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BIOLOGY AND ECOLOGY OF THE TEAK TRUNK BORER COSSUS CADAMBAE MOORE AND ITS POSSIBLE CONTROL

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ABSTRACT

Studies were made on the biology, ecology and possible control of the teak trunk borer *Cossus cadambae* (Lep., Cossidae). Its life cycle was annual and took about 249 days for completion The duration of the various life history stages were as follows egg-20 days; larva-213 days; pupa-11 days; adult—-5 days. The generations were continuous and overlapping. There were two peak periods of moth emergence—in May and in October

The distribution of this insect in the various teak plantations in · Kerala was studied and the infestation 'was found to be more prevalent in the Central and Northern Forest Circles. Although the proportion of infested trees in the affected plantations was high, the average proportion of infestation at the Divisional level was found to be very low (Southern Circle-0.03; Central Circle-0.06; Northern Circle-0.05). Studies on the annual progression of attack in a rnoderately affected plantation have indicated the spread of infestation at the rate of 14.5%, suggesting pest population build up over time.

Among the factors leading to infestation, mechanical injury to trees such as lopping of branches, extraction of leaves, etc. were considered important. Plantations found affected were above 20 years old and the infestation intensity was found to increase with age. Although teak is the principal host of this insect, it was also noted to attack *Grewia tiliaefolia* and *Terminalia bellerica* growing naturally in the affected teak plantations.

The progression of attack in plantations of varying levels of infestation intensity was studied in representative plantations. During the initial stages of infestation the affected trees showed only minimum damage. As the infestation progressed, the damage became more pronounced due to reinfestation of the already affected trees, with a small percentage of tree mortality. During these two phases the affected trees occurred in distinct patches. In the advanced phase when the attack was heavy, the infestation became uniformly distributed in the plantation due to the initially affected patches becoming confluent with the increase in the number of affected trees. This phase was also characterised by high rate of tree mortality.

The natural enemies of this insect consist of 2 species of birds viz. the golden backed woodpecker *(Dinopium benghalense)* and an unidentified barbet, both predatory on the larvae, besides 6 species of microbial pathogens

affecting various stages of this insect either in the laboratory or in the field. In the pathogenicity trials maximum larval mortality was observed in the case of treatment with the bacterium, *Serratia marcescens* (83.3%) followed by the fungi *Aspergillus flavus* and *Paecilomyces fumosoroseus* (57%).

Control trials using the insecticides Dimethoate, Monocrotophos, and Phosphamidon by trunk injection and O,S - Dimethyl Acetylphosphoramido-thioate by implantation were not successful. The efficacy of some of the pheromone components (Z5-12 AC; Z5-14 AC; Z3-10AC) of a related species, *Cossus cossus,* in different combinations was also tested in the field for mass trapping the moths, but was not successful.

Until suitable control measures are developed, a management strategy involving stage by stage elimination of the affected trees is suggested, This involves clearfelling of all the badly affected plantations, selective extraction of all the affected trees from plantations of low level attack during routine silvicultural thinnings and protecting the trees from mechanical injuries.

1. GENERAL INTRODUCTION

Teak is probably one of the few trees that has been successfully planted on a large scale in India. Unlike many other species that have been extensively tried in plantations, this tree has been able to withstand continued pest attacks. A large number of insects (about 150) are known to attack this tree in India. However, most of them cause only minor damage. Species that cause major damage in plantations and natural stands include two species of defoliators *(Hyblaea puera* and *Eutectona machaeralis)* and two borers—one in saplings *(Sahyadrassus malabaricus)* and the other in standing trees *(Cossus cadambae)* Of these, the latter has attained major pest status in some areas in southern India.

C. cadambae belongs to the lepidopteran family Cossidae. Cossids are popularly known as goat moths (because of the characteristic odour produced by many members of this group) and carpenterworms (due to the larval habit of boring in the wood). All members of this family without exception are internal feeders inside the woody tissues of plants. Although the number of recorded species are rather few, species belonging to many genera like *Cossus, Zeuzera, Azygophleps* and *Xyleutes* are widely distributed.

Literature records on the cossid pests of the world indicate that at least 15 species have been noted as pests of various forest or horticultural trees. Among the important carpenterworm pests, mention may be made of the european goat moth, *Cossus cossus* (attacking a variety of trees such as alder, ash, beech, birch, elm, oak, poplar, walnut, willow, etc. in USA); the southern heartwood borer, *Prionoxystus robiniae* (attacking several species of wild. ornamental as well as broad-leaved trees in USA and Europe); the leopard moth, *Zeuzera pyrina* (attacking ash, apple, beech, maple, oak, olive, elm, hazel, hickory, plum, walnut, etc. in Europe and USA) and the teak bee-hole borer, *Xyleutes ceramica* (attacking teak in several Asian countries).

In India, about 25 species of carpenterworms belonging to 6 genera viz. *Cossus, Xyleutes, Azygophleps, Zeuzera, Phragmataecia* and *Eremocossus* have been reported (Hampson, 1892). Of these, the economic importance as well as host range of only a few species have been fully investigated. The important carpenterworms affecting various tree crops in India are, the coffee borer *Zeuzera coffeae* (attacking about 30 plants including coffee, teak, mahogany and *Lagerstroemia;* Beeson, 1941); *Z. multistrigata* (attacking cherry, sandal and oak; Bharadwaj, 1982) and *Zeuzera* sp. (attacking poplars; Joshi *et al.* 1984).

1.1 Carpenterworms as pests of teak

Three species of carpenterworms viz. *X. ceramica. Z. coffeae* and *C. cadambae* are known to attack teak in the Asian region. Of these, the first two species attack both saplings as well as trees, while the last species attacks only grown up trees. *X. ceramica* occur in Burma, Philippines, Thailand, Indonesia and Java and is not considered to occur in India (Beeson, 1941); although Hampson (1892) has recorded it from Sikhim. *Z coffeae* which is widely distributed in the Indian and Indo-Malayan sub regions, is mostly a pest of tea and coffee although occasional outbreaks have been reported in forest nurseries and natural regeneration areas of teak (Beeson, 1941; Toxopeus. 1048). C. *cadambae* occurs only in India. Characteristically it attacks grown up teak trees and is never reported to damge seedlings or saplings.

1.2 Occurrence and pest status of C. cadambae

C. cadambae was first described by Moore (1885) in the Proceedings of the Zoological Society of London. Hampson (18923 who recorded it from Calcutta gave a general description which is based essentially on the wing pattern and colouration. Beeson (1941) recorded it as a minor pest of teak in southern India where it affected unhealthy or mechanically damaged trees. Bhandari and Upadhyay (1986) reported it as a pest of tendu *(Diospyros melanoxylon)* in Madhya Pradesh. They also gave a short account of its life cycle. Apart from these works, no study has been made on its biology or bionomics. Recently there have been several reports on its occurrence in teak plantations in Kerala. The present study was mainly undertaken to gather basic information on the factors leading to its establishment in plantations and to explore the possibility of managing it in affected areas.

2. LIFE HISTORY AND HABITS

Biology of this insect was studied in the laboratory by rearing the eggs collected from gravid females caught in light traps. Data so gathered were further supplemented by observations in the field.

2.1 Oviposition

A female moth lays about 380-600 eggs at a time. The eggs are pale brownish in colour measuring 1.2x1mm in size and are more or less spherical in shape. The chorion is reticulately sculptured resembling the bark of teak (Fig. 1).

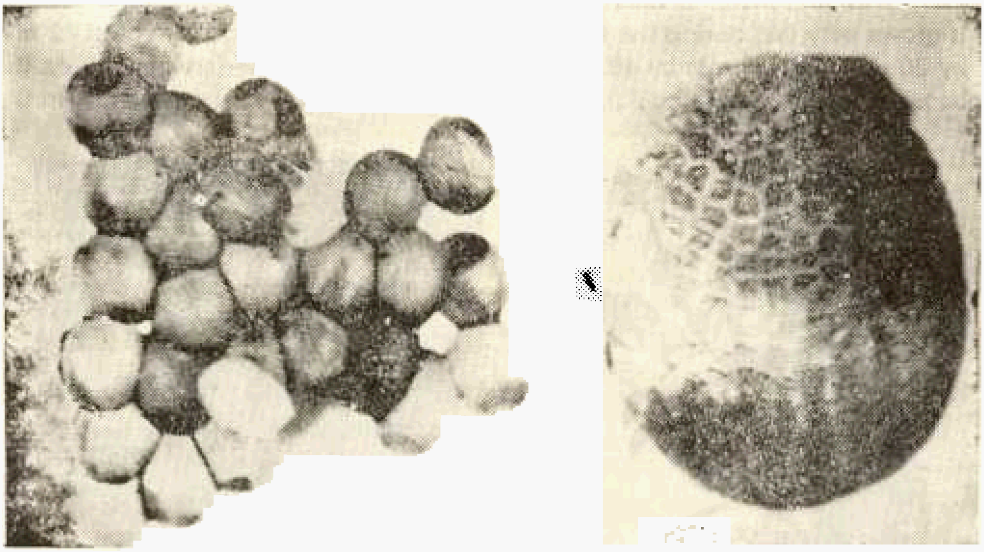


Fig. Eggs of C. *cadambae;* photograph on the left shows eggmass and on the right a highly magnified view of an egg.

Oviposition occurs mostly at dusk. Eggs are laid in small crevices or depressions on the bark of teak trees. Before laying the eggs, the female moth probe the bark by protruding and retracting its extremely long (about 15 mm long) ovipositor. When a suitable crack or hole is located, the ovipositor is pushed into it and the eggs laid inside in one or more batches. The eggs are arranged in linear rows and are pasted together with the help of a glutinous secretion which later hardens. According to Common (1970) larvae of *X. liturata* after hatching, live beneath this secretion for a few days prior to dispersal.

The eggs may be laid either on the main stem or on branches. The colour and sculpturation of the eggs match the surface of the bark rendering detection difficult. The incubation period is about 20 days (Table 2) after which the first instar larvae hatch cut by a medien split of the chorion.

2.2 Larval establishment

The newly hatched larvae are extremely active and move about on the bark. After sometime they get lodged in the axils of side shoots, in crevices or injuries on the bark or in sites of earlier infestation. They remain concealed under a web of silken fibres and start feeding on the bark. The frass and excreta formed get attached to this web which closely match the bark in colouration. thus concealing the larvae beneath it.

