# ECOLOGICAL STUDIES ON INSECT COMMUNITIES OF ANAIKATTY HILLS

Thesis submitted to the
BHARATHIAR UNIVERSITY, COIMBATORE

for the award of
DEGREE OF DOCTOR OF PHILOSOPHY
in
ZOOLOGY

By
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**March 2006**

## CERTIFICATE

This is to certify that the thesis, entitled "Ecological Studies on Insect Communities of Anaikatty Hills", submitted to the Bharathiar University, in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology is a record of original research work done by Mr. R. Eswaran during the period November 2002 to March 2006 of his study in the Division of Nature Education at Sálim Ali Centre for Ornithology and Natural History, Coimbatore, under my supervision and guidance and the thesis has not formed the basis for the award of any other Degree/Diploma/Associateship/Fellowship or other similar title to any candidate of any University.

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## DECLARATION

I, R. Eswaran hereby declare that the thesis entitled "Ecological Studies on Insect Communities of Anaikatty Hills " submitted to the Bharathiar University, in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology is a record of original and independent research work done by me during November 2002 to March 2006 under the supervision and guidance of Dr. P. Pramod, Division of Nature Education, Salim Ali Centre for Ornithology and Natural History, Coimbatore and it has not formed the basis for the award of any Degree/Diploma/Associateship/Fellowship or other similar title to any candidate in any other University.

Signature of the Candidate

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# SUMMARY

Community studies are relatively less in ecological entomology. Documentation of the communities of insects itself is a challenging job because of the inherent weakness in taxonomical brevity at the special level. The present study aimed primarily at exploring the patterns of insect diversity of a dry deciduous forest of Anaikatty hills, Western Ghats. As the term insect holds a large spectrum of organisms with a great level of taxonomic ambiguity, new approaches are needed to face the problems related with its diversity and distribution. The new approach attempted in this study was to examine the dynamics of diversity and abundance at different levels. At the broadest level an attempt has been made to study the composition and changes of insect families within and between different microhabitats of the landscape. At the intermediate level, the species composition, diversity and dynamics of one selected group of insects, viz., butterflies and at a finer level the aggregation and dynamics of the individuals of the selected species of butterflies were studied. The abiotic and biotic influences of these family levels, species level and individual level patterns were also studied.

Selection of insect collection methods is very important in the insect diversity studies. Pitfall and light trap, (two passive insect collection methods), were employed for the collection of insects from ground and nocturnal flying insects. Sweeping and beating sheet methods, (the two active methods), were employed to study the insects from vegetation. The insects were grouped according to microhabitats from where they were collected. Accordingly, pitfall insects were grouped into ground insects, insects collected by sweeping represented herb and shrub insects , insects collected from beating sheet method represented tree insects, and light trap insects represented nocturnal flying insects respectively

In general, hymenopterans were more abundant both in ground as well as on foliage. The numerical dominance of ants (formicidae) was expected as their colonies occupy these two microhabitats. However, hemipterans were abundant in the shrub level and so were the coleopterans among nocturnal flying insects. Thus, the predominant

group of insects was different for each microhabitat. The composition of families of insects was also different among microhabitats. This shows microhabitat preference of insects even at the higher taxonomic levels.

The pattern of seasonality of insects also varied among the microhabitats. Moreover, insects formed three distinct clusters based on seasonality as vegetation insects, nocturnal flying insects and ground insects in a clustering done by Bray-Curtis Cluster method (sing link). The insects sampled from shrubs and trees formed a cluster, which differed from other insects such as ground as well as nocturnal flying insects. Ground insects were found abundant during the summer months and vegetation insects were recorded more during the rainy months, which could be due to flushing of the leaves after the rain.

During the periods of high ant dominance such as summer months, the representation of other families of insects was relatively less; during the rainy months, ant abundance was less and the representation of other families in the collection was high. Predictable and definite seasonal fluctuation of insects at the family level identity suggests that there is ecological significance even for the family level identity among the insect studies.

The monthly abundance of hemipterans negatively correlated with monthly mean wind speed and temperature. Hymenoptera was also negatively correlated with the windy months. Hymenopteran family-diversity had a positive correlation with relative humidity, minimum temperature and number of rainy days. The abundance of orthoptera has shown a positive relation to the monthly mean wind speed. Since the orthopterans are hoppers with tough wings, wind might be affecting them less compared to other flying insects such as butterflies.

The different collection methods captured different components of insect diversity with varying efficiency. The methods differed in the identity of the insects they captured as well as the diversity. Pitfall has captured more insects but the family diversity

observed is by far less. Beating sheet had more diverse insects followed by the light trap. The size of the insects sampled also show some relationship with the type of sampling method. The sweeping and the beating sheet have captured larger sized insects. More number of smaller sized insects was collected by the pitfall. The light trap was found to capture medium sized insects.

Two active methods and two passive methods were used, among these, two operated during night and other two during day light. The effort in terms of the hours employed in collection was also different among methods however insects captured per hour were relatively uniform in all these methods. The results supports that a combination of different methods are needed for insect sampling in the biodiversity studies. These selected methods were simple to operate, less labour intensive, inexpensive and gave significant and reliable information about the insect diversity and dynamics of the region.

Butterfly community in the study area has a predominance of pierids, probably because of the relatively high abundance of their larval food plants. More species were recorded from the family Nymphalidae. The species richness and abundance of butterflies were highest during March and November. The relatively high rainfall of October (north-eastern monsoon) and April (summer showers) gave reasons to this pattern. More butterflies were encountered in northeast monsoon followed by summer, winter and southwest monsoon. As the study area is a dry deciduous forest in the rain shadow region of Western Ghats, and the wet season of this area is northeast monsoon, this pattern of butterfly abundance is expected. In general the butterflies exhibits a strong seasonality following the changes in climate and vegetation. However, there were variations in the pattern of seasonality among the family level as well as among the species of same family.

Species richness and abundance have showed a positive correlation with relative humidity. Monthly mean wind speed exhibited significant negative correlation with butterfly diversity. Although rainfall did not show direct correlation with butterfly

abundance of respective months, the preceding month's rainfall had a positive impact on the butterfly diversity; precisely a one-month time lag, as shown by the high rainfall in October and the abundance in November.

Butterfly abundance was also observed to coincide the breeding season of birds with a one-month time lag. Breeding activity of birds was more in March and October. The butterflies are abundant in March, April, November and December.

Diurnal activity pattern of butterflies was unimodal. It showed a peak between 10 am and 2 pm. However, few species such as *Pachliopta aristolochiae*, *Pachliopta hector*, *Delias eucharis*, and the some of the lycaenids (e.g., *Zizinia otis*) did not follow this pattern.

Anaikatty harbours nine endemic species of butterflies; some confined only to south India, while some the whole of Indian Subcontinent. Three Schedule I species of Wildlife Protection Act, 1972 were recorded from the Anaikatty hills. Seven Schedule II species and one Schedule IV species were also recorded from the study area. Moreover, study area harbours significant proportion of Western Ghats butterflies. The butterfly diversity didn't show any significant variation among the transects within the same landscape.

Mud-puddling of butterflies was observed in very large numbers during the period when the butterfly abundance was very high. All the mud-puddlers were males. Pieridae was the most abundant while Nymphalidae had more species. The group size with four species was recorded the most among the mud-puddlers. Mud-puddling could be acting as a way for alternate food source for butterflies and hence definitely has a significant role in the population dynamics of butterflies of the region.

Seven species of the butterflies were recorded migrating through the study area during the study period. The migration was more in the months of March, July, October and November. Although, direction of migration continued to change at local level quite regularly, particular direction was maintained at the regional level.

The danaids were observed as migrating in multi-species flocks whereas pierids as single species. Butterflies with damaged wings were also frequent; mainly of males. As the wing damage is an indirect measure of the age of the butterflies and the distance it traveled, it suggested that males were older or travelled more distance.

The migratory butterflies fed on nectar from the area during migration. Forty aggregation sites of migrating butterflies were recorded in the region. These sites were humid, shady and wind protected areas such as, hill slopes for aggregation. Very specific locations were identified in the region, which act as source areas for the mass production of butterflies just before migratory seasons.

The numbers of butterflies recorded in mud-puddling were more than those in the total transects counts although mud-puddling was recorded only in a few months. The study recommends that these mud-puddling, aggregation and mass production sites of butterflies should be considered in the planning and prioritization of conservation areas. The mass production sites and aggregation sites are of great conservation importance and hence is an ideal location for declaring butterfly-protected areas.

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## TABLES & APPENDICES

# Chapter 1
# INTRODUCTION

## 1.1. Insect diversity and community approach

Community is an assemblage of interacting species populations that occur together during a particular period in a specific area (Townsend *et. al.,* 2003; Claridge, 1987). The scales of space and time at which diversity patterns are expressed and the mechanisms that determine them have been major questions in ecology. These questions have also been tested on a wider range of organisms right from invertebrates to mammals (Rosenzweigh, 1995).

Coexisting species with similar ecological requirements may have different ecological adaptations to cope up with the seasonal variations. Kenagy and Bartholomew (1985) have studied five species of rodents in the Californian desert having similar ecological requirements but varied in their reproductive seasonality. It is reported that in spite of these differences all five species maintained stable population densities. There could be more than one solution to many of the ecological problems. Each species has unique spatial and temporal distribution that reflects its specific requirements of physical conditions and interactions with other species (Cody and Diamond, 1975).

The amazing diversity of insects and widespread taxonomic uncertainty at the level of species identification offer tremendous challenges in community ecology (Nowierski *et. al.,* 1999). Insects are the most diverse organismal group and community analysis is not frequent among entomological studies. The ubiquitous distribution of insects signifies them as a suitable option to test many questions related to ecology and evolution. However, research work on these lines is relatively low (Caltagirone, 1999).

Although the importance of ethological studies in ecological research and vice versa are recognized (Orians, 2000), such attempts are very few, probably because of the practical difficulties.

## 1.2. Why study insect community?

Insects are the most predominant biota in all continents including Antarctica. It is commonly believed that 76 per cent of the total animal species of the planet are insects (Mani, 1990). Estimates vary from 600, 000 to one million species of insects identified so far, which, authorities believe, are only a fraction since a larger percentage is yet to be discovered and reported (Erwin, 1991; Gaston, 1991; Hammond, 1992). Beetles alone include more than 3,50,000 species (Hawksworth and Kalin-Arroyo, 1995). In a recent estimate Alfred *et. al.* (1998) has reported 59353 species of insects from India.

Although insects are the most abundant organisms on earth, they have been considered only very less as a conservation icon. Taxonomic ambiguity and their position in lower trophic levels may have prevented the conservationists from using them as flagship species. Although all these reasons are acceptable, the ecological role of insects cannot be under estimated. Insects are excellent organisms for community and ecosystem studies as they occupy many niches and tropic levels (Schoenly, 1990; Chen and Wise, 1999).

A significant majority of insects have strong interactions with plants and other biotic components of any ecosystem (Ehrlich and Raven, 1964; Huffaker, *et. al.,* 1999). In tropical and temperate ecosystems, herbivorous insects exert comparable or greater grazing pressures on plants than do their vertebrate counterparts (Broadhead, 1958; Kreman *et. al.,* 1993). One of the reasons for their ubiquitousness is their radiation into every possible niche, usually with a high degree of specificity (Southwood, 1978; Kristensen, 1981). Whenever insect species evolved to exploit a new source of food, they became a resource for parasite, parasitoid or predator species that might have coevolved to exploit it (Huffaker and Gutierrez, 1999). About 25 per cent of all insect species are predators, parasites, or parasitoids mostly on other insects. Insects also form the primary food resource for most arachnids, many kinds of microorganisms, even a few insectivorous plants, and certain vertebrates including human beings.

Insects respond to the landscape changes quickly due to their short life span. The influences of weather changes on insects; their activity pattern, reproduction, egg laying and larval development; seasonal abundance of insects with that of food and the life history strategies are of immense interest in ecological entomology. Seasonal migration of insects is another important factor that provides great ecological insight into population studies and ecosystem functions.

### 1.3. Special emphasis on butterflies

Lepidoptera is one of the major orders of phytophagous insects that include scaly winged butterflies and moths. They are holometabolous and their life cycle passes through egg, larva, pupa and adult. Butterflies play many important roles in the ecosystem functions. Butterflies are important herbivorous insects that have a direct trophic relationship with plants (Ehrlich and Raven, 1964). Hence, butterflies are considered to be excellent indicators of plant diversity and ecosystem functioning. The members are of great value in conservation and environmental planning in a local scale. Butterfles have great potential for inclusion in faunistic analysis and environmental monitoring.

Butterflies form the food of many organisms such as spiders, reptiles, birds and mammals (Wynter-Blyth, 1957; Kunte, 2000). Caterpillars are major food source of insectivorous birds during both breeding and non-breeding seasons. The winter aggregations of monarch butterfly are reported as one of the main factors that determine the populations of four sympatric species of field mouse (Gleddinning and Brower, 1990).

Composition and structure of butterfly community of an area is depended on many biotic and abiotic factors. Competitive interactions within and among species and their relation with environment determines the butterfly community of an area. The migratory behaviour of certain butterflies is thought to be a regulatory mechanism to prevent overpopulation of species through dispersal (Dingle, 1996). In recent years,

ecological and evolutionary questions have been explored through butterflies (Boggs and Jackson, 1991; Gage *et. al.*, 2002) and the potential remains endless.

### 1.4. Objectives of the present study

This work, explores the variation of insect community in time and among the four habitat niches. The primary objective was to explore the distribution and changes in monthly abundance of insects in respond to climatic parameters in different locations of studied landscape. Here, abundance means the number of insects of a specific taxonomic category collected through a selected method from a location. For studying the distribution patterns, insects from ground, herbs and trees along with the nocturnal flying insects were collected using four different insect collection methods. For the uniformity across taxonomic level during analysis, identification was restricted to the family level. Butterflies were identified in species to elucidate the species-level patterns.

