The teak defoliator was recognized as a pest of teak in India as early as 1898 (Bourdillon, 1898). During the past 100 years, the major topics of interest were the impact, biology, ecology, natural enemies, and control strategies related to this insect.

A general description of the different life stages of teak defoliator was presented during the early part of the century (Stebbing, 1903). Two different species were described, *Hyblaea puera* Cramer and *Hyblaea constellata* Guen. along with a variety described as The Black Hyblaea- *Hyblaea puera* var. nigra. Descriptions of all the above said insects resembled each other except for the colouration in larvae and adults. Distribution of *H.puera* and *H.puera* var. nigra was continuous throughout India and Burma while *H.constellata* was recorded only from Burma. In the next year (Hole, 1904) it was reported that *H.constellata* differed from *H.puera* with respect to two characters which are (a) *H. constellata* has the outer margin of the forewing excised below the apex and excurved at the centre, whereas in *H. puera* the margin is evenly curved and not excised, and (b) in *H. constellata*, in the anal angle, on the under side of the hind wing, there is a single black spot, whereas in *H. puera* there are two such spots. He commended that it is untimely to regard *H.puera* var. nigra as distinct from *H.puera*. The present study does not consider the variety nigra as distinct from *H.puera*. All the three insects were grouped under the family Noctuidae until Zerny and Beier classified the genus *Hyblaea* Fabricius under the family Hyblaeidae in 1936 (Singh, 1955).

Early research in Burma (Mackenzie, 1921) was primarily aimed at estimating the economic impact caused by this insect and the methods to control it. Mackenzie estimated an annual financial loss of Rs.1.5 lakhs for plantations in
Burma and recommended that providing nesting boxes for birds that feed on defoliator larvae will help control the problem.

Attempts were made seventy years back by Beeson to map the outbreaks of defoliator at the same general location of the present study. Starting from August 1926, a special officer was put in charge to patrol the teak plantations at Nilambur and record the distribution and grade of defoliation (Beeson, 1928). The study showed that complete foliage loss due to the insect occurred during the months September and October. Since the observer did not confirm the presence of insect in the area, it is difficult to draw any conclusions as to the progression of outbreaks. Moreover the incidence of teak defoliator and teak skeletonizer was not distinguished while preparing the maps making it difficult to understand which insect caused damage when. This study indicated that control of the insect during the epidemic phase would be difficult and hence attempt has to be made to prevent the shift from endemic to epidemic phase. Beeson highlighted the difficulty in timely detection of outbreaks and commented that attempts to control teak defoliator requires the same alertness, as that demanded by forest fires.

In 1934, a set of silvicultural-cum-biological control measures was put forward (Beeson, 1934). They were: (a) sub-division of large blocks of pure teak (sub-division by means of pre-existing forest rather than of newly created stands or mixtures); (b) establishment of a varied flora under the teak canopy (at the outset by retention of coppice re-growth and miscellaneous seedlings rather than by artificial introduction of selected species at a later stage); (c) elimination of harmful plants (this category includes alternative food-plants of defoliator); (d) maintenance of an understorey in older stands (for its value as a shelter for beneficial animals and as obstacle to defoliators) (e) introduction of parasites and predators (after careful assessment of the defective factors of locality).

Establishment of a varied flora under the teak canopy to provide adequate breeding sites for natural enemies of the pest was tried in 1942-43 (Khan et al., 1944). Two plantations nearly two miles apart with differing levels of
undergrowth were compared with respect to the incidence of defoliation and presence of parasites. However, the experimental set up did not yield reliable conclusions. Even though the role of parasites was not empirically proved, faith in Beeson's recommendations persisted for a long period. But none of the recommendation were put to practice due to various reasons (Nair et al., 1997) except for an order issued in the then Madras state prohibiting the cutting away of undergrowth in teak plantations (Kadambi, 1951).

Intensive observations were made in June 1950 at the Nilambur teak plantations to identify the causes of defoliator outbreaks (Kadambi, 1951). These observations brought out the fact that some trees escaped defoliation amidst a completely defoliated stand. Based on observation on the intensity of defoliation, it was suggested that the presence of tender foliage at the time of larval appearance was the factor that predisposed trees to defoliation. Research on how some trees escaped defoliation was also recommended.