. The first instar larva is light reddish and measures about 2mm in length. It grows very fast during the initial instars. attaining a length of about 12 mm by 20 days and 26 rnm by 40 days. During this period the larva feeds on the bark or callus tissue, including outer sapwood. Larval feeding results in the

Fig. 2. a) Teak tree in the early stage of infestation. Note the back of lateral shoot.

b) Trunk showing damage caused by the borer.

girdling of the side shoots leading to die - back which is one of the initial symptoms of borer attack (Fig. 2a). By about **90** days, the larva attains a length of 4.7 cm (Fig, 3) and by this time it completesa tunnel of 6-7 cm in the sapwood. The wood particles eaten out by the larva could be seen accumulated around the tunnel entrance and it appears that *C.* cadambaedoes not feed on wood, bu.t only on bark and callus tissue that grows over the injured bark. The inner end of the tunnel is wider and the larva rests here with the 2 ends brought together i. e., the larva remains folded at Its middle. When irritated it moves briskly up and down inside the tunnel and ejects a brown maxillary fluid of musky odour which in the case of the european goatmoth C. cossus is reported to contain an 'aggregation pheromone' (Capizzi et a/, 1983). This could be one of the reasons for confining the attack to the already affected portions of the trunk leading to the characteristic honey-combed appearance of the affected wood (Fig. 2 b).

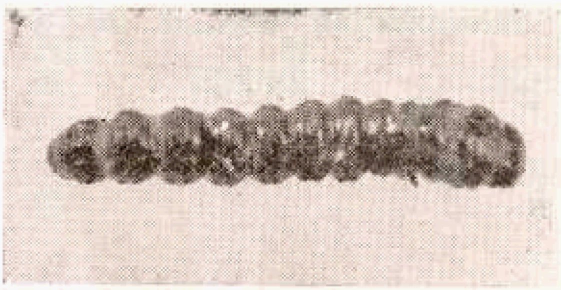


Fig. 3. Larva

The larvae are very aggressive and when kept together they attack each other. Similar observations have also been made for *X.* redtenbacheri and *Z coffeae.* In the former, the larvae are reported to feed even on the grubs of the cerambycid borer, *Cerambyx dux* in Malteso Isles (Saliba, 1977).

Larva\ growth after 3 months is slow and 5-months-old larvae measure about 5 cm. The rate of feeding is also low unlike in the earlier instars. A larva of this stage is capable of surviving upto 3 months without feeding and undergo pupation and produce normal moth when bred in the laboratory. Larval dormancy during unfavourable climatic conditions has been reported in *X.* ceramica (Beeson, 1941). Larval stage lasts for about 213 days.

2.3, Pupation

Pupation as observed in the field is summarised below:

During the premonsoon showers in May 1987, hundreds of larvae were observed falling from affected trees and crawling over the forest floor in a 1955-teak plantation at Palappilly (Chalakudy Forest Division). Many of them were found to be washed away along with the run off water. While moving 'about they were observed to probe with their head for an appropriate site to penetrate. In loose soil the larva initially fixed itself to the ground with its cremaster and penetrated its head into the soil by side to side movements.

When about half of its body has penetrated into the soil, it freed its posterior end which assumed an upright posture and then started to rotate its body, driving the anterior end slowly into the soil. This continued until the larva was well in the soil usually about 3-4 cm from the surface. The whole process lasted from half to one hour. Inside the soil it then prepared an oval pupation chamber by the sidewise wriggling movements of the body. The innerside of this chamber was lined with silken fibres. Additional layers of silk were then added so that a cocoon consisting of a tough layer of silk was formed (Fig. 4. a.b). The sand particles which got attached to this formed the outer-most covering of the cocoon. The cocoon was oval in shape and measured 3-3.5 cm in length and 9-11 mm in width at its middle. The cocoon with the insect contained inside was positioned longitudinally with the cephalic end directed towards the soil surface. The pupal period was about 11 days.

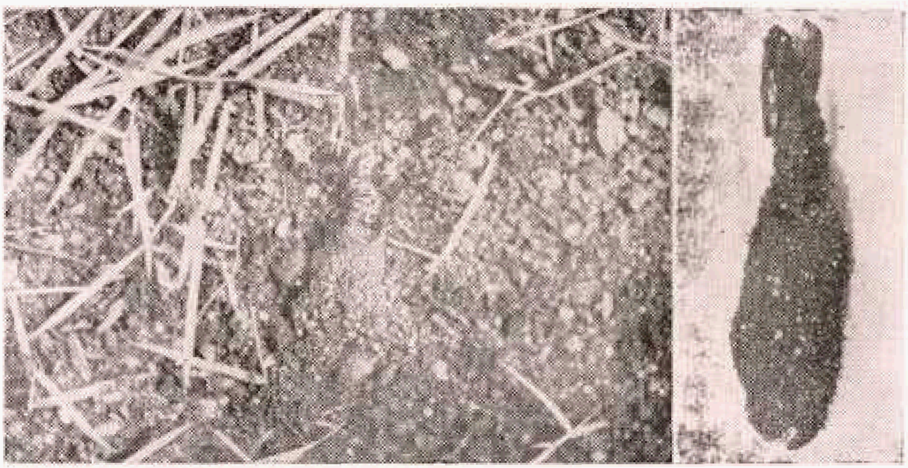
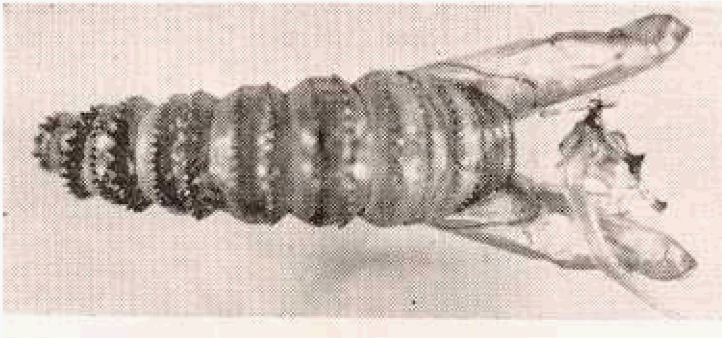


Fig. 4. a) Pupal exuvia projecting from the pupal chamber in the ground.

b) Puparium with the pupal exuvia.

The pupa is brownish in colour measuring 2.5 - 3.5 cm in length and is exarate i. e., the appendages are partially free. The cephalic end of the pupa bears an elongate process, the apex of which is expanded into a stout scoop-like frontal-spine which serves as a cocoon cutter during moth emergence. Transverse rows of spine-like processes are present on the dorsum of the abdominal segments (Fig. 5). Segments 2-7 have two rows each, the remaining have only one. Sexual dimorphism is evident in the size of the pupa-the males being smaller in size and the females larger - as wall as in the position of the genital aperture which appears as a ridged crevice on the ventral side of the 9th segment in males and as a smooth scar on the 8th 9th segments in the female.

Fig. 5.
Pupal exuvia.
Note the spines on the abdominal segments.



Most cossids pupate within its larval gallery in a puparium inside a 'pupal chamber' which is an enlarged part of the larval tunnel. In order to facilitate easy exit of the imago, they may also bore a separate emergence tunnel from the larval gallery reaching as far as the bark leaving only a thin layer of it which dries and cracks in the sun so as to be easily breakable to the pupa. Prior to eclosion the pupa cuts open the puparium and moves towards the emergence hole and gets lodged near the exit hole with its cephalic end slighly protruding outside. However, no instance of the larvae pupating inside the larval gallery was observed in the case of *C. cadadme* as reported by other workers (Beeson, 1941; Bhandari and Upadhyay, 1986).

2.4 Adult emergence

When the moth was ready for emergence, the cocoon moved to the soil surface aided by the movemnts of the pupa. The pupa then made a small exit hole at the cephalic end of the coccon with the help of the sharp cocoon cutter (frontal - spine) present on the head. It than pushed itself out of the cocoon for nearly half its ength by the to and fro movements of the abdomen, when the rows of teeth on the abdoman alternately slip and grip effecting forward movemnt Emergence of the moth occurred by a longitudinal split of the pupal sheath.

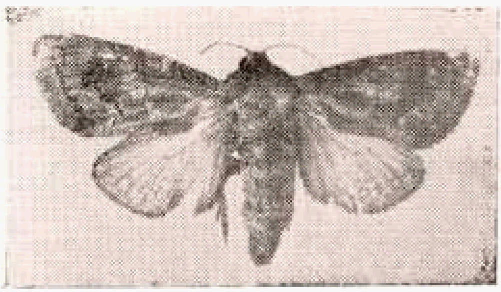


Fig. 6. Moth.

The moth is dull brown in colour and measures about 5 cm in wing expanse (Fig. 6). On the head, the mouth parts are atrophied and a distinct haustellum is not present. In the maxillary palpi, the apical segment is very small as compared to the penultimate segmant which is long and broad. The antennae are long and pectinate, the pectination being very pronounced in the male as compared to that of the female (Fig. 7). A detailed description of the moth is given by Harnpson (1892).

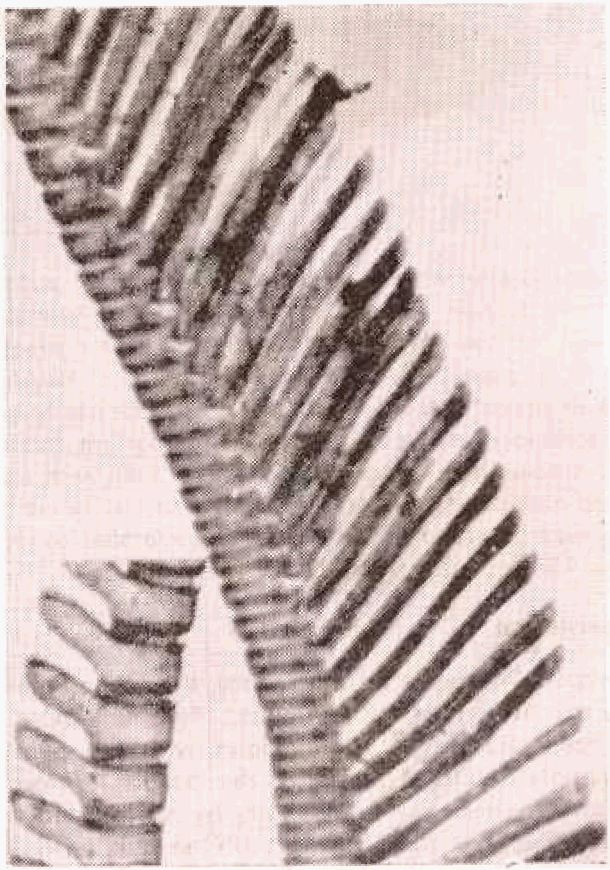


Fig. 7 Antennal segments of the male.
Inset: that of the female.