The specific objectives were to:

- document the insect diversity pattern at different times and microhabitats in the dry deciduous forest of Anaikatty hills.
- determine the butterfly species composition of the study area and its seasonal and spatial variations.
- examine the characteristics of the aggregation behaviour of butterflies and their importance on the ecology of butterfly populations of the area.
- study the relationship of climatic factors with the populations of insects of the study area.

### 1.5. Organization of the thesis

This thesis is organized into five chapters. Literatures pertaining to each major aspect are reviewed and discussed within that particular chapter. The present chapter introduces the subject and overall details of the study. The particulars of the study area, both biotic and abiotic aspects and the ecological history and biodiversity of Western

Ghats are in Chapter 2. Chapter 3 deals with the insect community structure and their variation in time and space. Chapter 4 deals with the butterfly community structure and diversity aspects. The aggregation of butterflies during migration and mud puddling is dealt within Chapter 5. The species composition, group size and its variation in butterfly aggregations are addressed here. Species composition of the butterflies and variation in time, habitat qualities of the migratory path are also presented in Chapter 5. The references and the appendices are presented at the end.

# Chapter 2

## STUDY AREA AND VEGETATION

This research work was conducted in the dry deciduous forest of the Anaikatty hills of Nilgiri Biosphere Reserve, Western Ghats. Western Ghats is one of the species rich biogeographic regions and one of the 26 biodiversity hotspots of the world (Mittermeier *et. al.,* 1999). The citations of the Western Ghats are found even in the literatues of 3rd century BC (Chandran, 1997). There are records that the rulers of west coast had spice trade with the Roman Empire and references to rice and millet cultivation in the South Indian hills about 2,000 year ago in old sangam Tamil literature (Chandran, 1997). This shows that the area has a long history of human influence and disturbance that might have had a significant role in the dynamics of the species composition of all organisms.

Western Ghats of India due to its geographic location, stable geological history, climate, heavy rainfall and good soil characteristics support a variety of tropical forest ecosystems including the wet evergreen forests (Chandrashekara and Ramakrishnan, 1994). The most dominant natural vegetation of Western Ghats is the evergreen forest (more on wet western region) and deciduous forests on eastern slopes.

Nilgiri Biosphere Reserve (NBR) part of Western Ghats is the first biosphere reserve of India. The Department of Environment and Forests, Government of India established NBR in 1986 for conserving the biological diversity in India (Suresh and Sukumar, 1999). It comprises 5500 sq.km forestlands of three states namely Tamil Nadu, Kerala and Karnataka. In Tamil Nadu, the biosphere reserve comprises whole Nilgiri District and parts of Coimbatore plains including Anaikatty hills (the study area).

### 2.1. Location of the study area

Anaikatty reserve forest ($76^0$ 39' and $76^0$ 47'E and from $11^0$5' to $11^0$ 31'N) Coimbatore, is a part of the NBR, Western Ghats (Map 2.1). This area falls between.

Nilgiri south and Sathyamangalam forest divisions on the north, Erode division on the east and Palghat forest division of Kerala state on the south border the Anaikatty Reserve Forest.

Total area of Anaikatty Reserve Forest is 4447.74 ha and the field sampling was largely conducted in an approximate area of 625 ha. The study site is located about 25 km north-west of Coimbatore city. This forest has an undulating terrain (610-750msl) with seasonal waterways with hill tops and south rising upto 1600msl. Rock formation in the study area is gneiss of Achaean age group, comprising of variety of rock types. Soil type in this forest is hard gravel in major portions and red loamy soil present in patches. Red loamy and sandy soil, reddish brown and brown soil and clayey soils mostly cover the plains. Humus is generally absent in the Anaikatty reserve forest (Soundarapandian, 1992).

**2.2. People and Land use pattern**

In India, about 50 million people live in and around forest with their major income through Non Timber Forest Products (NTFP). NTFP collection, firewood collection and cattle grazing are common in Anaikatty hills. The local people facilitate regular fire in the forest areas for leaf blade flushing of the commercially important plant, *Phoenix sylvestris*. It is used to make brooms, which is a source of income for the tribals (Pramod *et. al.*, 2003). Agriculture is prevalent in and around the forest areas such as Dumanoor and Chembukarai. Farmers tend to work in brick industries as labourers due to the infrequent seasonal rains and agricultural loss brought about by the wild animals (Pramod *et. al.*, 2003).

**2.3. Abiotic factors**

Coimbatore is remarkable for comparatively cool winds that blow across the west from May to October (monsoon) and downhill during November (winter) (Soundarapandian, 1992).

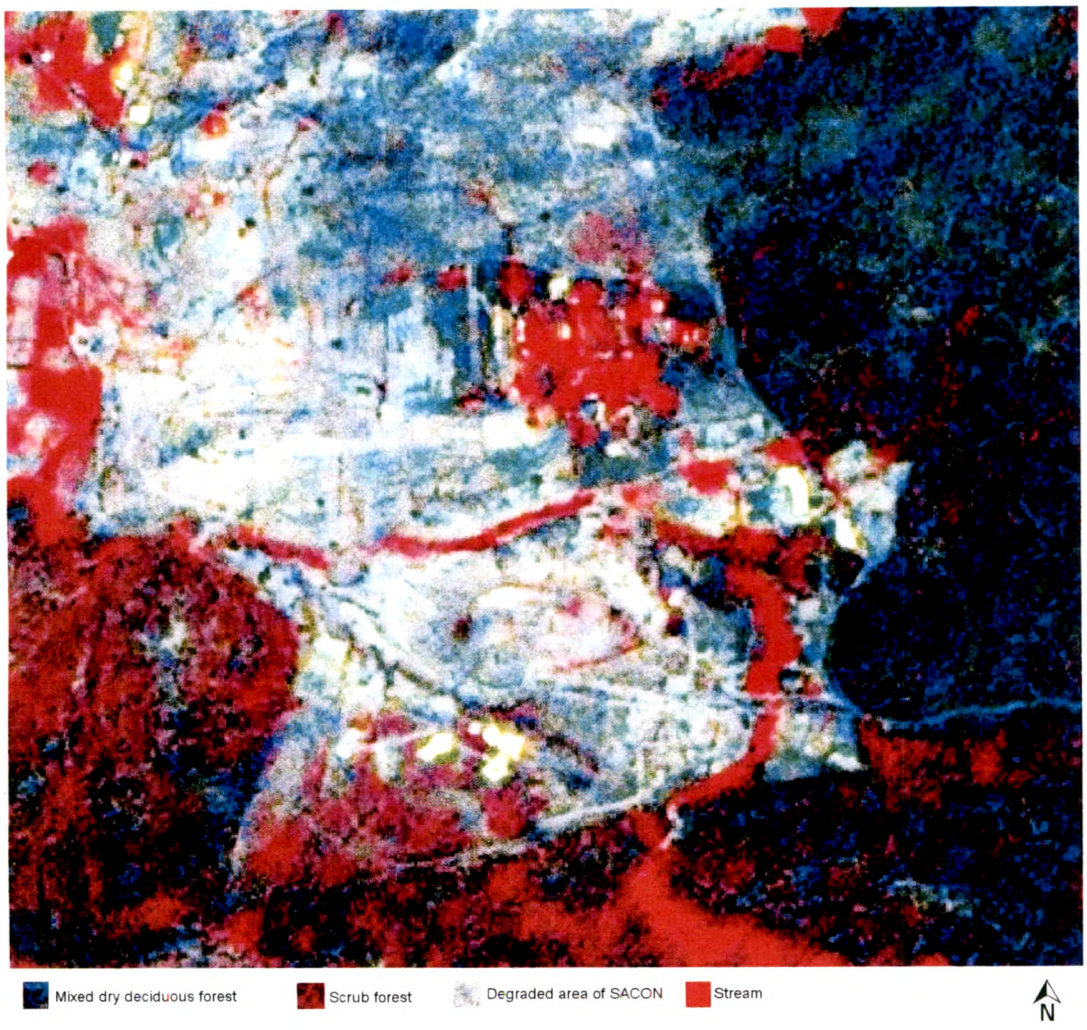
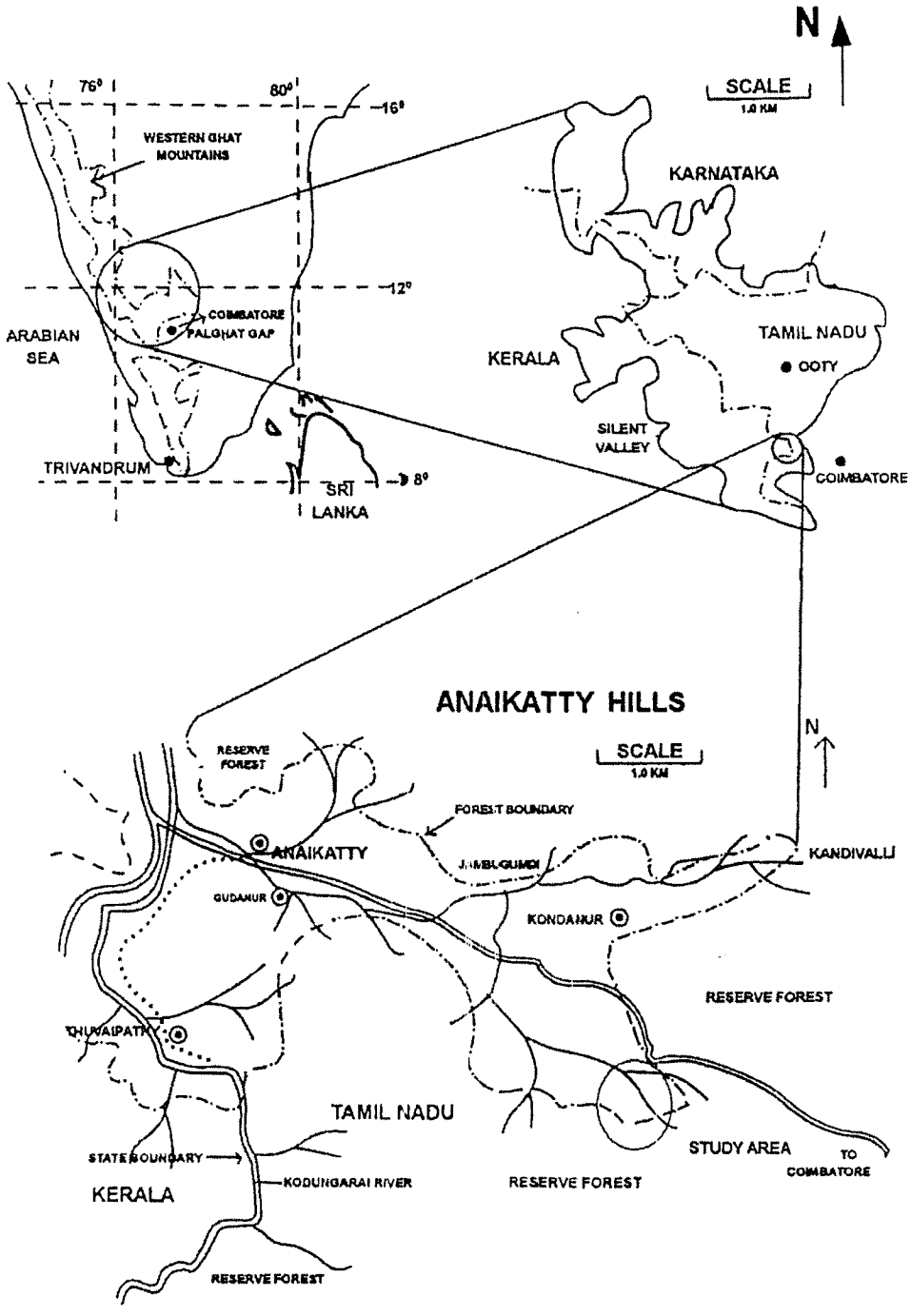



Plate 2.1. Habitat showing different vegetation type in Anaikatty hills




Map 2.1. The study area


Map 2.2. The intensive study area showing the transects (Source Survey of India – Topo sheet, 1971)

### 2.3.1. Seasons

Based on the climate, the seasons may be categorized into four for the region. Earlier bird studies (Nirmala, 2002) conducted in the same region also categorized the seasons in the same way.

Southwest monsoon (June, July, August)

The temperature of the season was found to fluctuate from 22.1°C to 32.6 °C. The monthly rainfall varied from 6.5 to 59.8mm. The area received less rainfall during this season compared to Northeast monsoon (Table 2.1 & 2.2).

Northeast monsoon (September, October, November)

The study area received maximum rainfall during this season and the monthly rainfall recorded from 13.6 to 288.8mm. The number of rainy days differed from one to 15. The temperature of the area was recorded between 21.1 °C and 33.3 °C. Moreover, the Northeast monsoon months were humid with 85 per cent to 91 per cent humidity (Table 2.1 & 2.2).

Winter (December, January, February)

The temperature fluctuated between 17.3°C and 33°C during winter in the area. The temperature was found maximum during February and minimum during December. The rainfall of the season varied form 0 to 25 mm. Numbers of rainy days were high during February (Table 2.1 & 2.2).

Summer (March, April, May)

Although summer temperature was more, the area generally received summer showers during the season. The rainfall of more than 100 mm was recorded during all summer months. The rainfall of summer season scored next rank to the Northeast monsoon (Table 2.1 & 2.2).

