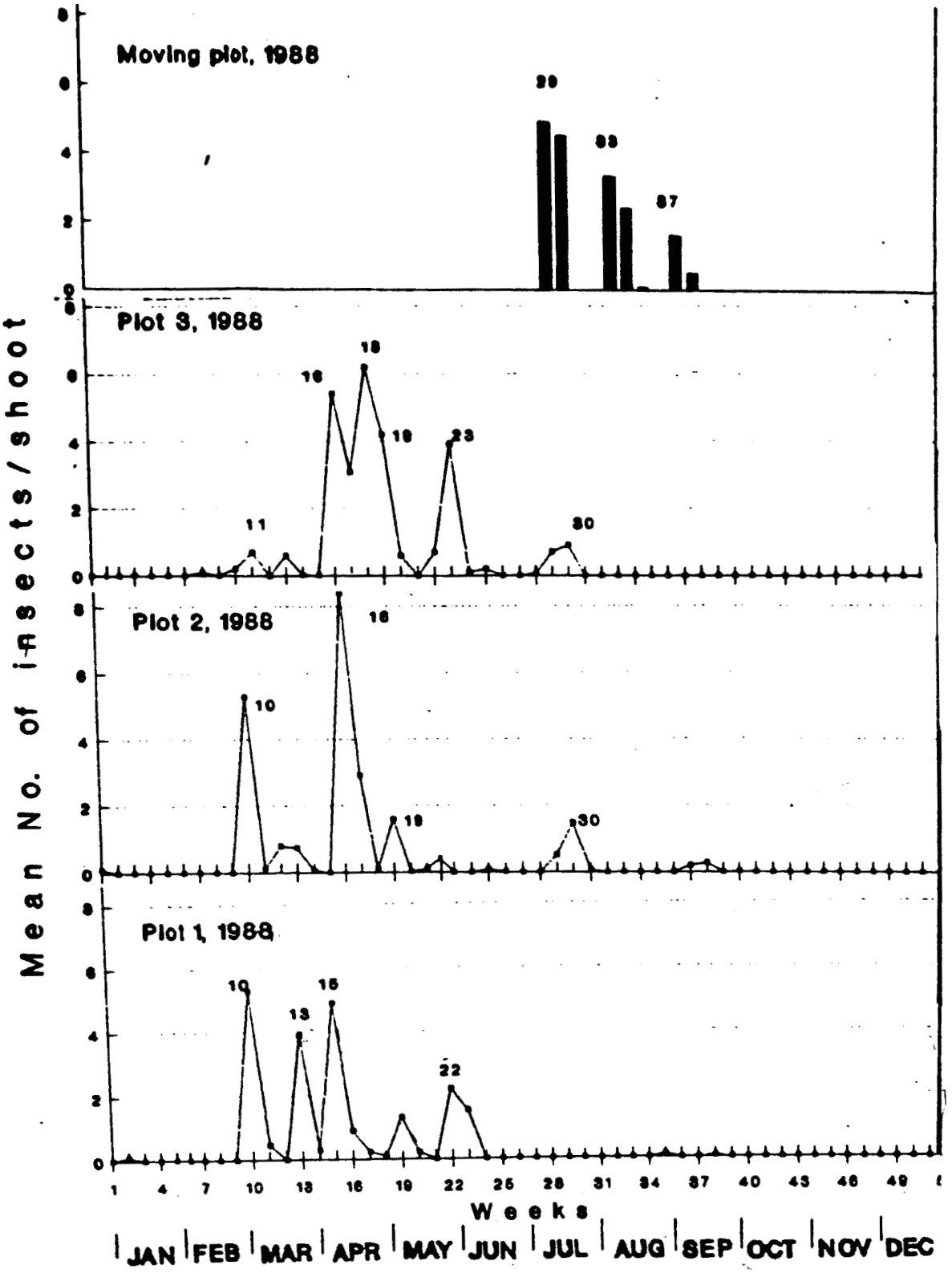


Fig. 2.2.3. Population trend of *H. puera* in 3 permanent plots and the moving plots in 1988. Moving plots were sampled only on the weeks shown. Week number is indicated for each major peak.

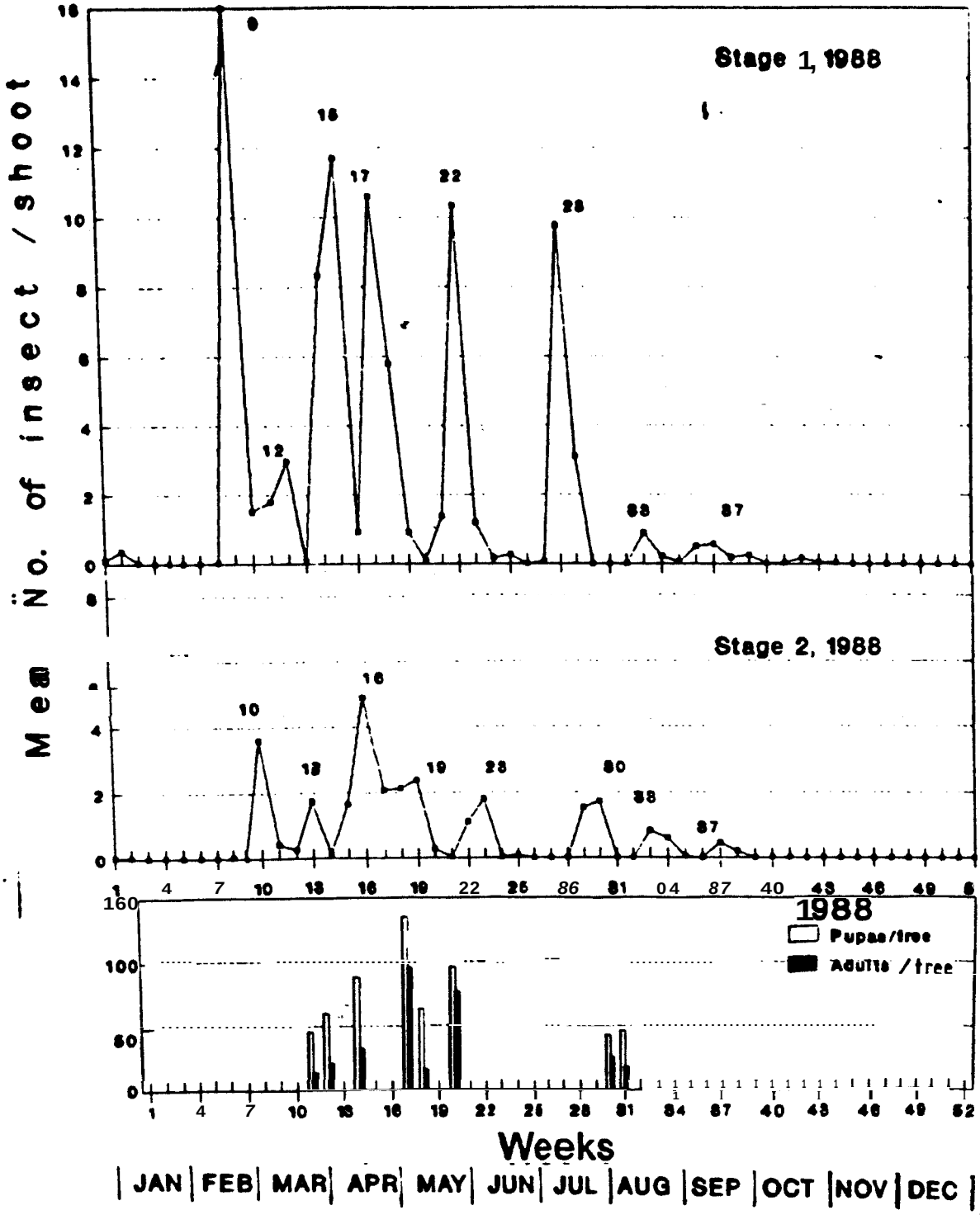


Fig. 2.2.4. Overall population trend in the study area in 1988 for Stage 1, Stage 2, pupae and adults.

in week Nos. 23 and 30 and two smaller peaks in week Nos. 33 and 37. Fig. 2.2.4 also shows the overall population trend for the early instars (stage l), which is in general agreement with the trend noticed for etage 2.

The pupal trend (Fig. 2.2.4) is in general agreement with the above except that the Stage 1 larvae in week No. 22, leading to Stage 2 larvae in week No. 23 was not represented as pupae. Reference to Fig. 2.3.7 (Section 2.3) will show that NPV disease was prevalent during this period. The collapse of this generation is attributed to NPV disease. Absence of pupal peaks corresponding to larval peaks of week Nos. 33 and 37 may be due to poor survival and sampling inadequacy because of low numbers.

Year 1989

The population trend during 1989, is shown in Fig. 2.2.5. The first population peak appeared in week No. 12 (mid-date 22 March) at a location outside Plot 1 where a moving plot was established. This was a patchy infestation, but the population density was high (3.5 insects per shoot). This patch infestation was not represented in any one of the permanent plots. A second peak appeared in week No. 14 (mid-date 5 April), in one of the permanent plots (Plot 2, Fig. 2.2.5) and week No. 15 in the same moving plot. At both these locations the infestation was patchy and the population density was low (1.8 to 2.7 insects per shoot). This population was not represented in Plots 1 and 3 . A third peak appeared in week No. 18 (4-5 May). It was widespread and occurred in all the 3 sample plots. The population density was fairly high (2.3 to 4.2 insects per shoot). A fourth peak occurred in the week No. 20-21 (17 to 23 May). It was widespread and appeared in all the sample plots. This was the major peak infestation of this season, with a very high population density (7.3 to 18 insects per shoot). A fifth major peak appeared in week No. 24 (14-15 June) in Plots 1 and 3 and the population density was very high (7.7 insects per shoot in Plot 1). There were two additional major peaks, but both were restricted to some plots - in week No. 29 (mid-date 19 July) in Plot 3 and week No. 37 (mid-date 16 September) in Plot 2. Fig. 2.2.6 summarises the overall population trend in the study area. The following general conclusions can be drawn. During 1989, considering the entire observation area, there were 4 noticeable population peaks. The most dominant was the 2nd peak (week No. 20). The first, second and the third peaks were also widespread, appearing in all the 3 permanent sample plots. Fig. 2.2.6 also shows the overall population trend for the early instars (Stage 1) which reflected the population trend for stage 2, except that the population size was larger.

The pupal trend (Fig. 2.2.6) is in general agreement with the above, except that the Stage 1 peaks of Week Nos. 23 and 28, leading to the Stage 2 peaks of Week Nos. 24 and 29, were very poorly or not repreeented by pupae. As in previous years, this is attributable to the occurrence of NPV disease during this

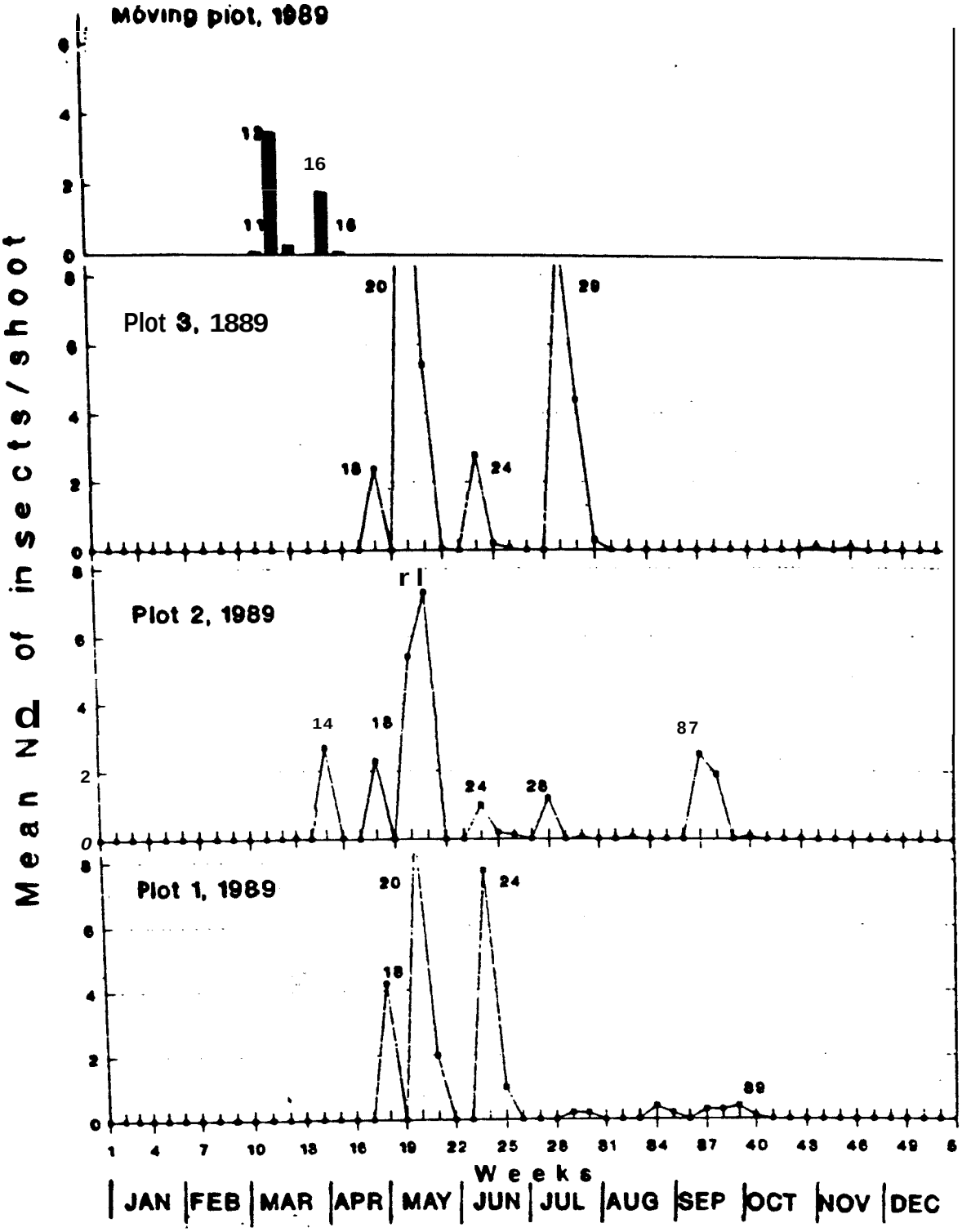


Fig. 2.2.5. Population trend of *H. puera* in 3 permanent plots and the moving plots in 1989. Moving plots were sampled only on the weeks shown. Week number is indicated for each major peak.

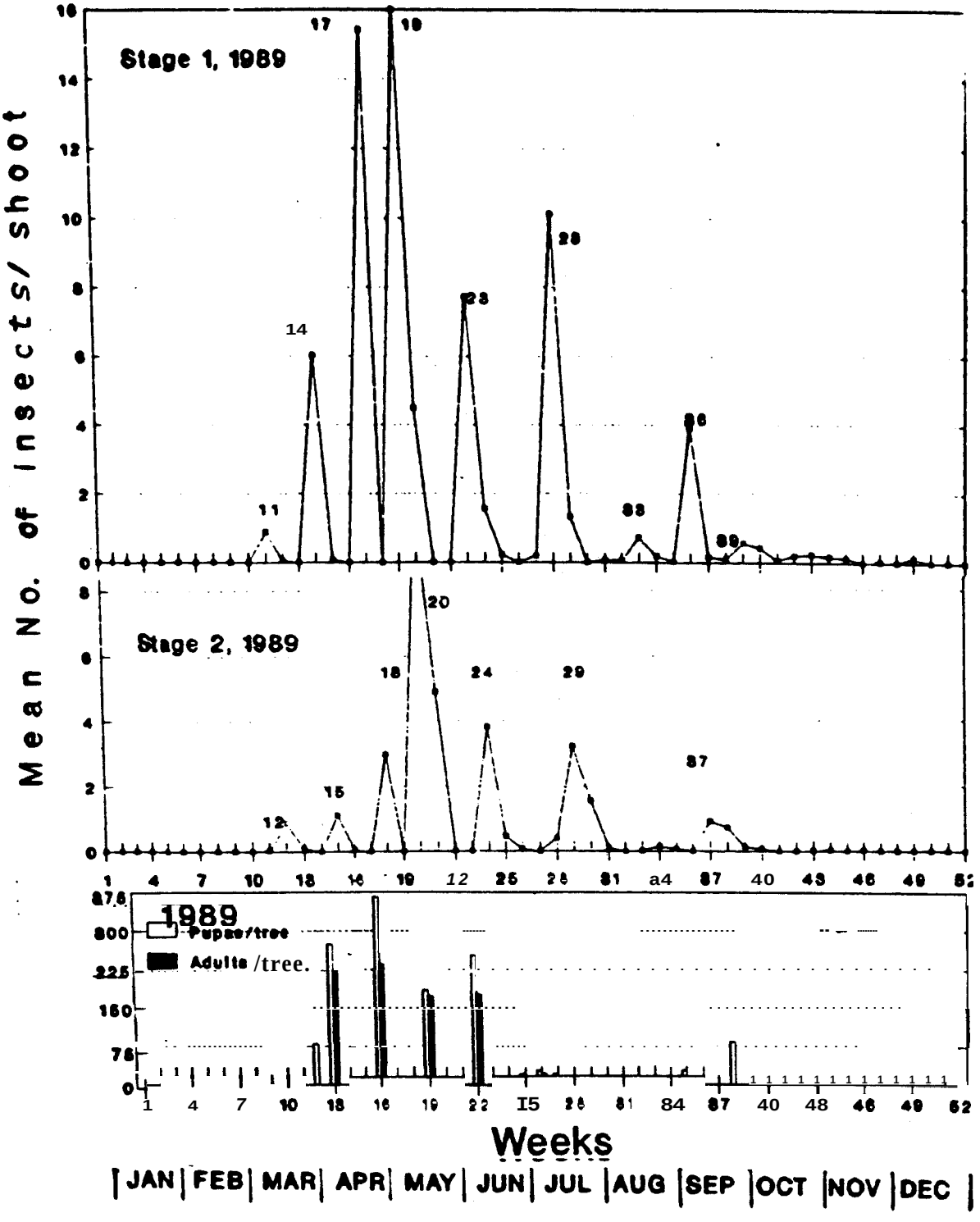


Fig. 2.2.6. Overall population trend in the study area in 1989 for Stage 1, Stage 2, pupae and adults.

period (Section 2.3, Fig. 2.3.7). It may also be noted from Fig. 2.2.6 that the pupae recorded on Week Nos. 12 (late March) and 38 (late September) did not yield adult6 although microscopic examinations were not made; both mortality appeared to be due to bacterial decay.

Conclusions

The general population trend of H. puera over the three years from 1987 to 1989 is shown in Fig. 2.2.7. Several distinct phases can be recognized. The first phase from the 4th week of February to 1st week of April is characterised by small-patch infestation which may appear erratically in some areas prior to the main infestation season. During this period, the population density is comparatively small. The next phase is characterised by heavy and widespread infestation and results in total defoliation of large extent of plantations. In the third phase, the population density declines and infestations again become erratic. Following a lull period, erratic infestations appear again in August, September or October and subsides. From then on, until the first phase begins again next year, the population remains very low, almost undetectable. Fig. 2.2.7 also shows the population trend of the early instars (Stage 1) which display the same trend. The peaks noticed for the early instars on week Nos. 41 and 45 were unusual. They resulted from unusually large number of eggs laid on the mature leaves of a few trees which failed to survive beyond the second instar. The pupal trend (Fig. 2.2.7) reflected the Stage 2 larval trend, in general. The effect of NPV on survival of the larvae to the pupal stage, noted in the yearly trends, is not reflected in the combined data for the 3 years, because of differences in the time of occurrence of the disease between years (Fig. 2.3.6, Section 2.3).

The factors which influence or determine the annual population trends are considered in the following sections.

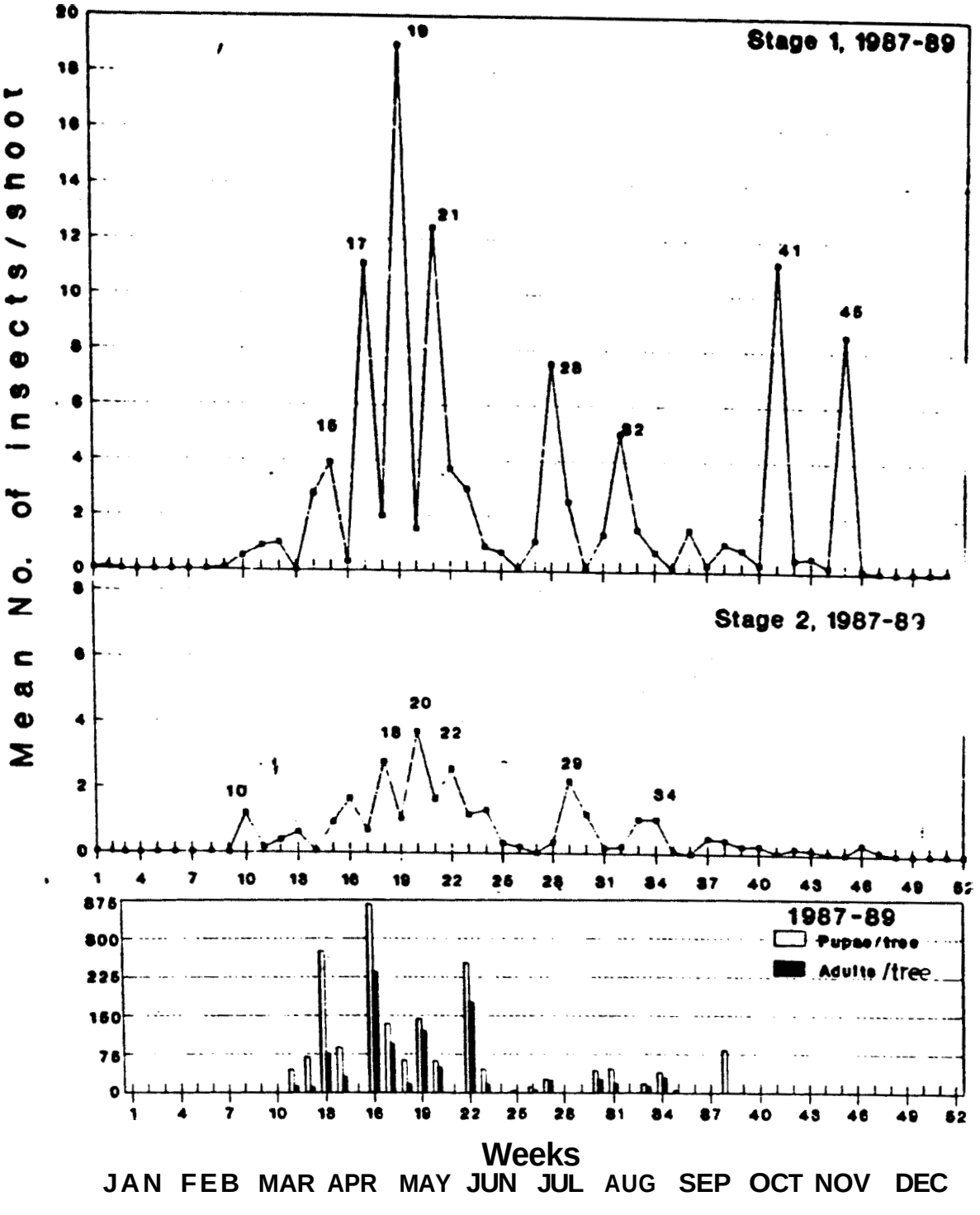


Fig. 2.2.7. Generalised population trend *of Hyblaea puera* for the years 1987 to 1989.