The moths are positively phototropic and are attracted to light and usually rest with the wings folded on the sides. When picked up with hand they remain passive and feign death. Moths attracted to light may be seen resting on the walls for very long periods (upto 12 hrs or more).

2.5 Longevity of moths

Laboratory reared as well as field collected moths were released in cages and were provided with honev diluted with water. However. they were not found to feed, probably due to the degenerate condition of the mouth parts.

In the laboratory they lived for 5-6 days. Longevity of adults of other carpenterworms is also reported to be short—in *Z. coffeae* it is about 2-6 days (Chang, 1984) and in *X. persona* about 16 days (Beeson, 1941).

2.6 Time of emergence

The time of emergence of the moths was also observed in the laboratory which mostly occurred between **6** p.m. and 9 p.m. Studies conducted at Palappilly using light traps also indicated a similar emergence pattern. Although more detailed information could not be gathered in this regard, studies made elsewhere on other species of carpenterworms have indicated the influence of temperature and light on moth emergence.

2.7 Seasonal emergence pattern

The seasonal emergence pattern was studied by trapping the moths in a William's type light trap (Fig. 8). An ordinary,100 W bulb was used for illumination. A cotton wad soaked in benzene kept in the collection chamber served as a fumigant for immobilizing the insects trapped. The trap was installed at a height of 1.5m above ground level in a. clearing within a 1925-planted teak plantation at Palappilly in the Chalakudy Forest Division which was heavily affected by *C. cadambae.* The trap was operated throughout night on all alternate days (from 6.30 p.m. to 6 a.m.) for a period of two years (1985-1987).

Fig. 8. Light trap used for moth sampling.

The number of moths collected on each day was recorded. From this, the average number of moths collected per day for each month during the period of study (1985-'86,1986-'87) was calculated. For comparison of trends in the emergence pattern of this insect, the seasonal index for each month was calculated by using the following formula :

$$\text{Seasonal index} = \frac{\text{month-wise mean}}{\text{overall mean}} \times 100$$

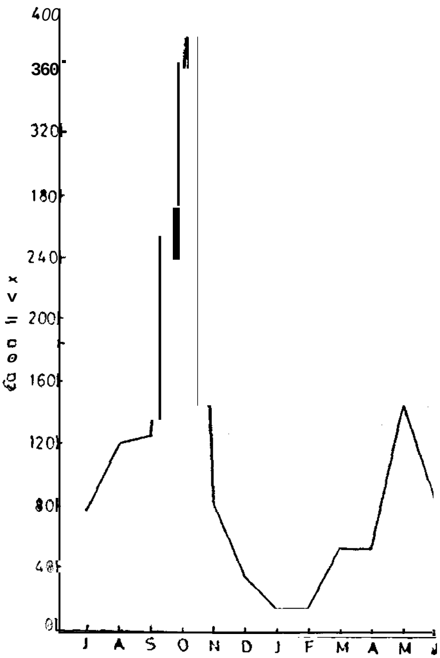
where, month-wise mean is the mean insect collection over 2 years for the corresponding month and overall mean is the mean of all monthwise means.

By calculating the seasonal index it was possible to interpret the percentage collection of moths per day in a given month in relation to the overall average of monthly collections (Table 1).

Table 1. Seasonal population trends in C. *cadarnbae*

Month	Monthly collection of moths during		Seasonal index
	1985-'86	1986-'87	
July	24	22	76
Aug.	47	103	120
Sep.	76	108	126
Oct.	59	300	382
Nov.	57	22	84
Dec.	5	48	36
Jan.	11	13	16
Feb.	12		16
Mar.	29	55	55
Apr.	19	60	54
May	200	17	148
Jun.	19	115	87
		Total	1200
		Average	100

Using this data, a graph was prepared which showed two distinct peaks, one beginning in May-June and the other in September-October (Fig 9). The population was very low in January and February. Then there was a slight increase in the population in March which remained steady until April. The population suddenly incresed following pre monsoon showers in May after which it sharply declined in June (in 1985-'86) and July (in 1986-'87) probably due to the intensification of the South-West monsoon. From August onwards the population increased with a pronounced peak immediately before the North-East monsoon in October. It then declined in November and the population remained at a low level until February. Observations in the field have shown that the emergence pattern coincides with the weather conditions, especially the rainfall. The first population increase occurred following the first premonsoon showers in April end or beginning of May. The decline in population in June coincides with the heavy South-West monsoon which is unfavourable for moth emergence. The increase in the population



from August to October when the rains are intermittent is due to the favourable conditions for pupation and moth emergence. The decline in pest population after the North-East monsoon could be due to the scanty rains and the prevailing dry conditions which are not very suitable for pupation. A certain extent of moisture content in the soil is necessary for the larvae to work into the soil for pupation and the increase in moth emergence during the rainy months could be related to the high pupation rate observed during this season when the larvae could penetrate easily into the moist soil. However, moth emergence was recorded throughout the year and it *is* not sure whether the moths collected in the drier months were

2.8 Sex ratio

During the two-year study period (1985 July to 1987 June), 1545 moths were collected in the light trap. Of these, 1372 were males and the remaining females, giving a sex ratio of 8:1. A similar trend was observed in laboratory reared moths as well. However, it is not certain whether the low number of females trapped actually represents their scarceness or related to their poor sensitivity to light as compared to the males.

2.9 Duration of life cycle

In C. *cadambae* the life cycle was found to be annual taking about 249 days for completion. The average duration of various stages were as follows. egg, 20 days; larva, 213 days and pupa 11 days (Table 2). In heavily infested plantations various stages of this insect were present throughout the year due to overlapping of generations. Many species of cossids have a very long life cycle In the case of *X liturata,* Fearn (1985) states that the life cycle varies from 2-4 years depending on the sex of the larva and the quality of the timber in which it is boring and that the male larvae often pupate after two years in the timber although the females may take a considerably longer period In the case of *X. ceramica,* the life cycle takes about 1 year for completion although, it may last upto two years in some cases (Beeson, 1941).

Table 2. Duration (in days) of various life history stages of C *cadambae* in the laboratory

No	Egg	Larvae	Pupa	Adult	Total
1	18	178	10	5	211
2	26	164	10	5	205
3	26	179	10	5	220
4	18	198	13	*6*	235
5	18	309	11	5	343
6	13	248	12	5	278
Average	20	213	11	5	249

2.10 Artificial rearing

Artificial rearing of cossids on cut branchwoods maintained greenish, by keeping the billets upright in buckets of moist sand dnd with the cut upper surface covered with thick plastic sheetings (McInnes and Carne, 1978), or in standing trees by confining the larvae to small cuts on the bark, under wiremesh cages, from which the larvae could establish themselves (Solomon, 1968), have Seen suggested VcFarland (1970) reported tuberous vegetables such as sweet potato, yams, beats, turnips, carrots, etc as suitable breeding materials for wood boring cossids and aegeriids. Similar methods were tried for breeding C *cadambae* as well, but were not successful. Therefore attempts were made to develop a suitable artificial diet and one of the diets tried for breeding the teak defoliator *H. puera* (Mathew *et a/,* 1990, *in press)* was found to be suited for mass breeding *C. cadambae* in the laboratory.

During the initial stages, the larvae were bred in groups in large plastic bottles (12 cm diameter) containing 5-7 cm thick layer of the diet. The surface of the diet was slightly scratched using a sharp sterile needle to ensure better initial establishment of the first instar larvae. After a week's growth the larvae were transferred to individual glass vials (8 x 2.5 cm) containing the artificial diet (4 cm thick) considering their aggressive nature. In every 20-25 days the diet was changed. When fully mature the larva measured 5.5—6 cm in length and 8—10 mm in diameter. The average larval period was 244 days (Range 164—309).

2.11 Impact of borer attack on the host

Extensive larval feeding leads to callus growth and often distorted bqrk formation. The 'bark that is lost due to larval feeding never recover6 and as a result ths wood is exposed. which may subsequently get infected by pathagenic/saprophytic fungi leading to decay of wood (Fig. 10). The fungus *Phialophora richardsii* has been isloated from wood attacked by C. *cadambae* (Sharma *et a/,* 1985). In this context it may be mentioned that attempts to inoculate the larvae on healthy trees were not successful. Perhaps, the fungal association might be essential for the larval establishment. It is probsbfe that the wood infected by fungal pathogens easily- breaks down and is more palatable to the larva and further researches are necessary to confirm this. Morris (1962) has also reported the occurrence of heart-rot in oaks attacked by *P. robiniae.*

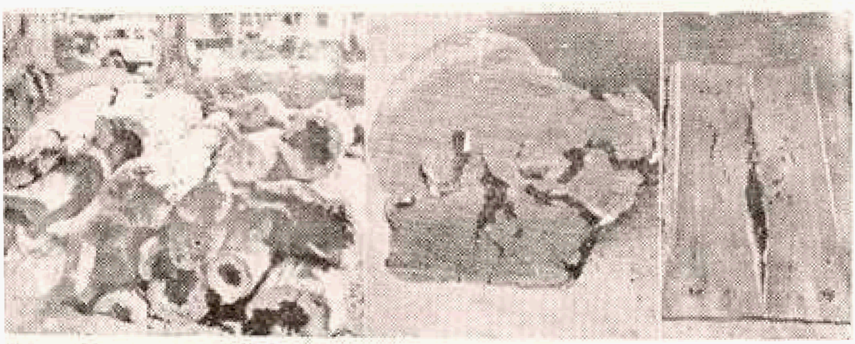


Fig. 10. Timber showing deterioration by fuingi subsequent to borer damage. Sections of woad showing tunnels made by C. *cadambae.*

Occurrence of borer holes in timber affected. by C. *cadambae* (Fig. 10) is a serious defect which adversely affect its commercial value. The larval tunnels are radial and follow a zig-zag course, reaching as far as the heartwood. Planks sawn from-such billets will have numerous holes and are not cherished for use in building construction, furniture making, etc.

