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TEAK DEFOLIATOR MANAGEMENT BY CONTROLLING EPICENTRE POPULATIONS - A CASE STUDY

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(Report of the Project KFRI 308/1988 Sponsored by the Kerala Forest Department-Development Fund, September 1988 – August 2001)

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CONTENTS

PROJECT PROPOSAL

1. Title of the Project	Teak defoliator management by controlling epicentre populations – A case study
2. Principal Investigator	Dr. V.V. Sudheendrakumar
3. Investigators	Shri. T. V. Sajeev and Dr. R.V. Varma
4. Objectives	To test whether controlling the epicentre populations of the teak defoliator can prevent subsequent larger outbreaks
5. Study area	Nilambur teak plantations
6. Duration of the project	September 1998 – August 2000
7. Funding agency	Kerala Forest Department-Development Fund

ABSTRACT

A study was carried out to test the impact of controlling epicentre populations of the teak defoliator, *Hyblaea puera* Cramer (Lepidoptera, Hyblaeidae) on further large-scale outbreaks. The data were gathered from about 8500 ha of teak plantations at Nilambur, Kerala, during the pest outbreak period in 1999 and 2000. The plantation area was divided into 189 observation units of about 50 ha each and each year the pest population was monitored from January onwards. On detection, each epicentre population was controlled with either a chemical (Quinalphos) or biological (*Bt*) insecticide, using ground operated sparying equipments, rocker sprayer, mist blower and an ultra low volume sprayer. In 1999, twenty epicentre populations ranging from 1- 125 ha in area, covering a total of 375 ha were detected between late February and mid April and control measures were adopted. Subsequent to control operations an area of 7532 ha was infested. The control operation was not successful as none of the sprayers used were efficient to target the insecticide to the canopy of tall trees as high as 30m and above. In 2000, sixteen epicentre patches ranging from 0.12 – 5 ha in area, covering a total area of 18.2 ha occurred between late February and late March and were successfully controlled using high volume motorised sprayer. About 2640 ha of teak plantations were infested subsequent to the control operations.

A comparison of the area under teak defoliator infestation between years in which epicentre control was carried out (1999 (unsuccessful) and 2000- (successful)) and the normal years (data on spatial dynamics generated under earlier studies in 1993 and 1998) indicated that the pest incidence in the year 2000 was very low and significantly different from all the other years. A comparatively smaller area under teak defoliator infestation in 2000 is attributed to the control of epicentre populations. The study also revealed a high correlation between epicentre populations and subsequent large-scale outbreaks suggesting the prospects of epicentre control.

As the conclusion in this study is exclusively based on the results of the successful experiment carried out in only one year (2000) alone, the result cannot be treated as fully valid. It also appears that the comparison of the data generated in 2000 with data of 1993, 1998 and 1999 alone is not fully valid. As the possibility of lean years with reduced infestation cannot be ruled out, a further long-term study is warranted for validating of the findings of this study.

1. INTRODUCTION

The teak defoliator, *Hyblaea puera* Cramer (Lepidoptera, Hyblaeidae) is the most serious pest of teak in India (Beeson, 1941). The infestation of this pest is a regular annual phenomenon in teak plantations. Based on studies in Kerala, Nair *et al.*(1985) reported that teak defoliator infestation resulted in a loss of 44 % of the potential volume increment in young teak plantations. In a 4-to 8-year old plantations, trees protected from defoliation by *H. puera* put forth an annual increment of $6.7 m^3 ha^{-1}$ compared to $3.7 m^3 ha^{-1}$ of unprotected trees. The above study revealed that managing the pest would enhance the productivity from the existing plantations.

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 (Beeson, 1941) and (2) chemical control using insecticides (Basu-Chowdhury, 1971). The biological control recommendations have never been practised by forest managers, for various reasons. Studies by Nair and Sudheendrakumar (1986) indicated that the recommended biological control measures could 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 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, 1985). Although chemicals may prove effective for immediate knockdown of the insects, there are several well-known problems associated with the use of insecticides in the forest ecosystem.

Development of alternative, ecologically sound pest management systems was therefore considered very important. It was also considered that an in-depth knowledge of the dynamics of pest populations is necessary to accomplish this. There are two pre-requisites for practical control of this long recognised pest: availability of good control measures and the ability to predict the outbreak well in advance to mount the control efforts - a nip in the bud approach. Regarding the control measure, a naturally occurring Nucleopolyhedrovirus (NPV) has been identified, tested and proved to be promising (Sudheendrakumar *et al.*, 1988; Nair *et al.*, 1996). A series of studies have been carried out in Kerala addressing the second pre-requisite, viz., proper timing of control operations. Although defoliator outbreak is a regular annual feature in teak plantations throughout Kerala, it is extremely difficult to predict the exact time and places of occurrence of these outbreaks. Data obtained in earlier studies (Nair and Sudheendrakumar, 1986) indicated habitual, short-range, gypsy type movements of emerging moth populations, suggesting that these populations developed in small patches and spread to larger and larger areas, generation by generation, affecting the entire teak plantations. Nair and Mohanadas, (1996) found that the outbreaks began in localised widely separated small patches and the initial build-up was strongly correlated with the occurrence of pre-monsoon showers.

Earlier, we (Nair *et al.*, 1998a) carried out a study to test the hypothesis that the outbreaks begin in small epicentres and spread progressively to extensive areas as a result of population built up in these epicentres. The study revealed that in large teak plantation areas, like Nilambur, *H. puera* outbreaks began in comparatively small epicentres which may be 0.6 to 12 ha in area. These epicentres were not constant over the years and did not represent highly favourable local environments. Instead, they were sites where a group of immigrating moths or moths locally present but concentrated by as yet unknown phenomena assembled and laid eggs. A major finding in the study was that many of the extensive outbreaks, which occurred subsequently, could be attributed to the pest population build-up in these epicentres. However immigration of moths from outside the larger study area and their role in causing outbreak was not ruled out. It appeared that many of the large scale outbreaks could be prevented by controlling the small epicentre populations.

An experimental study involving control of epicentre populations was recommended to examine the effectiveness of this approach to teak defoliator management. This study was hence taken up as a logical continuation of the above work.

2. METHODS

2.1. Study area

The study was carried out in about 8,500 ha of teak plantations (latitudes 11^{O} 10'N and 11^{O} 25'N and longitudes 76^{O} 10'E and 76^{O} 25'E) in Nilambur, Kerala during the pest incidence season in 1999 and 2000.