Table. 2.1. Climatic data of the Anaikatty hills during the study period (Mean values for two years)

| Parameters | | Winter | | | Summer | | | Southwest monsoon | | | Northeast monsoon | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov |
| Max. Temperature | Min | 29.7 | 30.7 | 32.4 | 34.4 | 35.5 | 30.9 | 30.6 | 31.2 | 31.1 | 31.6 | 29.9 | 29.1 |
| | Max | 30.3 | 30.8 | 33 | 35.8 | 36.3 | 35.5 | 32.9 | 32.8 | 32.6 | 33.3 | 31.1 | 29.7 |
| Min. Temperature | Min | 17.3 | 18.5 | 18.3 | 20.8 | 23.6 | 22.9 | 22.5 | 22.6 | 22.1 | 21.9 | 21.7 | 21.1 |
| | Max | 18.3 | 19 | 21.7 | 21.8 | 24.1 | 24.4 | 23.7 | 22.9 | 22.9 | 22.3 | 22.6 | 21.2 |
| Relative Humidity | Min | 87 | 85 | 80 | 80 | 81 | 82 | 78 | 83 | 81 | 85 | 90 | 90 |
| | Max | 89 | 86 | 85 | 87 | 87 | 89 | 83 | 84 | 85 | 88 | 91 | 92 |
| Wind speed | Min | 5.3 | 6.53 | 6.43 | 6.7 | 5.82 | 8.05 | 14.19 | 13.17 | 12.02 | 7.89 | 6.31 | 4 |
| | Max | 5.61 | 6.7 | 7.4 | 7.6 | 6.44 | 10.7 | 17 | 14.17 | 17.4 | 11.72 | 6.6 | 6.86 |
| Sunshine | Min | 7.1 | 8.06 | 9.44 | 9.2 | 7.92 | 4.65 | 6.4 | 4.16 | 5.1 | 8.19 | 4.7 | 5.42 |
| | Max | 8.09 | 8.3 | 9.7 | 12.98 | 9.3 | 7.34 | 6.59 | 6.7 | 6.68 | 8.42 | 6.02 | 5.6 |
| Rainfall | Min | 1.7 | 0 | 0 | 0.5 | 3 | 19.5 | 6.8 | 6.5 | 24.6 | 13.6 | 210.1 | 99.2 |
| | Max | 6 | 10 | 25 | 119.1 | 107.2 | 167.9 | 51.8 | 46.4 | 59.8 | 96.9 | 288.8 | 99.7 |
| Rainy days | Min | 1 | 0 | 0 | 1 | 0 | 2 | 0 | 1 | 1 | 1 | 10 | 5 |
| | Max | 1 | 1 | 3 | 4 | 8 | 11 | 7 | 4 | 6 | 7 | 15 | 7 |

Table 2.2 . Seasonal climatic variations of the study area

| Parameters | | Winter | Summer | Southwest monsoon | Northeast monsoon |
|---|---|---|---|---|---|
| Min. temp | Min | 17.3 | 21.3 | 22.1 | 21.1 |
| | Max | 21.7 | 24.4 | 22.9 | 21.9 |
| Max. temp | Min | 29.7 | 30.9 | 30.6 | 29.1 |
| | Max | 33 | 36.3 | 32.9 | 33.3 |
| Relative Humidity | Min | 80 | 81 | 78 | 85 |
| | Max | 87 | 89 | 85 | 92 |
| Wind speed | Min | 5.3 | 5.82 | 12.02 | 4 |
| | Max | 7.4 | 10.7 | 17.4 | 11.72 |
| Sunshine | Min | 7.1 | 4.65 | 4.16 | 4.7 |
| | Max | 9.7 | 12.98 | 6.7 | 8.42 |
| Rainfall | Min | 0 | 0.5 | 6.5 | 19 |
| | Max | 25 | 167.6 | 59.8 | 288.8 |
| Rainy days | Min | 0 | 0 | 0 | 1 |
| | Max | 3 | 11 | 7 | 15 |

## 2.4. Fauna

### 2.4.1. Mammals

Anaikatty hills harbours larger herbivores such as the Asian Elephant (*Elephas maximus*), Wild Gaur (*Bos gaurus*), Sambar (*Cervus unicolor*) and Chital (*Axis axis*). Carnivores such as Leopard (*Panthera pardus*), Wild Dog (*Cuon alpinus*); omnivores such as Sloth Bear (*Melurus ursinus*) and Wild Boar (*Sus scrofa*); and primates such as Common Langur (*Presbytis/Semnopithecus entellus*) are present. Common Mangoose (*Herpestes edwardsi*), Indian Three-striped Palm Squirrel (*Funambulus palmarum*), Black-naped Hare (*Lepus nigricollis*) and many species of field rats are the small mammals found in the Anaikatty hills.

### 2.4.2. Birds

Nirmala (2002) has recorded 187 species of birds in Anaikatty hills. Two endemic species such as Rufous Babbler (*Turdoides subrufus*) and Malabar Parakeet (*Psittacula columboides*) of Western Ghats were recorded from the study area. The study showed that insectivorous birds are abundant in the area.

### 2.4.3. Reptiles

Indian Rock Python (*Python molurus*), Brozebacked Tree Snake (*Dendrelaphis tristis*), Indian Rat Snake (*Ptyas mucosa*), Green Vine Snake (*Ahaetulla nasuta*), and Common Sand Boa (*Eryx conica*) are major reptiles present in the study area. A total of sixty species of reptiles were recorded from the Anaikatty hills (Mukherjee personal communication).

### 2.4.4. Amphibians

Common Asian toad (*Bufo melanosticus*), Red Narrow-mouthed Frog (*Microhyla rubra*) and Malabar Baloon Frog (*Uperodon systoma*) are the major species of amphibians observed in the study area. A total of ten species of amphibians were observed in the study area (Mukherjee personal communication).

## 2.5. Vegetation

Study of insect plant interaction has inspired the researchers to explore the coevolution between insects and plants. A report by Ehrlich and Raven (1964) enthused decades of both theoretical and empirical work designed to document all or part of the evolutionary scenario of insect-plant interactions. Many studies have explored the evolutionary responses of plants to insect herbivores (Feeny, 1977; Elle *et. al.*, 1999: Stone *et. al.*, 1996) and response of insects to escape from plant adaptations (Filchak *et. al.*, 1999; Aucoin *et. al.*, 1995; Doussourd and Denno, 1994).

The study of vegetation is vital to the study of insect because the vegetation composition determines the insect species (Janz and Nylin, 1998). Population pattern and seasonality of butterflies are also dependant on vegetation. Eswaran and Pramod (2004) reported that pierid dominance in the area is influenced by their host plants dominance. The population peaks of butterflies coincided with leaf flushing (Kunte, 1997). Murali and Sukumar (1993) reported that leaf-flushing phenology in trees moulded the insect-herbivore community of the seasonal forest of India.

### 2.5.1. Vegetation types of the region

Major forest types in Coimbatore division are of southern mixed dry deciduous (47%), southern thorn forest (29%), semi evergreen forest (8%) and wet evergreen forest (2%). Nearly eight per cent of the area consists of plantations of many types. Anaikatty reserve forest is a southern tropical mixed dry deciduous forest type (Champion and Seth, 1968) (Plate 2.1). Dominant trees in the forest belong to the genera are *Albizia, Acacia, Ziziphus, Chloroxylon* and *Tamarindus.* Dominant shrubs are *Cassia, Capparis, Flacourtia, Elaeodendron, Clausina, Randia, Premna* and *Pavetta. Lantana, Chromolaena* and *Parthenium* are the prominent weed genera in the open areas of the landscapes. Cattle grazing was observed frequently during the study period.

### 2.5.2. Vegetation of the study area

The plants enumerated are categorized into three types. Category one covers the plants with more than 20cm Girth at Breat Height (GBH). Category two contains the true shrubs vegetation and tree saplings with less than 20cm GBH and height of more than one foot. Herbs and seedlings of trees form the third category of plants. Vegetation analysis was carried out in four permanent one km transects laid in the study area for studying insects (Map 2.2)

The species were identified using the Flora of Tamil Nadu Carnatic (Mathew, 1983), Flora of Coimbatore (Chandrabose and Nair, 1988) and Flora of Presidency of Madras (Gamble, 1986, 1987).

The species richness and abundance among transects were compared. The diversity indices such as Shannon Wiener, Simpson, MargalefD, EquitabilityJ, Berger Parker, McIntosh, Brillouin and Qstatistics were calculated. The diversity variation between sites was analysed through beta diversity indices. Quadrats of specific sizes were used for the three categories of plants as follows:

**Category I plants**

One km belt transects were followed for the tree sampling. The trees present five metre on either side of transect were counted. All trees measuring more than 20cm GBH were recorded. The height of the tree was measured by using the marked pole.

A total of Sixty-one species of trees were recorded from the category I plant transects. Site three showed less species diversity and evenness (Fig. 2.1 & Fig. 2.2; Table 2.3).

**Category II plants**

All the shrubs and saplings of trees were classified into this category. All the category II plants present within the 5x5m quadrats were documented. There were thirty such 5x5m quadrats laid in each one km transect.

A total of 107 species of shrubs were recorded. The four transects showed relatively equal species richness and evenness. However, site three showed moderately higher diversity and evenness values (Table 2.7). It is in sharp contrast to the tree community where site three showed least diversity and evenness (Table 2.4).

**Category III plants**

All the true herbs and tree seedlings were classified into this category. The 1x1m quadrats were used for sampling category III plants. Two 1x1m quadrats were made in a shrub quadrat (5x5m). A total of 60 quadrats were laid in each 1km transects and hence totally 240 herbs quadrats were examined in four permanent transects.

A total of 83 species were recorded in this category. Although fifty-four species were catalogued in site three, it showed less diversity and evenness. However, site 3 showed higher dominance index values (Table 2.5).

**2.5.3. Diversity of plant species**

A total of 137 species of plants were recorded from all four sites (Appendix 1). Relatively species richness was similar among the sites. Among the four sites, site 3 was showed least diversity and evenness (Table 2.3). The beta diversity between sites was high in the case of Category I plants and low in the category III plants of the area (Table 2.6). This information of plants is important and is essential in understanding the processes behind the pattern of insect diversity in these areas.

Site three, which is a relatively open area among the four sites, had less category I plants and high diversity in category-II plants. This is due to the high grazing and human activities observed along the transect site 3.

The disturbed region had more shrubs, the sites which posses relatively more trees showed less diversity of category II and III plants. Relatively similar results were reported in earlier studies that primary forest harbour more trees, showed less penetration of sun light and the herb and shrub vegetation is low (Khera *et. al.,* 2001; Mehta *et. al.,* 1997).

As the general land scape largely covered by shrubby thorn and scrub jungle, Category II plants were the most dominant in the study area in terms of geographical coverage. Category III plants are more seasonal and they flourish only during the wet seasons of the year such as October- November and March- April months. Among the category I plants, *Limonia alatam, Bauhinia racemosa* and *Acacia* Spp. are the dominant ones in the study area. Among the category II plants, *Cassia auriculata, Cassia tora, Cassia siamia, Cassia fistula, Capparis grandiflora, Capparis grandis, Capparis sepiaria, Pavetta indica* and *Acalypha fruticosa* are the most dominant species.

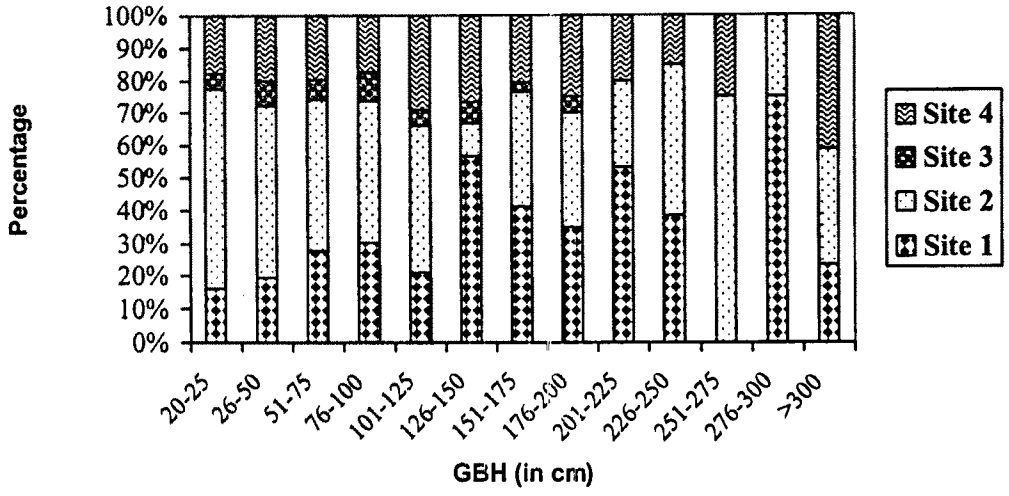



Figure 2.1. Girth class distribution of Category-I plants in four transects studied in the Anaikatty hills

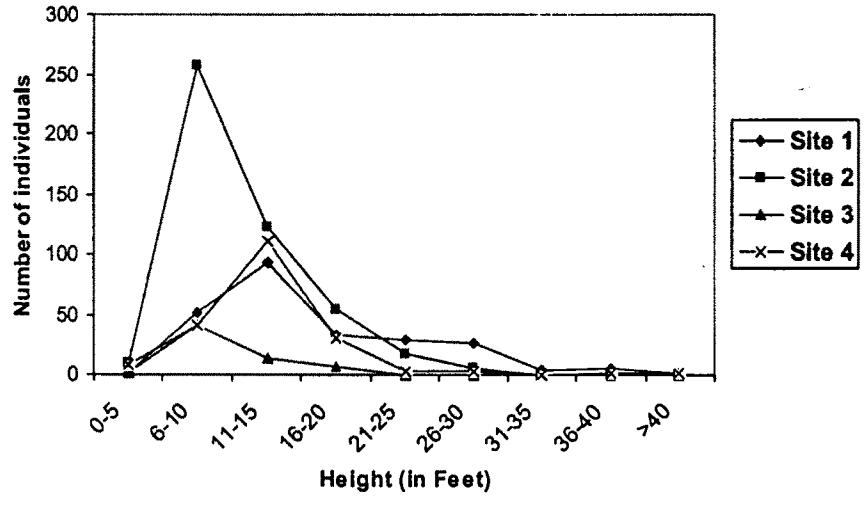



Figure 2.2. Height class distribution of the plants recorded in four transects studied. (Height is mentioned in feet).