3. ECOLOGY

3.1 Distribution of C. cadambae on teak in Kerala

Attack by C. *cadambae* was initially reported from teak plantations in the Trichur and Chalakudy Forest Divisions. To study its distribution in the different Forest Divisions, a sample survey was conducted under a stratified multistage sampling scheme. The Divisions formed the strata and the plantations, the first stage units. The plantations were selected based on probability proportional to size (PPS) with replacement. Altogether 48 plantations were selected (Table 3). The number of plantations selected in a particular Division was based on the proportion of area under teak in that Division in relation to the total area subject to a bare minimum of one plantation per Division. Although the intention was to cover only 5% of the total area, it could not be strictly followed since the selection was in terms of whole plantations.

Table 3. List of plantations selected for sampling

Division	Total area under teak (ha)	Details of plantation-blocks selected: Area of plantation selected (ha)	'tear of planting
Trivandrum	692.893	42.389	1962
Thenmala	1740.427	77.610	1965
Kallar Valley	1491.470	207	1972
Punalur	1109.580	61.500	1968
Konni	7712.720	239.945	1964
		176.870	1967
		257.9	1973
		540.9	1978
		99.442	1931
Rannii	3097.105	183.566	1960
		60.020	1972
Kottayam	3193.691	124.270	1954
		179.622	1966
Munnar	471.895	14.4	1975
Malayattur	4642.819	43.135	1953
		87.080	1961
		187.240	1965
Kothamangalarn and Kalady	3199.870	41	1973
		129.550	1974
		81.200	1976

Division	Details of plantation-blocks selected		
	Total area under teak (ha)	Area of plantation selected (ha)	Year of planting
Chalakudy	4786.030	89.334	1959
		240.377	1965
		83.630	1972
Vazhachal	1002.178	139.200	1379
Trichur	4311.140	593.978	1947
		62.876	1966
		127.707	1977
Parambikulam	6748.198	366.642	1962
		1260.610	1963
		1132.197	1964
		1454.067	1965
		622.810	1967
Nernmara	2377.340	83.370	1942
		59.200	1954
* Palghat	3319.040	23.000	1974
		93.680	1976
* Nilambur	8299.447	73.208	1929
		139.171	1963
		117.540	1967
		223.440	1971
		372.700	1973
		39.007	1978
* Kozhikode	4059.871	74.000	1976
		272.000	1978
		144.470	1961
		43.890	1962
Wynad	3710.870	26.710	1954
		123.080	1961
		142.480	1964
Tellicherry	116.399	104.689	1978
Total area	66082.983 ha	11542.702 ha	

Inclusive of plantations under Vested Forest Division.

3.1 1. *Sampling method*

Within each plantation selected, two transects were taken by cutting across the plantation from one corner to the other. A convenient row (usually the 5th) was selected on one boundary and a transect (AB) was taken along this to the other boundary (Fig. 11). Trees along that row as well as those on either sides of it were sampled. Upon reaching the opposite end, another transect (CD) was taken so as to arrive at the boundary where the sampling was initiated. Since the infestation was usually more intense on trees along the boundary or close to tracks present within the plantation, attempts were made to examine the trees on such locations also.

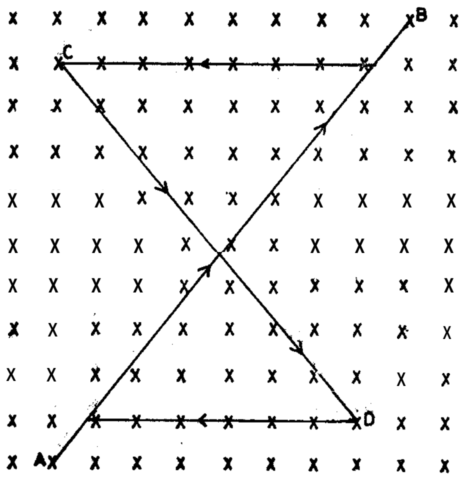


Fig. 11 Diagram showing the sampling pattern followed in plantations.

The following visual scoring system was used to assess the borer damage:

0 — Healthy tree, free of attack

1 — Low level infestation with at least one borer hole on the stem.

2 — M'edium level attack with several borer holes distributed on the stem at wider intervals

3 — Heavy infestation characterised by the occurrence of several feeding scars, distributed more or less uniformly throughout the trunk.

4 — Tree dead due to heavy infestation.

3.1.2 *Distribution of infestation*

the various plantations covered, 11 plantations belonging to 9 forest Divisions were found to be affected by *C. cadambae.* The location, area of planting as well as the proportion of affected trees in each plantation are given in Table 4.

Table 4. Infestation status of plantations found to be affected by C. *cadambae* in the sample survey.

Sl. No.	Forest Division	Name of Forest Range/ Plantation	Year of planting	Area of plantation in ha.	Propn. of affected trees in plantations surveyed	Remarks
SOUTHERN CIRCLE						
1.	Konni	Konni Range Aruvapulam	1931	6.37	0.380	Plantation adjacent to human settlements
2.	Ranni	Ranni Range Karikulam	1959	45	0.094	
CENTRAL CIRCLE						
3.	Kotha-mangalam	Thattakkad	1942	22	0.305	,,
		Thattakkad	1945	19	0.311	,,
4.	Malayattoor	Karakad	1952	52	0.145	,,
5.	Chalakudy	Pariyaram Range Mullappana	1965	138.800	0.034	Plantation slightly away from settlements
6.	Trichur	Wadakkancherry Range Ambalakkad	1947	164	0.575	Plantation Adjacent to human settlements
NORTHERN CIRCLE						
7.	Parambi-kularn	Parambikulam Range Parambikulam	1964	671.377	0.208	,,
8.	Nemmara	Meenchady	1946	60.64	0.185	,,
		Kanthalam	1957	37.71	0.198	,,
9.	Nilambur	Karulai Range Kallenthode	1967	20.85	0.321	

Among the affected plantations, the highest incidence of infestation was recorded at Ambalakad (57.5%) followed by Aruvapulam (38%) and Thattakkad (30.8%). The lowest values obtained were for Karikulam 9.4%) and Mullappana (3.4%)

The estimates of mean and the corresponding variance for the different Divisions were obtained as follows. The estimates are based on the assumption that a simple random sample of trees was taken for observation within each plantation surveyed.

$$\hat{\bar{Y}}_t = \frac{1}{n_t} \sum_{j=1}^{n_t} P_{tj}$$

where

$\hat{\bar{Y}}_t$ = estimator of the proportion of affected trees in the 't' th Division

P_{ti} = estimated proportion of infested trees in the 'j' th plantation of the 't' th Division

n_t = number of plantations selected in the 't' ,th Division

The variance estimate is given by

$$\hat{V}\left(\hat{\bar{Y}}_t\right) = \frac{1}{n_t(n_t - 1)} \sum_{j=1}^{n_t} \left[P_{tj} - \frac{1}{n_t} \sum_{j=1}^{n_t} P_{tj}\right]^2$$

The values obtained are given in Table 5. The highest estimated mean obtained was for Kothamangalam (0.205). Trichur (0.192) and Nemmara (0.192). The highest estimated variance obtained was for Trichur (0.0244). From the estimated mean and variance of infestation in the various Divisions, the estimated mean and variance of infestation for Kerala as a whole was calculated using the following formulae.

Estimators of population mean and variance of population mean are

$$\hat{\bar{Y}} = \sum_{t=1}^{K} \lambda_t \hat{\bar{Y}}_t$$

$$\hat{V}\left(\hat{\bar{Y}}\right) = \sum_{t=1}^{K} \lambda_t^2 \hat{V}\left(\hat{\bar{Y}}_t\right)$$

Where $\lambda_t = \sum_{i=1}^{N_t} M_{ti} \Big/ \sum_{t=1}^{K} \sum_{i=1}^{N_t} M_{ti}$

M_{ti} = Number of trees in the 'i'th plantation of 't' th Division

The values obtained were 0.04 (estimated mean) and 0.0002 (estimated variance) which are very low and indicate that the proportion of affected areas in Kerala as a whole, is very low. However, considering the drastic depreciation in the commercial value of affected timber, the damage caused is of economic significance.

Table 5. Proportion of infestation in the various Forest Divisions / Circles

Circle & Division	Estimated mean infestation in Division	Estimated mean infestation in Circle	Estimated variance of infestation in Division	Estimated variance of infestation in Circle
SOUTHERN CIRCLE		*0.02658*		0.00029
Trivandrum	0		0	
Thenmala	0		0	
Kallar Valley	0		0	
Punalur	0		0	
Konni	0.038		0.00129	
Ranni	0.047		0.00110	
HIGH RANGE CIRCLE				
Kottayam	0		0	
Munnar	0		0	
CENTRAL CIRCLE		0.05921		0.00009
Kothamangalam	0.205		0.00353	
Malayattoor	0.036		0.00099	
Chalakkudy	0.017		0.00014	
Vazhachal	0		0	
Trichur	0.192		0.02444	
NORTHERN CIRCLE		0.04814		0.00059
Pararnbikulam	0.052		0.00202	
Nemmara	0.192		0.00004	
Palghat	0		0	
Nilambur	0.080		0.00484	
Kozhikode	0		0	
Wynad	0		0	
Tellicherry	0			

3.2 Occurrence of infestation in areas not included in the survey

While conducting the sample survey, observations were also made in plantations located adjacent to the affected ones as well as those which are suspected to be affected based on information gathered from the Forest Offices. In addition to this, observations were also made on roadside trees, private plantings, etc. Data gathered in this way (Table 6) gives additional information on the distribution of infestation in the State. Thus, Malayattoor, Chalakudy and Trichur Forest Divisions contain several affected plantations besides those listed in Table 5. In addition to this, many affected trees were also noticed along the Konni-Punalur-Thenmala Road; Erumeli-Kottayam Road; Shoranur-Mannarghat Road; Mannarghat - Mukkali Road; Sethumadai - Parambikulam Road as well as Wadakkancherry - Pollachi Road. Infested trees were also noticed in natural stands at Nilambur and Parambikulam. In most cases tfiese trees appeared to be in the age group of 50-70 years or more. In all cases the affected plantations as well as roadside trees were under considerable stress, especially by human activities which involved frequent lopping of branches or plucking of the leaves for various purposes.