2.3. FACTORS INFLUENCING POPULATION TRENDS

2.3.1. INSECT PARASITOIDS

During the three years of sampling, 15 species of parasitoids were recorded from the study plots at Nilambur (Table 2.3.1). These include 8 species which were not recorded earlier from Nilambur. At the same time, 14 species recorded earlier from Nilambur were not encountered in our study. The total number of parasitoids recorded from **H.** *puera* from the Indian region now stands at 42; of which 26 have been found at Nilambur at one time or other - 10 from larvae and 16 from pupae.

Larval parasitism - quantitative aspects

Of the 6 larval parasitoids, the eulophid *Elachertus* sp. and the ichneumonid *Camptotypus areanus areanus* were present only rarely. The seasonal incidence of the other 4 species is shown in Fig. 2.3.1.

The most dominant parasitoid was the eulophid *Sympiesis* sp., which parasitized over 30 per cent of the larval population on several occasions. Eggs are laid in the 1st instar larvae and the parasitoid larvae feed externally. This was followed by the tachinid *Palexorista solennis* which parasitises late instars. The others were sporadic. Fig. 2.3.1 also shows the changes in the host population over time. It may be noted that the percentage of parasitism did not increase with increase in the host population, although most parasitoid species except *Sympiesis* appeared after the initial population build-up.

The use of percentage parasitism to quantify the impact of parasitoids can often be misleading, particularly when the host numbers fluctuate violently. For example cent percent parasitism by *Sympiesis* sp. was recorded in individual plots on several occasions when the host number was very small. Fig. 2.3.2 shows the actual numbers of parasitized larvae (by all parasitoids) in comparison with the total number of larvae. It may be seen that the number of parasitized larvae was very small compared to the total population of larvae. In addition, it is evident that the number of parasitized larvae did not increase when the total population increased. This was further examined by analysing the correlation between the two. Data for 258 sampling dates during 1987-89 were used for this purpose. The scatter diagrams (Fig. 2.3.3) show that there was no correlation between the number of parasitized larvae or the percentage of parasitized larvae and the total number of larvae.

Effective parasitoids should increase in number with the host population, usually with a lag, and similarly decline in number with the collapse of the host population. In other words, they should display a host density-dependent numeric response.

Table 2.3.1. Parasitoids of the teak defoliator *Hyblaea puera* at Nilambur

Host stage	Order and Family of parasitoids	Parasitoid species
Larva	HYMENOPTERA	
	Eulophidae	*Elachertus* sp.*[1]
		Sympiesis sp.*
	Elasmidae	*Elasmus* sp.*
	Ichneumonidae	*Camptotypus areanus areanus* (cam.)**[1]
		Eriborus gardneri Cush.**
	DIPTERA	
	Tachinidae	*Palexorista solennis* Walker
Pupa	HYMENOPTERA	
	Braconidae	*Phanerotoma* sp.[1]
	Chalcididae	*Brachymeria lugubris* (Wa1ker)[1]
		B. lasus (Walker)
		Psi1ochalcis carini Gena (Cameron)[1]
	Eulophidae	*Tetrastichus howardi* (0lliff)[1]
	Ichneumonidae	*Echthromorpha agrestoria notulatoria* Fabr.
		Xanthopimpla sp.[1]
		Theronia maskeliyae (Cameron)[1]
	DIPTERA	
	Tachinidae	*Exorista* sp.
		Peribaea sp.[1]

* Attacks early larval instars; ** Attacks middle larval instars; 1, Species recorded on H. *puera* for the first time in India.

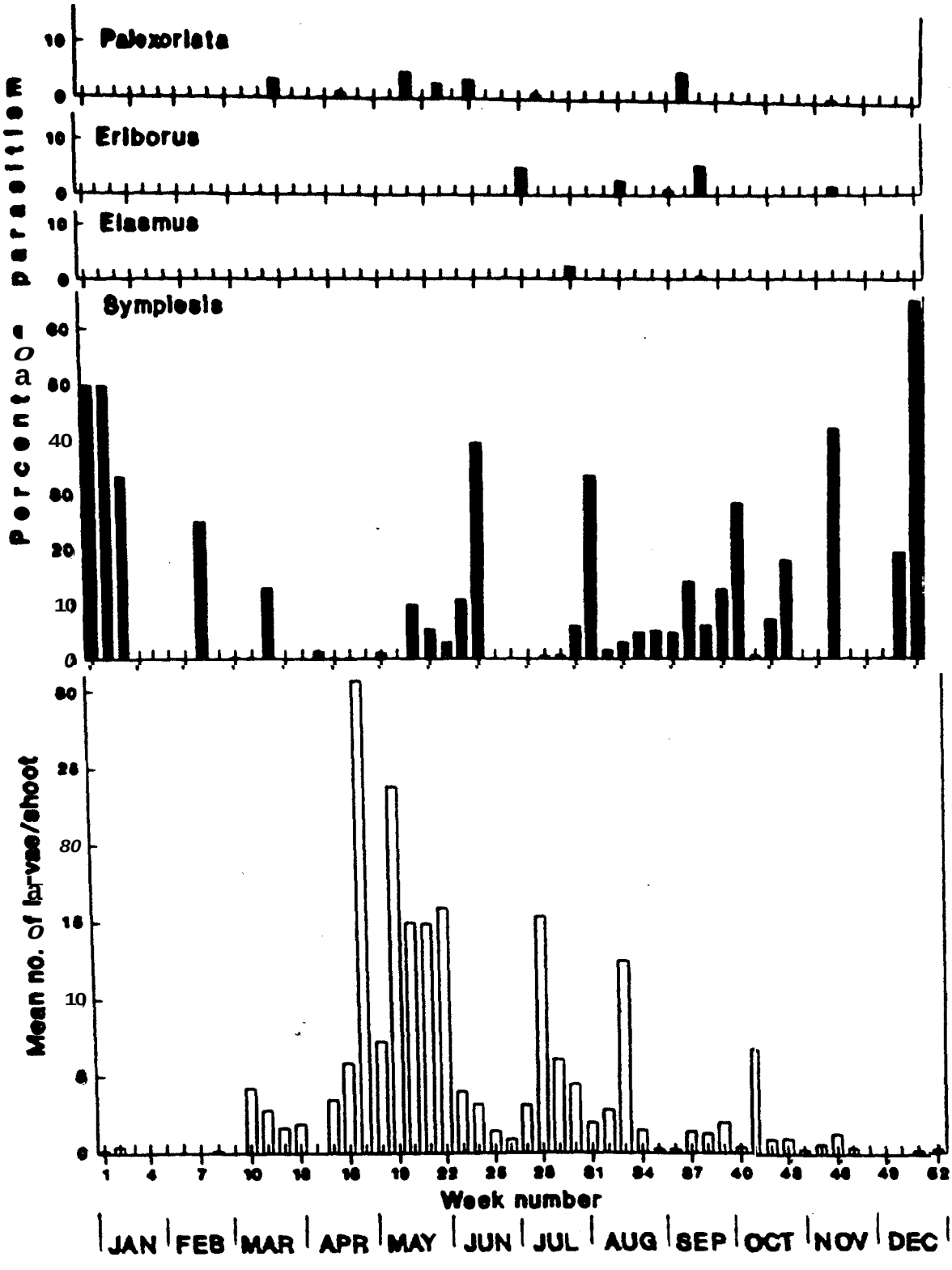


Fig. 2.3.1. Mean trends of percentage parasitism by the major larval parasitoids. The mean population trend of host larvae is also shown.

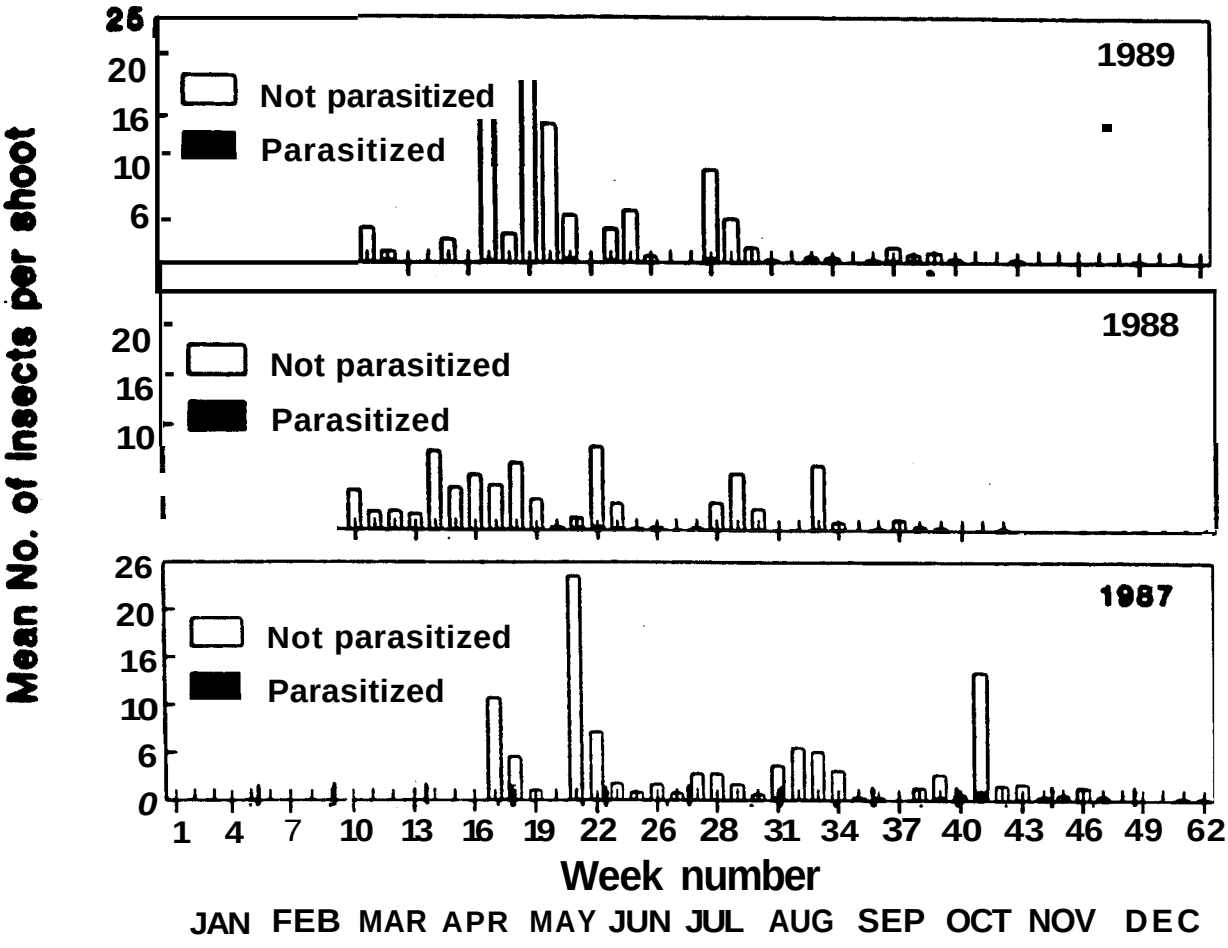


Fig. 2 3.2. Actual number of parasitized larvae (due to all parasitoids) in comparison with the total number of larvae. For each year, each value represents the mean of at least 3 plots.

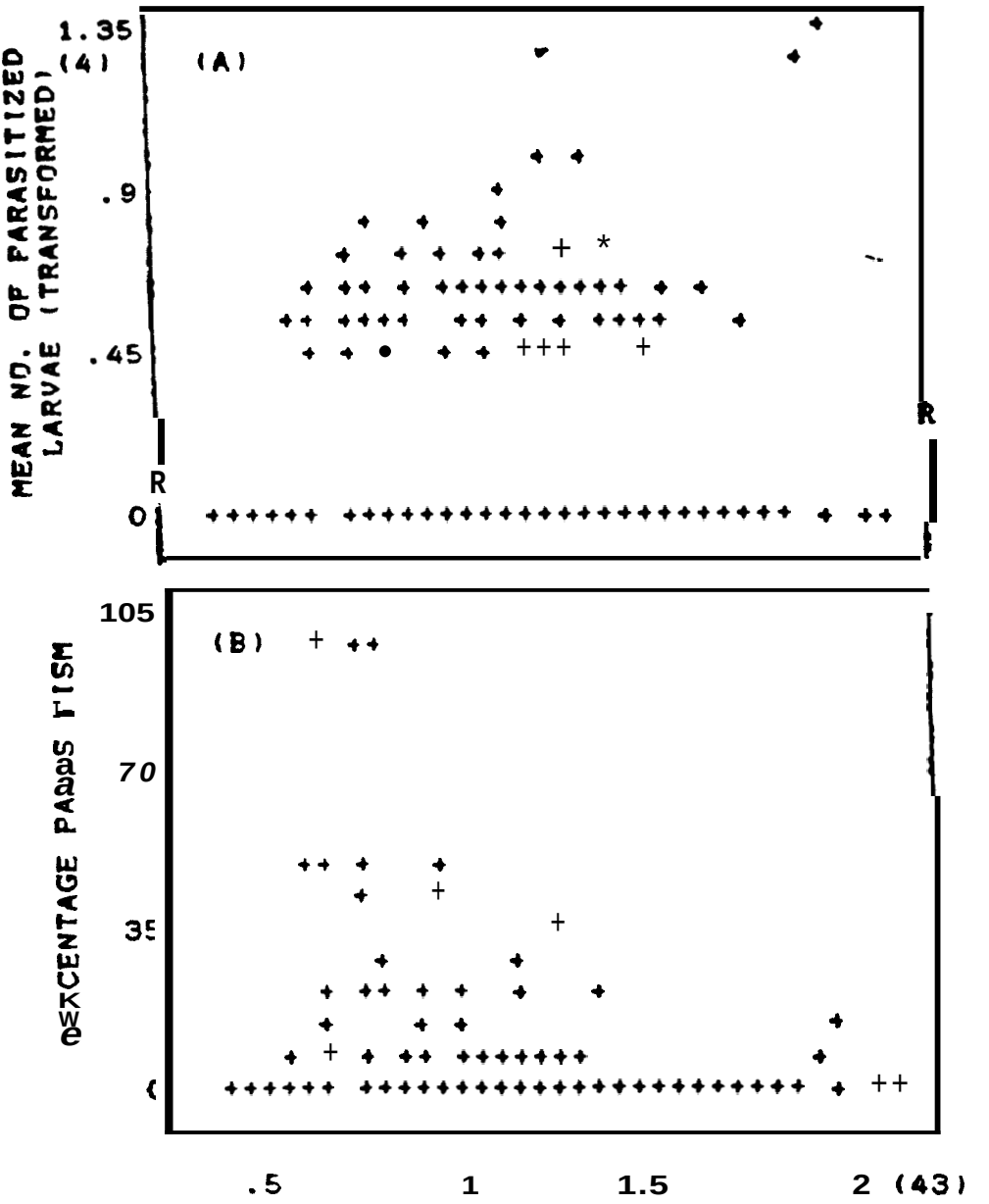


Fig. (A) Number of parasitized larvae plotted against the total number of larvae per shoot. (B) Percentage parasitism plotted against the number of larvae per shoot. The actual number of larvae per shoot which ranged from 0.1 to 43 and the number of parasitized larvae which ranged from 0 to 4 were transformed (raised to the power of 0.195 following Taylor's power law) to stabilize the variance.

Such typical responses predicted by the parasitoid/predator-prey-theory, have been demonstrated in several parasitoids, both in laboratory cultures and in field populations (see Dent, 1991).

At first sight, the above data euggest that the parasitoid population, particularly that of *Sympiesis* which was present more or less throughout the year may be regulated by factors other than host density, i.e., food availability. However, closer examination ehows that the observed parasitoid response is attributable to the unique spatial dynamics of the host population.

The spatio-temporal heterogeneity in the build-up of *H. puera* populations is obvious from the data presented in Section 2.2. Population outbreaks appeared at different times in different plots although there was coincidence on some occasions (see Figs. 2.2.1, 2.2.3 and 2.2.5, Section 2.2). It is obvious that parasitoid populations are unable to respond numerically to host density increase because of the highly mobile nature of H. puera populations. When a new generation of adult parasitoids is built up in a locality, the host moves away to another area. Similarly when a high-density population of the susceptible stage of host larvae is built up from an incoming population of moths, there is rarely a large resident population of parasitoids. This results in spatial separation of the host and its parasitoids, host migration helping it to evade the parasitoids (Nair, 1987). This explains the lack of numerical response of the parasitoids to host density. Under these circumstances, natural enemies locally conserved by the silvicultural methods recommended earlier cannot prevent outbreaks caused by an incoming wave of moth population.

Pupal Parasitism - Quantitative Aspects

Of the 9 pupal parasitoids recorded at Nilambur in our study, all except the chalcid *Brachymeria* lasus was very rare. The mean percentage parasitism by *B. lasus* was, however, very low (Fig. 2.3.4). The tachinid, *Palexorista solennis* which is essentially a parasitoid of late instar larvae often emerged from pupae, and it was consistently present (Fig. 2.3.4), although the per cent parasitism was higher in larvae (compare with Fig. 2.3.1).

As in the case of larval parasitoids, the pupal parasitoids also did not show a host density-dependent numeric response (Fig. 2.3.5), obviously for the same reason discussed earlier. It is also evident that parasitoids had little impact on the survival of H. puera pupae.

Some General Observations

The data presented above are based on the average trends of parasitism. Data from a minimum of 3 study plots in the ca. 1000 ha Kariem-Muriem teak plantations have been pooled over three years. While this facilitates us to arrive at significant general

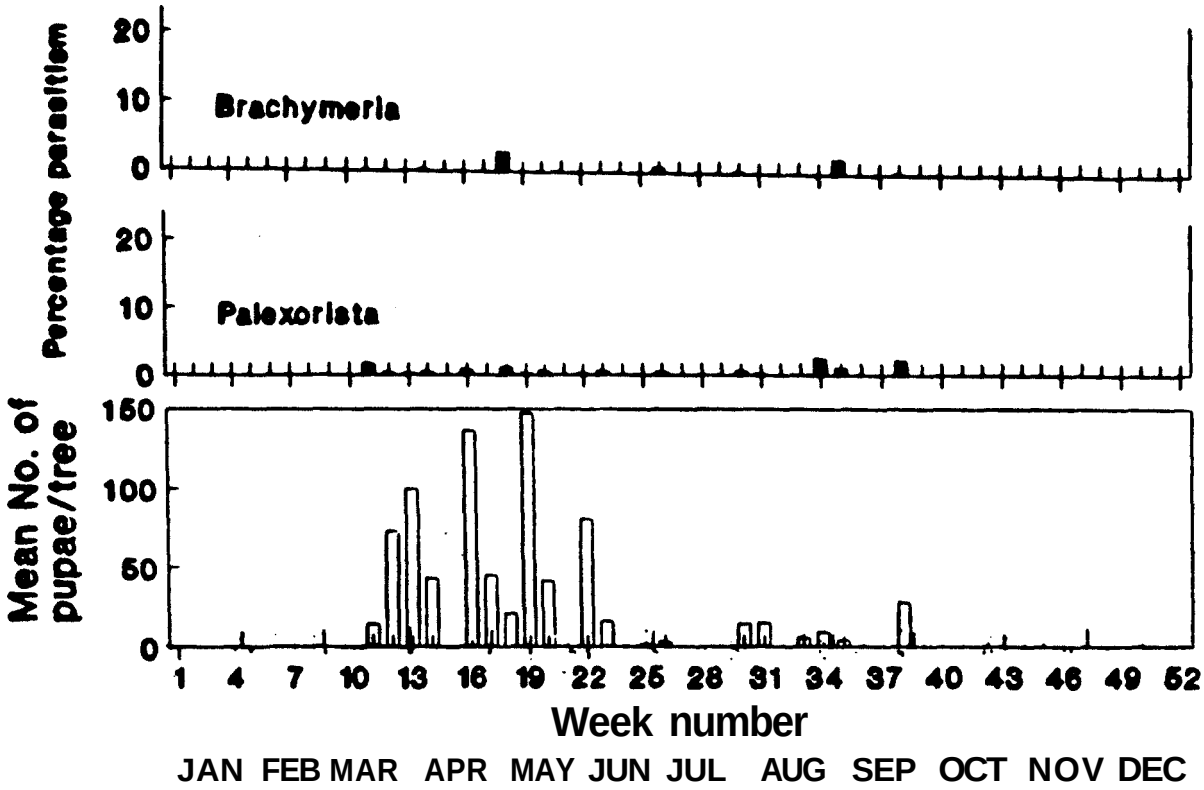


Fig. 2.3.4. Mean trends of percentage parasitism by the major pupal parasitoids and the mean population trend of host pupae over the year, during 1987-89.