Table 2.3. The alpha diversity indices of the plant community of four transects. The values calculated using data on all categories of plants in four transects as well as for the region (by pooling the data from all the transects)

| Sample | site 1 | site 2 | site 3 | site 4 | All |
|---|---|---|---|---|---|
| Species | 89 | 90 | 87 | 88 | 137 |
| Total | 6013 | 5504 | 10702 | 6322 | 28541 |
| Shannon Wiener | 2.895 | 2.833 | 1.994 | 2.628 | 2.804 |
| Simpson | 9.479 | 7.379 | 2.932 | 6.767 | 6.307 |
| Margalef D | 10.113 | 10.333 | 9.269 | 9.941 | 13.257 |
| EquitabiltyJ | 0.588 | 0.576 | 0.405 | 0.534 | 0.570 |
| Berger Parker | 0.245 | 0.305 | 0.570 | 0.296 | 0.362 |
| McIntosh D | 0.684 | 0.640 | 0.420 | 0.623 | 0.605 |

Table 2.4. The alpha diversity indices of the four transects for category-I plants.

| Sample | site 1 | site 2 | site 3 | site 4 | All |
|---|---|---|---|---|---|
| Species | 37 | 40 | 17 | 34 | 61 |
| Total | 282 | 467 | 62 | 201 | 1012 |
| Shannon Wiener | 2.687 | 2.911 | 2.422 | 2.516 | 3.061 |
| Simpson | 8.811 | 10.313 | 8.596 | 5.290 | 10.397 |
| Margalef D | 6.381 | 6.345 | 3.877 | 6.223 | 8.671 |
| EquitabiltyJ | 0.654 | 0.708 | 0.589 | 0.612 | 0.745 |
| Berger Parker | 0.220 | 0.261 | 0.290 | 0.418 | 0.265 |
| McIntosh D | 0.700 | 0.719 | 0.732 | 0.603 | 0.711 |

Table 2.5. The alpha diversity indices of the four transects for category-II plants

| Sample | site 1 | site 2 | site 3 | site 4 | All |
|---|---|---|---|---|---|
| Species | 48 | 45 | 54 | 47 | 83 |
| Number | 1739 | 1540 | 837 | 4071 | 9411 |
| Shannon Wiener | 2.885 | 3.099 | 3.129 | 3.089 | 3.341 |
| Simpson | 10.420 | 12.771 | 14.300 | 13.035 | 16.606 |
| Margalef D | 8.311 | 9.057 | 8.486 | 8.841 | 11.826 |
| EquitabiltyJ | 0.617 | 0.663 | 0.670 | 0.661 | 0.715 |
| Berger Parker | 0.178 | 0.192 | 0.145 | 0.180 | 0.135 |
| McIntosh D | 0.705 | 0.737 | 0.750 | 0.742 | 0.763 |

Table 2.6. The alpha diversity indices of four transects for category-III plants

| Sample | site 1 | site 2 | site 3 | site 4 | All |
|---|---|---|---|---|---|
| Species | 65 | 69 | 67 | 65 | 107 |
| Total | 2210 | 1823 | 2387 | 1393 | 7813 |
| Shannon Wiener | 1.966 | 1.561 | 1.091 | 1.820 | 1.833 |
| Simpson | 4.187 | 2.817 | 1.780 | 3.960 | 3.179 |
| Margalef D | 5.755 | 5.449 | 5.877 | 5.437 | 8.292 |
| EquitabiltyJ | 0.445 | 0.353 | 0.247 | 0.412 | 0.415 |
| Berger Parker | 0.418 | 0.523 | 0.739 | 0.396 | 0.524 |
| McIntosh D | 0.520 | 0.411 | 0.253 | 0.505 | 0.442 |

Table 2.7. The Beta diversity indices among transects for plants.

| Indices | Category I | Catgory II | Category III | All |
|---|---|---|---|---|
| Whittaker Bw | 0.614 | 0.434 | 0.498 | 0.395 |
| Cody Bc | 12 | 21 | 17.5 | 24 |
| Routledge Bi | 0.347 | 0.271 | 0.306 | 0.255 |
| Routledge Be | 1.415 | 1.312 | 1.359 | 1.291 |

# Chapter 3

# Patterns of insect diversity at higher taxonomic levels

## 3.1. Introduction

Changes in species assemblage of communities in space and time are important aspects of community ecology (Rosenzweig, 1995). Use of time or space by organisms depends on physiological adaptations developed by individuals of species populations. The variations possessed by many populations of species are one of the major factors determining the species assemblage of a community (Townsend *et. al.*, 2003).

The community structure can be described in a number of ways; the simplest is the number of coexisting species (Morse *et. al.*, 1988). More subtle descriptions of samples of organisms from a community include, the number of species in each abundance category (species-abundance distribution, or species-frequency distribution (Williams, 1953; May, 1975; Southwood, 1978; Sugihara, 1980)); the number of species of different body size classes (species-bodysize distribution (May, 1986; Griffiths, 1986)); and the abundances of each species versus body size (populations abundance-body size relationship (Damuth, 1981; Peters and Wassenberg, 1983; Brown and Maurer, 1986)). Summing all individuals of a particular size yields fourth pattern, the total number of individuals of a particular size, irresepective of species (total number of individuals:body size, or biomass-body size relationships (Janzen, 1973; Morse *et. al.*, 1985; Strayer, 1986))

The adaptive variations and their ecological significance among the members of a community are well studied in birds (Wiens, 1989). Only a few studies focussed on the adaptive variation among the members of an insect community such as dung beetles (Luff, 1978; Davis and Sutton, 1998; Finn and Gittings, 2003), butterflies (Braby, 1995;

Kunte, 1997), and ground beetles such as Cicindelidae and Carabidae (Pearson *et. al.*, 1986; Pearson and Carroll, 1997; Rodriguez *et. al.*, 1998; Cassola and Pearson, 2000; Butterfield *et. al.*, 1995). Stork (1987) studied the guild structure of arthropods in Bornean rain forest trees and reported the proportion of abundance of members of different guilds.

Variations in community assemblages and abundance of insects are regulated by many biotic and abiotic factors (Crawley, 1989; Berryman *et. al.*, 1987; Roy *et. al.*, 2001). Many researchers have highlighted the importance of abiotic factors such as temperature (Saulich *et. al.*, 1994; Yoshio and Ishii, 1994), humidity (Pollard and Moss, 1995; Lale *et. al.*, 1996; Posonby and Copland, 1996), rain (Wolda, 1978a, Pollard, 1988) and day length (DanilevSkii, 1965) on insect diversity. The effects of the biotic factors on insects were also the subjects of many studies (Berryman and Guitierrez, 1999). The predators of insects range from the invertebrates to vertebrates such as reptiles, birds and mammals (Pianka, 1975; Nair *et al.*, 1986). A majority of birds are true insectivores and control the insect populations significantly. Even many frugivorous birds depend on insects to fulfill energy requirements during breeding season (Pramod and Yom-Tov, 2000).

Ecological entomology is relatively less practiced in the tropical countries primarily due to reasons such as hurdles in species identification, and lack of funding (Gadagkar *et. al.*, 1990). The study of the insect diversity of an area needs an array of collection methods to represent insects from various niches (Gadagkar *et. al.*, 1990; Kharboutli and Mack, 1993). The species identification of the insects is the major hurdle for insect community studies. Though family level pattern of insects community has been studied well in aquatic insects, scientists working in terrestrial entomology are yet to take significant initiatives to explore the patterns of higher taxonomic levels and their ecological significance.

Scientists have recognized the contribution of higher-level taxonomic identity in the studies of biodiversity of an area. Moreover, it is in active consideration of the

biodiversity assessment of an area. Importance of higher taxonomic level is evident recently particularly for the rapid biodiversity assessment. Negi and Gadgil (2002) suggested the usage of higher-level taxonomic hierarchy such as genera and families of plant and ant as surrogate to species. Here the question arises regarding the level at which insect family can represent the extent of insect diversity of an area. Ravikumar (2005) analysed insect diversity parameters of four plantations and reported that the trends in diversity was similar at morphospecies, genus and family levels. For overall uniformity in comparison, the present work studied the insects at family level.

In India, entomological studies focused primarily on the taxonomy (Mani, 1990; Beeson, 1961; and references there in). A few studies focused on the ecological aspects (Gadagkar *et. al.,* 1989; Arun, 2000; Mathew and Binoy, 2003). The community aspects are studied in aquatic insects community (Burton and Sivaramakrishnan, 1993; Subramanian, 2003) and some studies highlighted the need of a methodology package for such studies (Gadagkar *et. al.,* 1990). Insect seasonality was studied as a part of ornithological studies in many places of Western Ghats (Vijayan, 1975, 1984,; Gaston, 1978; Shukkur, 1978; Gokula, 1998; Nirmala, 2002). The present work focused on the exploration of insect diversity at varied taxonomic levels in select microhabitats of the dry deciduous forest of Anaikatty hills.

The study attempted to answer the following questions

1. What is the family level and order level composition of insect community in the study area?
2. How does the insect community vary among microhabitats?
3. How does the insect community vary between the months, seasons and years?
4. What is the relative efficiency of insect collection methods and how does it explain the insect diversity patterns in nature?
5. What are the impacts of environmental factors on insect community?
6. How do the patterns vary between taxonomic groups of insects?
7. How do the patterns of different sized insects vary in different microhabitats?

## 3.2. Methods

Selection of insect sampling methods is critical in insect ecology studies. These methods range from planned and structured physical activities for observing, collecting or marking living insects to mathematical procedures for analyzing dynamic population processes (Kuno, 1981). Insect collection methods, their efficiency and history of their development has been discussed by Varley and Gradwell (1970); and Southwood and Henderson (2000).

Selection of a particular method may also depend on the taxa under study. For example, pitfall trap is useful for ground insect; fogging is useful for collecting insects inhabiting vegetation and the light trap is useful for the study of nocturnal flying insects (Southwood, 1978). Carabid beetles have been extensively studied using the pitfall trap method, which is reportedly simple, cheap and a relatively less labour-intensive (Halsall and Wratten, 1988). Pitfall trap method has been used widely for ecological studies focused on the seasonal, emergence trend and movement pattern of ground insects). However, the efficiency of the pitfall trap varies depending upon habitats and climatic conditions (Mitchel, 1963; Baars, 1979). Grassland insects were studied by suction apparatus (Stewart and Wright, 1995). Different bait traps have been used for the study of termites and ants (Berghoff *et al.*, 2003; Dawes-Gromadki, 2003). Malaise trap has been extensively used for the beetle study (Hutchinson, 1990). The principle of each method depends on the life cycle, diapause and behavioural characteristics of the insects under study (Kuno, 1991). Sweeping, transect and point count have been used for the study of butterflies. However, Pollard transect walk method is the most popular one among the population and diversity studies of butterflies (Moore 1975, Pollard *et al.* 1975, Walpole and Sheldon 1999).

Although numerous insect studies have been executed in many groups of insects, studies with the community approach are relatively less. To get a broader vision of all insects of an area we need a select set of insect sampling methods rather than a single method. Moreover, to suit the Indian conditions the methods must be less expensive,

durable and reliable. Insect studies with community approach using a specific group of insect collection methods will be less focused towards the species level interaction compared to a study that focuses on a single component of insect community by one or two methods. The available studies that highlight the role of methods on deciphering insect community pattern are all mostly from temperate regions and such studies in the tropical countries are needed to explore the trends in biodiversity rich tropics.

### 3.2.1. Study design

The present work tries to capture the broad pattern in the total insects of a tropical dry deciduous forest of Anaikatty hills, Western Ghats. The insects were sampled on monthly. To avoid over collection of the insects in the study area, minimum number of methods were used to answer the study questions. Sweeping, beating sheet, pitfall traps and light trap methods (Southwood, 1978) were used for insect collections. Two year insect sampling was executed using these methods except the light trap sampling that was used for one year.

### 3.2.2. Sweeping

Sweeping is effective for the collection of flying and jumping insects at the ground level and understorey vegetation (Southwood and Henderson, 2000). The hand net with 30 cm mouth diameter and less than 1 mm pore size cloth was used. Hundred sweeps were done in each one km transect by sweeping randomly in selected 10 sites with 10 sweeps at each site. The approximate area coverage per sweep was $0.8m^2$, and per sampling effort, it was $80m^2$ (0.8 x 100). A unit sampling effort of this method was 100 sweeps per transect. The sampling period was from October 2002 to September 2004. The sweeps were executed at the ground vegetation about 1m from the ground for collecting the insects on shrubs.

### 3.2.3. Beating sheet

Beating sheet method is an efficient method for the collection of insects from tree foliages (Southwood, 1978). Insects on the vegetation will fall down when the investigator beats the vegetation with a stick. This method was also executed in the four one km transects. The sampling period was between October 2002 and September 2004. Ten individuals of different species of plants were randomly selected per transect and used for the sampling. In this method, the 1-$m^2$ tray made of thick white cloth was kept under the vegetation and the tree or shrubs branches were beaten with the stick ten times in each plant.