Table 6. *Occurrence of C. cadambae in areas* not coming *under the sample survey*

Sl. No.	Forest Divn./ District	Name of plantation/ location	Year of Planting	Area in ha.	Infestation level	Remarks.
1	Trivandrum Dist.	A few roadside trees at Kulathupuzha	–	–	^	Trees heavily attacked
2	Konni Divn.'	Umayamkuppa	1955	38.06	+	Adjacent to human settlements
		Forest Guest House Campus	–	–	+	
3	Quilon Dist.	Several trees along Konni-Punalur Road, specifically at Vakayar. Koodal, and Kadakkamon	–	–	+	Most of the trees heavily attacked
4	Kottayam Dist.	Kangazha. Two trees along Kottayam-Erumeli route	–	–	+	—

Sl. No.	Forest Divin./ District	Name of plantation] location	Year of Planting	Area in ha.	infest- ation level	Remarks
5	Kotharnang- alam Divn.	Thattakkad	1942	22	++	Adjacent to human settlernents
6	Malayattoor Divn.	Arattukadavu	1926	3	++	,.
		,,	1928	23	++	,,
		,.	1930	12	++	I,
		Kaprikad	1928	6.110	++	,,
		I,	1932	15.740	++	,,
		,,	1933	4.250	++	,,
		,I	1948	15.710	++	,,
		8,	1950	9.310	++	*,
		I,	1951	6.50	++	,.
7	Chalakudy Divn.	Ramavarrna coup	1931	23.47	++	,.
		Vellikulangara plantation	—	—	++	,.
		Chakrani plantation	—	—	++	,,
		A few tree along Parryaram-Vazhachal road	—	—	+	,,
		Velupadom	1927'	29.541	++	,,
		,,	1961	24.43	++	*
		Cheenikunnu	1955	32.49	+	*
		I,	1959	126.76	+	,.
		.,	1960	4308	+	,,
		Pulikany	1925	12.07	++	,,
			1926	16.6	++	,,
		,.	1928	17.47	++	,,
		,,	1928	7.104	++	,,
		Kuttanchira	1935	92.58	++	,.
		,,	1936	—	++	
			1937	—	++	L"
		,,	1938	23.48	++	#,
		Kunathupadom	1936 .	24.24	++	*.
		Vettingapadom	1963	8.6	+	,.
		r.	1921	2.06	+	...
		Karikulam	1946	16.87	+	
		,.	1947	10.29	+	

Sl. No.	Forest Divin./ District	Name of plantation/ location	Year of Planting	Area in ha.	infest- ation level	Remarks
8	Trichur Divn.	Wadakkancherry (Pongode)	1947	190	+	Adjacent to human settlements
		Vazhani (Plantation adjacent to damsite)	—	—	++	,,
		KFRI Campus (several trees)	—	—	+	,,
		Pattikad (a few trees in the Govt. hospital campus)	—	—	++	,,
		Kuthiran (a few trees adjacent to National Highway)	—	—	++	,,
			—	—	++	,,
9	Palghat Dist.	Wadakkencherry (several trees along National Highway)	—	—	++	,,
		Chittilancherry (a small private plantation)	—	—	++	,,
		Mangalam (Roadside trees)	—	—	++	,,
		Meengara (Roadside trees	—	—	++	,,
		Paruthikad (Roadside trees)	—	—	++	,,
		Kollengode (Roadside trees)	—	—	++	,,
	Nemmara Divn.	Kanthalam	1957	37.71	++	,,
		Several trees along Mannarghat-Mukkaii Road	—	—	++	,,
10	Parambi-kulam Divn.	Thunakadavu	1924	85.20	+	,,
			1945	97.33	+	,,
		Several trees in plantations and natural stands along the Thunakadavu-Topslip Road	—	—	+	,,
11	Nilambur Divn.	Kallenthode	1968	—	++	,,

\+ Moderate
++ Heavy

The data thus gathered indicate that, the infestation is more prevalent in the Central and Northern Circles, while in the Southern Circle the infestation is confined to a few road side trees as well as a few plantations belonging to two Forest Divisions. Although the distribution of this pest is rather restricted within a few plantations at present, there are indications of its slow spread. This is evident at Parambikulam where the trees in some of the plantations (at Kuriyarkutty) have already started showing signs of borer attack.

The purpose of the sample survey was mainly to find out the distribution of C. *cadambae* in forest plantations of teak in Kerala. The estimates are of indicative value and for getting a more reliable account of the proportion of affected plantations. more intensive sampling in each Division might be necessary.

3.3 Progression of infestation in affected plantations

The rate at which the infestation progresses in 'affected plantations was studied in a 1955-plantation (area 32.49 ha) at Cheenikunnu in the Palappilly Range (Chalakudy Forest Division) during the period 1984-1986. A study Plot of 100 trees (10 trees each in 10 rows) was selected (Fig. 12). The initial infestation status of each tree was recorded. In order to monitor the changes that might occur at short intervals, monthly observaticms were made on 49 trees (7 trees each in 7 rows) which were located within the study Plot. In addition to this, 6-monthly observations were made for all the 100 trees to record changes in the infestation level. The number of trees belonging to the various infestation scores before and after the study are given in table 7.

Table 7. Infestation progression rate in C. *cadambae.*

Infestation scores	No. of trees belonging to each score before the study started	No. of trees belonging to each score after the period of study	Annual infestn. progression rate
1	38	45	3.5%
2	15	30	7.570
3	6	8	1%
4	2	7	2.5%

Data presented here shows that there was a rapid spread of infestation during the study period. When the study was initiated, 61% of the trees were affected which became 90% by the end of the study period. Annually. 14.5% of lhe trees acquired fresh infestation. This high infestation rate could be due to the high pest population pressure in the study area.

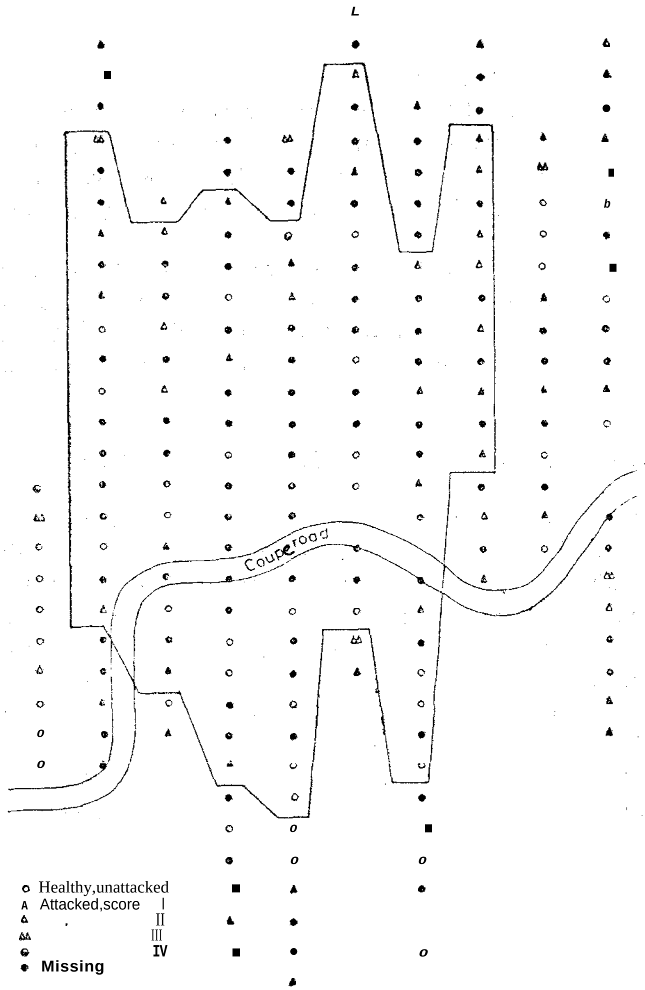


Fig. 12 Chart of the experimental Plot laid out at Palappilly for studying the infestation progression rate.

The progression of infestation was also studied. The transformation of trees from score 1 to score 2 was the highest (7.5%) followed by that from 0 to 1 (3.5%). There was also a 2.5% mortality of trees (score 4). This transformation rate may not be the same for plantations having a different level of infestation since pest population pressure is one of the important factors that determines the infestation progression rate. These results show that retaining an affected plantation will only result in the advancement of infestation leading to deterioration of the already affected trees as well as spread of infestation to the healthy ones.

3.4 Spatial distribution of infestation in plantations of varying infestation levels

At present no information is available on the establishment pattern of this insect in plantations over space and time Such information is very much needed for developing suitable management strategies and therefore an attempt was made to study this aspect in selected plantations of varying infestation intensities

3.4.1 Selection of study sites

Data iequired for this study were collected from three borer infested teak plantations in Kerala, which were so selected as to represent three distinct phases in the establishment of this insect. These phases include (i) an initial stage when the affected trees show only low level infestation, with a few number of borer holes on the trunk, (ii) an advanced stage of infestation characterised by the formation of several holes on the stem, and (iii) a later stage when the damage intensity bas substantially increased resulting in the complete bee-holing of the wooo. Plantations having the above situations were selected at Parambikulam, Thattakkad and Palappilly respectively, based on a sample survey taking into account, the number of affected trees present as well as their damage intensity These plantations belonged to the age group of 24-30 years The intensity of attack was rated by scoring the affected trees visually as mentioned earlier (3.1.1).

In each plantation thus selected, a series of rectangular Plots of size 20m X 8m were taken linearly starting from one boundary to the other. Each Plot contained 3-4 trees depending on the terrain as well as the extent of tree distribution due to various factors like illicit felling, windfall. etc. The number of healthy and affected trees as well as the intensity of attack on each of the affected tree was recorded. Negative binomial distribution was fitted to the data on the number of trees affected per Plot, for Parambikulam and Thattakkad plantations. Similarly binomial distribution was fitted to the data on the number of trees affected for Palappilly plantation. The probability density function of negative binomial is

$$P(x) = \binom{k+x-1}{x} \left(\frac{\mu}{k}\right)^{x} \left(1+\frac{\mu}{k}\right)^{-(k+x)}$$ where,

P(x) is the probability of 'X' individuals of a given attribute in the sampling unit, μ is the location parameter. k is the dispersion parameter and that of the binomial is

$$P(x) = \binom{n}{x} p^{x} q^{n-x}$$ where,

p is the proportion of the population that shows the attribute,

4 is (1-p) and n is the maximum number of individuals in the sampling unit.

The parameters in both the cases were estimated through the method of maximum likelihood. The methods given in Bliss and Fisher (1953) were followed in fitting the negative binomial distribution.

3.4.2 Distribution of infestation

Data on the infestation status at the three localities studied herein are given in Table 8. The percentage of affected trees was comparatively low at Parambikulam (19.08%) and Thattakkad (17.64%) as compared to that of Palappilly (83.84%). Although the percentage of affected trees in the first two localities were slmilar, the intensity of infestation in each of these Plots was found to vary.