The plantation maps were prepared by interpreting the aerial photographs. Only the teak plantations were interpreted and mapped. The map was brought to the scale 1:50,000 and major features like drainage and roads were marked by superimposing it on Survey of India (SOI) topographic sheets of the same scale. The area was divided into 19 blocks(Fig.1) and 189 Observation Units (OUs) (Fig. 2) based on natural boundaries of streams, roads and footpaths. The average area of one OU was about 50 ha.

2.2. Epicentre detection and recording of outbreak data

In each year, observations were made during January - June. Nineteen trained field observers were deployed in the field to locate and record outbreaks. Each observer was assigned a minimum of 10 Observation Units. (OU). As the life cycle of the teak defoliator is completed in about 19 days, observations at weekly intervals were made in each OU to detect the pest and to carry out control operations at the earliest opportunity.

The observers were supplied with copies of a map of the relevant block. Whenever an outbreak occurred, the approximate extent of infestation was estimated and marked in the map. From each infested location larval samples were collected. The larvae were reared in the laboratory until they moulted to

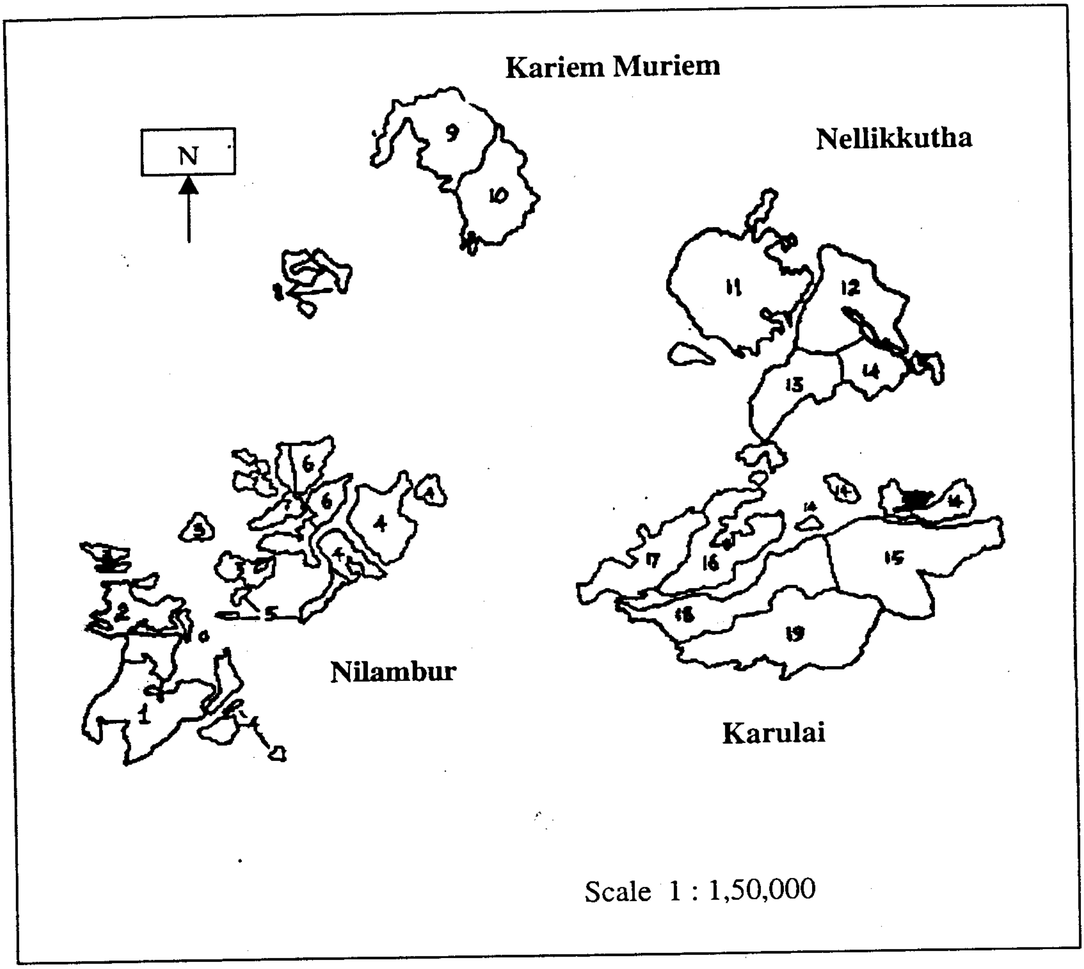

Fig. 1 Map of Nilambur teak plantations showing the 19 Observation Blocks

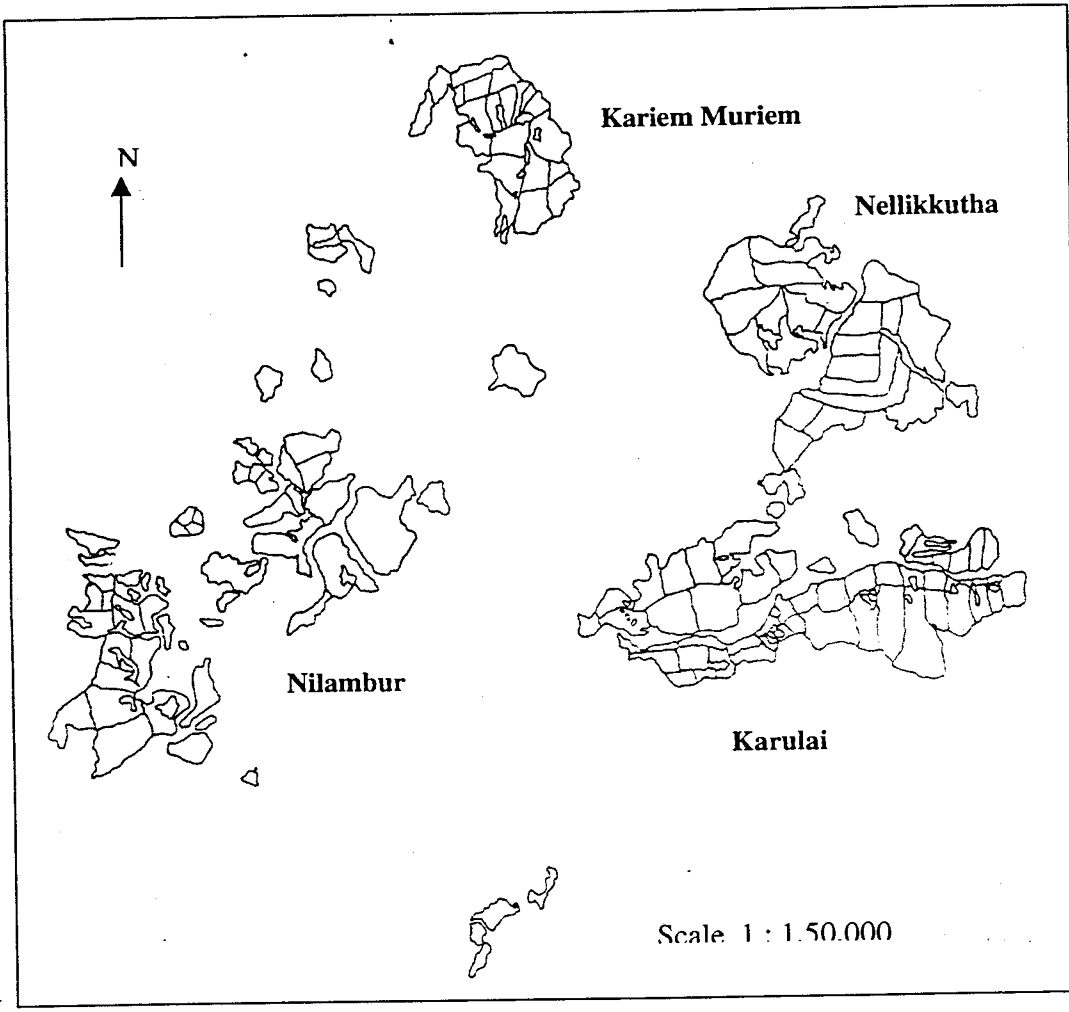

Fig. 2 Map of Nilambur teak plantations showing 189 Observation Units

the next stage - either the next larval instar or pupa. Based on this, the date of egg laying was back calculated

Using the duration of each instar (egg-one day; instars 1 and 2 –two days each, instars 3 to 5- three days each; pre-pupa- one day and pupa—four days) the temporal data on outbreaks was examined to see whether each subsequent outbreak can be explained on the basis of previous outbreak. To examine this, the generation time from egg to egg was used. Based on the duration of each instar (given above) and pre-oviposition period of 2 days, the egg-to-egg period works out to 21 days. Unpublished laboratory rearing data had shown that this period was sometimes completed in 19 days, when the larvae were maintained on teak leaf at ambient temperature. Therefore 19 days was taken as the minimum generation time. The maximum generation time was taken as 26 days by adding the oviposition period of 5 days (Sudheendrakumar, 1994) to the normal egg-to-egg period of 21 days. Thus, if an infestation (egg laying) was observed between the 20^{th} and 26^{th} day of an earlier infestation, it could be argued that the second represented the F1 generation of the first. While there is no certainty about this, the converse is always true, i.e., if the second outbreak did not occur during that interval, it was not caused by moths produced in the first outbreak, although the borderline cases may be suspect because of possible variation in the generation time under natural conditions.

2.3. Epicentre control operations

2.3.1. Control operation in 1999

Spray equipments

Three types of sprayers namely, rocker sprayer, Aspee Bolo mist blower and STIHL ultra low volume sprayer were used in the 1999 trial.