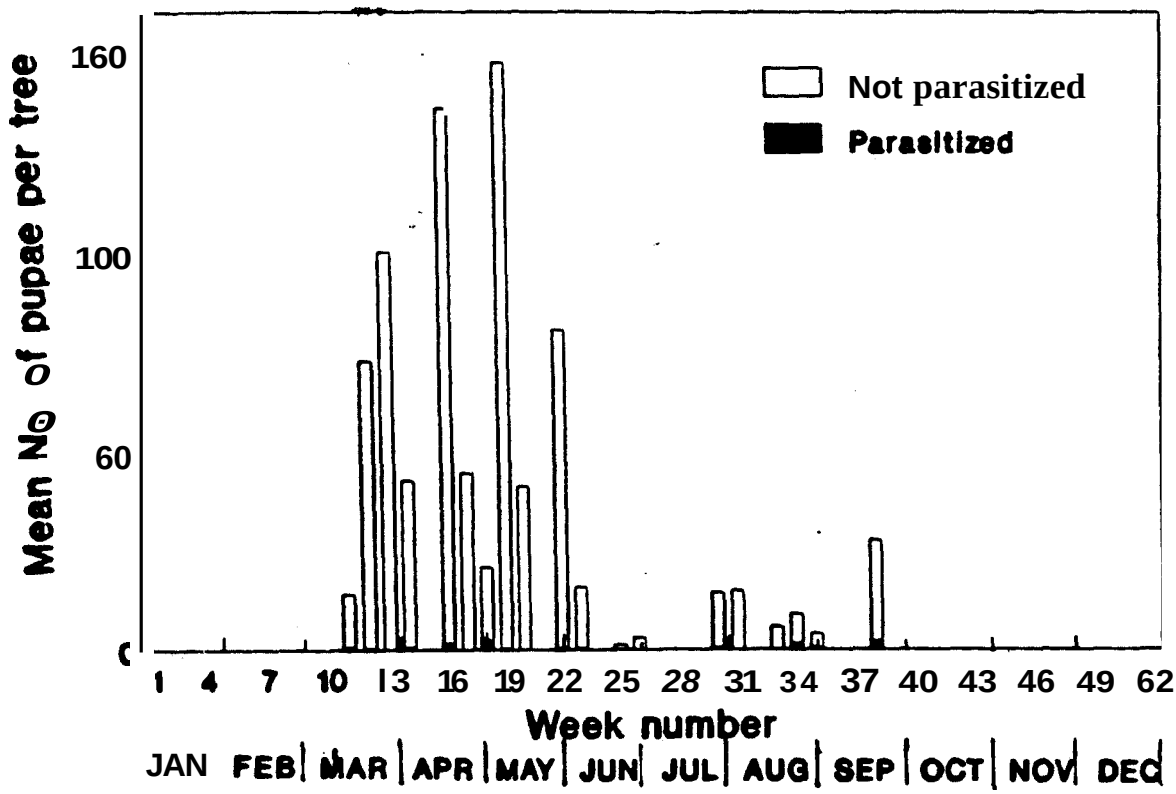


Fig. 2 3.5. Actual number of parasitized pupae in comparison with the total number of pupae. Each value is a mean for at least 3 plots, over the 3 years from 1987 to 89.

trends, such pooling of data over space and time leads to masking of some ecologically significant features. A common finding was the occurrence of unusually high incidence of parasitism by some species at particular sites, at particular times. For example, the incidence of the ichneumonid *Eriborus gardneri* reached about 32% in one plot in late September 1987 and 16% in one plot in late August 1989, but was practically absent at other times, except on two occasions. On some occasions, while searching for pupae on the ground, large numbers of dead 4th instar larvae were found underneath fallen leaves. *E. gardneri* had emerged from all of them, but such instances go unrecorded in regular foliage sampling. Khan and Chatterjee (1944) also found upto 35% parasitism by this species in Tithimatti, Coorg in 1942. Similarly, Sudheendrakumar (1986) reported that during a 2-year study, the ichneumonid *Stictopisthus* sp. was found only on one occasion, in July 1983, at Aravallikkavu where it parasitized 11% of the 85 larvae examined. Again, in field observations in a teak plantation at Pullamkandam, near Peechi, Trichur on 9 June 1977, an outbreak of H. *puera* larvae was found abruptly cut short by parasitoids. A batch of 200 larvae brought to the laboratory yielded only one adult; the rest yielded the tachinid *Palexorista solennis* or an unidentified hymenopteran (Nair and Sudheendrakumar, 1986). Such extreme cases of high parasitoid incidence appear to be common for many host-parasitoid systems, but are not often reported.

Discussion

From the data presented, it is obvious that parasitoids do not constitute an important factor affecting the population build-up of H. *puera* during the outbreak phase. Their contribution to regulation of host numbers during the non-outbreak period is less clear, but parasitoids do not appear to be a key factor responsible for driving the changes in the host population.

The ineffectiveness of parasitoids in regulating the host population is mainly due to the spatial heterogeneity in the distribution of outbreak populations of the host. We commonly assume that the hosts are distributed uniformly in space and that the parasitoids "search randomly for the hosts. There is increasing evidence that in the real world, prey populations will tend to have clumped distributions and parasitoids and predators may then spend more of their time in areas where prey are plentiful, i.e., non-random search in a patchy environment, leading to an aggregation of natural enemies (Hassel, 1984). A striking example of such clumping of natural enemies is the aggregation of flocks of crows often found in teak plantations during the later stages of defoliator outbreaks. Such behavioural mechanisms might be operating in some insect parasitoids as well. By aggregating in certain patches,, particulary of high host density, the parasitoids are leaving other patches as partial refuges from parasitism (Waage and Hassel, 1982), thereby ensuring the survival of both the host and the parasitoid. The same situation arises due to migration of

H. puera moths (Nair, 1987). The progeny of the incoming moths have little pressure from endemic natural enemies, and the successfully emerging parasitoid adults cannot find sufficient hosts to oviposit.

The potential of inundative release of parasitoids for control of H. *puera* may be discussed briefly here. Among the various categories of parasitoids, the egg parasitoids, particularly *Trichogramma* spp. are easier to mass-produce and are available commercially. However, in view of the sudden, unpredictable mass egg laying by immigrant moths during outbreaks and the short incubation period of 36 to 48 hours, timely field release of mass produced *Trichogramma* is impracticable, particularly in remote forest plantations.

The pupal parasitoids are also not suitable for inundative release. Firstly, pupal parasitoids exert their control only in the next generation of the host. Since the emerging moths move away *en masse* to other areas, plantations in a chosen area cannot be protected by releasing pupal parasitoids. Secondly, the pupal parasitoids are not very efficient (low parasitization rates), apparently because of the concealed habitat of the pupa. (The larval-pupal parasitoid *Palexorista solennis* which attacks the late larval instar was the most efficient within this group.)

The suitable candidates for inundative release, therefore, are to be found within the category of larval parasitoids. Among these, the bethylids and eulophids (in general) attack early larval instars, the braconids and ichneumonids, middle larval instars and the tachinid, late larval instars. Those which attack late instars are not very suitable, because by the time they are able to exert their influence, the damage is already done. Based on the available information, the most promising species for applied biological control of H. *puera* through inundative release of mass-reared parasitoids are the bethylid *Goniozus montanus* and the eulophids *Sympiesis* sp. and *Elasmus hyblaeae. Sympiesis* sp. has been reared on *Corcyra* in our laboratory (Bharathan and Sudheendrakumar, unpublished). More investigations are needed on these selected promising parasitoids. The usefulness of the braconid *Apanteles machaeralis* and the ichneumonid *Eriborus gardneri* also needs further study.

2.3.2 PREDATORS

Predators of *H. puera* larvae included insects, spiders and birds. The predatory insects and spiders recorded in this study are listed in Table 2.3.2. The insect and spider predators were recorded both in low-density and high-density populations. Although no quantification of the larvae removed by predators was made, general observations indicated that they are not major factors influencing the population trend.

Bird predation was observed mainly during periods of outbreaks. A total of 48 species were found to feed on *H. puera* (Table 2.3.3).

Table 2.3.2. Insect and spider predators of *Hyblaea puera*

Group/family	Species
Insects	
Carabidae (Coleoptera)	*Parena nigrolineata* Chd.
Pentatomidae (Hemiptera)	*Eocantheconidea furcellata* (Wolff)
Reduvidae (Hemiptera)	*Euagoras plagiatus* Burmeister
	Endochus sp.
	Rhinocoris fuscipes (Fabricius)
	Sphedanolestes (?)aterrimus Distant
Spiders	
Araneidae	*Leucauge decorata* (Black)
	Gasteracantha geminata (Fabricius)
	Neoscona laglazei (Simon)
	Leucauge fastigata (Simon)
	Gasteracantha hasseltii C.L. Koch
	Leucauge sp.
	Cyclosa sp.
	Neoscona sp.
Oxyopidae	*Oxyopes shweta* Tikader
	O. sikkimensis Tikader
	O. ratanae Tikader
Clubionidae	*Chirachanthium himalayansis* Gravely
	Clubiona ludhianaensis Tikader
Salticidae	*Phidippus* sp.
Lyssomanidae	*Lyssomanes andamensis* Tikader
Theridiidae	Airgyrodes sp.

Table 2.3.3. Bird predators of immature stages of *Hyblaea puera*

Common name	Scientific name	Feeding zone
Yellow-wattled Lapwing	*Vanellus malabaricus*	Ground
Blossom-headed Parakeet	*Psittacula cyanocephala*	Leaf
Hawk Cuckoo	*Cuculus varius*	Leaf
Indian Cuckoo	*C. micropterus*	Leaf
Baybanded Cuckoo	*Cacomantis sonnerati*	Leaf
Plaintive Cuckoo	*C. merulinus*	Leaf
Crow Pheasant	*Centropus sinensis*	Scrub
Whitebreasted Kingfisher	*Halcyon smymensis*	Leaf
Chestnutheaded Bee-eater	*Merops ieshenaulti*	Silk thread
Small Green Bee-eater	*M. orientalis*	Silk thread
Roller	*Coracias bengha1ensis*	Leaf
Small Green Barbet	*Megalaima viridis*	Leaf
Rufous Woodpecker	*Micropterus brachyurus*	Leaf, Stem
Irora	*Aegithina tiphia*	Leaf
Goldfronted Chloropsis	*Chloropsis aurifrons*	Leaf, Scrub
Red-whiskered Bulbul	*Pycnonotus jocosus*	Leaf
Red-vented Bulbul	*P. cafer*	Leaf
Jungle Babbler	*Turdoides striatus*	Leaf, Stem, Ground, Scrub
Rufous Babbler	*T. subrufus*	Ground, Scrub
Coorg Wren Warbler	*Prinia hodgsoni*	Leaf, Stem, Scrub
Tailor Bird	*Orthotomus sutorius*	Leaf, Stem, Scrub
Blyth's Reed Warbler	*Acrocephalus dumetorum*	Scrub
Greenleaf Warbler	*Phylloscopus trochiloides*	Leaf, Scrub
Magpie Robin	*Copsychus saulans*	Ground
Indian Robin	*Saxicolides fulicata*	Ground
Velvet-fronted Nuthatch	*Sitta frontalis*	Stem
Purple-rumped Sunbird	*Nectarinia zeylonica*	Leaf
Scally-bellied Green Woodpecker	*Picus myrmecophoneus*	Stem
Golden-backed Woodpecker	*Dinopium benghalense*	Leaf, Stem
Yellow-fronted Pied Woodpecker	*Dendrocopus maharattensis*	Leaf, Stem
Malabar Pigmy Woodpecker	*D. nanus*	Leaf, Stem
Indian Oriole	*Oriolus oriolus*	Leaf
Black-headed Oriole	*O. xanthornus*	Leaf
Black Drongo	*D. adsimilis*	Silk thread
Bronzed Drongo	*D. aenius*	Silk thread
Racket-tailed Drongo	*D. paradiseus*	Silk thread
Grey-headed Myna	*Sturnus malabaricus*	Leaf
Blyths Myna	*S.m. blythii*	Leaf, Scrub
Common Myna	*Acridotheres tristis*	Leaf
Jungle Myna	*A. fuscus*	Leaf
Tree Pie	*Dendrocitta vagabunda*	Leaf
House Crow	*Corvus splendens*	Leaf
Jungle Crow	*C. macrorhynchos*	Leaf
Malabar Wood Shrike	*Tephrodornis virgatus*	Leaf
Common Wood Shrike	*T. pondicerianus*	Leaf
Large Cuckoo Shrike	*Coracina novachollandiae*	Leaf
Small Minivet	*Pericrocotus cinnamomeus*	Leaf
Orange Minivet	*P. f1*	Leaf

The feeding habits ranged from picking the larvae from leaf, tree trunk or ground vegetation to capturing the larvae hanging on silk threads. Some species searched out pupae from the ground or leaf folds.

The following species were judged to be the most important predators - Jungle Babbler, Rufoua Babbler, Coorg Wren Warbler, Greenleaf Warbler, Goldfronted Chloropsis and Blyths Myna.

On some occasions, bird predation of *H. puera* pupae amounted to 47 to 79% of the total number of pupae sampled (Table 2.3.4). It is interesting to note that the higher ratio of predation were observed during the non-outbreak period.

Table 2.3.4. Bird predation of *H. puera* pupae

Date of Observation	Plot No.	No. of Pupae sampled	No. of pupae predated
12 May 1987	2	1011	105 (10%)
6 June 1987	2	424	4 (0.9%)
2 Aug. 1988	1	507	75 (15%)
2 Aug. 1988	2	620	93 (15%)
28 March 1989	Moving plot	408	95 (23%)
1 Sept. 1989	1	137	108 (79%)
28 Sept.1989	2	835	388 (47%)

In general, birds do not influence the population trend to any major extent during the outbreaks. Although a large number of larvae are consumed by birds during outbreaks, because of the immense number of larvae during the outbreaks, the impact of birds is very small. Their possible role in suppressing the early outbreaks remains to be critically studied.

2.3.3. DISEASES

Disease-caueing organisms of H. *puera* recorded in this study included the Nuclear Polyhedrosis Virus (Sudheendrakumar, *et al.*, 1988); the bacteria *Bacillus thuringiensis, B. cereus,* and *Enterobacter aerogenes;* and the fungus *Hirsutella* sp. (Mohamed Ali, *et al.,* 1991). The seasonal incidence of diseases and its impact on H. *puera* populations is examined below.

The disease incidence reported here is mainly attributable to NPV in the case of larvae and a combination of NPV and bacteria, notably *E. aerogenes,* in the case of pupae.

DISEASE INCIDENCE IN LARVAE

Due to the characteristic appearance of NPV killed larvae larval mortality due to NPV was clearly identifiable at the time of sampling. However, since death may occur within 72 hours of NPV intake, but the sampling was carried out only at weekly interval this sampling cannot be considered adequate to assess the impact of NPV under field conditions. Sampling at 3-day interval would have been necessary. Alternatively the sampled larvae can be observed in the laboratory, for manifestation of the disease. However, keeping the limitations in mind, the available data are examined here.

The recorded incidence of disease in *H. puera* larval populations during the years 1987 to 1989 are shown in Fig. 2.3.6. As examination of plot-wise data did not show any major differences between plots, the data for all plots were combined for each year. It may be seen that disease occurred almost throughout the year whenever the host population was present, but the percentage of incidence was higher following the initial host population outbreaks each year. Bacterial disease, however, was more prevalent during the early part of the season (see Fig. 2.3.7). For example, on 6 June 1987 (Week No. 23) dead and bloated larvae and prepupae were noticed in the field from which the bacterium *Enterobacter aerogenes* was consistently isolated.

Fig. 2.3.7 shows the quantitative relationships in the incidence of disease in larval populations over the 3 year study period. The number of diseased larvae recorded is very small compared to the total number of larvae. However, as noted above, the sampling of diseased larvae cannot be considered adequate. Sampling should have been done at more frequent intervals or continued observation of sampled larvae should have been made in the laboratory to bring out a more realistic quantitative impact of disease. As noted earlier (Section 2.2) information generated from the continuous sampling of larval instars and pupae indicated that NPV disease caused significant mortality of larvae in some generations in most years, particularly after the first few generations of the year.

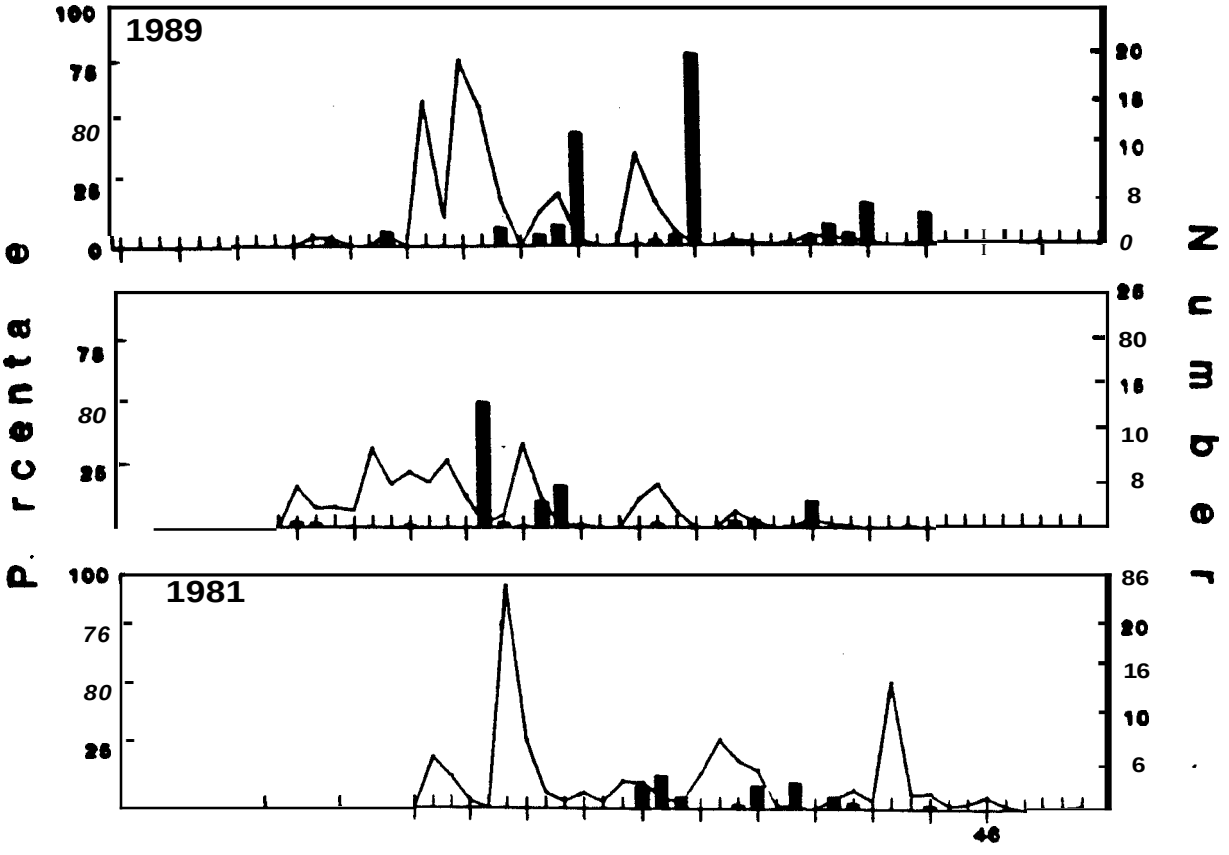


Fig. 2.3.6. Incidence of NPV disease in H. *puera* larval populations, 1987–1989, as recorded in weekly sampling. Percentage of diseased larvae (bars) are shown in relation to the mean number of larvae per shoot (lines) for each year. In 1987, sampling started only on Week No. 8.

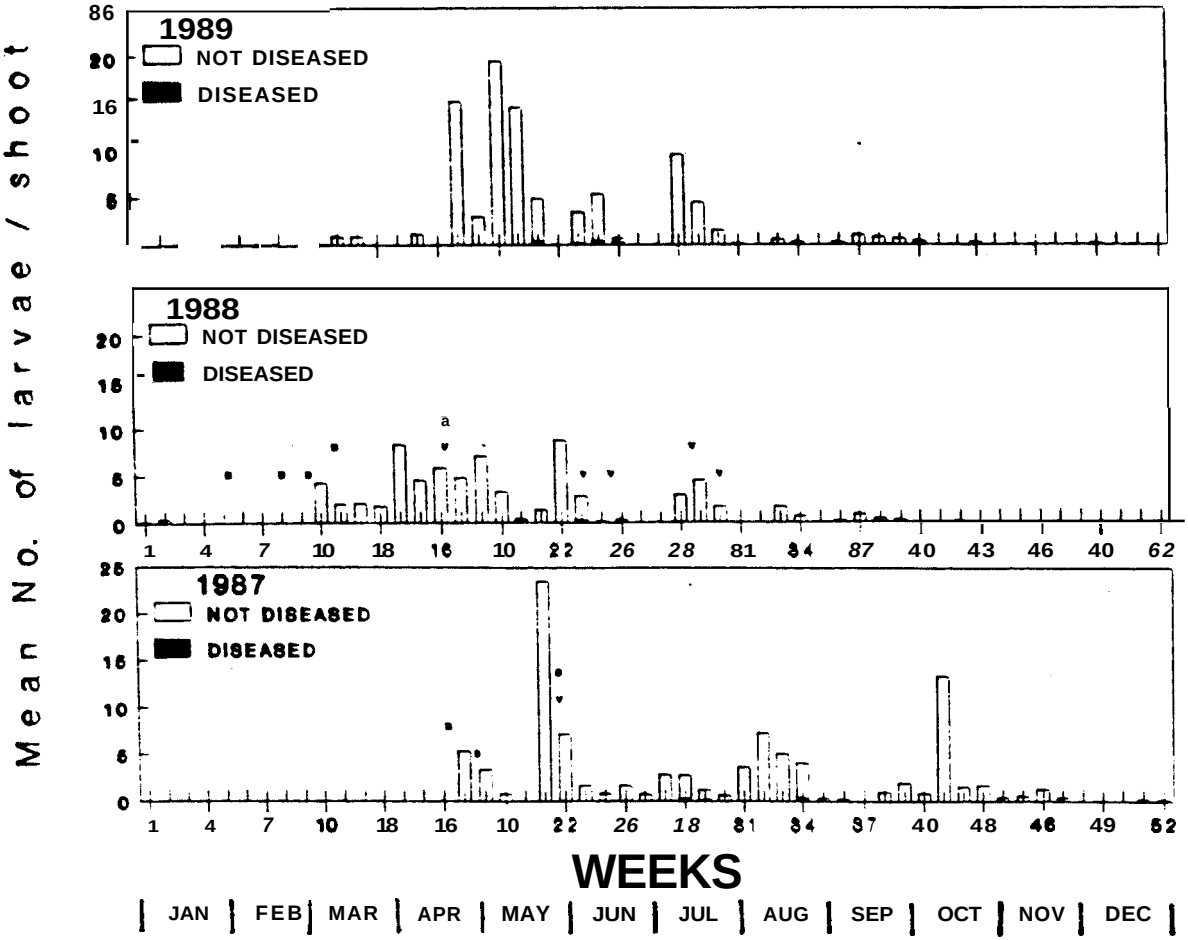


Fig. 2.3.7. Quantitative relationships in the incidence of NPV disease in H. *puera* larval populations, 1987-1989, as recorded in weekly sampling. The actual number of diseased larvae are shown in relation to the total number of larvae per shoot. In 1987, sampling started only on Week No. 8. Where identified, the disease agent (bacteria, B; virus, V) is indicated above the bar.