At Parambikulam all the affected trees belonged to a single intensify score class (score 1) while at Thattakkad and Palappilly the affected trees belonged to all the four intensity classes. When the relative numbers of affected trees belonging to the various score classes at Thattakkad and Palappilly were examined, it was found that there was a transformation of the affected trees from the low intensity scores to the higher scores with a certain extent of mortality of trees. That is. at Thattakkad out of 17.67% affected trees, only 5.57% belonged to score 1 and the remaining trees belonged to the other score classes (ie., score 2=4.02%. score 3=5.57%, score 4 = 2.48%). A similar trend was noticed at Palappilly as well (score 2 = 11.98%. score 3 = 26.35%. score 4 = 38.92%). Here the percentage of affected trees belonging to score 1 was low whereas that of others was very high (score 2=11.98%; score 3 = 26.35%; score 4 = 38.98%).

The infestation at each of the above localities was very characteristic and represented the various phases in the establishment of this insect. The situation observed at Parambikulam is typical of the initial phase, when the trees show only minimum damage with a few borer 'holes on the trunk. The situation at Thattakkad represents the second phase, when the already affected trees are subjected to reinfestation in the subsequent years. In the third phase as represented at Palappilly. there is a marked increase in the number of affected trees belonging to higher intensity scores resulting in extensive riddling of ihe timber and subsequent large scale tree mortality besides fresh attack on the unaffected trees (Fig. 13).

Fig. 13. General view of a plantation badly affected by *C. cadambae*
Inset: a tree rated under the infestation score '3'.

Table 8 Basic features of the data gathered from 3 localities

Locality	number of Plots	Total No of trees	% of trees affected under the various score classes				
			0	1	2	3	4
Parambikulam	90	414	80.92	19.08	0	0	0
Thattakkad	90	325	82.35	5.57	4.02	5.57	2.48
Palappilly	73	168	16.16	6.59	11.98	26.35	38.92

The distribution of two variables viz., number of trees present per Plot and the number of trees affected per Plot in each of the three localities were also studied. The test of independence between the two variables in different Plots showed them to be dependent in the case of Palappilly ($X^2 = 144.73$) and independent in the cases of Thattakkad ($X^2 = 5.81$) and Parambikulam ($X^2 = 11.86$). Therefore it was necessary to study the distribution of these two variables in the three localities separately. The estimates of the parameters in the fitted distribution are given in Table 9. They indicate that the variable,

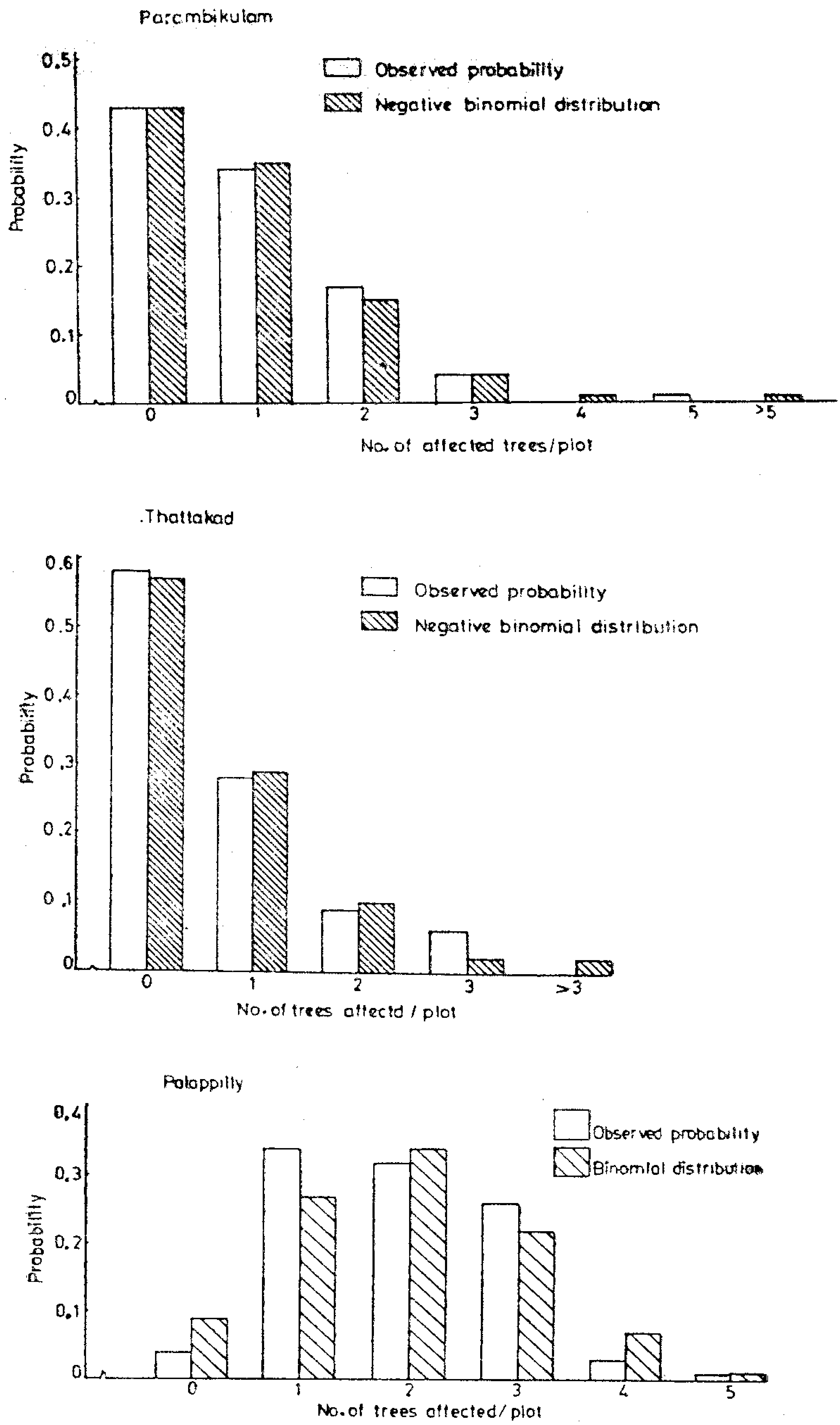


Fig. 14. Distribution of trees affected per plot in the three localities studied.

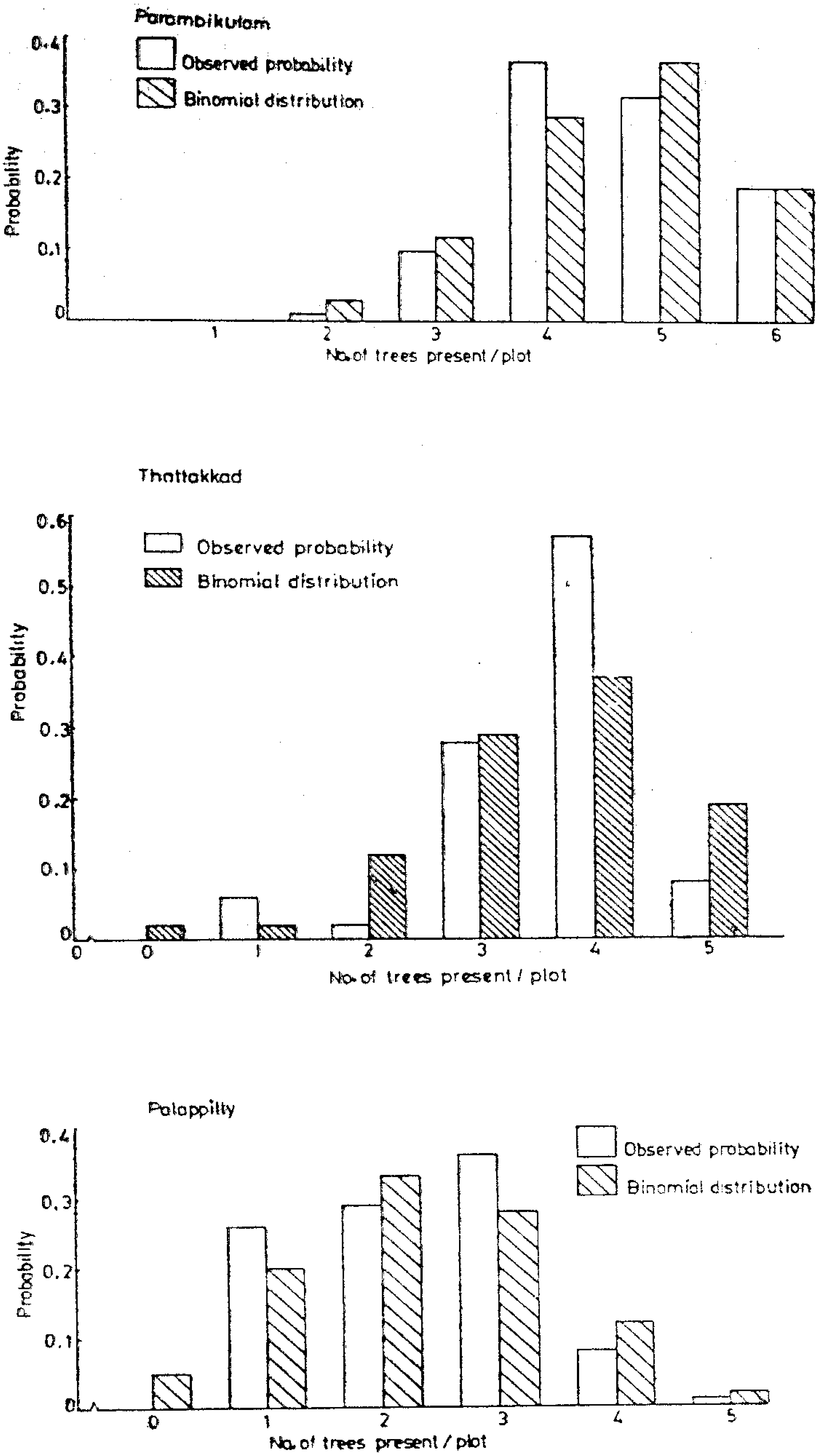


Fig. 15. Distribution of number of trees present per Plot in the three localities studied.

the number of trees affected per Plot, follows negative binomial distribution in the cases of Parambikulam and Thattakkad and binomial distribution in the case of Palappilly (Fig. 14). That is. the affected trees occur in definite patches or clusters in Parambikulam and Thattakkad, while at Palappilly the effected trees were uniformly distributed. The reason for the uniform distribution of affected trees at Palappilly might be due to the patches of affected trees getting confluent with the progression in the infestation over a period of time. The distribution of the number of trees present per Plot, which was also found to follow binomial in the cases of Parambikulam and Palappilly, did not follow a theoretical distribution in the case of Thattakkad (Fig. 15).