The first epicentre in 1999 was controlled by using a rocker sprayer. The delivery hose of the sprayer was taken up to the mid height of one of the teak trees and spraying was one to the canopy of the neighbouring trees taking care to reach the chemical on all sides. Even though two rocker sprayers were simultaneously operated, this method was found to be very laborious and time consuming. Hence, in the subsequent trials a motorized Ultra Low Volume sprayer - Stihl SR 400 and a mist blower- Aspee Bolo were used. The STIHL sprayer has a precise control over the spray swath and droplet size and the vertical reach aided by its booster attachment. is 12 m. The mist blower sprayer has a vertical reach of 6 m.

Spray chemicals- 1999

In 1999, only chemical insecticide was used. Quinalphos (Ekalux 25EC) was used at the rate of 4 ml/litre of water with a sticker spreader (Tween 20). In general, foliar application of the insecticide was adopted. The chemical was also applied on tree trunks to control the larvae descending from treetop after feeding. On some occasions ground spraying was adopted to target the pupae in the ground.

2.3.2. Control operations in 2000

In the 1999 trials, the major problem identified was the inability of the ULV sparyer and mist blower to deliver the spray to the treetop which affected the success of pest control.. The average height of the infested trees in most of the locations was 25-30 m and the maximum reach obtained by the spraying systems was only about 12m.

So, for control operations in 2000, a high volume motorized sprayer (*BIRLA YAMAHA* brand), which could carry the spray spectrum up to 30 m height through a delivery hose, was used. In infested areas, the delivery hose of the sprayer was taken up to the mid height of the tree and all the surrounding trees were sprayed. The spraying was made when the larvae were mostly in the fourth instar stage within the leaf fold. In rare situations when the larvae descended for pupation before canopy spraying could be done, ground spraying was done to kill the pupating stages.

Spray chemicals- 2000

The spraying was carried out using a commercial biopesticide based on the bacterium, *Bacillus thuringiensis kurstaki* (*B.t*) (The brand "HALT", a product of Wockhardt was used). The chemical pesticide Quinalphos (Ekalux 25 EC) was used only in few occasions. Ekalux was used at the rate of 3 ml per litre of water with sticker spreader (Tween 20). In the case of *B.t*, a dosage of 1g in 1 litre of water was used. Controlled burning of the leaf litter was occasionally done to kill the pupae in certain locations where timely foliar spraying could not be done. In some locations, natural fire occurred which helped to wipe out the pupal stages.

2.3.3. Evaluation of spray effect

The sprayed areas were visited the next day for evaluating the spray effect. Light traps were setup to monitor newly emerged moths in the sites where control operations were made. Presence or absence of live stages of the insects in the sprayed areas was recorded. In locations, where the first spraying was not successful, a second round of spraying was carried out.

2.4. Past data used in the study

As control operations were carried out on both the years, data on epicentre development and population trend from the same study area during 1993 (Nair *et al.*, 1998a) and 1998 (KFRI unpublished data) were used as control sets to evaluate the impact of epicentre control on subsequent outbreaks.