DISEASE INCIDENCE IN PUPAE

In the case of pupae, death occurred due to infection by NPV or bacteria in the larval stage. However, the primary cause was not distinguishable without laboratory examination. Occasional microscopic examination of moribund pupae showed that most death was caused by *Enterobacter aerogenes.* This organism was consistently isolated from dead pupae. *B. thuringiensis* and *B. cereus* infections were also encountered, but very rarely. Infection by the fungus *Hirsutella* sp. was also recorded on two occasions.

The incidence of disease in pupae over the 3 years is shown in Fig. 2.3.8. A substantial proportion of pupae were killed by diseases. For example, in 1988, in Plot 2, out of 129 pupae sampled on 14 March, 124 (96%) were dead and out of 1174 pupae sampled on 4 April, 1101 (94%) were dead, both due to disease. Bacterial disease was prevalent during the early part of the season. NPV is believed to be responsible for the greater proportion of the mortality recorded subsequently, although specific microscopic examinations were not made.

Disease caused about 23% mortality of the pupae in 1987, 33% in 1988 and 44% in 1989.

DISCUSSION

This study has shown that diseases caused by bacteria and NPV lead to mortality of larvae as well as pupae. Although the proportion of larvae killed by diseases as brought out by this study was small, this may be due to inadequacy of the sampling methods, as noted earlier. In the case of pupae, about one third of the total population was killed by disease. Some pupae were found partially empty and dried-up when opened. This could not be attributed to any specific disease, but is included in the above mortality; a precise break-up of the mortality due to various diseases was not possible.

compared to parasitoids and predators, diseases appear to be a more important mortality factor. Although drastic decline of larvae due to NPV,was not recorded in the disease sampling, as noted earlier (section 2.2), other evidences indicate collapse of some generations due to NPV disease. In future studies, a better estimate of disease incidence in larvae can be obtained by examining field-collected larvae by maintaining them in the laboratory for 72 hrs. However, extreme care is necessary to prevent contamination of the field samples with NPV from the laboratory.

Based on the results presented above, bacterial and NPV diseases must be recognized as major mortality factors for both larvae and pupae.

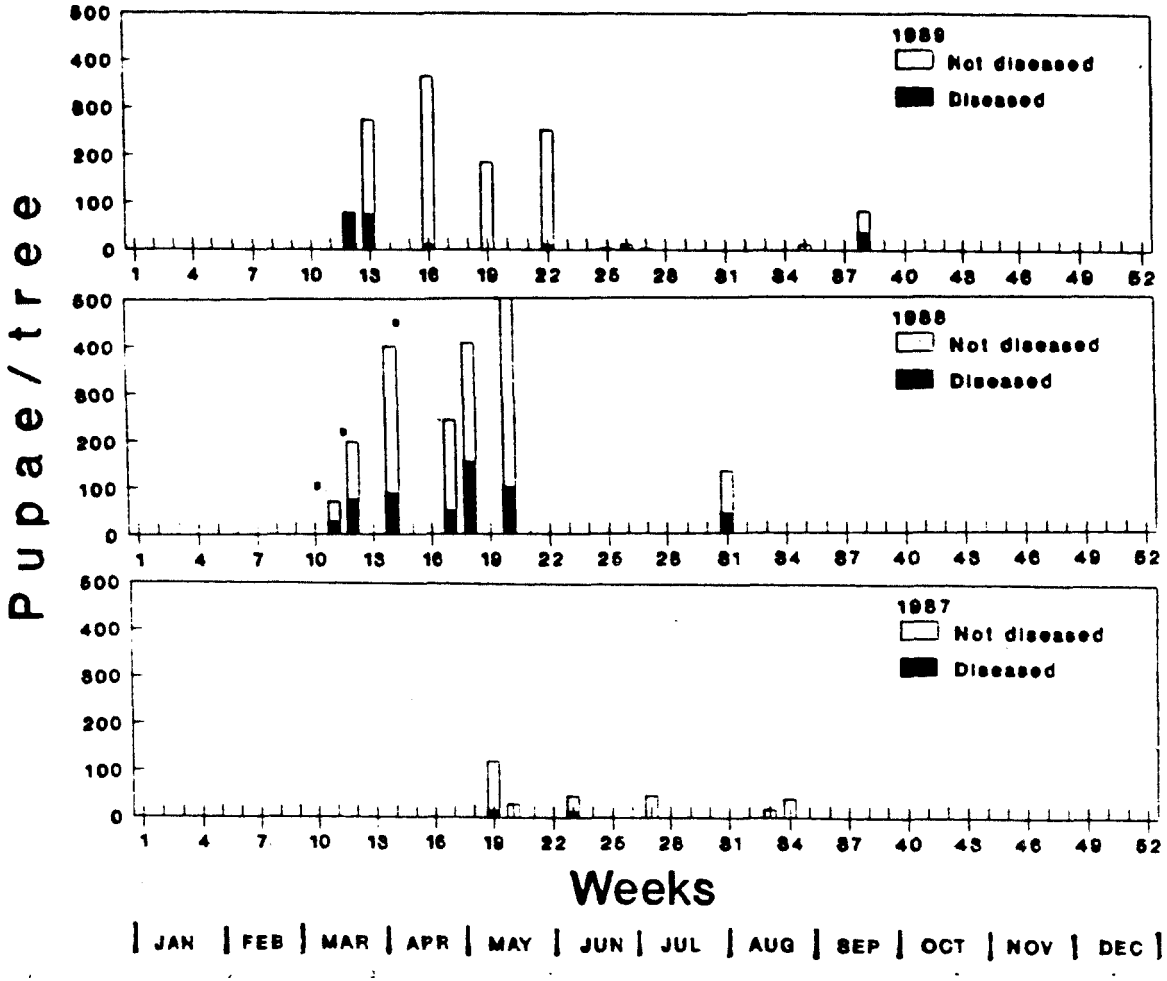


Fig. 2.3.8. Incidence of disease in *H. puera* pupal populations, 1987-1989. Where identified, bacterial disease is indicated by the letter 'B' above the bars. The larger number of pupae per tree in 1988 and 1989 is partly due to improvement in the sampling method.

2.3.4. UNKNOWN MORTALITY FACTORS

Apart from the mortality factors identified in the above eections, some mortality due to unknown factors occurred (Fig. 2.3.9). Most of it was in 1987, during the later part of the season, mainly from October to December. This was mainly attributable to death of early larvae hatching out from eggs laid on mature leaves. This unusual egg-laying was referred to in an earlier section (Section 2.2, Fig. 2.2.2). As dead, dried up larvae were present on the older leaves it was evident that this mortality occurred due to unsuitability of the leaves during the off-season.

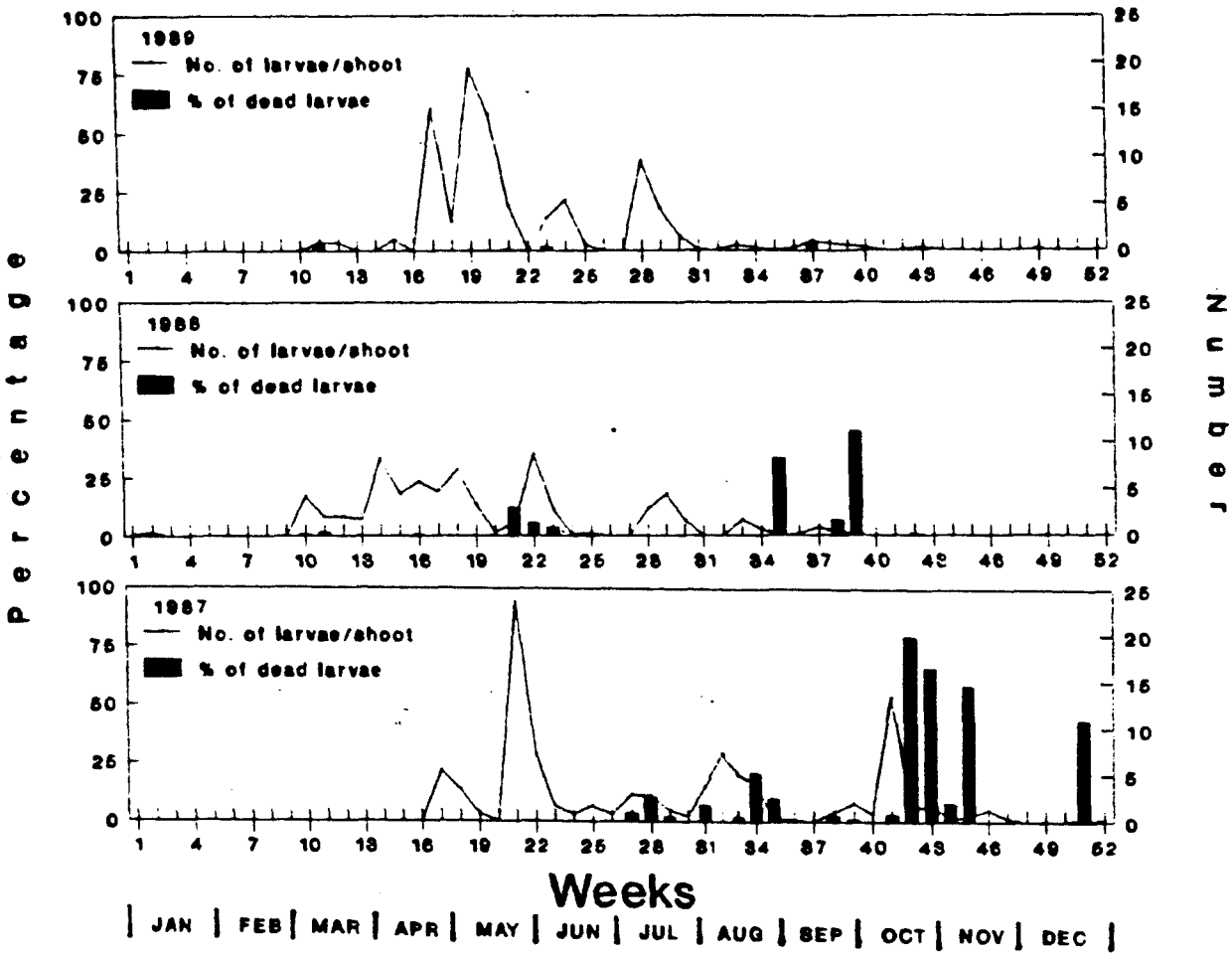


Fig. 2.3.9. Population trends in the years 1987 to 1989, and the percent mortality caused by unknown factors.

Fig. 2.3.10 shows this mortality in relation to the total larval population. It is evident that this factor was not eufficient to explain the changes in the larval population.

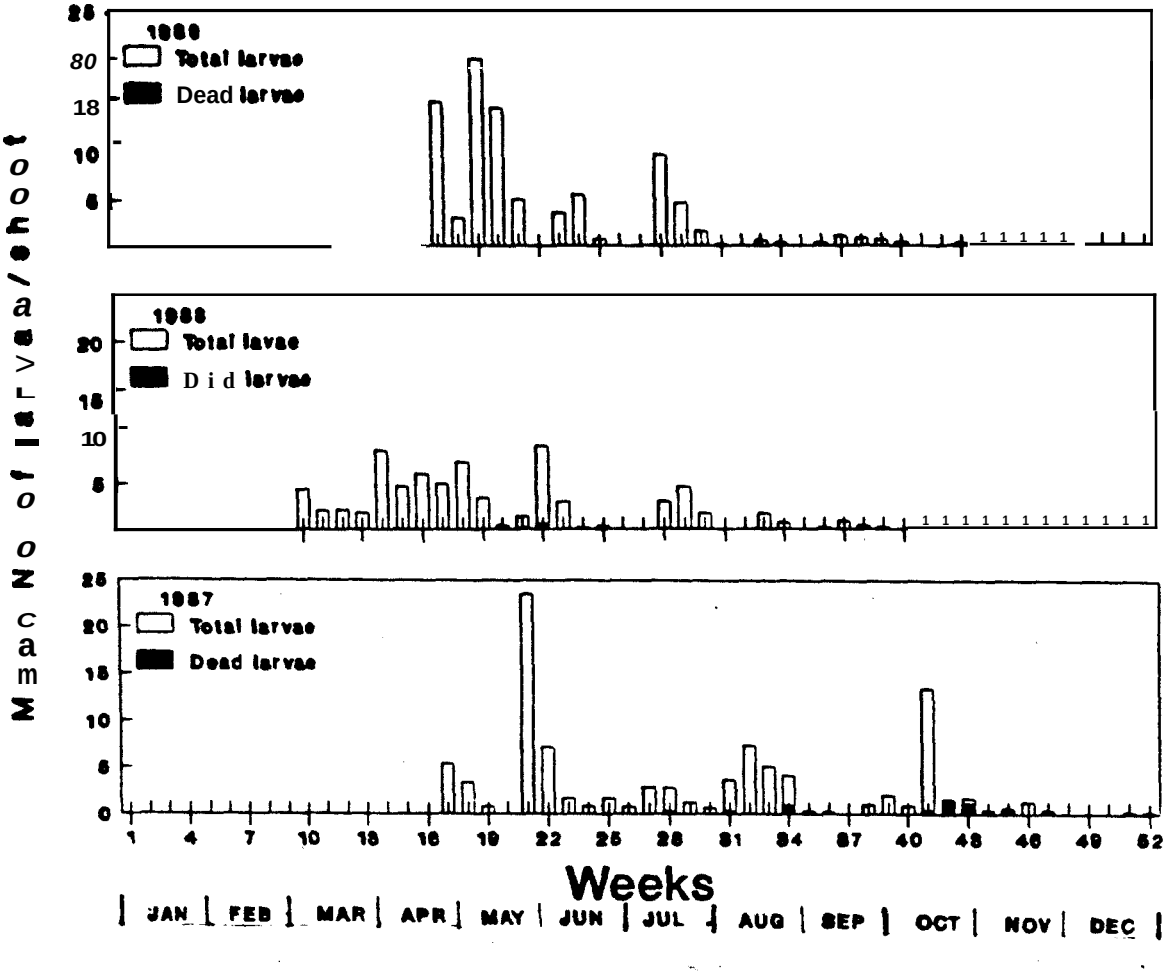


Fig. 2.3.10. Same as Fig. 2.3.9, with mortality due to unknown factors expressed as number of dead larvae.

2.3.5. TREE PHENOLOGY

Tree phenology can be expected to influence the population size and survival of H. *puera*. Since eggs are laid only on tender leaves under natural conditions (Section 2.1.3), the flushing time as well as the quantity of tender foliage may have the greatest influence.

Information gathered on the number of tender and mature leaf pairs in each sampled shoot during the weekly population sampling is examined here.

Fig. 2.3.11 shows the foliage composition during the 3 years of study, along with the insect population trend. It is evident that the yearly population outbreaks occurred after the appearance of tender foliage but there was some delay between the appearance of tender foliage and widespread population outbreaks. The decline of the population to non-outbreak levels followed the decline in the abundance of tender foliage. It appears that a delayed (positive) feed-back mechanism driven by tender foliage is necessary for large-scale population outbreaks. However, other factors may also be important.

The time-lag between the initiation of flushing and the full-fledged outbreak of the insect is apparently due to the time requirement for building up a large population of moths for mass outbreaks, which is accomplished in a generation or two. The quantity of tender foliage available is an important factor for population build-up. This became evident in 1988 when the early outbreaks occurred unusually early in the first week of March when flushing had not advanced sufficiently to sustain a large population of larvae. When the infestation occurred in the permanent sample plots 1 and 2, only about 10% of the trees possessed new, tender leaves; others were either leafless or possessed old leaves only. Even in the 10% of flushed trees, the leaves were very small.

From these results it is obvious that the survival of the larvae and the build-up of large moth populations necessary for initiating mass outbreaks depends on the supply of adequate quantity of tender foliage. This would explain the time lag between flushing and development of regular outbreaks.

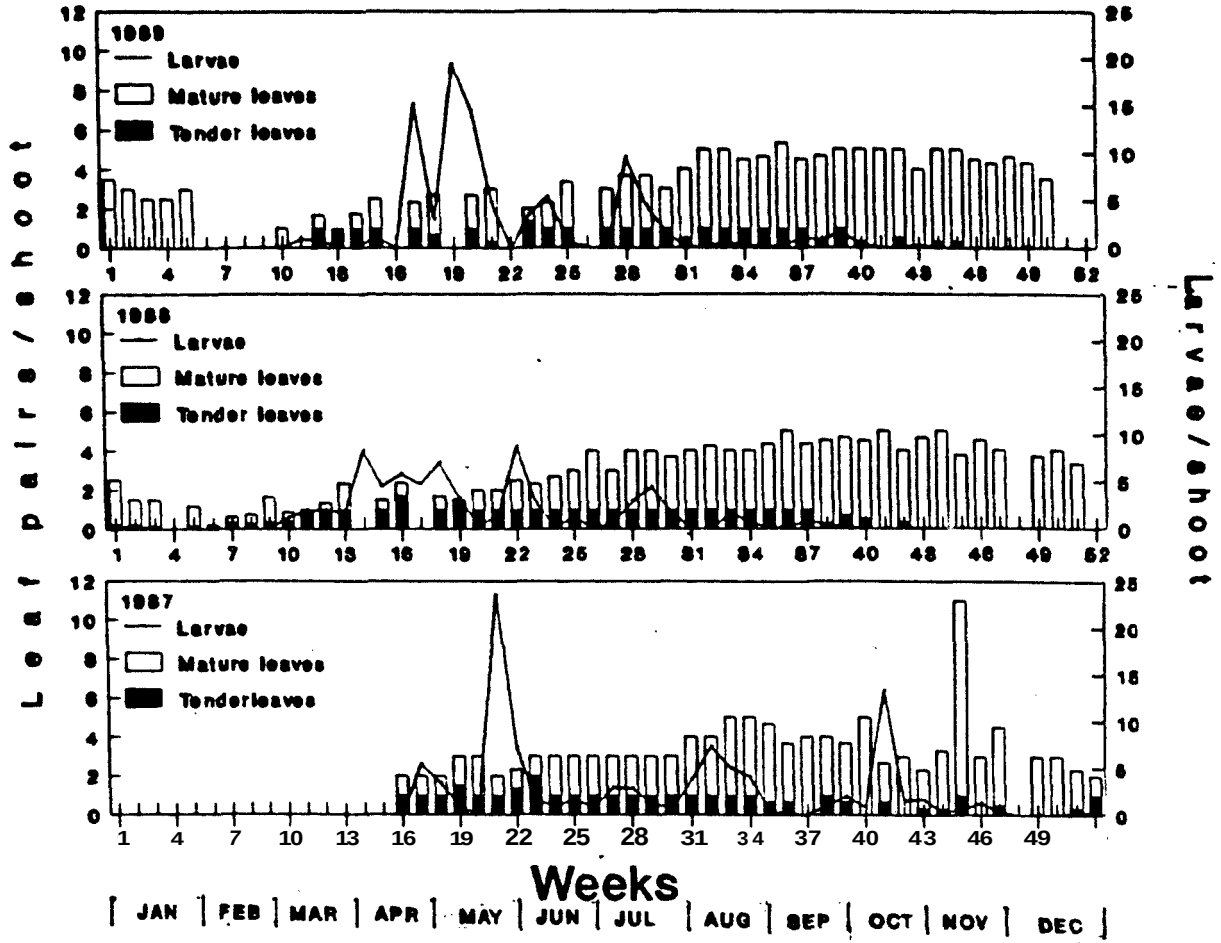


Fig. 2.3.11. Seasonal changes in foliage composition and insect population trends over three years. Observations started in April 1987.

2.3.6. RAINFALL

coincidence of the South-West monsoon rainfall and the first outbreaks of *H. puera* has been noted earlier from epecific observations at Nilambur (Nair and Sudheendrakumar, 1986) and from general observations in the literature for other areas (Nair, 1988). This relationship is examined here for Nilambur for the years 1987-1989.

Rainfall data used is the average of daily records made in the rain gauges maintained (1) in the KFRI Sub-centre at Nilambur and (2) the Agricultural Farm, Muttikkadavu at a distance of about 8 to 10 km from the study area.

Fig. 2.3.12 shows the population trends during the 3 years of study and the rainfall pattern. It is obvious that the first outbreak coincided with the first rainfall, although in 1988 there was no population peak corresponding to the earliest rainfall which occurred on 15 February. However, there was no correlation between the subsequent infestation peaks and the rainfall. The 1988 data is very valuable for arriving at this conclusion. In that year, rainfall occurred unusually early in the fourth week of February, and correspondingly the first *H. puera* outbreak also occurred unusually early. Evidence of such correlation between rainfall and first outbreak is likely to be missed often, if population sampling is carried out only in pre-fixed plots. In this study three widely spaced-out permanent study plots and the "moving plots" facilitated us to capture evidence of this correlation. Since the pre-monsoon showers may also be confined to some patches, weather records from standard weather stations may fail to bring out the correlation. Data from several or localised weather stations are needed to establish this correlation.