The time taken for the transformation from one phase of infestation to the other couldnot be arrived at, but it seems that this is a slow process perhaps requiring several years, due to the biological specialities of this insect.

Table 9. Estimates of the parameters for fitted distribution and goodness of fit.

Locality	Variable	Binomial distribution		Negative binomial distribution	
		P	X^2	k	X^2
Parambikulam	V_1	0.76	3.80 (ns)		
Thattakkad	V_1	0.72	26.18 (**)		
Palappilly	V_1	0.40	9.20 (ns)		
Parambikulam	V_2			0.92	3.31 (ns)
Thattakkad	V_2			0.83	2.93 (ns)
Palapilly	V_2	0.33	6.18 (ns)		

V_1 = Number of trees present per Plot
V_2 = Number of trees affected per Plot
ns = non significant
** = significant at 1%
p, k are parameters of the respective distributions

The study has shed some light on the distribution pattern of *C. cadambae* in teak plantations in Kerala under varying levels of infestation. During the initial phase of attack, the infestation usually goes unnoticed since the feeding scars are not prominent. At this stage a considerable number of trees get attacked. The second phase is chardcterised by further deterioration of the already affected trees due to reinfestation in the subsequent years, leading to mortality of trees besides slow spread of attack to the healthy trees in plantations. During these two phases the affected trees are usually confined to distinct patches. *C. cadambae* being highly mobile orgianisms, can fly to the other parts of the plantation or even to other plantations in the vicinity resulting in the spread of attack. ,During the last phase, the infestation spreads at a faster pace leading to a more or less uniforrn distribution of attack in the plantation.

3.5 Relationship between age of trees and infestation

As stated previously (Section 3.1) the survey was carried out in plantations of differing age groups which ranged from 10-56 years (as on 1987) The youngest affected plantation was 22 years old. The proportion of affected trees in this plantation was very low (0.034). The oldest plantation found affected was 56 years old and the proportion of affected trees was 0.380. The infestation level was found to be dependent on the age of plantations (X2=815.6569) in the test of independence between these two factors. The correlation coefficient between age and proportion of affected trees in different intensity scores were also calculated (Table 10). It was found that as the age of the plantation increases the proportion of affected trees in the plantation also increases. There was also an increase in the damage intensity of the affected trees. As a result, the proportion of trees belonging to various intensity scores also increased. This was because, the affected trees were subjected to reinfestation over the years. Soepardi (1934) who studied the incidence of the beehole borer, *X. ceramica* on teak in Indonesia has also reported a similar correlation between infestation and age of trees. This shows that unless the infestation is controlled in the initial stage itself, it is likely to aggravate with increasing age.

Table 10. Relationship between age of the plantation and proportion of infestation.

Score	Correlation coefficient	
	Affected plantations only n = 25	Including both affected & healthy plantations n = 74
1	0.133841	0.598143ns
2	0.574032**	0.661746**
3	0.642532**	0.678273**
4	0.740023**	0.694281**
Overall infestation	0.755384**	0.753727*

*,** significant at **p** = 0.05 and 0.01 respectively; ns non significant.

3.6 Natural enemies

3.6.1 Predators

Information on the natural enemies of C. *cadambae* is scanty. Attempts were made to trap the parasitic/predatory insects by setting up sticky traps near the borer holes or by pasting the eggs on the bark so as to attract the egg parasites. In addition to this, periodical larval sampling and rearing was also carried out for information on the extent of parasitism. However, no parasitic or predatory insects could be collected. Observations in the field indicated the occurrence of two species of predatory birds viz. the lesser golden-backed woodpecker *(Dinopium benghalense)* and an unidentified barbet. both feeding on the caterpillars after extracting thsm from the larval tunnels.

3.6 2 Microbial pathogens

Six species of microorganisms (Table 11), 4 belonging to fungi and the remaining to bacteria, were isolated in pure culture and identified. *Aspergillus flavus. Paecilomyces fumosoroseus* and *Serratia marcescens* were isolated from infested caterpillars collected from a teak plantation at Palappilly in the Trichur Forest Division. Infestation due to the bacterium S. *marcescens* was noticed in a very small percentage of larvae collected from affected trees and occasionally in cultures maintained in the laboratory. The remaining microorganisms viz. *Penicillium citrinum. Fusarium solani* and *Pseudomonas* sp., were from larvae which possibly got contaminated while rearing the caterpillars in the laboratory.

Excepting *P. citrinum* and *F. solani,* the pathogenicity of all the microorganisms was tested by allowing them to acquire The inoculum either through topical application or by introduction into the gut of larvae by mixing in the diet on which they were maintained. In the case of bacterial pathogens, a turbid suspension containing the microorganism was both applied on to the caterpillars as well as mixed in the diet so as to ensure sufficient exposure to the pathogen. Maximum larval mortality (83.3%) was recorded in the case of treatment of S. *marcescens.* This was followed by *A. flavus* and *P. fumosoroseus (57%)* and *Pseudomonas* sp. (28.5%) (Table 11). In these treatments the larvae became inactive after 42-72 hrs and mortality occurred within 7 to 10 days in the case of *A. flavus* and *P. fumosoroseus* and *5-7* days in the case of *S. marcescens.* Considering the high percentage mortality effected within the shorter period, the latter may be considered as the most effective pathogen.

Table 11. Microorganisms recorded to cause mortality of C. *cadambae.*

Microorganism	Place of collection	Stage of the insect susceptible	% Mortality
1. *Aspergillus flavus* Link (IMI Nos. 301149, 301150)	Palappilly	Larva, pupa & adult	57
2. *Paeci/omyces fumosoroseus* (Wize) Brown and Smith (IMI No. 301152)	Palappilly	Larva 9 adult	57
3. *Penici//ium citrinum* Thom. (IMI No. 301153)	Laboratory	Larva	Not tested
4. *Fusarium solani* (Mart.) Sacc. (IMI No. 301154)	Laboratory	Larva	Not tested
5. *Serratia marcescens* (Bizio) (IMI No. B. 11386)	Palappilly; Laboratory	Larva	83.3
6. *Pseudomonas* sp. (IMI No. B. 11387)	Laboratory	Larva	28.5

Manifestation of infection due to the fungal pathogens *A. flavus* and *P. fumosoroseus* might be through the soil since the larvae pupate only in the ground.

Larval mortality due to a fungal pathogen. *Beauveria bassiana* has been reported, of the bee-hole borer *X. ceramica,* which is a major pest of teak in Burma. Direct application of this pathogen is known to cause 95% larval mortality under laboratory conditions {Ghaiglom, 1966). Similarly, mycelial growth of the wood decaying fungus *lrpex mollis* has been reported to circumvent the pupae of the southern hardwood borer, *P. robiniae* in the tunnels, thus preventing the eclosion of moths (Solomon and Toole, 1971). However, no such studies have been made previously with C. *cadambae* and this is the first report of mortality caused by microorganisms in this insect.

3.7 Alternate hosts

Other than teak, C. *cadambae* ıs known as a pest of tendu *(Diospyros melanoxylon)* in Madhya Pradesh (Bhandari and Upadhyay, 1986). In the present Study, this insect was noticed to attack *Grewia tiliaefolia* and *Terminalia bellerica* growing naturally in *Cossus* affected teak plantations at Peechi, Wadakkancherry and Palappilly. unsuccessful attempts of larval establishment have been noticed on *Bridelia squamosa* (at Wadakkancherry) and *Xylia xylo-*

(at Palappilly). The observations made in this study indicate that teak is the principal host of C. *cadambae* in Kerala and its choice of alternate hosts, is rather limited unlike other cossid pests.

4. CONTROL TRIALS

The control trials attempted here were of a preliminary nature and involved the screening of certain insecticides by trunk application and field evaluation of the pheromone components of a related cossid, C. *cossus*. The intention of these studies was to assess the effectiveness of these methods of control so as to conduct detailed studies at a later stage.

4.1 Insecticidal control

Since the dttacked trees were widely scattered in the affected plantations, treatment ot individual trees only was feasible. Trunk application of insecticides either by the tree infusion method (Ghosh *et a/,* 1984) or by implantation method was tried in order to minimise pesticide application .in forest ecosystems on ecological considerations.

4.1.1 Trunk injection of insecticides

The tree infusion device used for injecting insecticides consists mainly of metallic nozzles which are tightly screwed in holes drilled in the sapwood at a height of about 1m above the ground. The nozzles are connected to a distributor through pressurised polythene tubes which in turn is connected to a reservoir provided with a dripping device and a regulator cock.

Three insecticides viz. Rogor (dimethoate), Dimecron (phosphamidon) and Nuvacron (monocrotophos) were used for the trials. Two concentrations (viz. *2%* and 4%) of each insecticide were tested. Six affected trees (belonging to score 2) having an approximate girth of 60 cm at breast height were selected at random from an affected patch of trees in a 1955 - plantation at Cheenikunnu (Chalakudy Division). Solutions of the above concentrations were prepared and about 500 ml each of the solutions was infused. For this purpose the solution was taken in the reservoir and the regulator cock was adjusted so that the solution will drip into the nozzles at the rate of intake by the tree through the sapflow. The intake of solution was complete in 4-5 hours. Observations were made on the 2nd. 7th. 14th, 30th. 45th and the 60th day by cutting the affected branches and examining them for mortality of larvae contained therein. Although heartwood of teak is known to be a non-conducting tissue, it was presumed that the larvae while working through the sapwood or while eating on the bark would get in contact with the insecticide. As no larval knockdown was observed during the period of observation. it was presumed that there was no diffusion of chemicals into the wood sufficient to cause mortality of larvae. Since the results were not promising no further trials by this method were conducted.