2.5. Data analysis

2.8.2. Estimation of area infested by offspring populations of epicentres

To understand the effect of controlling the epicentre populations, the total area infested in different years was compared. The significance of difference between outbreak pattern in the four years (1993, 1998, 1999 and 2000) was tested using paired t-test. The test was done for each of the combinations of years. The data for the years 1993 and 1998 were truncated so as to be of the same time span as of years 1999 and 2000. The data were log-transformed (log x +1) for the t-test.

Estimation of area infested by offspring populations of epicentres

The relationship between two successive poulations was determined as per the methods described in section 2.2. The objective of this was to identify the outbreaks, which could have been caused by epicentre populations. The total period of monitoring in each of the four years (February to June) was split up based on the generation time of teak defoliator. In all the years, four specific groups were discernable. The first of them was a series of epicentre populations. The second group of outbreaks occurs after a lag and in concordance with the egg laying time of the moths emerged from the epicentre population. Similarly, the third and fourth groups occurred after a lag from the second and third group of outbreaks respectively. In this study, these four distinct outbreak groups are called as generations, even though some of the outbreaks in any given group is known to be not caused by any preceding outbreaks. Thus one generation is a group of all the outbreaks, which originated in close temporal proximity and separated from the preceding or succeeding group of outbreaks by a specific time lag. For each of the four generations, the area infested by population resulted from epicentre population was calculated and the change in area infested in successive generations was compared between years.

3. RESULTS AND SISCUSSION

3.1. Population trend in 1999

3.1.1. Endemic population

Prior to the occurrence of early outbreaks, existence of sparse endemic population of the teak defoliator was recorded in the study area (Table 1). Almost all stages of the insect, except the pupa and adult were found in the teak plantations. The insect stages were found on isolated flushed coppices or trees and were very few in number. The estimated egg laying dates indicated the presence of moths in the plantations in January itself.

Table 1. Endemic population status of *Hyblaea puera* at Nilambur in 1999

Date of observation	Block No.	Stage and No. of larvae
01- 7 February	7,18	A few eggs, 5 larvae
08-14 February		Nil
15-21 February	10, 18	A few eggs (<10) and 10 larvae
22-28 February	7, 8, 11,12, 14, 16	14 larvae
04- March	8	1 larva

3.2. Detection and control of epicentres in 1999

Out of 189 grids within the 19 blocks, 104 grids had tender leaves by fourth week of March. The first set of epicentres occurred in the last week of February by which time only aboutr 60 per cent of the trees were in good flushing. The epicentre build-up was found to be associated with the summer rain, which occurred in the last week of February in 13 blocks.

The chronology of defoliator outbreak is presented in Table 2 and the details of epicentre control operations are presented in Table 3. The first wave of epicentre build-up occurred in late February, starting at Muriem (Ambalakkunnu road), where an area of 12 ha was infested. Following this, epicentres were located at Kariem (Vettilakkolli)- 4 ha, Nellikkuthu (Thottappala)- 3 ha, Padukka (Kalkulam)- 1ha, Erampadam (Ramankadavu)- 1ha, Sankarangode- 60 ha, Nellikkuthu (Chelakkadavu)- 2 ha and Chathamporai (Chaliyarmukku)-1 ha. The egg laying is estimated to have occurred in these locations during 23 – 28 February. Insecticidal spraying on foliage was carried out in all the above locations between 2^{nd} and 8^{th} . The total area under infestation was about 84 ha.

A second wave of infestation occurred in April in 9 blocks which also comprised the 7 blocks in which the first wave of infestation occurred. The size of the epicentre increased, the total area under infestation growing to about 290 ha from the 84 ha area of the first wave. The size of the epicentres varied from 1 to 125 ha. Foliar application of Ekalux (see Methods) was resorted to control the pest in all locations except at three locations namely, Nellikkuthu (Block 11; 40 ha), Punchakkolli (Block 12; 8 ha) and Sankarangode (Block 17; 125 ha) where ground spraying of insecticide was carried out. The third wave of infestation in May was quite widespread covering an area of 7424 ha. An area of 7532.5ha was infested subsequent to the control of epicenter buid-ups. The total area infested during the year was 7907 ha (recorded up to the end of June).

3.3. Population trend in 2000

Endemic population

Presence of endemic population was observed during February. The larvae were very few in number on isolated trees in different locations mostly on coppices (Table 4).

Table 2. Chronology of defoliator outbreaks at Nilambur during 1999

Sl .No of outbreak	Date of egg laying	Area infested (ha)	No. of patches	Possibly originated from previous outbreaks
1	23-28 February	84.0	8	No
2	23-31 March	40.5	2	No
3	24-28 March	75.0	6	No
4	08-11 April	28.0	3	No
5	14-20 April	178.0	9	Yes
6	26-27 April	48.0	1	No
7	02-07 May	1242.0	8	Yes
8	03-08 May	1206.5	11	Yes
9	05-09 May	1851.0	16	Yes
10	8-11 May	234.0	4	Yes
11	7-12 May	1740.0	5	Yes
12	05-11 May	60.0	1	Yes
13	10-14 May	410.0	3	Yes
14	26-31 May	680.0	3	Yes
15	31 May-04 June	30.0	1	Yes
	Total area infested (ha)	7907		

Table 3. Details of epicentre control operations during 1999

Sl.No. of outbreak	Date of control operation	Block	Place	Area (ha)	Method of spray
1	02 March & 08 March	10	Ambalakkunnu road,	12.0	Foliar
2	07 March	9	Vettilakkolli	4.0	Foliar
3	08 March	11	Thottappala	3.0	Foliar
4	06 March	13	Kalkulam	1.0	Foliar
5	07 March	8	Ramankadavu	1.0	Foliar
6	08 March	17	Thannipotti	60.0	Foliar
7	06 March	11	Chelakkadavu	2.0	Foliar
8	06 March	6	Chaliyarmukku	1.0	Foliar
9	02-03 April	10	Muriem	39.5	Foliar
10	07 April	9	Kariem	7.5	Foliar
11	07 April	8	Erampadam	1.0	Foliar
12	08 April	13	Padukka	1.5	Foliar
13	08 April	11	Nellikkuthu	2.0	Foliar & ground
14	08 April	6	Chathamporai	1.0	Foliar
15	09 April	11	Nellikkuthu	3.0	Foliar
16	11-13 April	17	Sankarangode	60.0	Foliar
17	15 April	10	Muriem	2.0	Foliar & ground
18	16-17 April	11	Nellikuthu	40.0	Foliar & ground
19	18 April	12	Punchakkolli	8.0	Ground
20	19-20 April	17	Sankarangode	125.0	Ground
			Total area infested (ha)	374.5	