The observed correlation between early outbreaks and the first rainfall support the conclusion that the weather system causing the rainfall, somehow aids moth aggregation and movement. Several evidences, including the continuous presence of larvae, albeit in small numbers, during the non-outbreak period, and the appearance of early outbreaks in discrete, disconnected patches rule out the possibility of pupal aestivation or diapause and emergence of moths following the rain (Nair and Sudheendrakumar, 1986). On the other hand, several evidences indicate aggregation and migration of *H. puera* moths (Nair, 1988) but the exact role of the weather system in such displacement of moth populations remains to be worked out.

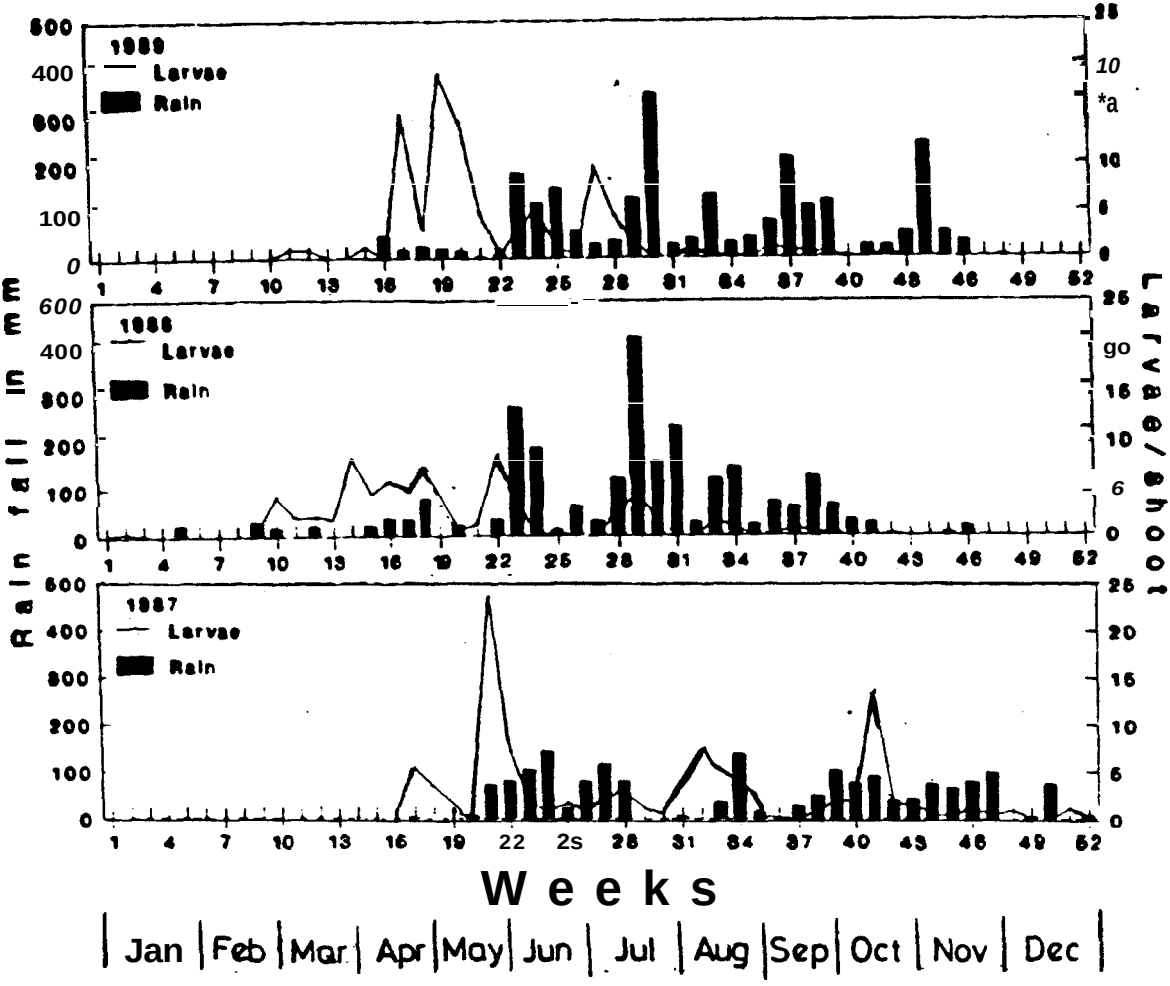


Fig. 2.3.12. The relationship between rainfall and *H. puera* infestation in teak over three years (1987-1989).

EARLY EVENTS IN POPULATION OUTBREAKS

K.S.S. Nair and K. Mohanadas

3.0. Abstract

Based on field observations, it is shown that in teak plantations, the first noticeable event in the chain of events leading to widespread outbreak of the caterpillar, *Hyblaea puera* is the sudden occurrence of discrete patches of fairly high-density infestations at tree tops. This follows a long period of near-absence of the insect population during the leaf-fall and early flushing period and appears to coincide with the first occurrence of localised pre-monsoon showers. These tree-top infestations cover small patches (0.5 to 1.5ha) and are widely separated in space. This transitional stage between very sparse endemic populations and high-density outbreak .populations is followed by more high-density infestations still confined to a few, but larger, patches. Wide-spread outbreaks covering the entire plantations occur in the next phase. The evidences indicate that *Hyblaea puera* population outbreak is of the "eruptive" type and take us closer to understanding the causation of outbreak and its prevention.

3.1. INTRODUCTION

As is evident from Section 2, in Kerala, the major outbreaks of Hyblaea puera usually occur between April and June, the pre- and early monsoon season. The population remains very small at other times, being lowest and hardly traceable from November through February. What happens between February and the first visible outbreak in April or May is not known. An understanding of the transition from the sparse population in the off-season to the high-density, mobile populations in the outbreak season is necessary, both for its theoretical interest in the context of recent theory and classification of forest insect outbreaks (Berryman, 1986, 1987) as well as for developing suitable management strategies against the pest. In order to understand the sequence of events preceding the population outbreaks, we made a systematic surveillance of selected belts of teak plantations at Nilambur during the critical period. The results are reported in this Section.

3.2. MATERIALS AND METHODS

The study was carried out in 1987 in teak plantations at Nilambur in North Kerala, with some supporting observations in South Kerala. Nilambur has about 100 km^2 of teak plantations, distributed over about 500 km^2 of geographical area. The study area comprised representative plantation belts at Panayangode, Aravallikkavu, Valluvasseri, Karulai, Nellikutha and Kariem-Muriem (see Fig. 3.1). These areas were chosen because of their proximity to forest roads which facilitated observation of the entire study area on foot.

During February and March (pre-outbreak period), 'the plantations were visited at fortnightly intervals and general observations made on tree phenology and presence of *H. puera* larvae. From April onwards until the insect outbreaks became widespread, more detailed observations were made at weekly intervals. Five field observers were deployed to cover the entire study area on foot. Each observer was given blueprints of the plantation map of his observation area, on which, at weekly intervals, they scored the level of flushing and infestation, at pre-designated representative sites. Perambulating different portions of the observation area each day, each observer covered the entire observation area assigned to him in a week, and repeated the observations all over again. Thus the interval between consecutive observations in a given site was a week. We collected the maps at weekly intervals, verified the observations at random, and made detailed observations in the areas where early outbreaks were detected. The dates of infestation were worked out by back-calculating from the stage of the insects present on the observation date.

Observations in South Kerala consisted of periodic, general observations during March and April, on the flushing and infestation statue, in the more or less contiguous stretch of plantations on either side of the Konni-Achencoil-Chenkottah road.

Rainfall data were obtained from the raingauge maintained by the Kerala Forest Research Institute subcentre at Nilambur, near Valluvasseri.

3.3.RESULTS

The chronological changes in tree phenology and infestation status during the observation period are summarised below.

Ni1ambur

February

During February, there was progressive increase in leaf shedding. In general, roughly 25% of the old leaves had fallen by the first week which increased to about SO per cent by the third week. The quantity of new leaves remained very low with conspicuous variability in its spatial distribution. Variability existed between observation areas, between patches within the same plantation belt and between trees within a site. For example, when observed on 6-7 February, in most areas, most trees had no new leaves, but isolated trees (roughly 10 per cent of the total) had one pair of partially grown new leaves per shoot. In these trees, about three quarters of the old leaves had been shed. Such trees with advanced flushing often occurred in groups at some sites within the same plantation belt. In addition, plantations in some areas like Kariem-Muriem were phenologically more advanced than others. And within these areas, isolated trees showed further advanced phenology. Thus, all grades of phenological development were noticeable at this time. Many isolated trees along the river bank at Nellikutha had two pairs of tender leaves, while some rare trees at Champankolly within Kariem-Muriem had some terminal shoots with upto six pairs of new leaves and inflorescence heads. The general picture at the end of the month, however, was absence of new leaves, except for a single pair of partially developed tender leaves per shoot in isolated trees.

In about six man-hours of search, no H. *puera* larva was detected in the first week of February, but two larvae (third instar) were found in the third week, on tender leaves, in coppice growth at Kariem-Muriem.

March

Shedding of old leaves and appearance of new leaves progressed steadily during March, and by the third week, the majority of trees had at least one pair of tender leaves,

although some trees were still leafless or possessed only old leaves. In areas with advanced flushing, further growth of new leaves had occurred. At Kariem-Muriem, trees along the ridge-top had more new foliage than those in the valley. The first pre-monsoon rainfall of the year (0.6 mm) was recorded on 23 March.

Sometime between 17 and 23 March, fairly dense infestation occurred in small patches in three widely separated areas within the observation belt (Fig. 3.1). Evidence of this infestation was obtained only on 10 April by which time no insect stages were present. Therefore it was not possible to work out the exact date(s) of infestation. The infestation characteristics at each site are described below.

(a) *Near Padukka in Karulai:* The infested patch, about 1.25 ha in extent, was situated near Padukka towards the end of the Karulai plantation belt along the Karulai-Nellikutha forest road (site 'a' in Fig. 3.1). The trees were about 20 meters tall. The infestation was of comparatively low density and confined to the top of the trees. At the time of infestation, most shoots had only one pair of tender leaves and most of the leaf area was consumed. Search on the ground on 10 April did not yield any pupae or pupal exuvia.

(b) *At Kollenthodumukku, near Kallianthodu, in Karulai:* The infested patch covered an area of about a hectare, but only some trees which possessed tender leaves at the time were infested. The trees were about 15m tall. The area is situated on a stream bank (site 'b' in Fig. 3. 1) and was characterised by early flushing. Only one pair of leaves was affected.

(c) *At Aravallikkavu:* The infested patch covered about 0.6 ha. The trees were over 15m tall. Most trees within the patch were infested, but the infestation was of mild intensity, generally affecting only the distal half of the leaf, although some leaves were consumed more fully. The area is situated on a stream bank (site 'c' in Fig. 3.1).

Apart from the above patch-infestations, most plantation areas had a sparse, dispersed population of second or third instar larvae, when observed on 20-21 March. For example, in a row of 30 flushed trees at the ridge top at Kariem-Muriem, larvae were noticed on tree numbers 1, 11, 12, 17, 20 and 22 in the row. This infestation differed from the tree-top infestations described above in that the insect population was very sparse and dispersed, with only one or two larvae per leaf on some leaves of some trees. Many larvae collected and examined were parasitised by *Sympiesis* sp. (Hymenoptera, Eulophidae).

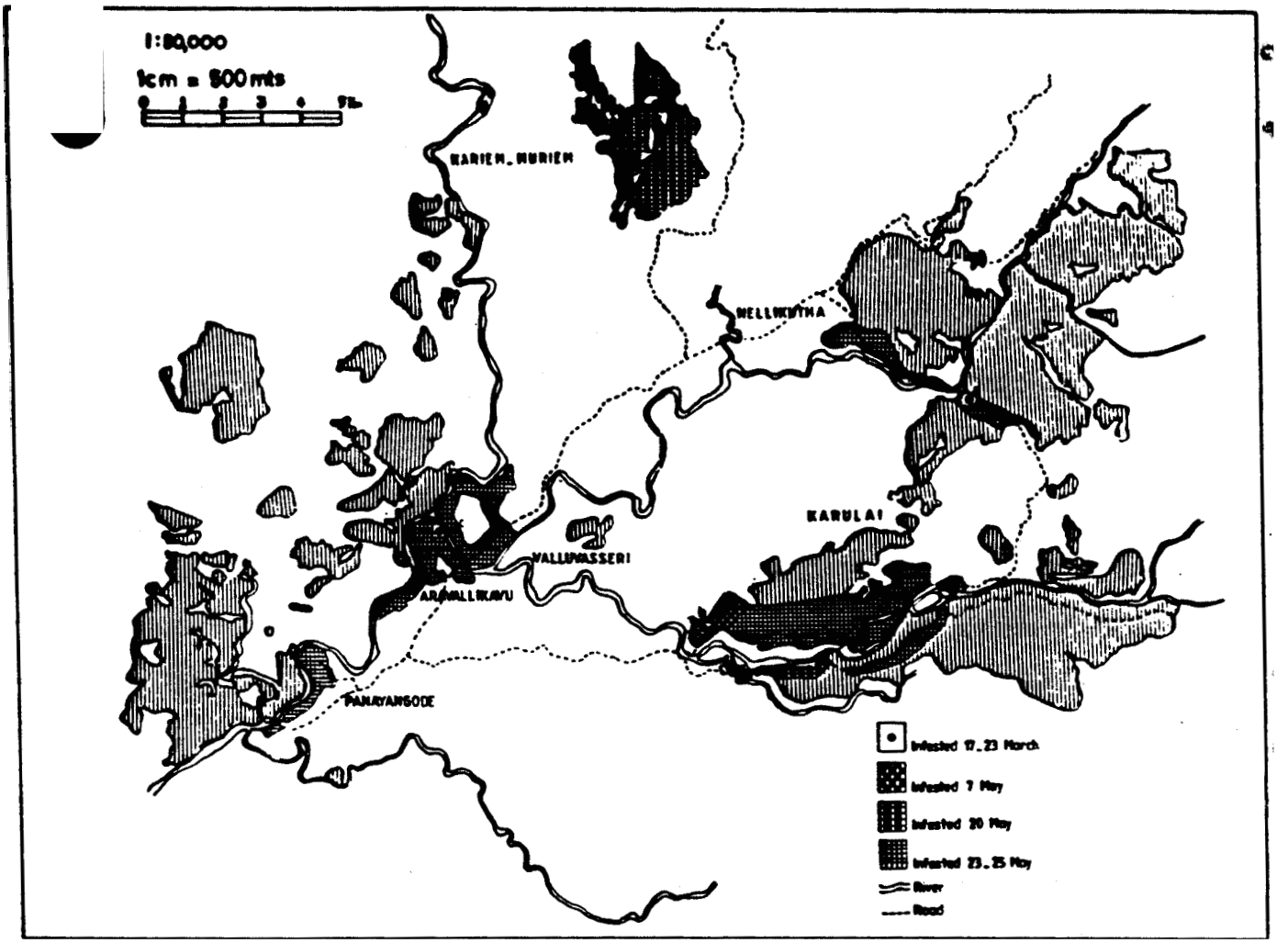


Fig. 3.1. Map of Nilambur teak plantations, showing progressive distribution of outbreaks of *Hyblaea puera.* Areas other than those marked by vertical lines were kept under observation. Locations of earliest outbreaks are indicated by arrows 'a' to 'c' and of subsequent major outbreaks by different patterns (see legend within the figure). Small-patch-infestations other than the earliest are not shown.

During April , the development of new leaves progressed further, extending to most areas, but some areas were still devoid of new flueh of leaves. In most areas, flushing did not progress beyond partial growth of the first pair of leaves, while in some areas two pairs of new leaves per shoot was common. Mild rainfall (0.2 mm) was recorded on 9 April, followed by further rains on 25 April (1 mm) and 29 April (1.8 mm).

During the first, second and third weeks of April, sparse populations of second and third instar larvae were noticed in most areas. In the third week, most larvae were found parasitized by Sympiesis sp. Older larvae were not encountered. Presence of the same stages over the first three weeks indicates continuous presence of egg-laying adults. Absence of older larvae was probably due to parasitism and predation.

On 24 April, a concentrated infestation covering about two hectares occurred near Vettilakolly at Kariem-Muriem. The trees were about 10 m tall. The infestation was dense, affecting almost all the tender leaves at the top canopy. No larvae were traceable outside this patch at this time.

Between 26-27 April, two additional, concentrated infestations occurred at Kariem-Muriem, at a distance of about 3 km from the first infestation. Each of these patches covered less than a hectare and were separated from each other by a distance of about 100 m only. The infestations were dense. Between the above three patches of infestation, a few isolated trees were moderately infested, but no infestation occurred at other places.

May

There was no major change in phenology during the early part of May but with the onset of widespread rainfall on 20 May, there was a spurt in the flushing intensity. By the end of May, most trees had two to three pairs of new leaves per shoot.

Between 1-2 May, a new patch-infestation covering less than two hectares occurred at Thannikkadavu in Kariem-Muriem, about 3 km from the point of the second infestation noted above. Light to moderate infestation was also noticed on some isolated trees at Kariem-Muriem, but no larvae were found in other observation areas.

On 7 May, another infestation occurred at Karulai, between Kallianthodu and Charalkunnu covering the patch where one of the earliest (17-23 March) patch-infestation had occurred. This time, the infestation covered a larger area (Fig. 3.1). No infestation was detected in other observation areas, except for those at Kariem-Muriem referred to earlier.

On 20 May another larger infestation occurred at a different location in Karulai (Fig. 3.1). Simultaneously, the entire Kariem-Huriem area was also densely infested (Fig. 3.1).

Between 23-25 Hay, widespread infestation occurred over the remaining observation areas, viz., Panayangode, Aravallikkavu, Valluvasseri, Karulai and Nellikutha (Figure 1). Reports from the Forest Department indicated widespread infestation at this time covering most other teak plantatione at Nilambur.

South Kerala

March

When observed on 12-13 March, most trees in the plantations at Konni had old leaves, but a small number, dispersed throughout the plantations, had new leaves at various stages of development. Flushing progressed further during the latter half of the month. By 30-31 March, when mild rains occurred in some areas, most trees had at least one pair of new leaves per shoot. Between 12-13 March, no larvae were detected in general observations. Between 17-24 March, two patch-infestations were detected - one at Mannarappara in Konni, covering about a hectare and the other at about 3 km from Achencoil, covering about half a hectare of a mixed plantation of teak and *Bombax* malabaricum. Both were typical tree-top infestations, but the latter was less dense. During this period, some scattered trees were also moderately infested.

Between 30-31 March, a patch-infestation covering about 2-3 hectares was noted in a road-side plantation at Arippa.

April

By 7-8 April, flushing had advanced further and most trees had 1-3 pairs of new leaves per shoot.

A sparse population of third to fifth instar larvae was present in most areas at this time. Unoccupied, small leaf-folds representing parasitized or predated third instar larvae were also seen. Stray moths were found resting on teak leaves in some places. But some areas were dervoid of even a sparse population of larvae.

Between 17-20 April, widespread infestation occurred all over Arippa, Konni and Achencoil plantations.

3.4.DISCUSSION

A summary of the chronology and characteristics of the denser infestations during the early part of the growth season is presented in Table 3.1. The following conclusions can be drawn from the observations for Nilambur.

Table 3.1. Chronology and characteristics of the major infestations of *H. puera* in the observation areas at Nilambur and South Kerala, in 1987, prior to the occurrence of widespread outbreak

Dates	Outbreak characteristics at	
	Nilambur	South Kerala
17-24 March	Light, tree-top infestation in 3 small patches (0.6 - 1.25 ha)	Light or dense tree-top infestation in small patches (0.5 - 1 ha)
30–31 March	-	Patch infestation (2 - 3 ha)
17-20 April	-	Widespread infestation
24 April	1 patch (2 ha)	-
26-27 April	2 patches (<1 ha)	-
1-2 May	1 patch (<2 ha)	-
7 May	1 large patch (>15 ha)	-
20 May	2 large patches (15 - 800 ha)	-
23-25 May	Widespread infestation	-

The first noticeable event in the chain of events leading to widespread outbreak was the sudden occurrence of concentrated, but comparatively light, infestations at tree-tops, restricted to a small number of discrete patches. At Nilambur, it occurred between 17 and 23 March and appeared to coincide with the first occurrence of localised pre-monsoon showers. Prior to this period, although tender leaves were present, it was difficult to find larvae, and the small number that were located were present at lower canopy levels, not at tree-tops as in the above infestation. The occurrence of patch-infestations was coincident with or followed (observations were not frequent enough to show the exact sequence) an increase in the sparse population in most areas. After about a month (24 April to 2 May), a series of small-patch infestations appeared again in an area where new flush of leaves was prevalent (Table 3.1). The next development was the occurrence of outbreaks in larger patches (7-20 May). These were also limited to a few discrete areas. Sparse populations continued to occur in other areas and isolated trees or small groups of trees were diffusely infested. What followed next was an extensive outbreak, covering most of the uninfested areas within a few days.

This sequence of events indicates population build-up in local 'epicentres' and step-wise spread to larger and larger areas. This is characteristic of the 'eruptive' type of outbreak as per Berryman's (1986, 1987) classification scheme. Within the Nilambur area, full eruption was achieved in about two months of the appearance of 'epicentres'.

The infestation characteristics in South Kerala suggests that the first tree-top infestation noticed at Mannarappara between 17-24 March, which was followed by heavy, widespread outbreak between 17-20 April, was similar to the second series of outbreaks at Nilambur starting 24 April (Table 3.1). It is obvious that the characteristic first step in the sequence of outbreak events is the appearance of concentrated, but low-density tree-top infestation in small patches (i.e., epicentres), but we missed observing them in South Kerala. This is not unexpected, because unlike at Nilambur, the observations in South Kerala were not frequent and did not cover extensive areas. It may also be noted that in 1987 the widespread outbreak in South Kerala occurred about a month earlier than at Nilambur. Similar observations of earlier occurrence of outbreak in South Kerala where the pre-monsoon rains occur earlier than at Nilambur, has also been reported previously (Nair and Sudheendrakumar, 1988).