One of the suggestions put forward by Kadambi in 1951 was to test the resistance of trees that were found escaped amidst a defoliated stand. This was attempted in a study started in 1983 in Kerala (Nair et al., 1997). Trees, which escaped defoliation during one year, were observed in the next year. Many of these trees were found infested and grafting from ten trees, which had escaped defoliation under natural conditions, were readily attacked when exposed artificially to the insect. This meant that there was no genetic resistance to the pest. A comparison of resistance in the different clones at Nilambur and Arippa orchards indicated that none were resistant. Since the clones were all from Kerala, it was concluded that search for resistance may be continued using clones from other parts of India and abroad. Another study using twenty different clones (Ahmad, 1987) collected from southern parts of India was done in 1987. One among the ten clones from Tamil Nadu (Top slip) showed the highest resistance to defoliator attack and another clone from Kerala (Karulai) showed the highest growth increment. The study proposed intraspecific crosses between these two clones for further improvement towards pest resistance and higher yield.
In a two-year light trap study at Jabalpur in 1978 and 1979 (Vaishampayan et al., 1983), collection of teak defoliator moths was restricted to July, August and September. Two explanations were put forward: migration of moths and diapause.

Although the importance of biological control agents was highly emphasized during the early period, aerial spraying of chemical pesticides was done in 1965 (Basu-Chowdhury, 1971) and 1978 (Singh et al., 1978). The first spraying was on an experimental basis in an area of 76 ha at Konni teak plantations in Kerala. The second spraying was done at Barnawapara plantations in Madhya Pradesh. In the second spray application, very few larvae survived in the sprayed plots as compared to the untreated controls. Although it was claimed that there was no adverse effect on wildlife including birds, the facts remain that 80 l. Malthion, 75 l. Fenitrothion and 260 kg. Carbaryl were deposited over an area of 460 ha.

Argument against aerial spraying of chemicals was put forward (Nair, 1980) based on three major reasons: (a) a realistic estimate of loss due to defoliator attack is not arrived at to calculate the cost-benefit ratio of aerial spraying, (b) environmental hazards and (c) adverse impact on natural enemies of the pest. Large-scale application of chemical pesticides against the teak defoliator has not been reported except in nurseries and private sector plantations, in recent years.

An attempt was made during the period 1979 to 1982 to answer the long-standing question of economic impact of the teak defoliator (Nair et al., 1996). Experimental plots in a four year old plantation were given selective protection against one or both of the two major defoliators or left unprotected for a period of five years. Measurements of trees at the end of the experimental period showed that the annual increment loss is 3 m$^3$ per ha in 4-8 year old plantations at 64% stocking. Projections based on this estimate indicated that protected plantations
could yield the same volume of wood in 26 years as unprotected plantations would yield in 60 years, provided other necessary inputs are given.

Evidences for migration of the defoliator moths were independently brought out by two groups of researchers during the later part of 1980's (Nair and Sudheendrakumar, 1986; Vaishampayan et al., 1987). The first study based on survey of defoliation along the Western Ghats and detailed observation of infestation characteristics at Peechi and Nilambur in Kerala proposed a model for the population dynamics of teak defoliator with short-range migration of moth populations. The second study relied on eight-year light-trap data from Jabalpur and showed a close link between defoliator outbreaks and the arrival of monsoon. It suggested that Kerala situated at the extreme southwest part of the country is a centre of origin of activity of *H.puera* from where moths migrate northward along with the progression of southwest monsoon.

A synthesis of information on the population dynamics of teak defoliator appeared in 1988 (Nair, 1988). It dispelled the notion that diapause occurs some time during the life history of the insect. Instead, it placed migration as the cause of absence of defoliator activity during part of the year. In almost the same way as Kadambi suggested in 1951, it emphasized the relation between presence of tender foliage and the susceptibility to defoliator incidence. It was also brought out that defoliator incidence is not associated with stand and site conditions of teak which means that outbreaks cannot be prevented by increasing the stand vigor through silvicultural management practices.

A renewed interest in the role of biological control agents in combating the defoliator attack was seen during the past decade. Of particular importance is the nuclear polyhedrosis virus that was isolated from defoliator larvae (Sudheendrakumar et al., 1988). In the same year, observations were made on the bird predators of defoliator larvae which showed that 58 species of birds were feeding on defoliator larvae during the months of March, June and July (Zacharias and Mohandas, 1990). Studies on the parasitoids of teak defoliator at Nilambur
during 1983-94 and 1987-89 recorded 15 species—seven from larvae and eight from pupae (Nair et al., 1995). Effectiveness of the dueteromycetous fungi, *Beauveria bassiana* (Bals.) Vuill, in causing mortality to the defoliator larvae was studied in 1993 (Rajak et al., 1993). It showed that the early larval instars were more prone to fungal infection. It is curious to note that a sixth larval instar of *H. puera* was used in this study while none of the earlier or later studies indicates the presence of the same.