Table 4. Endemic populations recorded in 2000

Date of detection	Block Number	No. of larvae detected
1-7 February	5,6,18	9
8-14 February	7,9,10	8
15-21 february	5,7,10,11	11
22-29 February	5,13	3

3.4. Detection and control of epicentres in 2000

The chronology of defoliator outbreak is presented in Table 5 and the details of epicentre control are presented in Table 6. The first epicentre was detected on 25 February in an area of 5.25 ha. Subsequently 3 patches having an area of 0.91 ha, 2.16 ha and 3.16 ha were found on 26, 27 and 28 February respectively. During the period from 7 March to 4 April, 16 epicentres ranging in size from 0.12 to 2.5 ha were controlled. In three locations insecticide- Ekalux was used and in six locations, *Bt* based biopesticide, Halt was used. In three locations a combination of Halt + Ekalux was used. In two locations- Aravallikkavu and Kavalamukkatta, ground fire aided pupal control. In another two locations control was offered by natural parasitoids. In Sankarangode, heavy parasitism by *Palexorista solennis* (Diptera: Tachinidae) was observed on larvae in all the ten trees infested. In Edakkode, all the first instar larvae present on the ten infested trees were parasitised by *Sympiesis hyblaeae* (Hymenoptera: Eulophidae).

3.5. Impact of control

Year 1999

The first four outbreaks appeared to be of independent origin, as they could not be related to previous populations. All these populations were subjected to control. Of the remaining outbreaks in April, except the one occurred in a single patch on 26-27 all others were explainable as they could be attributed to previous populations. Similarly all the subsequent outbreaks in May were

Table 5. Chronology of teak defoliator infestation in 2000

Sl. No of outbreak	Date of egg laying	Area infested (ha)	No. of patches	Possibly originated from previous populations
1	25 –28 February	11.5	8	No
2	06 March	0.25	1	No
3	10 – 16 March	4.5	3	No
4	15 – 16 March	1.5	2	No
5	23 – 27 March	0.5	1	Yes
6	29 – 30 March	0.25	1	Yes
7	31 March- 2 April	108.0	2	Yes
8	31 March –10 April	554.5	3	Yes
9	01 – 07 April	346.5	13	Yes
10	1 – 10 April	48.0	3	Yes
11	13 – 16 April	15.0	2	Yes
12	17 – 19 April	20.0	2	Yes
13	18 – 25 April	58.0	4	Yes
14	20 – 23 April	639.5	8	Yes
15	05 – 08 May	160.5	3	Yes
16	16 – 18 May	7.5	1	No
17	17 – 21 May	552.5	6	No
18	20 – 31 May	16.5	1	Yes
19	21 – 23 May	12.5	1	No
20	04 – 06 June	0.5	1	No
21	13 – 15 June	100.0	1	Yes
Total area infested (ha)		2658.0		

Table 6. Details of epicentre control operations during the year 2000.

	Place	Block	Area (ha)	Method of control
07- 09 March	Muriem	10	2.5	canopy spraying
09-March	Kanakuthu	7	1.0	canopy spraying
09-March	Kanakuthu	7	0.25	canopy spraying
10-March	Sankarankode	17	1.5	canopy spraying
13-March	Cherupuzha	18	0.5	ground spraying and natural fire
12-March	Chathamborai	6	5.0	canopy spraying
13-March	Pokkode	5	0.5	canopy and ground spraying
14-March	Aravallikkavu	4	0.3	ground fire
24-March	Pokkode	5	0.5	canopy spraying
22-March	Sankarankode	17	0.12	natural mortality due to parasitism
25-March	Chathamborai	6	1.0	canopy spraying
28-March	Pokkode	5	1.0	canopy spraying
29-March	Edakkaode	8	2.0	canopy spraying
01&02 April	Kavalamukkatta	19	1.5	ground fire
04-April	Pokkode	5	0.5	canopy spraying
04-April	Edakkaode	2	0.12	natural mortality - parasitism
		Total area (ha)	18.29	

explainable as they could be related to previous populations. That many outbreak populations were related to previous populations (Table 2) gave the impression that proper control of early outbreaks could have reduced the intensity of subsequent outbreaks. However, epicentre control seemed to have not much impact on reducing the intensity of pest incidence. In many epicentres where insecticide was sprayed, large-scale emergence of moths was detected. An area of 7532.5ha was infested subsequent to the control of epicenter populations in an area of 375 ha. The total area infested during the year was 7907 ha (recorded up to the end of June).

The result indicated that the control operations were not successful which can only be attributed to the inefficiency of the spraying systems used. In general, the infestations occurred in tall trees and the sprayers could not carry the insecticide upto the crown to give a full coverage and hence the failure.

Table 7. Chronology of outbreaks in 1993

Sl.No. of infestation	Date of egg laying	Area infested (ha)	No. of patches	Possibly originated from previous population
1	19 February	14.3	2	No
2	26 February	10.0	1	No
3	17 March	38.8	1	Yes
4	20 March	512.0	1	Yes
5	21 March	1.7	1	Yes
6	26 March	0.12	1	Yes
7	03 April	254.4	3	No
8	07-20 April	934.4	24	Yes
9	23 April	11.9	1	Yes
10	25-26 April	18.1	4	Yes
11	28 April	1.5	2	Yes
12	05 May	114.7	3	Yes
13	08-30 May	2498.9	47	Yes
14	02-16 June	2531.5	67	Yes
15	28 June	4.25	1	Yes
	Total area infested (ha)	6946.5		

Year 2000

In all the epicentres subjected to control, mortality of larvae was almost total which suggested the control operations were successful. However, subsequent outbreaks were recorded (Table 5). During the year, subsequent to the control operations in 18 ha, a total of 2640 ha plantations were infested. The total area infested was 2658 ha (recorded upto June) as against the 7907 ha infested in 1999.