### 3.2.4. Pitfall

It is an efficient method to capture ground insects (Southwood, 1978), 10$m^2$ plots were prepared in five physiognomically different areas. Four types of plastic traps were used for the study. The plastic traps with varied mouth size (diameter) such as 105mm, 81mm, 74mm and 30mm size were used. However, the number of traps in a particular mouth size was increased to reach the same perimeter coverage by the different types of traps. Obrtel (1971) maximized insects capture per unit area by manipulating the number of traps. The traps were laid in a plot to capture the insects from all over the plot. Petroleum jelly was applied inside the trap all around the mouth as a round line and it will prevent the escape of fallen insects. The traps were kept from 1600hrs to 800hrs. The sampling period was from September 2002 to August 2004. Effort of collection between the sites and between the months was equal so that comparisons can be made with less complication.

### 3.2.5. Light trap

Light trap is an efficient method to capture the phototactic flying insects at night (Southwood, 1978). The trap was set for 12 hours from 1800hrs to 0600hrs. A white

fluorescent lamp was used as a light source. The light trap for longer duration reduces the efficiency of trap due to the accumulation of insects in the collection chamber (Trematorra *et. al.,* 1996). Thus, insects attracted to the light trap were collected once in two hours and sampling times were 2000hrs, 2200hrs, 2400hrs, 0200hrs, 0400hrs and 0600hrs. The capturing efficiency and variation of the insects trapped in different hours of sampling were studied. The sampling period was from November 2003 to October 2004.

### 3.2.6. Preservation, identification and categorization of insects

The insects collected were killed with ethyl acetate soaked cotton and transferred to vials containing 70 per cent ethyl alcohol. The collected insects were identified at the family level following the Encyclopedia of Entomology (Capinera, 2004).

The insect sampling was stopped after the incidence of families reached plateau (Fig. 3.29). The insects were sorted based on their niches such as ground insects, vegetation insects and nocturnal insects. The insects collected through pitfall were categorized as the ground insects. The insects collected through the sweeping and beating sheets methods were grouped as insects from vegetation. Insects collected through light traps were grouped as nocturnal flying insects. The vegetation insects were further subdivided as insects from the trees (beating sheet) and herbs & shrubs (sweeping). These sampled insects were coded as Ground insects (**GRi**), Herb and Shrub insects (**HSi**), Tree insects (**TRi**) and Nocturnal Flying insects (**NFi**) for easy recognition and description in the text. Insects were also categorized into the following inclusive class ; size classes based on their length ; <2mm, 2-4mm, 4-6mm, 6-8mm, 8-10mm, 10-15mm, 15-20mm and >20mm.

### 3.2.7. Analysis

The relative abundance of the major families of insects during different months were calculated and compared. Cluster analysis was used to group the insect families

based on seasonal abundance using Bray Curtis – Single linkage method. Effect of environmental variables on the insect diversity was studied by correlation analysis.

Along with the exploration of overall pattern of insect diversity, a comparison between the sampling methods was also done. Variation of specificity of the insect collection methods in sampling the specific orders and families of insects were also analysed. The efficiency of a method in capturing different sized insects was also analysed. The effectiveness of the package of sampling methods used in depicting seasonal variations of the insects of the area was also tested. The term 'abundance' hereafter means the total number of insects encountered in the transect / transects.

Capturing specificity of the insect collection methods to depict the seasonal and spatial variations of the insect diversity and abundance of the area was analysed. Cluster analysis was used to know the variations in capturing specificity of insect collection methods during different seasons. Correlation analysis was employed to know the relation between the insect collection methods. The alpha and beta diversity indices were also calculated to study the insect diversity variation among the transects.

### 3.2.7. Diversity Analysis:

Biodiversity Pro and SPSS software were used for the statistical analysis. We have used the following indices to analyse the data for richness, abundance and evenness.

#### 3.2.7.1.a. Alpha diversity

**a. Richness Indices: (Unambiguous and straight forward index of species richness)**

Margalef index,

$$R_1 = \frac{S - 1}{\ln (n)}$$

where, s = the total number of species

n = the total number of individuals

**b. Species Diversity**

The two most widely used indices were calculated as follows

**Simpson's index**

$$\lambda = \sum_{i=1}^{s} P_i^2$$

where $P_i$ is the proportional abundance of the $i^{th}$ species,

$$P_i = \frac{n_i}{N}, \quad i = 1, 2, 3, \ldots\ldots\ldots\ldots\ldots S$$

Where $n_i$ = the number of individuals of the species

N = known total number of individuals for all species

**Shannon Wiener index**

$$H' = -\sum_{i=1}^{S^*} (P_i \ln P_i)$$

**Berger-Parker index**

This index was considered by May (1975) to be one of the best. It is a simple measure of the numerical importance of the most abundant species.

Let d = Nmax/N, where Nmax is the number of individuals in the most abundant species and N is the total number of individuals in the sample.

The Berger-Parker index is then simply 1/d.

**McIntosh index**

D = N-U / N-Sqrt(N), where N is the total number of individuals in the sample and U is given by the expression :

U = Sqrt(Sum[n(i)]), where n(i) is the number of individuals in the ith species and the summation is undertaken over all the species.

**c. Evenness Indices:**

Equitability or evenness refers to the pattern of distribution of the individuals between the species

**Equitability J**

This measure of Equitability compares the observed Shannon-Wiener index against that distribution of individuals between the observed species which would maximize diversity

If H is the observed Shannon-Wiener index, the maximum value this could take is log(S), where S is the total number of species in the habitat. Therefore the index is:

J = H/log(S).

**3.2.7.1.b. Beta Diversity**

Beta or differentiation diversity is a measure of how different (or similar) ranges of habitats or samples are in terms of the variety of species found in them (Magurran, 1988).

**Whittaker's measure of βw**

$$\beta w = S/\alpha - 1$$

Where S = the total number of species recorded

$\alpha$ = the average sample diversity

**Cody index**

$$\beta_c = \frac{G(H) + l(H)}{2}$$

where g(H) = the number of species gained along the habitat transect

l(H) = number of species lost over the same transect

**Jaccard index**

It is a most widely used index. The Jaccard index is calculated using the equation:

$$C_J = j/(a+b-j)$$

where *j*= the number of species common to both sites

*a*= the number of species in site A and
*b*= the number of species in site B.

**Sorenson index**

$$C_S = 2j/(a+b)$$

where *j*= the number of species common to both sites
*a*= the number of species in site A and
*b*= the number of species in site B.

**Morisita-Horn**

$$C_{mH} = \frac{2\sum (an_i bn_i)}{(da+db)aN.bN}$$

where aN = total number of individuals in site A
$an_i$ = number of individuals in ith species in A

## 3.3. Results

### 3.3.1. Overall patterns

From the four sampling methods, 17847 individuals were collected in all four insect sampling methods (Table 3.1). Maximum number of insects (63%) was collected by pitfall followed by light trap (16%), sweeping (11%) and beating sheet method (10%) respectively (Fig. 3.1). However, the familial richness captured among methods was relatively comparable (Fig. 3.2).

Insects belonging to 14 orders were recorded from the study area (Table 3.1). Nine orders were common to all the methods. Three orders were specific to pitfall method and one order (Phasmatodea) was exclusively collected from beating sheet and sweeping method (Fig. 3.4).

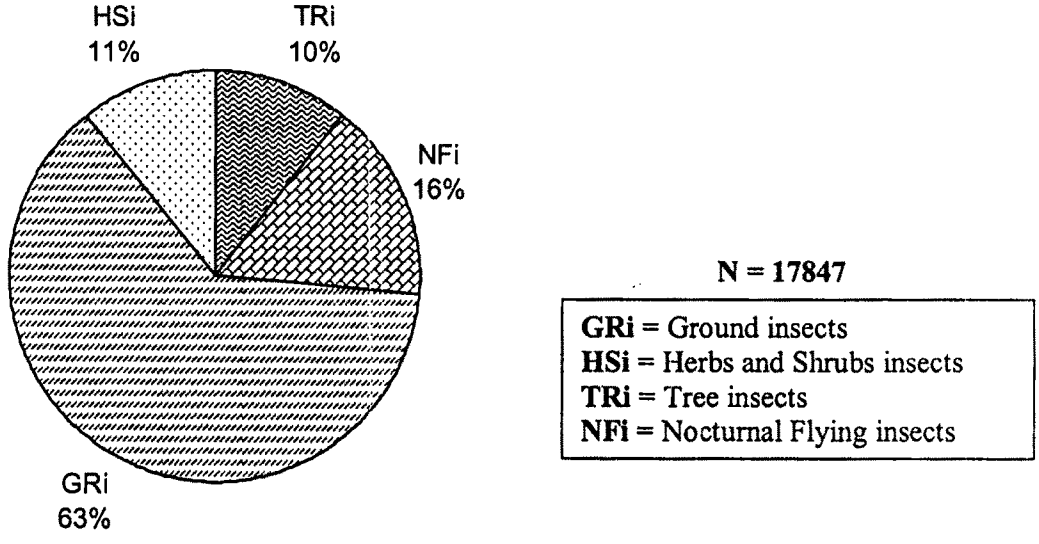



Figure 3.1. Percentage composition of the insects collected from the four different microhabitats.

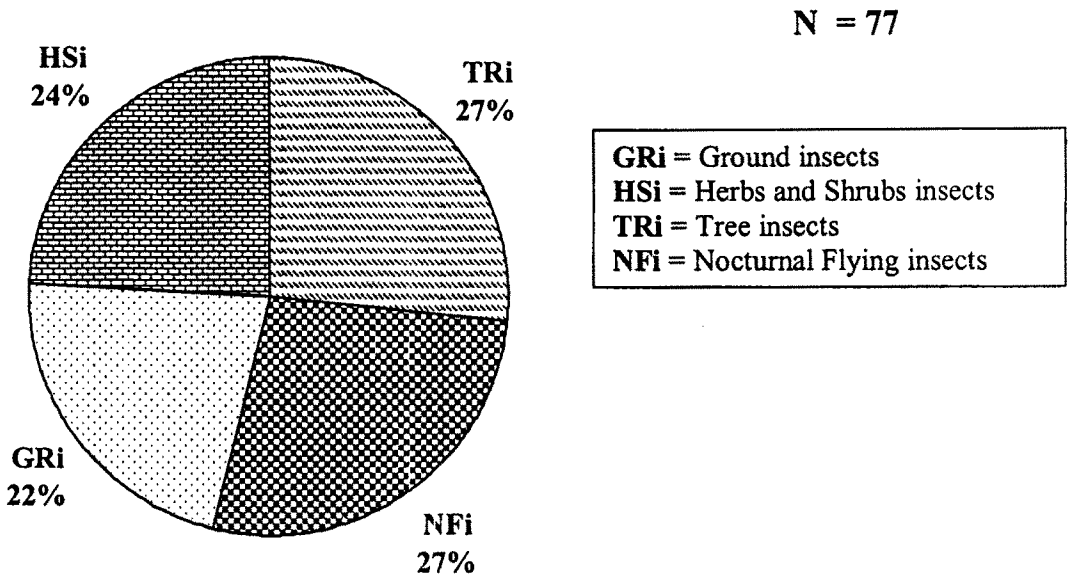



Figure 3.2. Percentage composition of the insects families observed in four microhabitats.

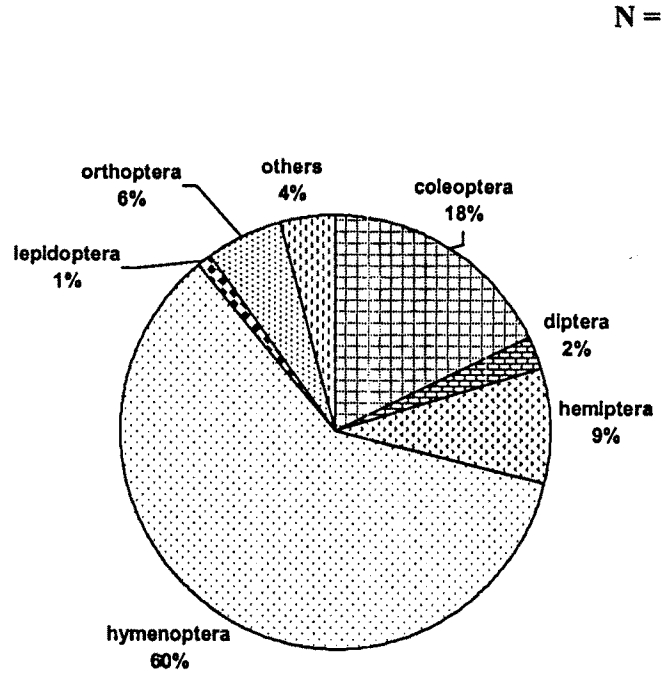



Figure 3.3. Percentage composition of the general insect community.

Totally 77 families of insects were recorded from the study area. Among them, 26 families were common to four methods. Five families were collected only from pitfall traps. Sweeping and beating sheet have exclusively captured 13 families, and 14 families were recorded only from light trap. Light trap and pitfall shared two families. Light trap, sweeping and beating sheet methods shared nine families. sweeping, beating sheet and pitfall shared eight families (Fig. 3.5).

Hymenoptera was the most abundant insect order followed by Coleoptera, Hemiptera, Orthoptera and Diptera respectively. Neuroptera was the least abundant in the sampling (Table 3.1 & Fig. 3.3). Among the families, the majority of individuals belonged to Formicidae followed by Chrysomelidae, Staphylinidae, Coreidae and Acrididae. However, maximum number of families recorded belonged to Coleoptera (Appendix 2).