4.1.2 *Trials using insecticide implants*

Insecticide implants mainly of acephate were shown to be useful in the control of leaf mining dnd bark boiing insects The introduced chemical was shown to remain active within the tree and give protection from insect attack upto one year

Two formulations of acephate *(O,S* - Dimethyl acetyl phosphoramido-thioate) as 97% Orthene in 2 gm and 8 75 gm catridqes, were tested in the field There were 3 treatments including control having three replicates The trials were cariied out in a 1955-planted teak plantation at Cheenikunnu The trees were having an average girth of 60 cm at breast height Nine trees having more or less the same level *of* infestation (score 3) were selected at random from a large pdtch of affected trees The trees were numbered from 1-9 Fig 16 shows the layout of the experiment. Trees 1, 4 and 6 formed treatment 1, 5, 7, and 9 formed treatment 2 and trees 2, 3, 8 formed the control The number of implants required for each tree was determined by measuring the circumferance of the tree at breast height and dividing it by 4 as standardised by the manufacturers (Creative Sales Inc., USA). The required number of holes were then drilled on rhe trunk starting from about 30 cm above ground level with a hand drill using a drill bit of 9.4 mm size. The holes were drilled in such a way that they spiral up and were just enough to hold the implant (about 3 cm in depth and 1 cm in diameter) (Fig. 17). After plugging the implant into the hole, its head portion was slightly tapped so that the outer end *of* the catridge was flush with the cambium layer. The end of the catridge was then broken with a nail having a blunt tip to release the insecticide and the site of insertion was closed with bee-wax. On coming in contact with the plant sap, the chemical will be taken up by the tree in the sapflow. Observations were made as in the case of trunk injection method. No mortality of larvae was observed. Moreover, the chemical was found to have some phytotoxic effect on teak as portions of wood surrounding the holes drilled for implantation became dead leaving a cavity. However, in observations made after about a year, there were indications of the cavity being covered up by fresh tissues.

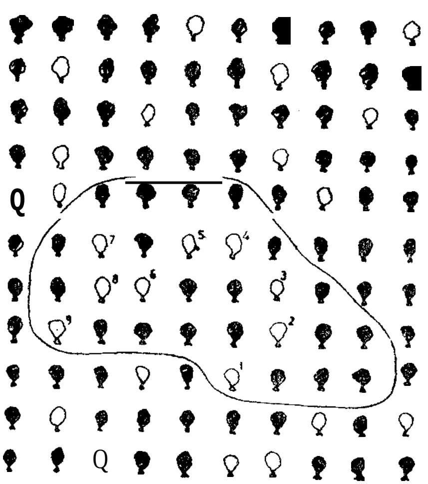


Fig. 16. Disiribution of affected trees in a teak plantation at Cheem nikunnu, Healthy trees are shown in dark, Numbered (1 to 9) trees in the encircled area were used for 'implantation' studies.

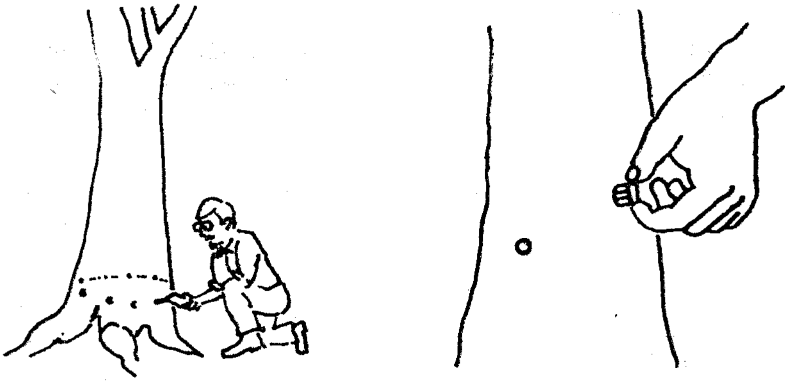


Fig. 17. Figures showing the location on the trunk where .the holes were drilled for 'implantation'.

Attempts to control cossid pests by direct application of an insecticide into the borer holes or by spraying an insecticide on the affected trees have been tried earlier. Awadallah *et al.* (1983). reported that 5 or 6 sprays of fenthoate (Cidial) at 0.2% or mixtures of endrin and dicrotophos (Bidrin) at 0.35% or DDT and methyl parathion at 0.5 and 0.15% respectively applied at 3-week intevals gave best control of *Z. pyrina* on pear trees in Egypt. In another trial using high volume spraying of phosphamidon, the larval infesta-tiorn was reduced to about 10% in two years (Talhouk, 1965). However Ghaiglom (1966) who made extensive studies on the control *of* the teak bee-hole borer *(X.* ceramica) using sprays or aerosols of insecticides like DDT, dieldrin, mevinphos, etc. found that chemical treatments were quite impracticable on a plantation scale. The results obtained in trials conducted in this studv have also led to a similar conclusion.

4.2 Field trials using pheromone formulations

Coss as are known to posses a strong pheromonal response and commercial for mulations of pheromone components of a number of cossid pests are currently being used in several countries for control or monitoring purposes.

Since isolation and characterisation of the pheromone components is a laborious and time consuming task, it was decided to screen some of the synthetic pheromone formulations of a related species viz. C. *cossus* for mass trapping C *cadambae* Of the 9 components recognized by Caprizzi et *a/* 983) in C. *cossus* 3 were shown to have attractancy for the males. They are 25-12 AC, 25-14 AC and 23-10 AC. These were tried here separately as well as in combinations at different loadings (Table 12).

Table 12 The pheromone components of *C.cossus* at various loadings used in field trials against *C. cadambae.*

No.	Pheromone component	loading
2	z5 - 14 AC	
3	**Z3** - 10 AC : 25- 12 AC : 25 - 14 AC (In 1 : 2 : 1 ratio)	

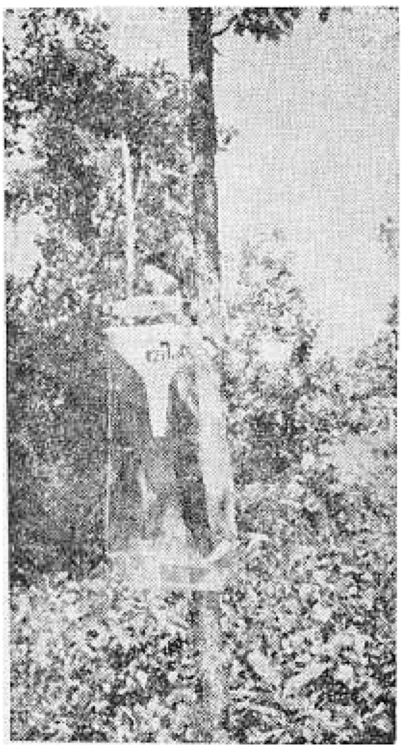


Fig. 18. Pheromone trap set up in the field for screening the pheromone formulations of *C. cossus.*

The study was carried out in 4 square Plots (15m x 15m) located' 'in a heavily affected teak plantation at Palappilly. The distance, between any two Plots was 60m. Five poles, 4 at the corners and one in the middle, were fixed in each Plot. The length of the poles above ground level was fixed at 1.5m. The trials were carried out separately since' the samples of pheromone formulations were received at different times.

The traps used in these trials were the standard funnel-type. It consisted of a funnel with a hood over the mouth, in the centre of which there was provision to hang the septa (Fig. 18). Observations were made each day continuously for a period of 3 weeks. No insects were trapped except for some ants *(Camponotus* sp.) which accidently walked in. Screening of the other components reported from C. *cossus* however, could not be carried out since these were not available. Detailed investigations on the characterisation of the active components of the sex phermone of *C. cadambae* and its formulation are worth trying for possible control/monitoring of this pest.

5. CONCLUSIONS AND RECOMMENDATIONS

The study has shown that C. *cadambae* which was considered to be a pest of minor importance in the 1940's is slowly emerging as a serious pest of teak in Kerala. Although its principal host is teak, instances of attack on *Grewia tiliaefolia* and *Terminalia bellerica* growing naturally in affected teak plantations in Kerala and tendu in Madhya Pradesh have been recorded.

Specialised conditions are necessary for the build up and establishment of C. *cadambae* in plantations. Trees weakened as a result of mechanical injuries (such as lopping of branches) are more susceptible to attack. The callus tissues and coppice shoots formed as a result of mechanical injuries provide favourable conditions for Its establishment. As a result, infestation is noticed mostly in plantations that are adjacent to human habitations or on trees along roadsides which are subject to stress conditions.

The attack by this insect results in the girdling of side shoots which subsequently fall off leaving a scar on the wood through which the larva tunnels into the wood. Infested trees suffer repeated attacks during subsequent years leading to the riddling of the timber with several holes. Although the proportion of infested trees in the affected plantations was fairly high, the proportion of infested plantations in the various forest Divisions was low. The highest proportion recorded was for Kothamangalam (O 205) followed **by** Trichur (0.192) and Nemmara (0.192). The estimated mean infestation for the State as a whole was only 0.04 showing that the attack is not widespread in Kerala.

During the initial phase, the infestation goes unnoticed but in the later phase it becomes more pronounced as a result of reinfestation of the already affected trees. Thus, as the age of the plantation increases, the intensity of attack also increases. Fresh infestation at the rate of 14.5% per year was recorded in the case of plantations that are moderately attacked.

The control trials carried out have shown that it is not feasible to control C. *cadambae* using trunk injection of insecticides mainly due to the larval habit of boring into the heartwood where the bole injected pesticides hardly gets translocated. The microbial pathogens reported to be useful in controlling some cossid pests also are unlikely to be of any practical use due to difficulties involved in their application and also due to the fact that their success is dependent on a number of edaphic as well as biotic factors. The six species of microbial pathogens and 2 species of predatory birds recorded in this study are of academic importance and are not directly useful in developing management strategies.

Another aspect that remains to be studied is the chemical characterisation of the sex phermone of C. *cadambae.* Cornmercial formulations of pheromones for many cossids are currently available and are widely used for control as well as monitoring purposes. If developed, pheromone formulations, will be a cheap and environmentally safe substitute for insecticides for managing this pest in forest plantations.

Since studies in the above lines are likely to take some time to be proved useful or not, for immediate application in the field it might be necessary to follow appropriate silvicultural management strategies to check further spread of this pest and to ensure maximum yield from plantations that are already affected. The following strategy is therefore suggested:

1. All plantations badly affected by *C. cadambae* (most of them are above 25 years old) may be clearfelled since their existance will only result in the deterioration of the affected trees besides spreading infestation to the healthy trees.

2. The affected trees in plantations of low infestation intensity may be extracted during the routine silvicultural thinnings.

3. Plantations, especially in areas prone to infestation may be kept free of mechanical injuries such as lopping of branches, plucking of leaves etc.

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