Except an epicenter of 0.5 ha observed during 23-27 March, all other epicentres recorded in March could not be attributed to the progenies of the previous populations. The endemic population was not strong enough to develop into an outbreak. However, most of the outbreaks occurred in April were attributable to the progenies of the populations of March which were in fact subjected to control. Though considerable reduction in the outbreaks could be observed subsequent to control of epicentre populations, the occurrence of further outbreaks suggests that an absolute control of a population cannot be achieved under field condition. It is possible that certain number of insects could survive the control operation and these insects could cause another infestation. If it is assumed that the control is absolute, then the subsequent infestations can only be attributed to immigrant moths. Further data are necessary to explain this phenomenon.

3.6. Outbreak pattern in 1993 and 1998

Outbreak pattern in 1993

The chronology of infestation in 1993 is given in Table 7. In 1993, up to June, a total area of 6946.5 ha was infested by the teak defoliator. With an initial infestation in an area of 24 ha, the incidence progressed through March covering an area of about 514 ha. Subsequent outbreaks in April were still larger and the major peaks occurred in May (2613.6 ha) and June (2535.75 ha).

Outbreak pattern in 1998

The chronology of infestation in 1998 is given in Table 8. The insect build up was recorded during 30 March to 01 April in six patches covering an area of 145 ha. The infestation progressed through May- June. The peak incidence was recorded in May covering an area of 4691 ha. During the year an area of about 9147.5 ha was infested.

Table 7. Chronology of outbreaks in 1993

Sl.No. of infestation	Date of egg laying	Area infested (ha)	No. of patches	Possibly originated from previous population
1	19 February	14.3	2	No
2	26 February	10.0	1	No
3	17 March	38.8	1	Yes
4	20 March	512.0	1	Yes
5	21 March	1.7	1	Yes
6	26 March	0.12	1	Yes
7	03 April	254.4	3	No
8	07-20 April	934.4	24	Yes
9	23 April	11.9	1	Yes
10	25-26 April	18.1	4	Yes
11	28 April	1.5	2	Yes
12	05 May	114.7	3	Yes
13	08-30 May	2498.9	47	Yes
14	02-16 June	2531.5	67	Yes
15	28 June	4.25	1	Yes
	Total area infested (ha)	6946.5		

Table 8. Sequence of outbreaks in 1998

Sl.No. of infestation	Date of egg-laying	Area infested (ha)	No. of patches	Possibly originated from previous population
1	30 March- 01 April	145.0	6	No
2	02 April	9.5	2	No
3	03 April	2.0	1	No
4	08-13 April	27.0	3	No
5	18-22 April	763.0	8	Yes
6	24 April	200.0	1	Yes
7	27-28 April	100.0	1	Yes
8	29 April – 5 May	1336.0	8	Yes
9	07 May	180.0	1	Yes
10	12-22 May	3055.0	26	Yes
11	28-30 May	120.0	1	Yes
12	01-02 June	960.0	5	Yes
13	03-06 Jun	1950.0	11	Yes
14	09-12 June	300.0	3	Yes
	Total area infested (ha)	9147.5	77	

3.7. Comparison of the insect outbreak pattern during the study period (1999 and 2000) with outbreak pattern in 1993 and 1998

The survival of teak defoliator particularly the early instar larvae depends on availability of tender foliage. The phenology of teak is influenced by rainfall. Early outbreak of teak defoliator is also known to have a strong correlation with premonsoon showers. During the years 1993, 1998, 1999 and 2000, the rain pattern remained almost similar suggesting that the environmental conditions were similar in all the years under study (Fig. 3).

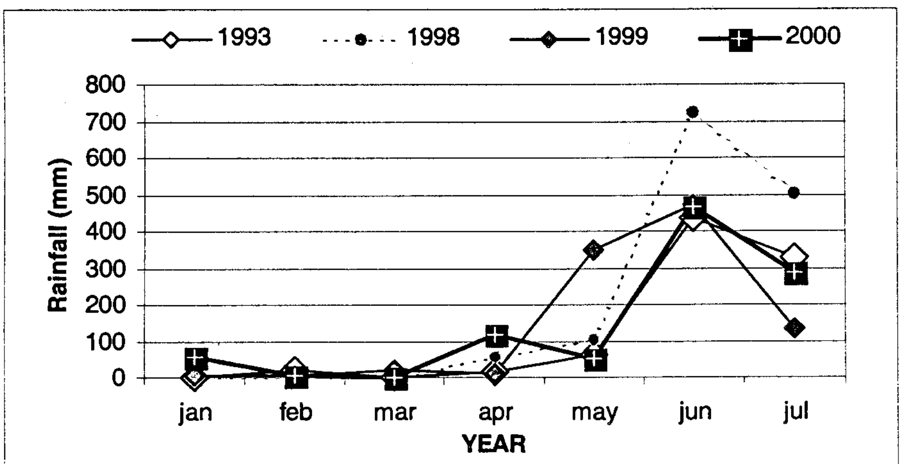

Fig. 3. Monthly rainfall pattern in the years 1993, 1998, 1999 and 2000

In 1993 and 1998, the infestation during February–April was confined to smaller areas. In both the years, largest area was infested during May- June (Fig. 4a,b). However in 1999, when defoliator control was attempted in the plantation, the infestation pattern was found to be quite different from the former years (Fig. 4c). During the period February – April only an area of 374 ha was infested and in May the infestation covered a total area of 7471 ha (Fig. 3c). In 2000, the pest outbreak showed a decreasing trend from April onwards and the total area infested was only about 2658 ha (Fig.4d). The unusual infestation trend in 1999 remains unexplainable .