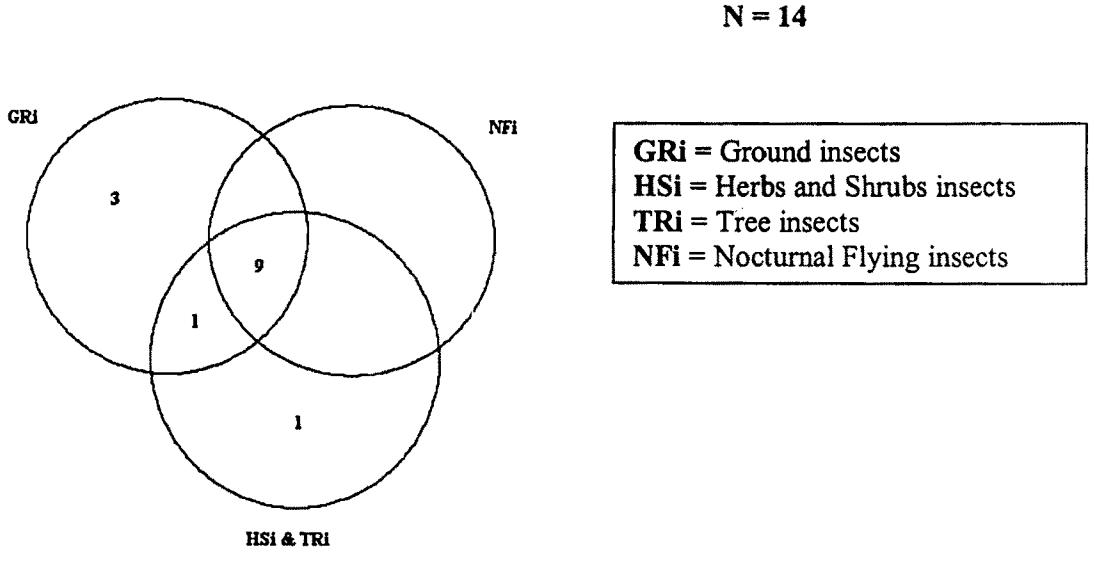
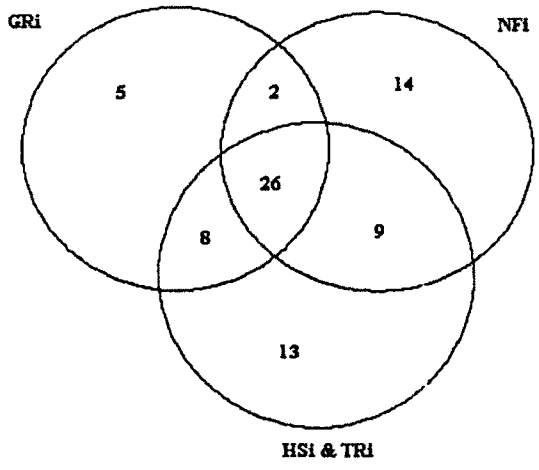



Figure 3.4. Ven diagram showing the distribution of insect orders in microhabitats

N = 77




**GRi** = Ground insects
**HSi** = Herbs and Shrubs insects
**TRi** = Tree insects
**NFi** = Nocturnal Flying insects

Figure 3.5. Ven diagram showing the distribution of insect families in microhabitats.

Variation in the number of insects captured per month or season was not significant. Highest number of insects were captured in February was the most abundant month and lowest in October (Fig. 3.6). The insect abundance was relatively high in winter (29%) followed by summer (26%), southwest monsoon (24%) and Northeastmonsoon (21%) (Fig. 3.6 & 3.7). The seasonal abundance of insects showed three clusters such as ground insects, nocturnal flying insects and vegetation insects (sweeping and beating sheet insects). (Fig. 3.8 & 3.10).

The total insect abundance showed a negative correlation with the rainfall (r= -0.59 p=0.05), number of rainy days (r = -0.64 p=0.05) and with relative humidity (r = -0.7348 p=0.05) (Table 3.8).

Among the eight size classes of insects, 2-4mm sized insects were the most abundant and <2mm sized insects were the next abundant. The size class distribution was unimodal (Fig. 3.11).

### 3.3.2. Composition of insects

Pitfall insects represent Ground insect community (**GRi**), sweeping insects represents Herb and Shrub insects (**HSi**), beating sheet insects represent Tree insects (**TRi**), light trap insects represent Nocturnal Flying insects (**NFi**) respectively

#### 3.3.2.1. Insects from the ground (GRi)

The 11,186 insects collected from the ground (pitfall) belongs to 13 orders and they could be grouped into 41 families (Table 3.1 & Appendix 2). Hymenoptera was the most abundant order in the sampling and Coleoptera, Orthoptera, Hemiptera, Isoptera and Diptera followed it. Formicidae was the most abundant family and it was followed by the Gryllidae, Carabidae and Neanuridae (Appendix 2). The monthly abundance pattern of the ground insects was the bimodal with peaks around the months of September and February. Abundance was the least in October (Fig. 3.9 & 3.13). Most of the ground insects were captured more during summer but the family richness was found relatively poorer.

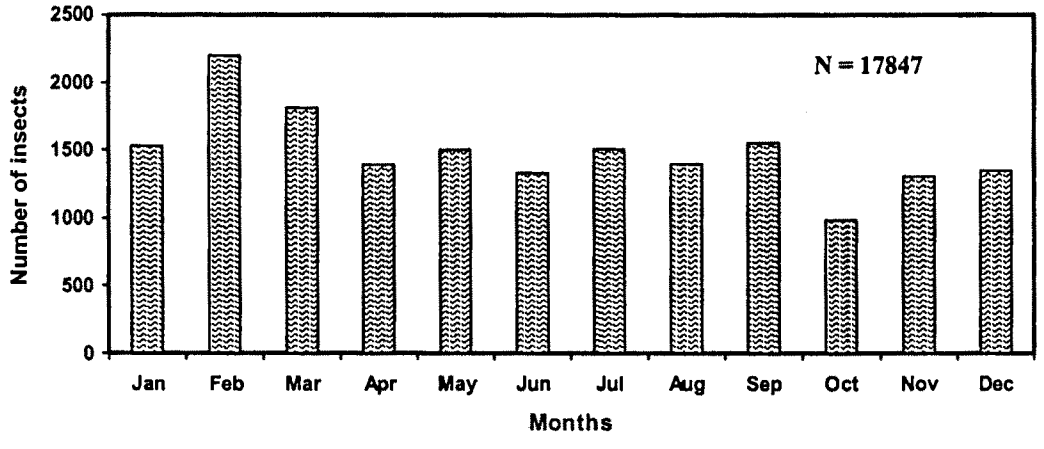



Figure 3.6. Monthly abundance of insects collected in all samples together.

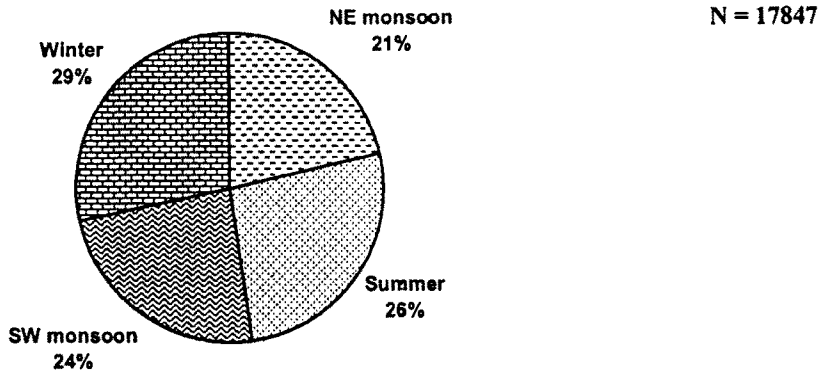



Figure 3.7. The seasonal proportion of total capture of insects (NE monsoon = Nort East Monsoon; SW monsoon = Soth West monsoon)

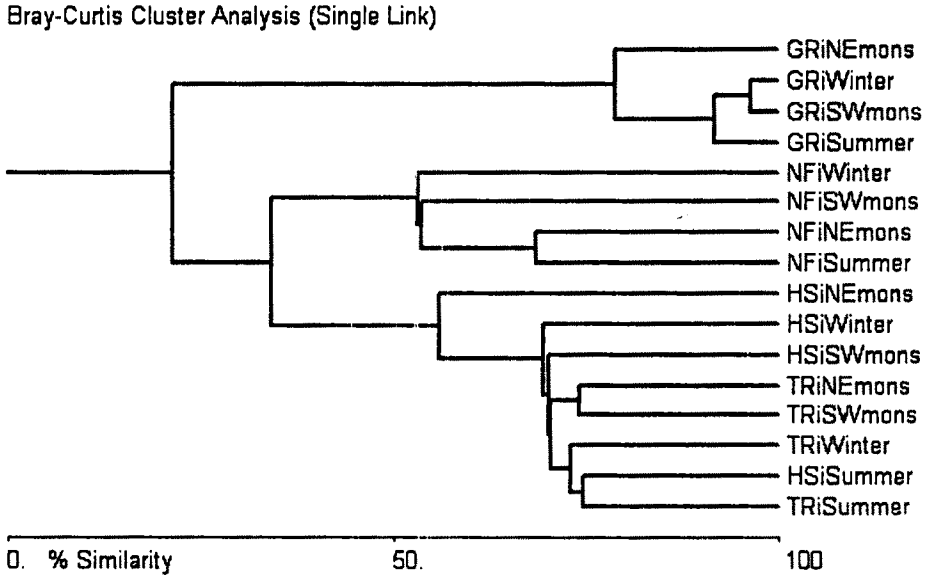



Figure 3.8. Dendrogram showing the seasonality variations of insects of different microhabitats.

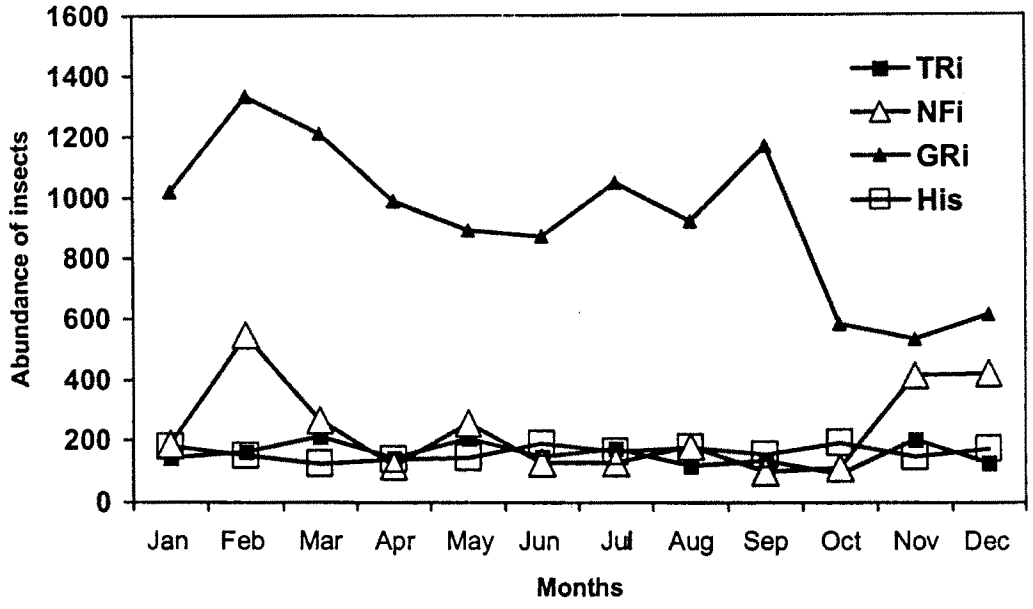



Figure 3.9. Temporal fluctuations of the insects of four different microhabitats

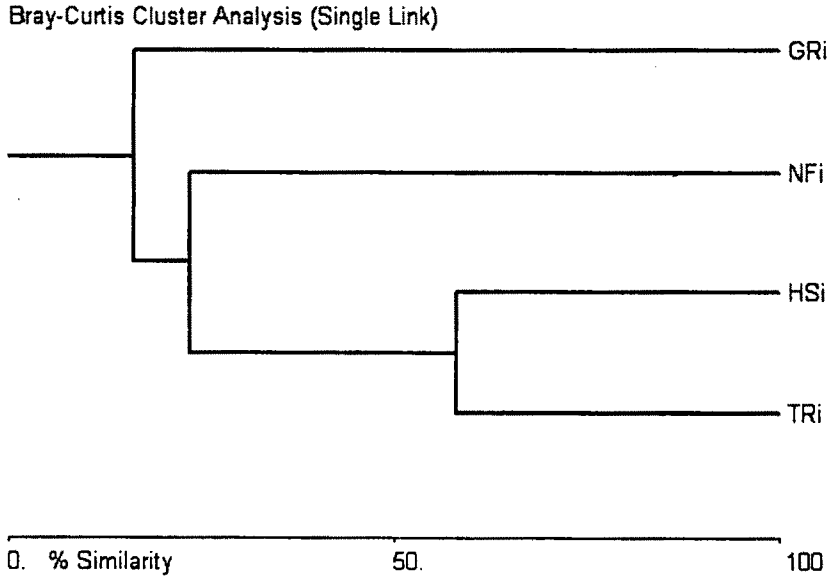



Figure 3.10. Dendrogram showing the clustering of insects of different microhabitats

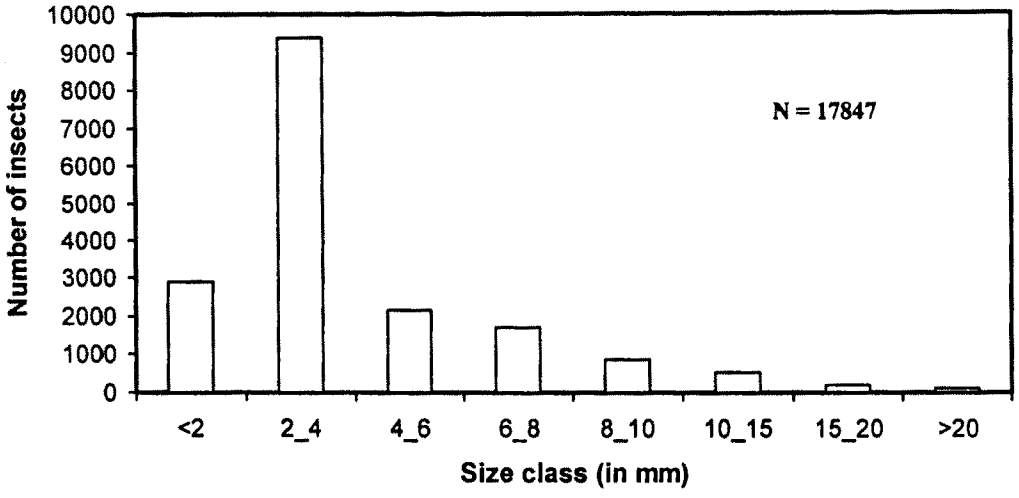



Figure 3.11. Size class distribution of insects of four different microhabitats.