The second series of outbreaks at Nilambur starting on 24 April also appeared to coincide with the occurrence of pre-monsoon showers (only a mild shower of 0.2 mm was recorded earlier, on 9 April). Only the second series of outbreaks during a season becomes generally noticeable and it has been a general observation that the outbreak coincides with the arrival of pre-monsoon showers. For example, in 1988, when the monsoon rains arrived early at Nilambur, with fairly good pre-monsoon showers

in the lamt week of February, the firmt noticeable outbreak occurred In the firmt week of March (Section 2). Since theearly pre-monmoon shOwers are very localised and does not always get recorded in routine recordings at weather mtations, more detailed micro-level observation8 are necermary to establish the correlation between rainfall and the firmt occurrence of patch-infestation.

Occurrence of heavy infestations in fairly large, discrete patches, prior to the incidence of widespread outbreaks, has also been reported earlier (Nair and Sudheendrakumar 1986; Nair 1988). The most significant finding of the present study is the detection of the earliest outbreaks in widely separated, small patches. The characteristics of these infestations are (1) they are very widely eeparated in space, (2) cover only a small area ranging from about 0.5 to 1.5 ha, and (3) the population density is low compared to the typical tree-top infestations which follow. Obviously, this represents the transitional stage between sparse endemic populations and high-density outbreak populations.

The factors which trigger this transition remain unknown. One or more of the following may be involved - (1) Failure of natural enemies to limit the host population, i.e., failure of a negative feed-back control loop, (2) Positive feed-back on population growth exerted by increasing availability of food (tender foliage) during the early growth season, (3) Shift in moth behaviour, leading to aggregation, in response to some environmental cue such as rainfall, (4) Sudden arrival of a group of moths during the pre-monsoon rains, brought in by passive aerial displacement of moths from far-off places as, in the case of spruce budworm moth (Greenbank, et al. 1980). Sighting of characteristic aggregations of newly emerged moths has been reported earlier (Nair, 1988), suggesting the possibility of mass dispersal. More investigations including closer observations of moth behaviour in relation to pre-monsoon rains are needed to understand the critical sequence of events leading to outbreaks. Elucidating the relative roles and interactions between whether, phenology, moth behaviour, and natural enemies in the causation of outbreaks is a challenging task. But this is necessary for developing suitable control strategies. The most important question is whether the development of widespread outbreak in a given locality can be prevented by controlling the early tree-top infestations in isolated patches. This approach will be successful if population eruptions originate from local epicentres and are spread by short-range dispersal of moths, but if long distance movement of moth aggregations, aided by monsoon winds, plays a key role in triggering outbreaks, control will be more difficult. In any case, this is an important area for future research which transcends the traditional boundaries of entomological research.

Section 4

REPRODUCTIVE BEHAVIOUR OF *HYBLAEA PUERA* AND THE ROLE OF PHEROMONES

V.V. Sudheendrakumar

4.0. Abstract

Reproductive behaviour of the teak defoliator, Hyblaea *puera* was studied under laboratory conditions. The pre-mating period of both sexes of the moths from the field population was 2 days. However, the pre-mating period of the moths from the laboratory culture was 3 days. Females were monogamous, whereas a male mated with several females during its lifespan. Mating occurred during the second half of the night. A characteristic courtship behaviour was exhibited by both sexes of the moths. Preliminary trials indicated presence of a female sex pheromone.

Pre-oviposition period (after mating) was 18-24 hr. Oviposition occurred between sunset and midnight. The mean oviposition period was 7 days. The number of eggs laid varied between 287-606 with an average of 434. The number eggs laid was maximum on the first day of oviposition.

4.1. INTRODUCTION

The study was undertaken as a first step towards exploring the utility of pheromones in the control of H. *puera.* Pheromonal control has gained considerable importance in recent years as a component of Integrated Pest Management of lepidopteran pests in forest plantations (Daterman *et al.*, 1980). But in India little work has been done in this direction.

Basic data on different aspects of reproductive behaviour are important pre-requisites for planning, evaluating and interpretting pheromonal control experiments against insect pests (Shorey, *et al.*, 1976). Hence, in the present study data were collected on mating, courtship and oviposition behaviour and patterns. The presence and role of female sex pheromone was also studied. Though isolation and field testing of pheromone was originally envisaged as part of a collaborative project with U.S. Dept. of Agriculture, these aspects could not be undertaken as the project did not materialise.

4.2. MATERIALS AND METHODS

4.2.1 General

All the experiments reported here were carried out under laboratory conditions. The moths used were obtained from laboratory culture as well as from the field. In the laboratory, two cultures of H. *puera,* one on teak leaf and the other on an artificial diet were maintained. The initial stock of larvae for these cultures were collected from teak plantations in Nilambur.

Rearing of H. *puera* on teak leaf

Adults which emerged from the initial stock were kept together for mating and after mating the females were shifted to glass bottles (17cm x 7cm) which formed the oviposition chamber. The glass bottle was covered with muslin cloth. The females were fed with diluted honey (10%) provided on a 2cm x 2cm rubber foam piece hanged "into the bottle. The eggs laid on the muslin cloth cover of the bottle were sterilized by dipping the cloth cover along with eggs in 1% solution of sodium hypochlorite for 15 min. After thorough rinsing in freshwater, the cloth was spread over a blotting paper to drain off water and thereafter kept in glass bottles. The newly emerged larvae were fed with tender teak leaves which were pretreated with 200 ppm solution of streptomycin sulphate to prevent bacterial infection of larvae.

Rearing of *H. puera* on artificial diet

To ensure a continuous supply of moths a culture of *H. puera* was also maintained on an artificial diet described elsewhere (Mathew *et al.,* 1990).

Maintaining the moths in the laboratory

The moths obtained from laboratory cultures (on leaf or artificial diet) and field collected pupae were maintained separately. On emergence, the moths were sexed (details given below) and kept in separate of glass bottles. The date of emergence of each moth was recorded and those emerged on a particular date were kept together. As far as possible care was taken to maintain the males and females in separate rooms so as to avoid chances of chemical communication between them until they were brought together for experimentation. The colony was maintained at room temperature, 25OC-32OC and 1ight:dark cycle of about 12:12h.

Sexing of the moths

The male and female moths were sexed on the basis of the morphological features of their legs (Fig. 4.1). The hind tibia of male is narrow (Fig. 4.la) and without long hairs along its outer side. The hind tibia of female (Fig. 4.lb) is distinctly broader than that of male and is provided with dense long hairs along its outer side. In male, attached close to the base of the hind coxa is present a white elongate sac which encloses a brush organ (Fig. 4.2). The brush organ consists of several elongate hairs kept together and having their origin at the base of hind tibia (Fig. 4.2). When viewed from the ventral side of the moth, a white sac can be clearly seen one on either side of the abdomen (Fig. 4.3).

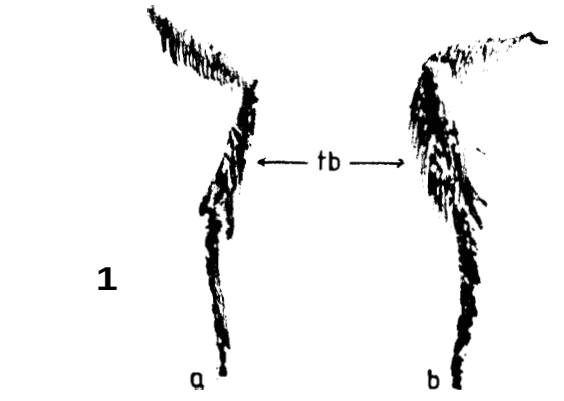
4.2.2 Mating behaviour

Time of mating

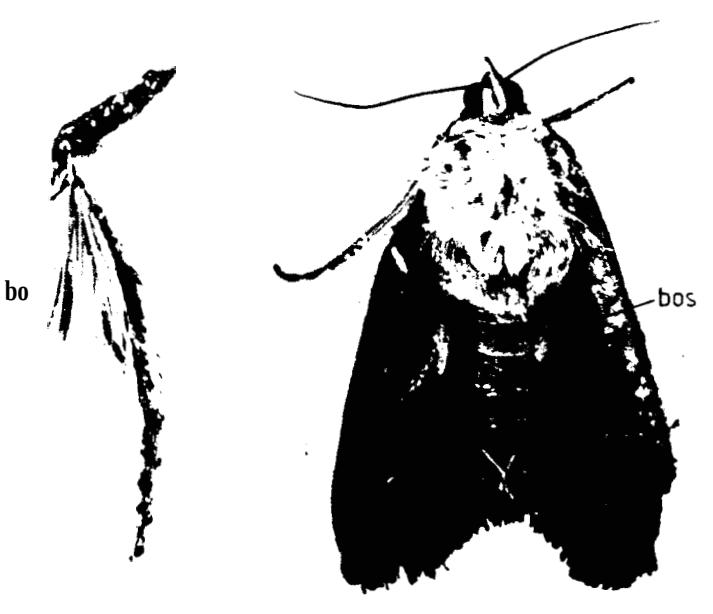
In moths generally mating takes place during night. Preliminary observations were made to ascertain whether in **H.** ***puera*** mating takes place during day or night. To find out the optimum time of mating, 35 pairs of moths were directly observed during the scotophase between 18.00 and 06.00 h. Each pair was lodged in a glass bottle (17cm x 7cm) with the mouth of the bottle covered with a muslin cloth. Observations were taken at half an hour interval and the time of mating of each pair was recorded. A 15W lamp covered with a thick white cloth provided just sufficient light to make observations without disturbing the normal activities of the moths.

Sexual maturity

The objective of this study was to find out the optimum age at which the males and females mated. Males and females in the



1



2 3

Fig. 4.1. Hind leg of *H. puera*- (a) Male (b) Female (tb) Tibia

Fig. 4.2. Hind leg of male showing brush organ (bo)

Fig. 4.3. Ventral aside of male - (bos) Sac enclosing brush organ

age group of zero hour (immediately after emergence) and above were included in the experiments. In studies on the sexual maturity of males and females, opposite sexes of at least 5 days old were used. Separate experiments were conducted to understand difference if any in sexual maturity between laboratory reared and field collected moths (emerged in the laboratory from the field collected pupae). Single pair was observed in glass jars. When successful mating occurred, date and time of mating were recorded. Each pair was observed till mating occurred or till the experimental male/female was ten days old.

Mating capacity

The ability of males of H. puera to mate with and inseminate more than one female either on successive nights or in a multichoice situation with several females on the same night was investigated.

To study the first aspect, 20 males of 3 to 4 day old were used. Each male was provided with a virgin female and allowed a mating time of 5 h between 01.00 and 06.00 h. After the experiment the female of each pair was transferred to another bottle for oviposition. Thus each male was provided with one virgin female every successive night till its death. Mating was confirmed based on whether the females exposed to a particular male laid fertile eggs. The experiment was replicated thrice.

To study the second aspect, 10 unmated males of 3 to 4 day old were used. Each male was provided with three virgin females (5 days old) in a glass bottle during the scotophase and allowed a mating time of 5 h between 01.00 and 06.00 h. After the experiment the three females from each container were transferred to three separate bottles, and observed for laying fertile eggs. As only mated females laid fertile eggs, it was possible to find out the number of females with which a male successfully mated on a particular night.

Courtship behaviour

More than 50 pairs of sexually mature adults were used in direct observations on courtship behaviour. Each pair was held in a glass bottle (20cm x lOcm) and the activities of male and female were observed and recorded. Observations were made under dim light between 01.00-06.00 h - the normal mating period.

Role of sex pheromone in mating

The classical method of prepariong the pheromone extract from female Lepidoptera is the excision of the pheromonal gland usually located in the abdominal tip or the entire abdominal tip (Golub and Weatherston, 1984). Hence, as a preliminary trial, extracts of abdominal tips of 3 to 4 days old virgin female H. puera was prepared and the response of the males to this extract

was tested. The extract was prepared in two eolvents namely Dichloromethane and Ethylalcohol on a tribal basis. Abdominal tips (last three abdominal segments) of 75 moths were macerated in 25 ml of each aolvent and filtered through Whatman No.1 filter paper. The filtrate was used for the bioassay.

A glass olfactometer described elsewhere (Chandran and Prabhu, 1984) was used for the bioassay. It consisted of two 500 ml conical flasks, A and B each closed with a two holded rubber cork. The flasks were interconnected through a glass tube and flask A and flask B possessed an inlet tube and exit tube respectively. The exit tube was connected to an aspirator. By working the aspirator air could be drawn into flask A and through the connecting tube to chamber B and finally to aspirator.

Virgin males of 3-5 day old were used for the bioassay. For each test, five males were kept in flask A of the olfactometer. Ten drops of the abdominal tip extract was taken ona filter paper strip (2cm x 5cm). After the extract got evaporated, the filter paper was placed in the flask B of olfactometer. Air was drawn into the olfactometer by working the aspirator. The behaviour of the male moths was observed and recorded. A control set was always kept for each experiment in which the solvent alone was applied on the filter paper and filter paper was put in the olfactometer after the solvent got evaporated. The experiment was conducted during the second half of scotophase and the observations were made under reduced light. All experiments had three replicates.

4.2.3 Oviposition behaviour

The aspects studied were preoviposition period, time of oviposition, duration of oviposition, fecundity and substratum preference for oviposition. The moths obtained from the laboratory culture were used in this study.

Mated females were individually maintained in glass bottles covefred with muslin cloth (oviposition chamber) and fed with 10% honey solution. Observations were taken at hourly interval and the time of oviposition was recorded. To record duration of oviposition the females were kept under observation till their death and data on oviposition were recorded daily. Fecundity was estimated by counting the eggs laid by each female during its lifetime. The adults were maintained in the laboratory under a 1ight:dark cycle of 12:12 h.

4.3. RESULTS AND DISCUSSION

4.3.1 Mating behaviour

Time of mating

Table 4.1 shows the various timings at which mating took place. Mating activity in H. puera was found restricted to second half of the scotophase, between 01.00 to 05.00 h. The peak

period of mating was between 02.00 to 03.00 h. In very rare cases some pairs mated between 22.00–01.00 and 05.00–06.00 h.

Table 4.1. Time of rating

Mating time (h)	% moths mated
<22.00	0
22.00–23.00	2.8
23.00–00.00	2.8
00.00–01.00	5.7
01.00-02.00	17.1
02.00–03.00	28.6
03.00–04.00	17.1
04.00–05.00	20.0
05.00–06.00	5.7
>06.00	0

A single peak period of mating per night as observed in *H. puera* is known in the noctuid *Anadevidia peponis* (Sasaki, 1976) and the pyralid moth *Eutectona machaeralis* (Gopakumar and Prabhu, 1984). However, two peak periods of mating is also known in some moths as reported in the case of Jute hairy caterpillar *Diacrisia obliqua* (Islam and Alam, 1979).

Sexual maturity

Males from laboratory culture

Laboratory reared males did not show mating activities until they became 3 day old (Table 4.2). Out of the 30 males studied, 80%mated at the age group of 3–6 days suggesting it as the peak period ofmating. Within this age group highest percentage of males mated at the age of 3 days (33%). Among the test males 14% did not involve inmating throughout their life period.

Males from field collected pupae

Males which emerged from field collected pupae started their mating activities at the age of 2 days (Table 4.2). About half

Table 4.2. Sexual maturity in laboratory reared and field collected males of H. puera

Age of moths (days)	% Mating	
	Laboratory reared males (a)	Field collected males (b)
1	0	0
2	0	28
3	33	20
4	13	10
5	20	5
6	13	8
7	0	3
8	7	3
9	0	0
10	0	0

No. of males observed a = 30; b = 40.

% Unmated a = 14; b = 23.

of the males (48%) mated at the age group 2-3 days. The peak age of mating was 2 days at which 28% of the males mated. About 23% of the test males did not mate till their death.

Females from laboratory culture

Female *H. puera* from the laboratory culture was found to receptive at the age of three days (Table 4.3). The peak mating age group was 3-6 days and the peak age was 3 days (28.5%).

About 26% of the females did not mate at all. Mating was found to take place even in the case when females more than ten days old were provided with a male partner. In one instance a 18 day old female successfully mated which is the maximum mating age, recorded.

Table 4.3. Sexual maturity in laboratory reared and field collected females of *H. puera*

Age of moths (days)	% Mating	
	Laboratory reared female moths (a)	Field collected female moths (b)
1	0	0
2	0	34
3	29	24
4	14	11
5	17	11
6	14	3
7	0	0
8	0	3
9	0	3
10	0	3

No. of moths observed a = 42; b = 38.
%Unmated a 26; b = 8.

Females from field collected pupae

In the case of female moths emerged from the field collected pupae, mating was observed at the age of 2 days (Table 4.3). The peak mating age group was 2-5 days, and the maximum number of females mated at the age of 2 days (34%).

The study ahows that there is a delay of about 24 hours, to start mating activity in the case of moths from laboratory culture in comparison to those from the field population.

The sexual response of virgin female moths in general was found declining beyond ten days old. Host of the moths became inactive by this time. One reason for this is probably the stress conditions under which they are maintained in the laboratory. However, there were rare instances of older females (16-18 days) getting successfully inseminated under laboratory conditions.

Mating capacity

Figure 4.4 shows the number of matings performed by individual males during their life span. The highest frequency was six matings. Considerable variation was noted in the number of females successfully inseminated by individual males with a maximum of seven and a peak of six. Out of the 40 males observed about 20% remained unmated during the observation period of two weeks.

Table 4.4 shows the result of the multichoice test in which each male was provided with three females per night. During the three day period of observation, no male was able to mate with more than one female in a night. Out of the ten males observed, one female did not mate at all and six mated on all the three days and three mated only on two days.

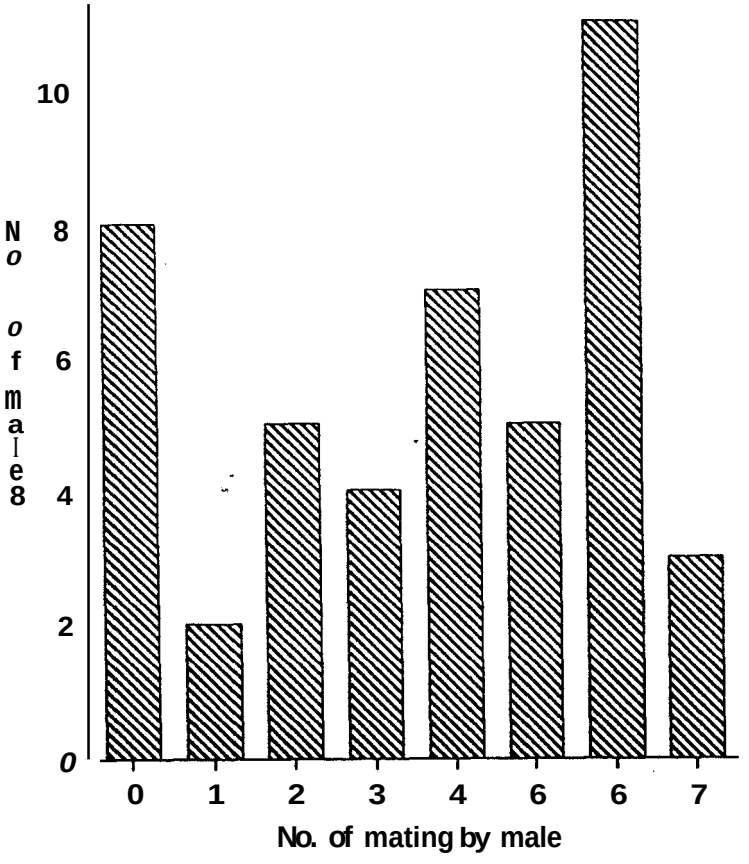


Fig. 4.4. Mating by male during lifespan

Table 4.4. Number of females inseminated by ten males each confined with three virgin females on each of three successive nights

Male No.	Night 1	Night 2	Night 3	Total mating
1	1	0	1	2
2	0	0	0	0
3	1	1	1	3
4	1	1	1	3
5	0	0	1	3
6	1	1	1	3
7	1	1	1	3
8	1	1	0	2
9	1	1	0	2
10	1	1	1	3

Courtship behaviour

Male courtship behaviour

Sexually active males exhibited a characteristic courtship behaviour which involved the following steps in a sequential order.

1. Rapid movements within the cage including running or flying.
2. Periodic fluttering of wings and wing expansion.
3. Raising of body on hind legs to assume a standing position with head touching the floor.
4. Releasing the hair brushes located on the hind tibia and keeping it opened, fan like.
5. Chasing the female.
6. Raising the forewings above the abdomen in 'V' shape.
7. A circling movement near the female prior to mating.

Female courtehip pattern

1. Rapid movements including flight

2. Opening and vibrating the wings at intervals keeping the antennae raised up

3. Standing erect on hind legs and raising wings above abdomen to assume 'V' shape

4. Assuming the normal position at the end of the above steps.

Though in general the males and females exhibited all the various steps of their courtship behaviour, some mated, atleast omitting a few steps. In very rare cases, instant mating occurred immediately after caging without exhibiting any courtship behaviour.

Mating

At the end of the courtship behavious the male approached the female and exhibited either a clockwise or anticlockwise circling movement (Fig. 4.5a) and finally remained quiet facing the back of the female (Fig. 4.5b). At this stage the male kept its wings raised up (Fig. 4.5c). The male then took a 90° anticlockwise turn and extended and curved its abdomen towards the female genitalia (Fig. 4.5d) and established genital contact (Fig. 4.5e). Subsequently the male took another 90° anticlockwise turn (Fig. 4.5f) and closed its wings and assumed the normal position. Thus in copula the male and female assumed a back to back position (Fig. 4.5g). The duration of copulation varied between 50-220 min (Mean 104 min) (Fig. 4.6).

Once the copulation was over the partners separated €or which female usually took the initiative. However, some pairs have occasionally been seen in copula during day time as the male had not succeeded in disengaging its genital apparatus presumaly after initiating copulation during the preceding night. Similar observation has been reported in some noctuids (Callahan and Chapin, 1960).

Among Lepidoptera, females of many species exhibit a typical calling behaviour by lifting the wings and curving the abdomen and by protrusion and retraction of terrminal abdominal segments during which it apparently releases the pheromone from the exposed glands to attract the male (Islam and Allam, 1979; Ellis and Brimacombe, 1980). A similar calling behaviour was not observed in H. puera. It is possible that the calling behaviour was not conspicuous in H. puera as the experimental moths were confined to small glass containers having limited space and the male was already in close range of the female and even visual cues could serve the purpose.