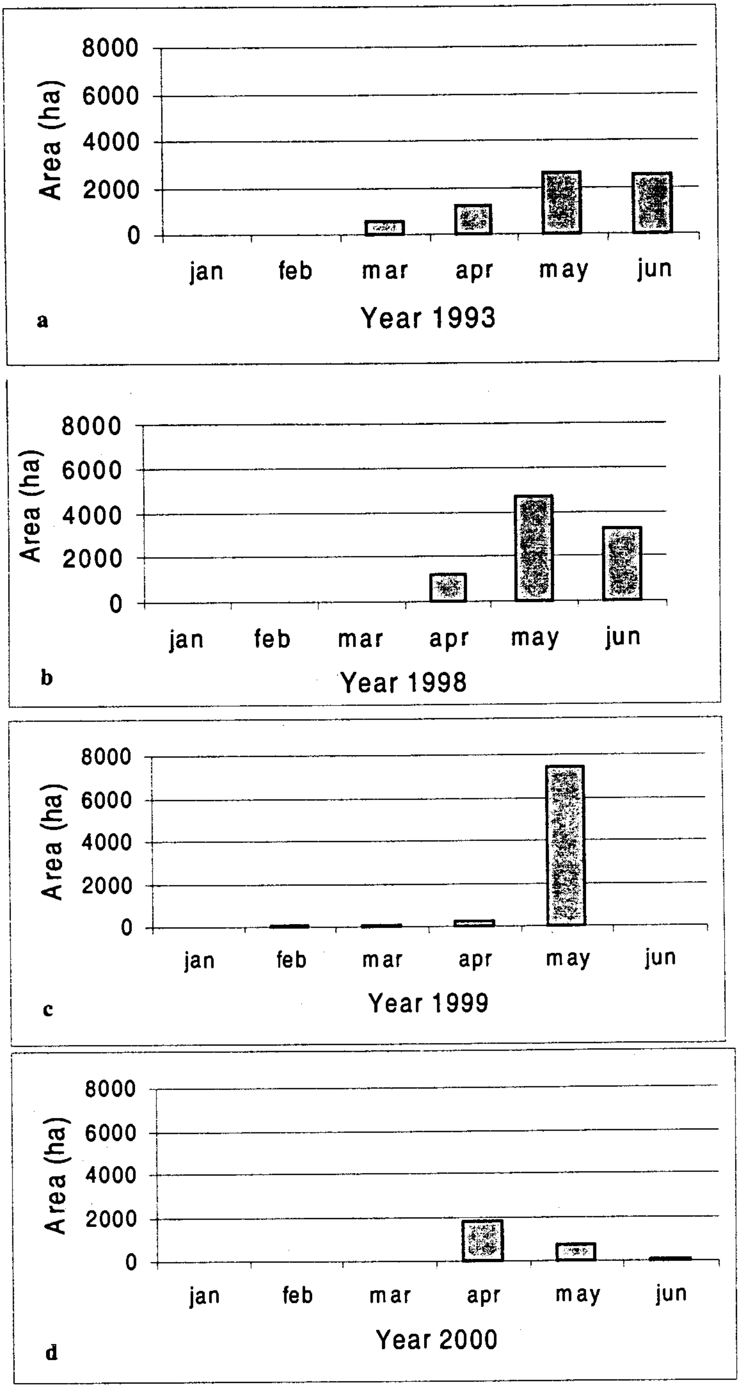

Fig. 4 a-c. Area under teak defoliator infestation in different months during the years 1993, 1998, 1999 and 2000, in Nilambur

The results of paired t-test between each of the combinations of years are given in Table 8. It can be seen that the pest incidence pattern (area infested) in the year 2000 when epicentre control was carried out is significantly different from the pattern in the years 1993 and 1998 when no pest control was done. The overall comparison of the pest situation in the normal years with the year in which epicentre control was satisfactorily carried out indicated that, epicentre control could reduce large-scale outbreaks.

Figure 5 shows the exponential trend of area infested in successive generations of teak defoliator in each of the four years under comparison. It can be seen that during the years when epicentres were not controlled and the year in which the control operations were unsuccessful, there was sharp increase in the area infested from generation 1 to 4. However, in the year 2000, when epicentre control was successful, there was only a slight increase in the area infested. The drastic difference in the infestation trend between years indicated that a major part of outbreaks was reduced because of controlling epicentre populations.

3.8. Estimation of area infested by offspring populations of epicentres

The impact of epicentre control on subsequent outbreaks needs an explanation in the background of the question whether local populations form the epicentre populations or not. In reality epicentre control could be effective only if the local populations have a major role in outbreak development.

Table 9 shows the split up of the total area infested each year into the probable area infested by progenies of epicentre populations. In 1999, All the populations which developed upto 11th April were of independent origin and could not be related to the endemic populations which were too small to contribute to any future outbreaks (Table 3). However in the subsequent outbreak period, except an outbreak occurred on 26-27 April in an area of 48 ha in a single patch all other outbreaks could be related to Previous outbreaks. In the year of the 7907 ha infested, infestation in 7632 ha (97%) could be explained as related to previous outbreaks.

Table 8. Comparison of area infested in different years

Combination of years	t-value	2-tailed significance	Remarks on Significance of difference between years
1993 x 1998	2.02	.046	Significant
1993 x 1999	3.13	.002	Highly significant
1993 x 2000	-4.26	.0001	Highly significant
1998 x 1999	1.06	.293	Not significant
1998 x 2000	-2.14	.034	Highly significant
1999 x 2000	-0.91	.362	Not significant

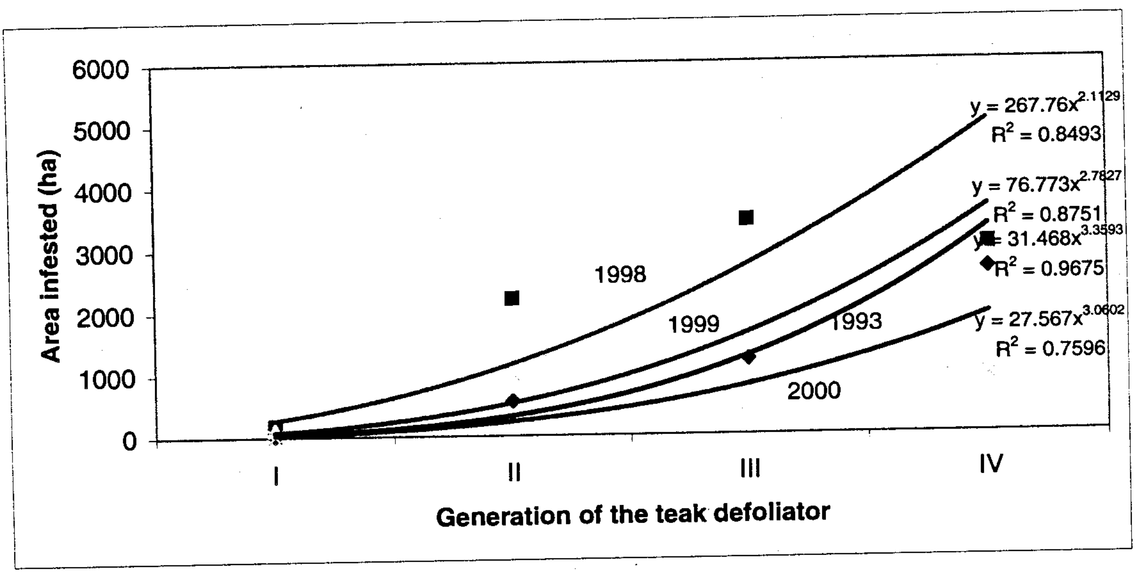

Figure 5. Exponential trend of area infested in successive generations of teak defoliator in the years 1993, 1998,1999 and 2000.