Northeast monsoon was the season in which least number of ground insects were collected although more families were represented during this season.

Insects of the size class 2-4mm were the most abundant followed by those which were <2mm (Fig. 3.12).

### 3.3.2.2. Tree insects (TRi)

The beating sheet yielded 1867 insects. Hymenoptera was the most abundant order, followed by Coleoptera, Hemiptera, Orthoptera and Blattodea respectively (Table 3.1). Formicidae was the most abundant family followed by Coreidae, Chrysomelidae, Blattidae and Pentatomidae respectively (Appendix 2).

Maximum insects were collected in May followed by March (Fig. 3.13). The familial richness was greater during Northeast monsoon and summer. Insect abundance did not show any prominent variation between the seasons although summer season was the most abundant.

Monthly abundance differed among sites. The abundance variations observed between the sites were statistically significant.

The insects with size class 2-4mm were abundant in this sampling method. This abundance pattern was similar to the ground insects. However, 4-6 mm insects were the second abundant size class followed by 6-8mm insects. The fourth abundant size class was <2mm (Fig. 3.12).

### 3.3.2.3. Herbs and Shrubs insects (HSi)

The sweep net yielded 1940 insects falling into ten orders within 45 families. Hemiptera was the dominant order followed by Orthopterans, Hymenopterans, Coleopterans and Dipterans respectively (Table 3.1). Acrididae was the most abundant family followed by the Coreidae, Formicidae and Muscidae.

October was the month of abundance during the study period followed by June. Insect abundance was more or less similar in all the months peaking during the monsoon rains (Fig 3.13). Southwest monsoon was the insect abundant season and summer was the least abundant season. Family richness was similar in all the seasons except during winter when the insects captured was also less. Pattern of monthly abundance deviated significantly among four sites.

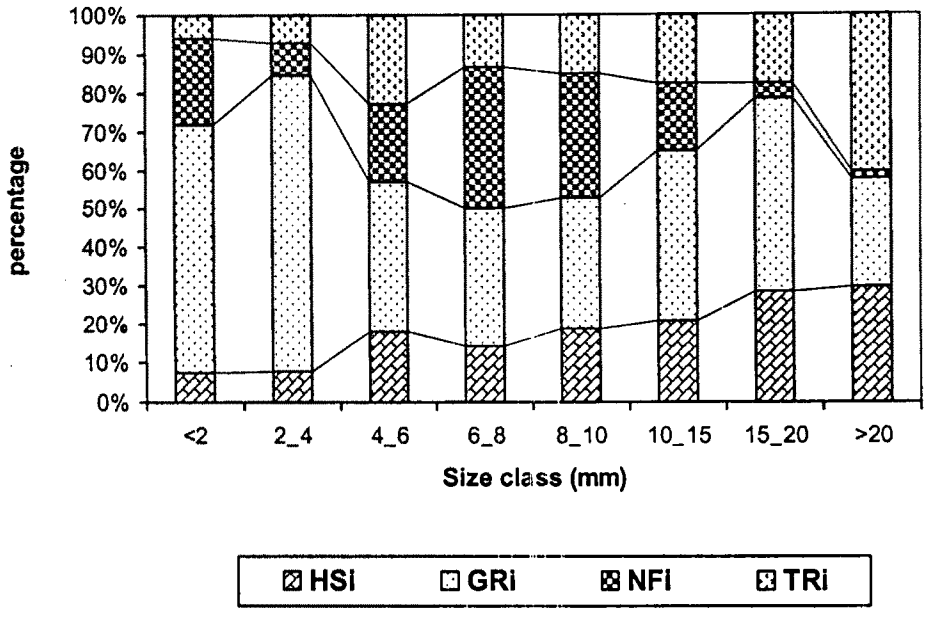



Figure 3.12. Percentage composition of insects of different size class of four microhabitats.

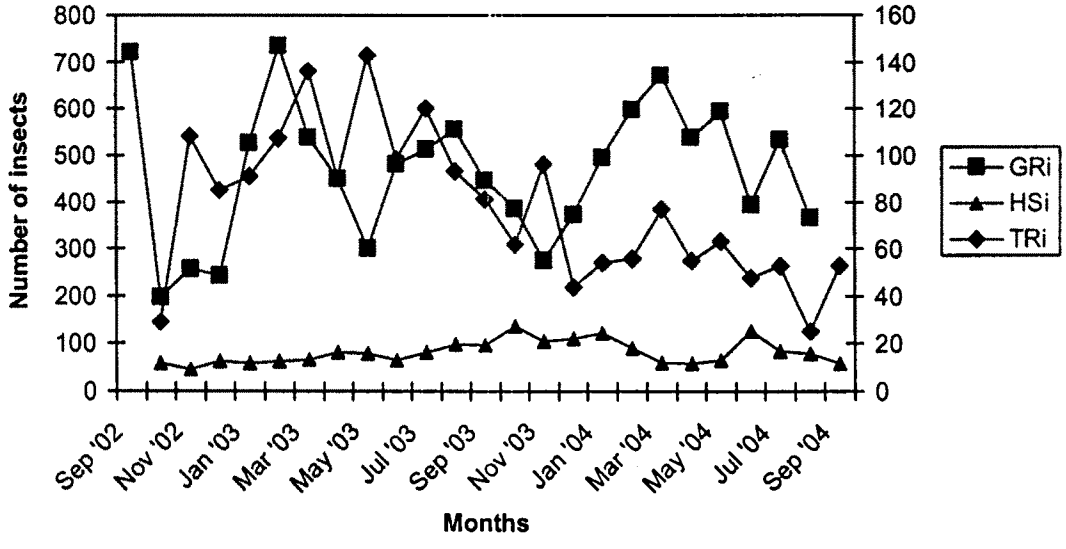



Figure 3.13. Monthly fluctuations of insects collected from three microhabitats.

The insects with 2-4mm size class were abundant in the sweeping method. and 4-6mm, 6-8mm and <2 mm sized insects followed it. This pattern of the abundance was similar to the insects collected in the beating sheets (Fig. 3.12).

### 3.3.2.4. Nocturnal Flying insects (NFi)

Light trap yielded 2854 insects comprised of nine orders and 51 families of insects. Coleoptera was the most abundant insect order, followed by Hemiptera, Diptera, and Lepidoptera (Table 3.1 & Appendix 2). Chrysomelidae was the most abundant family of insects, followed by the Staphylinidae. Scarabaeidae was the third most abundant family (Appendix 2).

From the Light trap study it was seen that insects were maximum during February and least during September. (Fig. 3.14). Winter was the abundant season for the nocturnal flying insects. The family richness was also observed in the same pattern.

The 2-4 mm sized insects were found more in the sampling and <2mm sized insects followed it. The size class distribution was bimodal compared to unimodal pattern observed in the ground and vegetation insects (Fig. 3.12).

The greatest capture was between 2000hrs and 2200hrs. The nocturnal insects were attracted more to the trap in the evening time and early night hours, and then the abundance was reduced. The abundance was relatively less during the late hours of night sampling (Fig. 3.15).

### 3.3.3. Variation within Orders

### 3.3.3.1. Coleoptera

Twenty-one families of beetles comprised the 3162 individuals were collected from the study area. Beetles were abundant in February and November though a smaller peaks were observed in the May and August.

Although Chrysomelidae and Staphylinidae showed the opposite trends of abundance, they were not statistically significant. Scarabaeidae did not show a prominent relation with other families and it showed a distinct abundance pattern with peaks in August and October when other major families were less abundant. Most Coleopterans were collected in winter (Fig. 3.16; Table 3.7).

When Coleopteran families were clustered based on their monthly abundance pattern, Cleridae showed a separate cluster with less than 10 per cent relationship with other families (Fig. 3.17). Coccinellidae and Buprestidae showed closest per cent similarity. Other ecologically similar families were the Trogossitidae and Bostrychidae, and Dermestidae and Cucujidae (Fig. 3.17).

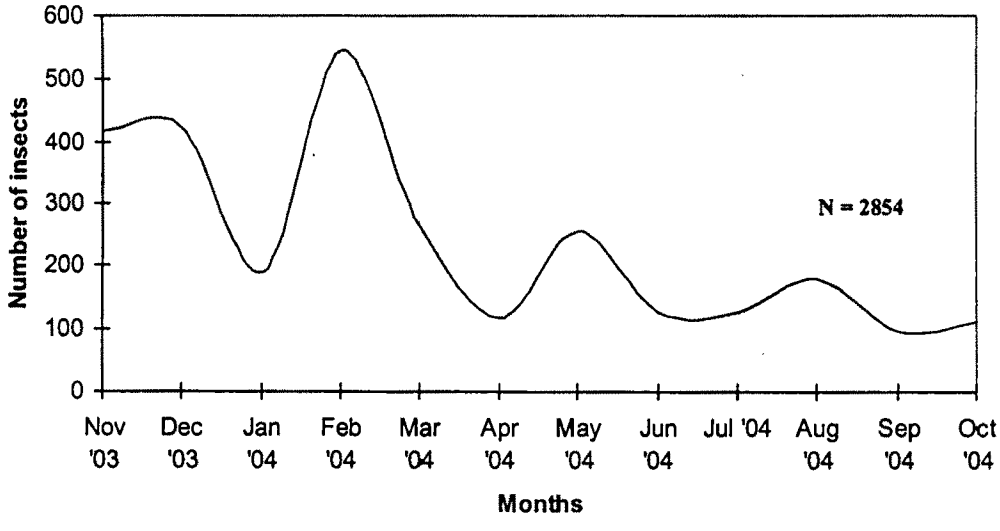



Figure 3.14. Monthly abundance fluctuations in the nocturnal flying insects (Light trap method)

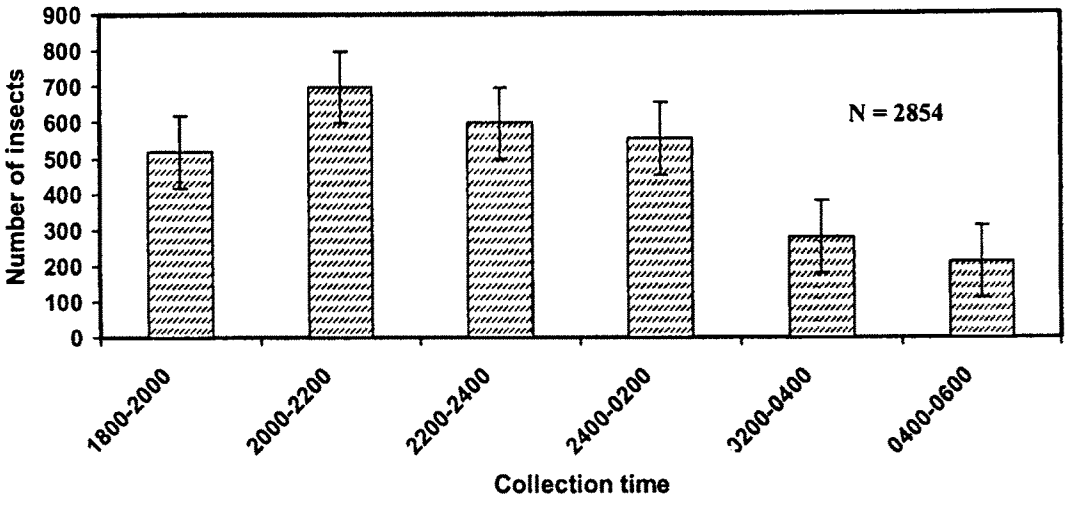



Figure 3.15. Nocturnal flying insects collected in different sampling time windows.