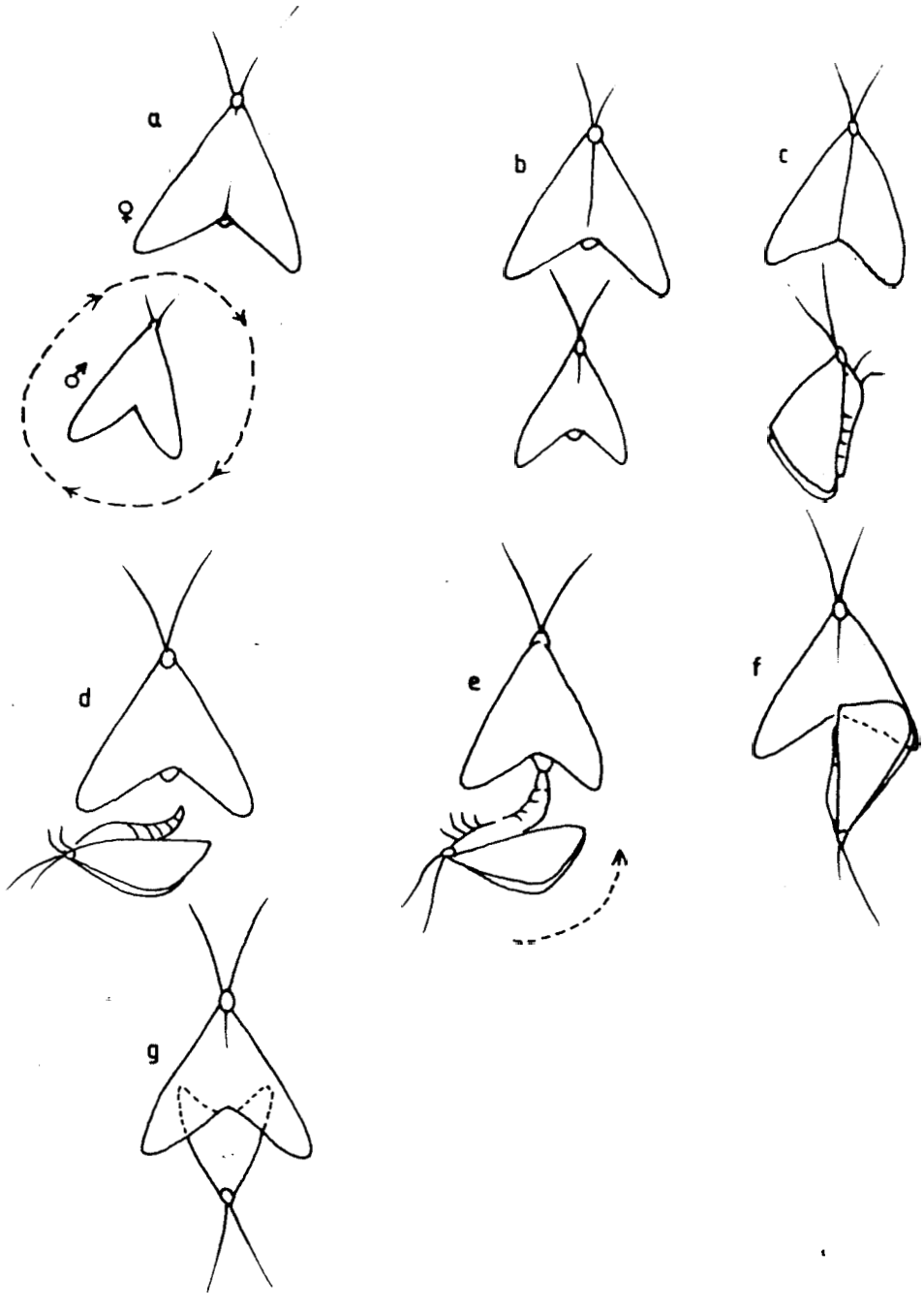


Fig. 4.5. Courtship pattern in *H. puera*

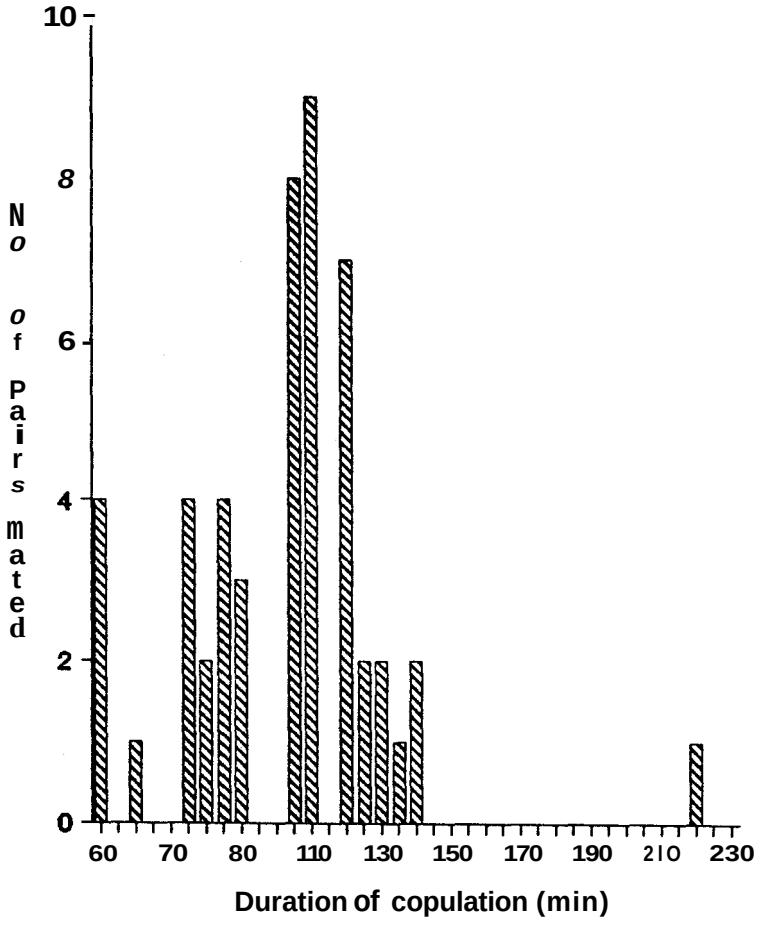


Fig. 4.6. Duration of copulation

Display of hair brushes observed in male *H. puera* , as part of courtship behaviour, has already been reported in a number of species of moths including the forest pests, Atteva fabriciella (Murthy and Chattoraj, 1978) and Eutectona machaeralis (Gopakumar and Prabhu, 1984). The association of the display of hair brushes with male pheromone dispersal has been reported in the oriental fruit moth, Grapholitha molesta (Baker et al., 1981). Gopakumar and Prabhu (1984) also reported a similar possibility of pheromone dispersal through hair pencil display in E. machaeralis.

Possible role of sex pheromone in mating

The result of the study is presented in Table 4.5. The response of the male moths to the female body extract was evaluated based on the various steps in the courtship behaviour exhibited by them.

Table 4.5. Response of males to the extract of abdominal tips of feule

Solvent used for extraction	Number of males ehowing response							
	Rapid movements		Wing flutt-ering and wing ion		Standing on hind legs		Releasing hair brushes	
	E	C	E	C	E	C	E	C
Ethyl alcohol	11	10	0	0	0	0	0	0
Dichloromethane	12	13	3	0	2	0	2	1

Number of males per treatment - 15
E = Experimental; C = Control

It may be seen from the data that the female abdominal tip extract in ethyl alcohol could not elicit any characteristic courtship response in the male moths. However, tests with dichloromethane extract gave some evidence of presence of an attractant pheromone in it. The important steps of the courtship behaviour taken into consideration in the bioassay were, wing fluttering, standing erect on hind legs and display of hair brushes. When exposed to dichloromethane extract, out of the 15 males, 3 exhibited wing fluttering and wing expansion and 2 males stood erect on legs. None of the control males exhibited these two steps. It may be asumed that wing fluttering as well as standing erect on legs are performed by the males in response to some olfactory cue released from the dichloromethane extract.

The display of hair brushes does not appear to be a specific response to a pheromone as the number of males that exhibited this behaviour did not vary significantly between experimental and control sets.

The results indicate that traces of a sex pheromone is present in the extract of the abdominal tip of female **H.** ***puera*** and that the pheromone gland is apparently situated in the terminal segments of the abdomen. Between the two solvents tested for the extraction of the pheromone only dichloromethane was found to be partially successful. However, as the percentage of males which showed positive response to this extract was very low, dichloromethane does not appear to be a good solvent for extraction of the pheromone constituents of **H.** ***puera.*** Hence further studies are needed to arrive at a suitable extraction method with a better solvent system.

4.3.2. Oviposition behaviour

Preoviposition period and time of oviposition

As a rule, a female H. *puera* which mated during the early morning hours of a particular day laid its first batch of eggs on the same day evening, the preoviposition period being 18-24 h after mating. Normally oviposition started at sunset and prolonged upto midnight. Major share of the eggs was laid before midnight.

Preference for substratum for oviposition

Under laboratory condition the substrata available for the moths to lay eggs were the inner surface of the glass container and the lower surface of the muslin cloth used to cover the top of the container. Presence of teak leaf in the container was not required to initiate oviposition. Eggs were laid both on the glass surface as well as on the muslin cloth cover. Observation on the egg laying pattern of 26 females indicated that the moths have a preference to lay eggs on the cloth (C) rather than on the glass surface (G). The percentage of moths which laid eggs during their first day of oviposition on C, G and C+G were 58, 27 and 15 respectively. Apparently the moths prefer cloth surface for oviposition because of its soft and rough texture which facilitate attachment of eggs as in teak leaf.

Duration of oviposition

The duration of oviposition of H. *puera* varied between 1-11 days with 7 days being the median (Table 4.6). However, only about 15 percent of the females were observed laying eggs for more than one week. Once the oviposition started, egg laying occurred every day until the end of the oviposition period. In a small percentage of the females (25%) oviposition period was discontinuous as no eggs were laid on certain days. However the total number of eggs laid by such moths were comparable with that of normal moths.

The life span of the H. *puera* females varied from 3 to 28 days with an average of 13 days. In the case of a female which mated at the age, 3-4 day, egg laying was completed during the average oviposition period of 6-7 days. Thus the moth could complete its oviposition before it crossed the average lifespan. However, when mating was delayed oviposition also got delayed. Data based on 14 females indicated that a delay of about one week to start oviposition (due to delay in mating) did not affect the normal oviposition period as well as fecundity. There was no correlation between mating time (age) and the oviposition period as well as the fecundity (r = 0273 and .0010 respectively).

Table 4.6. period

No. of females observed	Duration of Ovipoeition (days)
12	1
10	2
12	5
18	6
23	7
9	8
4	9
3	10
1	11
Total 92	

Fecundity

Under laboratory conditions the total number of eggs laid by *H. puera* females varied from 287 to 606 with an average of 434 (n = 31). The number of eggs laid was maximum on the first day of oviposition and thereafter the number decreased progressively (Fig. 4.7).

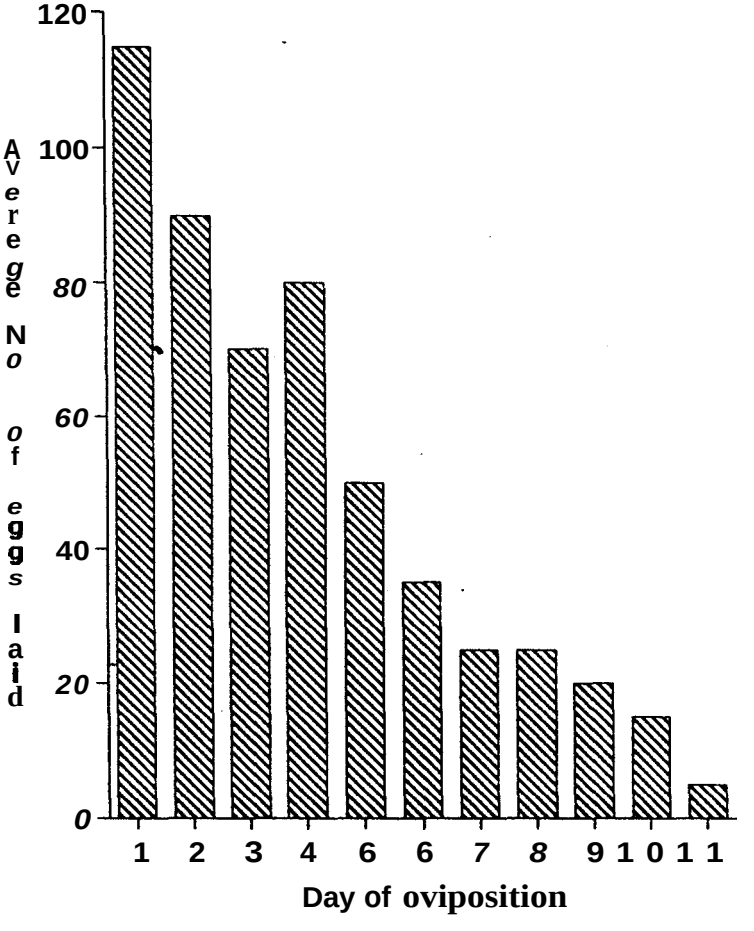


Fig. 4.7. Fecundity rate of *H. puera*

4.4 Conclusions

The objective of the etudy was to generate information on mating and oviposition behaviour of *H. puera.* The behaviour of the moths emerged from field collected pupae as well as from the laboratory culture was observed.

While mating occurred at the age of 2 days in most moths of field population, moths from the laboratory culture did not mate until they were at least 3 days old. This may be because the environmental factors under which the larvae bred in the laboratory were different from those experienced by the field population.

The female moths were monogamous while the males mated with several females during its lifespan. As the male-female ratio of *H. puera* is almost the same, male polygamy is advantageous from the point of its application in pest management programmes involving manipulation of the males.

Experiments indicated presence of a sex pheromone in the female moths. However, the response of the male moths to the crude pheromone extract was very weak. Hence, further studies are required in this line to understand the role of pheromone in the mating behaviour of *H. puera.*

The observation on the oviposition period of *H. puera* as about one week and that most of the eggs are laid during the first half of the oviposition period are in conformity with the report on this species from Thailand (Laknavichian and Napompeth, 1990). Though oviposition occurred daily during the oviposition period, unpublished field data (Mohanadas, personal communication) suggest that the moths do not oviposit in the same locality continuously. During the peak pest incidence period, larvae observed in a particular locality belonged to the same age group. Continuous egg laying in the same locality would have resulted in forming a larval population of different larval instars there. Hence it appears that the moths after laying eggs in one locality for one or two days move to another locality to continue oviposition. This could also be true as the larval population located in two distantly separated patches of teak plantations during the early part of the infestation period usually differed in their age at least by 2-3 days. However, further field studies are required to prove the above hypothesis.

FIELD EVALUATION OF PHENOLOGICAL RESISTANCE FOR PROTECTION OF TEAK AGAINST *HYBLAEA PUERA*

K.S.S. Nair and K. Mohanadas

5.0. Abstract

Attempt was made to test whether teak plantations raised from early-flushing clones can be used as a means of protection from the defoliator, taking advantage of 'phenological resistance', i.e., escape of trees with mature foliage from egg-deposition. The results were inconclusive because the grafted early-flushing clones did not repeat the phenological behaviour of parent trees and all trees suffered defoliation when outbreak occurred. The trial needs to be repeated with clones in which early flushing is known to be genetically determined.

5.1, INTRODUCTION

In an earlier etudy (Project Entom 12/83: Nair *et al,* 1989) a search was made in Kerals for teak clones resistant to attack from the teak defoliator, Hyblaea *puere.* Extensive areas of plantations and natural forests including three seed orchards representing 31 plus trees were examined during periods of defoliator outbreak. It was found that many isolated trees were left distinctly unattacked in the midst of totally defoliated trees. However, detailed investigations revealed that the escape of these trees from defoliation was not due to genetic resistance but due to, what may be called, 'phenological resistance'. Tender leaf is essential for egg laying by *Hybleea puera* moths and for establishment and survival of young larvae. Phenological resistance arises due to asynchrony between the flushing time of the tree and time of abundance or arrival of gravid moths, in a given locality. Trees which flush early have a greater chance of escape from defoliation.

In this study, an attempt was made to test whether teak plantations raised from early flushing clones can be used as a means of protection from the defoliator. Some late flushing as well as intermediate clones were also included for comparison.

5.2. MATERIALS AND METHODS

Nine clones of teak were tested in this study, by planting them out in the field and observing their susceptibility to attack during the course of natural insect infestation.

The planting was done in about 0.25 ha at Panayangode in the Nilambur Forest Range. This plot was situated within a large area planted up with teak by the Forest Department in the same year. For each clone, 49 plants were planted up 2 m spacing between plants in a 7 tree x 7 tree rectangular sub-plot. Each sub-plot had a border row of mahogany *(Swietenia macrophylla)* plants on all sides and nine such sub-plots within a rectangular 0.25 ha area constituted the larger study plot.

Of the 9 clones tested, 8 were from Nilambur which included 4 early flushers, 2 late flushers and 2 intermediate. These clones were selected in 1987 by extensive observations on the phenological behaviour of trees in teak plantations at Nilambur. Crown branches from selected trees which showed bud break at various times were collected and suitable buds were grafted onto 1-year old teak stumps as described by Venkatesh *et al.* (1986). Early flushing clones represented trees which were in full flush (some with flowers) by early February and the late flushing clones represented those which flushed in early May, all at Nilambur. Others flushed in between. The ninth clone (not strictly a clone, but a mixture of clones) consisted of a mixture of graftlings representing 4 selected trees from Kulathupuzha, Konni, Parambikulam and Peechi which escaped defoliation under natural conditions in an earlier study (Nair *et al.,* 1989).

The grafted polypotted seedlings were planted out in pits of 30cm x 30cm x 30cm on 9 July 1987. Observations on susceptibility to defoliation were made whenever there was incidence of defoliator attack in the surrounding plantation of same age.

5.3. RESULTS AND DISCUSSION

No major defoliator infestation occurred in the experimental area during the year 1987, although planting was completed in July 1987.

In the first week of March 1988, following a good rainfall, there was heavy infestation of H. puera in the plantation. All the 9 experimental plots suffered total defoliation at this time. There was no difference between the 9 clones, and all leaves, both young and old, were consumed by the high-density larval population.

A similar heavy infestation occurred in the area in the third week of June 1989. Observations made on 21 June showed that the experimental saplings in all the plots were defoliated, with no distinction between the clones.

In January 1990, observations were made on the flushing behaviour of the different clones in the study plots. The results (Table 5.1) show that the experimental saplings did not repeat the original flushing behaviour of the mother trees. In mid-January when the observations were made, the percentage of saplings possessing tender leaves was very low among the early flushers, except for one clone (Clone No.2, Table **5.1)**, and among the late flushers one clone (Clone No.6, Table 5.1) had a high percentage of saplings with tender leaves.

These results suggest that all the phenotypic expression of early or late flushing may not have a genetic basis. The early/late flushing behaviour of some of the trees from which graftlings were prepared for this study may have resulted from edaphic influences.

That water availability influences the flushing behaviour of teak saplings was shown earlier (Nair et al, 1989). Other unknown factors such as selection of buds from particular branches of trees may have also influenced the flushing behaviour of graftlings in the same way as early or late flowering of grafts is determined by the position of the bud in the mother tree. It is also not clear whether the flushing behaviour of saplings will be the same as that of older trees. An additional complication may have resulted from grazing of some saplings within the experimental plots by goats.

Table 5.1. Flushing Status of out-planted experimental clones

(on 19 January 1990)

Original flushing habit	Clone No.	Percentage of saplings with new flush
Early	1	11
	2	54
	5	11
	7	2
Middle	3	53
	9	91
Late	4	0
	6	88
Mixed	8	46

The present results indicate that the usefulness of early flushing clones must be tested with clones in which early flushing is known to be determined genetically. This will require further investigations into the genetics of flushing in teak.

The prospects and constraints of using early flushing clones for protection of teak against the defoliator, *Hyblaea puera* were discussed in an earlier report (Nair et al, 1989). The present study did not yield any conclusive practical results on the usefulness of early flushing clones.

Section 6

GENERAL CONCLUSIONS: IMPLICATIONS OF THIS STUDY FOR MANAGEMENT OF THE TEAK DEFOLIATOR AND OUTLOOK FOR FUTURE

K.S.S. Nair, V.V. Sudheendrakumar and K. Mohanadas

The need to control the defoliator *Hyblaea puera* in plantations of teak is now well established. Earlier studies carried out at this Institute (Nair *et al*, 1985) showed that 4- to 8-year old plantations can gain an additional increment of 3 cu.m. of wood per hectare when protected from the defoliator. Projections indicated that, in theory, trees protected from defoliation will be ready for harvest in less than half the normal rotation period of 60 years, provided, of course, that other inputs for growth are given.

Having established the need for control, our attention has been focused on developing appropriate methods for control. Over the past several years we have examined various options for this purpose. We have concluded that the long-advocated silvicultural-cum-biological control will not be effective against this highly mobile pest with heavy and sudden population outbreaks. While chemical insecticides which have been tried in the past may afford short-term protection, their use entails recurring cost and long-term ecological problems. Limited search for defoliator resistant teak (Nair *et al,* 1989) did not yield positive results. A naturally occurring disease caused by a Nuclear Polyhedrosis Virus (NPV) has been identified and laboratory tests have given promising results (Sudheendrakumar *et al,* 1988; Mohamed Ali *et al,* 1991). Another biocontrol agent, *Bacillus thuringiensis* which is now commerically available, is also promising.

The present study was a logical continuation of our earlier studies and addressed the following four specific objectives.

1. To further examine the scope of using insect parasitoids - not for restoration of the natural biological control as advocated earlier but for artificial biological control by inundative release of selected parasitoids (Section 2.3.1).