In 2000, the epicentres that developed during 25-28 February were of independent origin possibly from a single source, which were not attributable to the sparse endemic population. Similarly, except a 0.5 ha patch developed during 23-27 March, all other epicentres developed during March could not be attributed to the progenies of the previous epicentres suggesting that they were of independent origin (Table 5). However, most of the outbreaks which occurred in April were attributable to the progenies of previous populations of March. Similarly 3 out of the 6 outbreaks developed in May and 2 out of the 3 outbreaks developed in June were attributable to previous populations. In the year, of the 2658 ha infested, infestation in 1919 ha (74%) could be explained as related to previous outbreaks. Compared to the 1999, a reduction in the involvement of epicentre population was observed in 2000.

Table 9. Percentage area infested by probable offspring of epicentre populations in Nilambur teak plantations

Year	*Total area infested (ha)	*Area infested by progenies of epicentre populations	*Percentage area infested by progenies of epicentre populations
1993	7530	6902	95
1998	9148	8964	98
1999	7907	7632	97
2000	2722.5	2019	74

* corrected to the nearest integer

In 1993, of the 7530 ha of total area infested, infestation in 6902 ha (95%) could be explained as related to previous outbreaks. Similarly in 1998, infestation in about 98 per cent of the total area could be related to progenies of epicentre populations.

It can be seen from above data that in all the years observed, major outbreaks could be related to earlier epicentre populations and the role of immigrant moths if any appears to be insignificant. Nevertheless, further confirmation through a more reliable method preferably molecular studies is required before a conclusion is made on the relationship between populations.

4. GENERAL DISCUSSION AND CONCLUSIONS

The general concept of managing a plantation pest relies on application of pesticide in the whole infested area. This method has relevance only in a situation when the information on the pest outbreak pattern is lacking and the control operation is inevitable. The economic importance of the teak defoliator outbreak prompted the forest entomologists in the past to test the usefulness of aerial spraying of insecticide (Singh, 1985). Studies carried out in the recent past (Nair *et al.,* 1985) have thrown light on the characteristic outbreak pattern of the teak defoliator which suggested the irrelevance of insecticidal application in the total plantation area as a measure to control teak defoliator. The finding that teak defoliator outbreaks begin initially as small epicentres gave a new insight into the teak defoliator management.

In the present study, the interpretations were based on field studies carried out during 1999 and 2000. For a comparative analysis, similar data generated by us in the past (1993 and 1998) were also used.

The results indicate the possibility that the control of epicentre populations could reduce the intensity of infestation during the subsequent outbreaks. The area under infestation varied significantly between the year in which control was made and the years in which no control was made. However, it may be noted that the conclusion is exclusively based on the results of the successful experiment carried out in 2000 as the 1999 data were not useful as the control operations were not fully effective. It also appears that the comparison of the data generated in 2000 with data of 1993, 1998 and 1999 alone is not fully valid. The possibility of lean years with reduced infestation also cannot be ruled out. In 1992 the total area under infestation at Kariem-Muriem upto July was only about 100ha which comprised 10 per cent of the total plantation area. (T.V. Sajeev, KFRI, personal communication).

The total success of epicentre control depends on whether the outbreak populations are caused by local populations or not. The mechanism used to relate the parentage of populations was based on "developmental period" of the insect, *i.e*, the time required for completing one generation of the insect. Even though the control operation was successful in the year 2000, further outbreaks did occur but not on a large scale. This phenomenon could be explained only on the basis of the involvement of immigrant moths from far away places. As evident from the study in all the years under consideration, a small percentage of the outbreak could not be explained, as they were not caused by offspring of the previous populations suggesting immigration of moths. The method used to relate two populations in this study was not absolutely reliable as it gave only a circumstantial evidence (Nair *et al.*, 1998a)). A more reliable method involving molecular techniques could probably throw light on the relationships between populations. Until more reliable data on the structure and role of epicentre populations are available, it may not be possible to say a final word on the prospects of epicentre control. In spite of the lacunae existing in our knowledge on the above aspect, the control of epicentre populations as a method of teak defoliator management appears to be promising.

In this study, chemical pesticide was used for the experimental control trials. However, their continuous use is not recommended in regular pest control programmes. The bio pesticide based on *Bacillus thuringiensis kurstaki* was found to be very effective. However, one of the major factors limiting its continuous use is the high cost involved. Further, bacterial pesticides are not considered to be very safe as they can kill other lepidopterans including the silkworm. The use of baculoviruses in pest management is well understood. Baculoviruses are considered to be very safe for field application as they are host specific. In field studies carried out in Kerala, Nair *et al.* (1998b) demonstrated the efficacy of *Hyblaea puera* nucleopolyhedrovirus (*Hp*NPV) as a potential biocontrol agent against the teak defoliator. It is also worth mentioning that the baculovirus, *Hp*NPV is able to spread both horizontally (within a population) and vertically (between generations) and gets magnified in the field after the spray operation. These qualities of *Hp*NPV can help not only to suppress epicentre populations, but also to initiate epidemics in populations caused by immigrant populations of moths. Epicentre control involving *Hp*NPV thus appears to be promising.

The detection of epicentres and controlling them is a very laborious activity demanding very high manpower. As observed in the past and as evident from this study, the epicentres are not developed in constant sites over years (Nair *et al.*,, 1998) which makes their detection a difficult job. However, this exercise at the landscape level would be the only option, as "total control" covering the whole plantation is impractical. It is suggested that the possibility of using other mechanism involving pheromones may be explored for detecting the population before the epicentre phase so as to simplify the monitoring practices currently adopted.

The study indicated that epicentre controlling epicentre populations could reduce the intensity of subsequent defoliator outbreaks in teak plantations. However, further validation of the result by carrying out a long-term study is suggested.

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