In an attempt to understand the spatial distribution of defoliator outbreaks Nair and Mohanadas (1996) kept the road-side plantations at Aravallikavu, Valluvasseri, Karulai and Kariem-Muriem at Nilambur under observation during the pre-outbreak season in 1987. The study showed that the first noticeable event in the chain of events leading to wide spread outbreak of defoliator is the sudden occurrence of fairly high-density, tree-top infestations in small, discrete patches covering 0.5 to 1.5 ha. These infestations were proposed to be the transitional stage between an endemic population and an epidemic and were designated as epicentres from where wide spread outbreaks originate.
CHAPTER III

GENERAL METHODS

3.1. INTRODUCTION

This chapter summarizes the general methods used in the study; additional, specific details are described in the respective chapters. The work involved three major types of investigations- study of spatial distribution of defoliator outbreaks, monitoring of moth populations using light-trap and field observations on moth behaviour.

All investigations were carried out in teak plantations at Nilambur, in north Kerala (Fig.3.1.). Specific methods used for monitoring moth populations are described in Chapter 6, and for studying the field behaviour of moths in Chapter 7.

3.2. THE STUDY AREA

The study area is located between Latitudes 11°10' N and 11°25' N and Longitudes 76°10' E and 76°25' E, and fall within Nilambur North and Nilambur South Forest Divisions. The teak plantations cover an area of about 8516 ha spread out in a geographical area of 25,750 ha (Fig.5.1, Chapter 5).

The spatial distribution of outbreaks was studied at two spatial scales- in a continuous block of about 1000 ha of plantations at Kariem-Muriem over a three year period and in the entire teak plantations at Nilambur covering over 8500 ha., over one year.

The Kariem Muriem teak plantation is located in the Vazhikkadavu Forest Range of Nilambur North Forest Division, between latitudes 11°22.7' and 11°25.7' and longitudes 76°16.44' and 76°18.47'. This area, located 16 km from Kerala Forest Research Institute (KFRI) Subcentre at Nilambur was chosen for detailed
study because of good accessibility and information based on previous studies at KFRI that it is an area prone to repeated infestations almost every year.

3.3. PREPARATION OF PLANTATION MAPS

Before the start of observations, a map of Nilambur area, showing all the teak plantations was prepared by interpreting aerial photographs in the scale 1:15,000. This map was brought to 1:50,000 scale and features like drainage, roads, and contours were marked by superimposing the map over Survey of India (SOI) topographic sheets. This composite map was used for plotting the defoliated sites.

3.4. OBSERVATIONS AT KARIEM MURIEM

The study area at Kariem Muriem was divided into twenty grids based on natural boundaries like streams, footpaths and roads (Fig.4.1). Each grid had an average
area of 50 ha. A group of ten grids referred to above formed a block and was under observation of a single individual. Two individuals trained to identify and report defoliator outbreaks were deployed in the area to assist in the study. Each of these observers was asked to complete one round of observation within a period of 15 days.

Within each grid, the level of tender foliage and the presence or absence of defoliator outbreaks was observed by criss-cross perambulation. However, this method did not permit detection of very low populations of the insect, which required intensive search. Only populations, which caused visual defoliation of the tree, were detected.

Weekly visits were made to the plantation to verify the reports from observers. In addition, whenever the observers reported an infestation, the site was personally visited to gather information on (1) the date of egg laying and (2) the area infested. Two visits were made for this purpose, one at the beginning of the infestation to determine the date of egg laying and the other at the end of the infestation to determine the area infested. The following procedures were used.

**Determination of the date of egg laying:**

Larval samples were brought from each of the infested sites and were reared in the laboratory until they moulted. Based on the date of moultning, the date of egg laying was arrived at by back-calculation based on the time span needed for each previous larval instars (preoviposition period- 2 days, egg- 1 day, Instars I to V- 2,2,3,3 & 3 days respectively and pupa- 5 d).

**Determination of area infested:**

This was done usually when the insect was in the pupal stage because by that time the full damage to the tree would have occurred, making it easier to estimate the infested area. A sketch of the infested area was made based on landmarks like
roads, streams, etc. on copies of plantation maps prepared earlier. The area was estimated using Geographic Information System (GIS) as described in Chapter 4.

3.5. OBSERVATIONS IN THE ENTIRE NILAMBUR TEAK PLANTATIONS

The study area at Nilambur was divided into 149 grids and 20 observers were employed to report defoliator incidence. The area under supervision of each of the observers was visited at least once every week to verify their observation. Whenever outbreak was reported, the date of egg laying at the site and the area under outbreak was determined as described above.