2. To explore the possibility of using phenological resistance to protect the trees from the defoliator (Section 5).

3. To explore the use of sex pheromones in the management of *H. puera* populations (Section 4).

shed further light on the population dynamics of H. *puera* (Section 2, 3).

The reeults obtained have been presented and discussed in the respective eectione. The practical implications of these results for management of the teak defoliator and the future efforts needed are discussed briefly below.

Insect Parasitoids

The study showed that insect parasitoids do not constitute an important factor regulating the host population during the outbreak phase. They did not respond either numerically or functionally to increase in the host population. This is because of the highly mobile nature of the host population (Section 2.3.1), the moths emerging from an infested area moving away to another area to initiate a fresh outbreak, leaving behind the parasitoid population built up in the current generation.

Under the circumstances, there is no scope for controlling the pest by restoring the naturally occurring biological control by the silvicultural-cum-biological control measures advocated earlier. However, parasitoids can be used, by inundative release, i.e., field release at appropriate times of large numbers of selected artificially reared parasitoids.

The desirable characteristics of such potentially useful parasitoids include (1) parasitation of early larval instars to effect control before damage has progressed; (2) parasitisation efficiency, i.e., killing power; and (3) amenability for mass production. Three species of potentially useful parasitoids have been identified for Kerala - the eulophids *Sympiesis* sp. and *Elasmus hyblaea,* and the bethylid *Goniozus montanus.* Several others including the well-known egg parasite *Trichogramma* spp. have been shown to be unsuitable, for various reasons (Section 2.3.1). Before practical control can be achieved, the following actions are needed.

1. Develop mass-rearing techniques for the selected parasitoids and conduct field tests.

2. Develop outbreak prediction/pest surveillance methods to facilitate timely release of parasitoids attacking the early larval inatars.

In addition, the possible role of parasitoids during the non-outbreak period in preventing the host population from reaching the outbreak threshold needs to be invetigated further. If parasitoids do play a key role in this, they can be used to prevent the development of an outbreak, rather than controlling it after the outbreak has erupted. This calls for further studies on the population dynamics (see below).

Phenological resistance

The teak defoliator moths lay eggs only on tender leaves (Section 2.1.3). Trees with mature leaves escape from defoliation because they do not elicit egg-laying. This kind of resistance has been called phenological resistance. In this study an attempt was made to test whether teak plantations raised from early flushing clones can be used as a means of protection from the defoliator, taking advantage of phenological resistance.

The results were inconclusive because the grafted early flushing clones did not repeat the phenological behaviour of the parent stock and all clones suffered defoliation when outbreak occurred. It is necessary to repeat these trials with clones in which early flushing is known to be genetically determined. This requires knowledge of the genetic control of flushing in teak and the influence of age, edaphic factors, etc.

Pheromones

The present study brought out valuable basic information on the reproductive behaviour of H. *puera* moths. The results did not indicate presence of a strong sex-attractant pheromone in the female moths. Progress could not be made towards isolation of sex pheromones because the anticipated external expert collaboration did not come through. Further studies are needed particularly to explore the presence of an aggregation pheromone, probably produced by newly emerged males, which may be involved in bringing the moths together for, mating, migration, etc.

There is no scope for using sex pheromones for controlling outbreak populations by mass trapping, because of the enormous numbers of moths involved in outbreak populations. However, the use of pheromones for monitoring low-density pre-outbreak populations of H. *puera,* and in managing them to prevent development of outbreaks is a very promising line of research. It is possible that outbreaks develop in local epicentres through moth aggregation.

Population dynamics

This objective of elucidating the population dynamics of H. *puera* occupied our greatest attention and effort in this study for two reasons.

1. Successful application of control measures such as use of NPV, *B.* t, or parasitoids depends on our ability to time the application/release of these control agents appropriately,

2. An understanding of the causation of outbreaks may suggest ways to nip the problem in the bud and prevent the development of extensive outbreaks.

Let us consider the contribution of this study towards these two aspects, i.e., outbreak prediction and causation of outbreaks. The detailed results have been presented in Sections 2 and 3; only the practical aspects and future research needs are highlighted here.

Outbreak prediction/surveillance

The rapidity with which outbreaks of the teak defoliator occurs and spreads over extensive plantation areas have been known since long. As early as 1934, Beeson (1934) wrote that unless plantations can be reliably patrolled for the detection of incipient outbreaks and spraying operations carried out with the speed of a fire-fighting organization, chemical control will not be practical. Although defoliator outbreak is a regular annual feature in many parts of India and elsewhere, it is extremely difficult to predict or even to observe the exact time of occurrence of outbreak in a given area. The infestation becomes visible only about 3 days after the egg laying has occurred, when the 2nd instar larvae cut out small leaf-folds in the tender leaves. And in about a week thereafter the trees become totally defoliated. This creates difficulties in the timely application of control measures. The problem has some similarities to a dacoity situation. Although we may have the guns ready, we cannot pull the trigger unless we detect the decoits. In the same way, although we can kill the insects by many means (with NPV, *B. t.*, parasitoids, etc.), we cannot use these weapons unless we know when and where the outbreaks will occur. That is why we need to develop appropriate outbreak prediction methods or methods for real-time monitoring of pest activity.

Our study has shown that following a long period of near-absence of the teak defoliator population during the leaf-fall and early flushing period, the first noticeable event in the chain of events leading to widespread outbreak is the sudden occurrence of comparatively low-density, patchy infestations at tree-tops (Section 3). However, since these patches are small (0.5 to 1.5 ha.) and far between, it is not easy to trace them by ground surveillance. Use of pheromone traps or light traps may be useful. Suitable light traps and pheromone traps need to be developed and tested. There are difficulties in the use of conventional electricity-or battery-operated light traps in remote forest areas; development of solar-powered traps seems to be the solution. Use of pheromone traps requires specialised research for identification of aggregation and/or sex pheromones and their synthesis. As discussed above, this is a profitable approach not only for pest surveillance, but also possibly for management of low-density populations to prevent outbreak development. In future research, high priority must therefore be given to pheromone research.

This etudy has further brought out the close correlation between the time of occurrence of the first pre-monsoon rain showers and the appearance of high-density patchy outbreak of H. *puera,* within an area (Section 2.3.6, and 3). This is the forerunner of Widespread outbreaks. Thus, the occurrence of the first pre-monsoon showers in an area can be taken as the calling bell to look for high-density patchy infestations by ground surveillance and start control operations (use of NPV, *B*. t., parasitoids, etc.) where infestations are detected. From then onwards, it is necessary to maintain continuous surveillance.

Long-term studies using moth catch data from light traps and/or pheromone traps, and weather data (rainfall, wind velocity, wind direction, temperature, etc.) from recording stations located within plantations can lead to development of empirical outbreak prediction models. This must also receive attention in future research.

Causation of outbreaks

The exact cause(s) .of outbreak, that is, the circumstances leading to the transition from low-density residual populations to the high-density tree top infestations still remain unknown although the present study has provided some leads for further investigation.

Evidence has been obtained to indicate that the outbreak begins in small epicentres and subsequently spreads to larger areas like an expanding chain reaction. Several infestation characteristics suggest the occurrence of short-range gypsy-type of movement as well as long-distance mass movement of high-density moth populations (apparently aided by pre-monsoon wind patterns). Based on the available information, H. puera population outbreak appears to be of the 'eruptive' type. If this is confirmed, widespread outbreak can be prevented by controlling the early infestations in the epicentres. However, elucidating the relative roles and interactions among weather, phenology, moth behaviour and natural enemies in the causation of outbreaks still remains a challenging task. Several questions need to be answered. Is the transition from low-density to high-density population the result of any one or more of the following?

(i) Failure of natural enemies to limit the host population, i.e., failure of a negative feed-back control loop.

Positive feed-back on population growth exerted by increasing availability of food (tender foliage) during the early growth season.

(iii) Shift in moth behaviour, leading to aggregation, in response to some environmental cue such as rainfall.

(iv) Sudden arrival of a group of moths during the pre-monsoon rains, brought in by passive aerial displacement of moths from far-off places, as in the case of spruce budworm moth (Greenbank, et *al.,* 1980).

Our ability to prevent outbreaks will depend upon the answers to these questions. If population eruptions originate from local epicentres it is easy to prevent outbreaks but if long-distance movement of moth aggregations aided by monsoon winds plays a key role in triggering outbreaks, control will be more difficult. Whatever be the method of control used, knowledge of the cause(s) of population eruption can greatly aid control. Further investment on research into this aspect will be certainly rewarding. Detailed observations on moth behaviour under field conditions may hold the key for our greater understanding of the causation of outbreaks.

REFERENCES

Baker, T. C.; Nishida, R.; and Roelofe W. L. (1981) Close-range attraction of female oriental fruit moths to herbal scent of male hair pencile. *Science,* 214: 1359-1360.

Basu-Chowdhury, J.C. (1971) Interim Report on Konny Aerial Spraying Project. Appendix 3 In K.G. Vasudevan, Working Plan for Nilambur Forest Division, 1967-68 to 1976-77. Government of Kerala: 165-168.

Beeson, C.F.C. (1934) The biological control of teak defoliators. *Indian For.,* 60(10): 672-683.

Beeson, C.F.C. (1941) *The Ecology and Control of the Forest Insects of India and the Neighbouring Countries.* 1961 reprint, Government of India, New Delhi.

Beeson, C.F.C. and Chatterjee, S.N. (1939) Further notes on the biology of teak defoliators in India. *Ind. For. Rec. (n.s.) Ent.* 5:357-379.

Berryman, A.A. (1986) Forest insects: Principles and practice of population management. Plenum Press, New York, 279 pp.

Berryman, A.A. (1987) The theory and classification of outbreaks. In: *Insect outbreaks* (Eds. P. Barbosa and J.C. Schultz). Academic Press, California, 3-30p.

Callahan, P.S. and Chapin, J.B. (1960) Morphology of the reproductive systems and mating in two representative members of the family Noctuidae, *Pseudaletia unipuncta* and *Peridroma margaritosa* with comparison to *Heliothis zea. Ann. Entomol. Soc. Am.,* 53:763-82.

Chandran, E.K. and Prabhu, V.K.K. (1986) Localisation of the site of production of sex pheromone in female *Opisina arenosella Walker* (Lepidoptera:Cryptophasidae). *Proc. 111 Oriental Entomology Symp.* 1984, Trivandrum,1:103-107.

Chatterjee, P.N. and Misra, M.P. (1974) Natural enemy and plant host complex of forest insect pest of Indian region. *Indian For. Bull.* No.265, 233p.

Daterman, G.E.; Startwell, C.; and Sower, L.L. (1980) Prospects for controlling forest lepidoptera with controlled release pheromone formulations. pp 213-236, In: *Controlled Release* of *Bioactive Materials* (Ed. R. Baker), Academic Press.

Dent, D. (1991) *Insect Pest Management.* CAB International, Wallingford (U.K.) 604p.

Ellis, P.E. and Brimacombe, L.C. (1980) The mating behaviour of the Egyptian cotton leaf worm moth, *Spodoptera littoralis* (Boisd). *Anim. Behav.,* 28:1239-1248.

Fujii, A. .and Miyaehita, K. (1973) Further studies on the reiterative mating ability in males of *Spodoptera litura* (Lepidoptera, Noctuidae). *Applied Ent. Zool.,* 8:131-137.

Greenbank, D.O.; Schaefer, G.W.; Rainey, R.C. (1980) Spruce budworm moth flight and dispersal : new understanding from canopy observations, radar and aircraft. *Xem. Entomol. Soc. Can.,* 110-149.

Golub, M. and Weatherston, L. (1984) Techniques for extracting and collecting sex pheromones from live insects and from artificial eourcee. pp 223-285, In: *Techniques in Pheromone Research* (Ed. T.A. Hummel and T.A. Miller), Springer-Verlag, New York.

Gopakumar, B. and Prabhu, V.K.K. (1986) Sexual behaviour in *Pyrausta machaeralis* Walker (Lepidopter, Pyralidae). *Proc. III Oriental Entomology Symp.,* 1984, Trivandrum, 1:109-117.

Hassel, M.P. (1984) Host-parasitoid models and biological control. 73-92. In *Pest and Pathogen Control - Strategic, Tactical, and Policy Models.* edited by G.R. Conway, John Wiley & Sons, Chichester (U.K.)

Islam, B.N. and Alam, M.Z. (1973) Mating behaviour of jute hairy caterpillar *Diacrisia obliqua* Walker (Lepidoptera, Arctidae) 1. Precopulatory behaviour patterns in adults. *Appl. Ent. Zool.,* 14:303-309.

Khan, A.H. and Chatterjee, P. N. (1944) Undergrowth in teak plantations as a factor in reducing defoliation. *Indian Forester* 70(11):365-369.

Lakanavichian, S. and Napompeth, B. (1990) Ecological study on teak defoliators, *Hyblaea puera* and *Eutectona machaeralis* in Thailand. pp 155-166, In: *Proc. IUFRO Workshop on Pests and Diseases of Forest Plantations.,* Bangkok.

Mathew, G.; Sudheendrakumar, V.V.; Mohanadas, K.; and Nair, K.S.S. (1990) An artificial diet for the teak defoliator *Hyblaea puera* Cramer (Lepidoptera, Hyblaeidae). *Entomon,* 15:159-163.

Mohamed Ali, M.I.; Varma, R.V.; and Sudheendrakumar, V.V. (1991) Evaluation of microbial pathogens for biocontrol against important insect pests of *Ailanthus* and teak. KFRI Research Report No.72, 44p.

K.S.S. (1987) Migration, a mechanism of parasite evasion. In *Advances* of *Biological Control Research in India,* edited by K.J. Joseph and U.C. Abdurahiman, University of Calicut, Calicut, India.

Nair, K.S.S. (1988) The teak defoliator in Kerala, India. Chapter 14, pp 267-289, In: *Dynamics of Forest Insect Populations* (Ed. A.A. Berryman) Plenum Press, New York.

Nair, K.S.S.; Kedharnath, S.; Koshy, M.P.; Sudheendrakumar, V.V., Varma, R.V.; Mohanadas, K. and Mathew, G. (1989) Search for natural resistance to the insect pest, *Hyblaea puera* in teak. KFRI Research Report No.62, Kerala Forest Research Institute, 30p.

Nair, K.S.S. and Sudheendrakumar, V.V. (1986) The teak defoliator, *Hyblaea puera* Defoliation dynamics and evidence for short-range migration of moths. *Proc. Indian. Acad. Sci. (Anim. Sci)* 95 (1): 7-21.

Nair, K.S.S.; Sudheendrakumar, V.V.; Varma, R.V.; and K.C. Chacko (1985) Studies on the seasonal incidence of defoliators and the effect of defoliation on volume increment of teak. KFRI Research Report No.30, Kerala Forest Research Institute, Peechi 680 653, Kerala, India, 78p.

Sasaki, M. (1976) The calling behaviour and related circadian rhythm in the cucumber looper *Anadevidia peponis* (Lepidoptera:Noctuidae). *Bull. Fac. Agr. Tammagava Univ.,* Japan No.16:64-70.

Shorey, H.H.; Gaston, L.K.; and Kaae, R.S. (1976) Air permeation with gossyplure for control of pink bollworm. In: *Pest Management with Insect Sex Attractants,* (Ed. M. Beroza), American Chemical Society, Washington, D.C., 67-74.

Singh, P. (1980) Aerial spraying of chemicals to control teak defoliators. 901-907. In *Proceedings of the Second Forestry Conference*, Vol. 2, Forest Research Institute & Colleges, Dehra Dun, India.

Southwood, T.R.E. (1978) *Ecological Methods with particular reference to the Study of Insect Populations,* 2nd edition, The English Language Book Society and Chapman and Hall, Cambridge, 524p.

Sudheendrakumar, V.V. (1986) Studies on the natural enemies of the teak pests, *Hyblaea puera* and *Eutectona machaeralis.* KFRI Research Report No.38, Kerala Forest Research Institute, Peechi 680 653, Kerala, India, 28p.

Sudheendrakumar, V.V.; Mohamed Ali, M.I. and Varma R.V. (1988) Nuclear polyhedrosis virus of the teak defoliator *Hyblaea puera. J. Invertebr. Pathol.* 51:307-308.

Waage, J.K. and M.P. Hassel (1982). Parasitoids as biological control agents - a fundamental approach. *Parasitology,*

Appendix

PROJECT PROPOSAL

Code No. : **KFRI 101/1987**

Title : **Development of a management strategy for the teak defoliator, *Hyblaea puera***

Co-ordinator : **K.S.S. Nair - Entomology**

Investigators : **K.S.S. Nair, V.V. Sudheendrakumar, K. Mohanadas (Entomology) K.C. Chacko, M.S. Jayaraman (Silviculture)**

Additional investigators will be co-opted at a later stage as necessary to study relevant aspects of Ecology and Meteorology.

Objectives :

1. **To understand the cause-effect relationships of annual defoliator outbreak6 and collapses with particular reference to the role of wind patterns, tree phenology, natural enemies and alternative hosts.**

2. **To develop a strategy for management of the pest using the above knowledge and test it under field conditions.**

Practical utility:

Serious loss of increment caused by the teak defoliator necessitates development of a suitable management strategy. Possibility of control using a viral pathogen is being explored under a separate project. This project will evaluate 3 additional approaches towards control.

1. **Various natural mortality factors will be evaluated to determine their usefulness for control. Insect parasites will receive special attention.**

2. **The usefulness of phenological resistance, i.e., escape from defoliation due to early flushing, which was demonstrated in a previous study, will be field-tested. If plantations raised from early flushing clones show consistent resistance, it will provide a cheap, simple, safe and lasting solution to the defoliator problem.**

3. **Information will be gathered on the cause-effect relationships of the origin of outbreaks in plantations in order to try to solve the problem by attacking the root cause.**

Outline of research:

The study will be divided into two phases - (1) Studies to be carried out straight-away with Institute funds, and (2) Studies to be carried out with external support, when the funds become available. For operational efficiency, the entire programme is divided into convenient subprojects and responsibilities assigned to individuals/groups. Some parts of the project will be terminated and merged with the externally sponsored project at appropripate time depending on the nature of support available and others will be completed under this project. Since discrete parts of the study are expected to be completed within a shorter period, separate reports will be brought out as appropriate. The subprojects and the proposed plan of work under each is given below.

I. Life-table of *Hyblaea puera* and assessment of the potential of parasitoids for control

(Investigators : K. Mohanadas, K.S.S. Nair)

The main objectives of these studies are (1) to obtain population estimates of various life stages of the pest during natural infestations and construct life tables to identify key mortality factors, and (2) to try and breed promising parasitoids and test them for control efficiency.

Plan of work

1. Study plots will be selected in teak plantations at Nilambur and using suitable sampling methods, population estimates of egg, larva, pupa and adult of Hyblaea will be gathered. The data will be subjected to statistical analysis using standard methods to determine key mortality factors.

2. The incidence of parasites and predators and their behaviour will be studied and attempts made to breed selected species in the laboratory. Promising species will be tested for control efficiency.

This part of the study is expected to be completed during April 1987 to March 1990.

11. Reproductive behaviour of *Hyblaea puera* and the role of pheromones

(Investigator : V.V. Sudheendrakumar)

The main objectives are to gather basic data on reproductive behaviour, establish the presence and role of pheromones, isolate them and examine their utility in the pest management programme.

Plan of work

1. Laboratory cultures of H. *puera* will be maintained and behavioural observations made on courtship, mating, oviposition, etc.
2. The presence of pheromones will be studied by suitable experiments, the pheromone source identified and their roles established using crude extracts.

3. When suitable facilities become available under external collaboration, the chemicals will be isolated, field tested, and various ways of using them for management of the pest explored.

   Basic behavioural observations and studies using crude extracts are expected to be completed during April 1987 to September 1988.

III. Field evaluation of phenological resistance for protection of teak against *Hyblaea puera*

(Investigators : K.S.S. Nair, K. Mohanadas, M.S. Jayaraman, K.C. Chacko)

The objective is to test whether teak plantations raised from early flushing clones can be used as a means of protection against the teak defoliator.

Plan of work

1. Early flushing teak trees will be located in plantations and/or natural forests and large number of graftlings produced. These will represent trees which flush at various time intervals starting from the earliest, in the same general area.

2. Established graftlings will be planted out, over a 3-year period, in plots within current planting areas or within older plantations at suitable open sites.

3. Data will be gathered on the flushing time, the persistance of the early flush and the incidence of defoliator attack, and compared with similar data from routine plantations to determine the usefulness of phenological resistance.

A minimum period of 5 years will be required to test the usefulness of phenological resistance, and the observations may be continued further to confirm the results but the investment in terms of research effort is small after the plantations have been established during the first 3 years.

IV. Investigations into the patterns and causes of teak defoliator outbreaks

(Investigators : K.S.S. Nair, K. Mohanadas and others from Entomology, Meteorology & Ecology to be co-opted as necessary)

The objective is to elucidate the conditions which lead to the annual outbreaks of the teak defoliator in forest plantations of Kerala, particularly with respect to the role of natural forests, tree phenology and wind patterns, in order to try and develop a strategy for preventing outbreaks by striking at the root cause.

Plan of work

1. Attempts will be made to discover the mechanism of survival of the insect during the non-outbreak season by extensive surveys in selected natural forests and plantations using light traps, trained local "insect detectives", etc.

2. Data will be gathered on the flushing pattern of teak and other host plants in different parts of Kerala to examine the relationship between flushing of host plants and defoliator outbreaks.

3. The influence of meteorological factors, particularly of wind systems, on the behaviour of moths emerging from outbreak sites will be studied with respect to formation and movement of swarms. Attempts will be made to construct mathematical models of the spatial distribution pattern to analyse the causes of outbreaks.

4. Laboratory as well as field investigations will be made on the possible occurrence of diapause.

5. The influence of volatile chemical components of tender teak leaves on the behaviour of moths and the cause-effect relationships between host, site and insect outbreaks will be examined.

Progress on these studies depends on definite and more or less continuous availability of a vehicle for field observations and adequate man-power, both scientific and supporting field staff. Some aspects of the study will be taken up straight away to prepare the ground for effective implementation when external financial support is obtained.

Date of commencement	:	April 1987
Likely date of completion	:	March 1992 (5 years)
Special facilities		Nil
Whether financed by external agency		Part of the work depends on external support; support is being sought from US-India Fund.