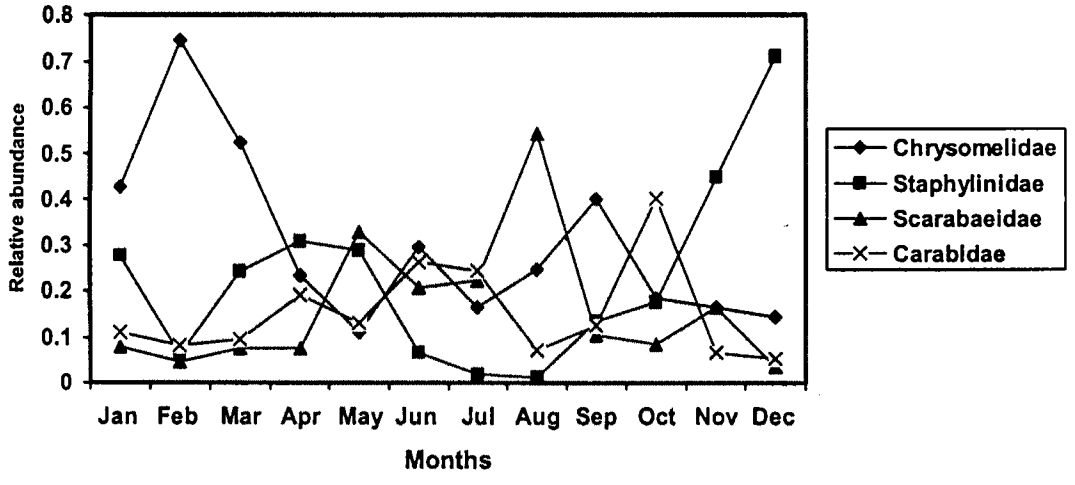



Figure 3.16. Monthly abundance variations of four major families of Coleoptera

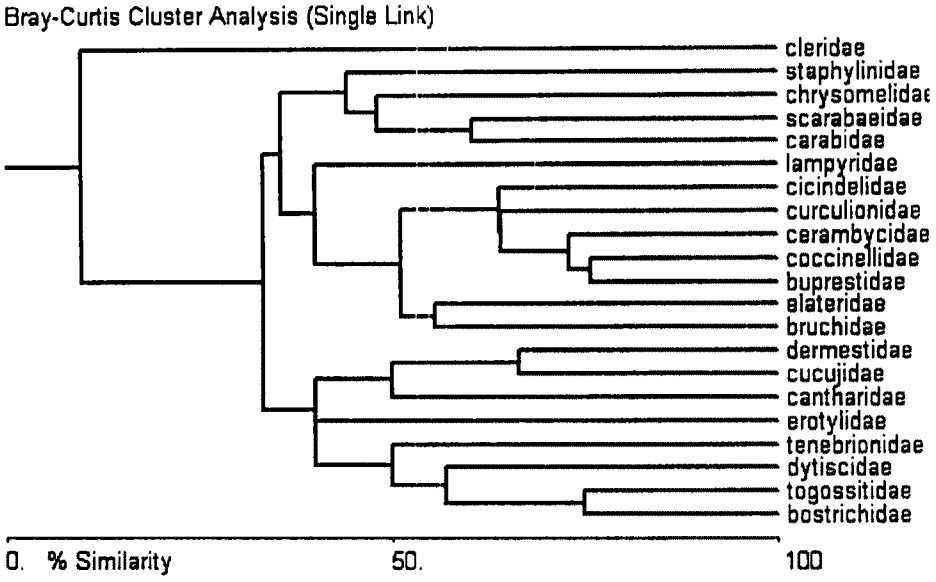



Figure 3.17. The dendrogram of the families of Coleoptera clustered based on their abundance similarities in seasonality

### 3.3.3.2. Hemiptera

A total of 1576 bugs were collected, which comprised of 13 families. September was the most abundant month for Hemiptera and March, June and December were the other months showing abundance. May was the least abundant month. Family diversity was found more in January (12 families). May and August were the least family diverse months (8 families). The bugs were most abundant in the Northeast monsoon (Fig. 3.18; Table 3.7).

Coreidae and Pentatomidae have shown negative relation in their abundance along the months. Pyrrcohoridae and Cicadellidae did not show significant relation with other families (Fig. 3.18).

The cluster analysis of Hemipteran families segregated them in to two distinct clusters. Coreidae, Pentatomidae and Cicadellidae formed a separate cluster. Pentatomidae and Cicadellidae have maximum similarity. Certain families which exhibited closer similarity among them were Tingidae with Cercopidae, Lygaeidae with Membracidae, and Reduviidae with Pyrrhocoridae (Fig. 3.19).

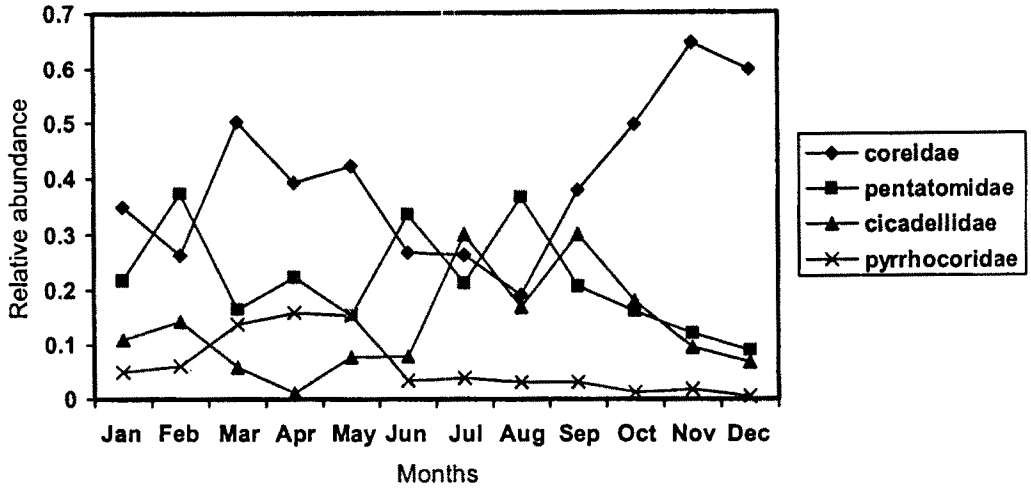



Figure 3.18 . The monthly relative abundance of major families of Hemiptera.

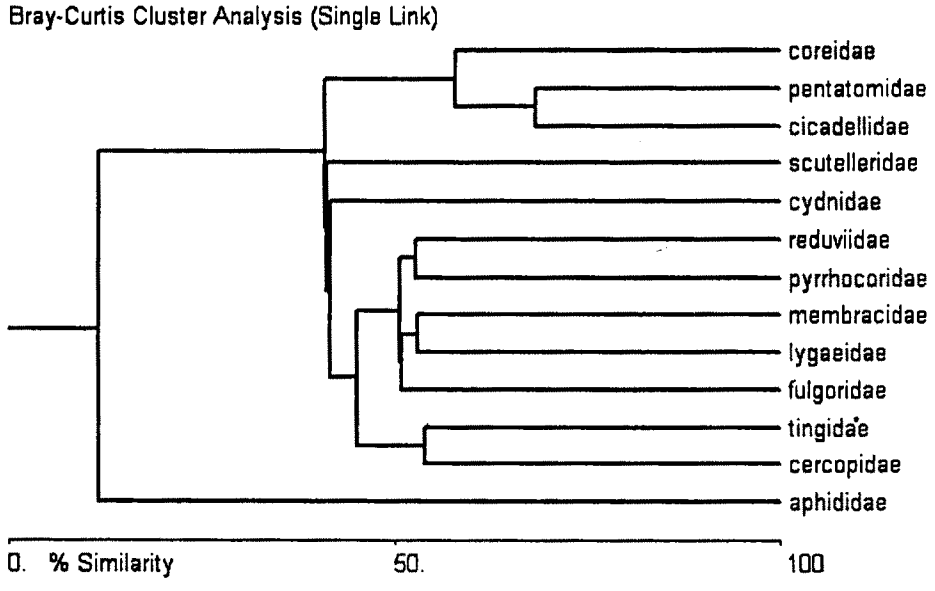



Figure 3.19. The dendrogram of the families of Hemiptera based on seasonal abundance.

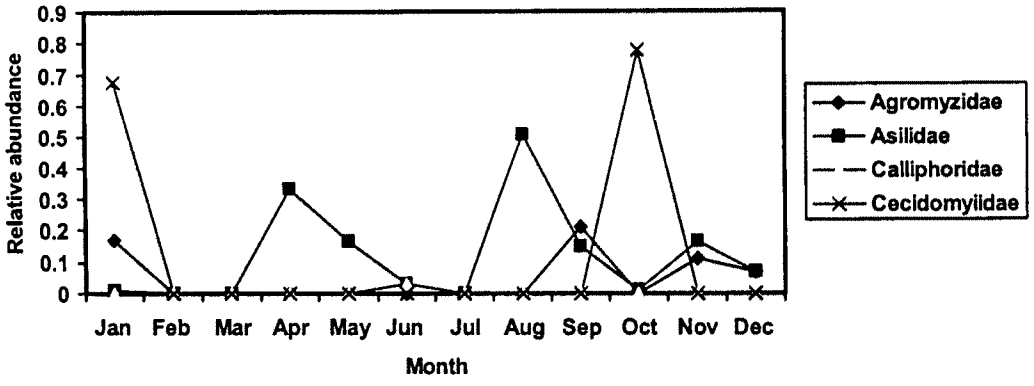



Figure 3.20. The monthly relative abundance variation of major families of Diptera

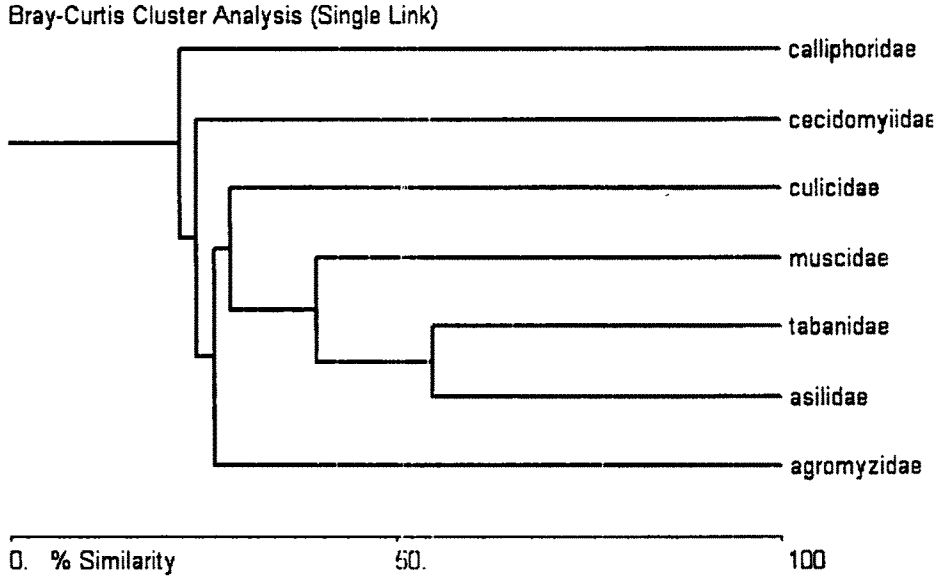



Figure 3.21. Dendrogram showing the Dipteran families based on seasonality.

### 3.3.3.3. Diptera

Seven families of flies comprising from 434 individuals were collected during the study. The January was found to be the most abundant month. The familial diversity was greatest in January as well as in June, September and October. Flies were abundant during southwest monsoon and winter (Table 3.7).

Among the dominant families, Asilidae was found abundant in many months and Cecidomyidae was abundant in October. However, these families were totally absent in some months (Fig. 3.20).

The seasonality of dipteran families was less similar with some exception of Tabanidae and Asilidae which showed relatively greater similarity (Fig. 3.21).

### 3.3.3.4. Hymenoptera

A total of 10694 individuals from eleven families were recorded during the study period. January and October were the hymenopteran dominant months. Insects showed least abundance during August but the maximum number of families was observed in this month. The hymenopetrans were abundant in the winter season (Table 3.7).

Formicidae was the abundant family and it formed a separate cluster and showed complete dissimilarity in seasonality with other families (Fig. 3.23). However, among hymenopterans, greater similarity in the monthly abundance was observed between Evanidae and Chalcidae. Mutillidae, Tenthredinidae and Megachilidae also had analogous similarity (Fig. 3.22).

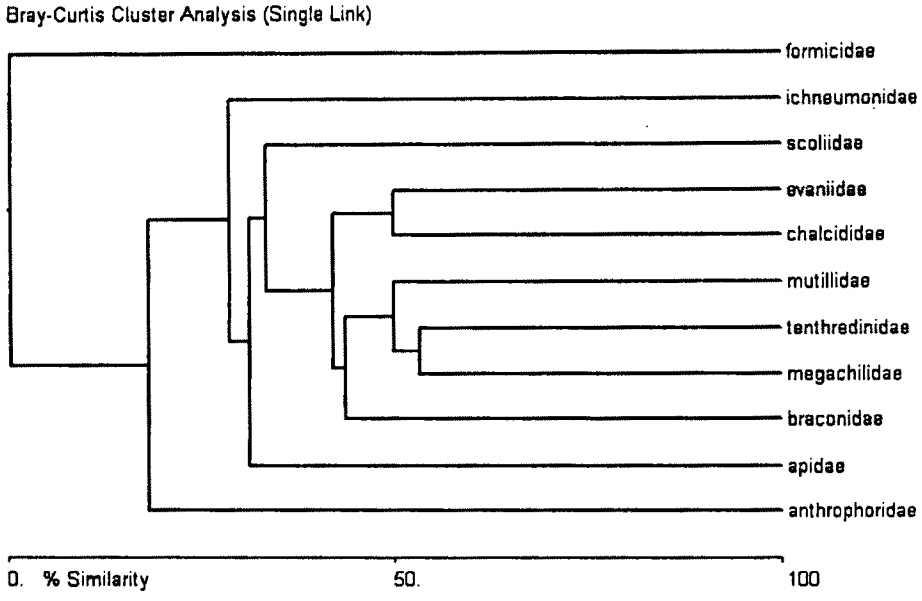



Figure 3.22. Dendrogram showing the hymenopteran families clustered based on seasonality.

### 3.3.3.5. Orthoptera

One thousand and eleven individuals falling into four families were recorded from the study area. August was the most abundant and December was the least abundant months for Orthoptera (Fig. 3.23; Table 3.7).

Monthly abundance of Gryllidae and Acrididae were positively correlated (r = 0.755 p= 0.01). Tetrigidae and Tettigonidae were negatively correlated (r = -1.00 p = 0.01) (Fig. 3.23). Gryllidae and Acrididae showed 75 per cent similarity (Fig. 3.24).

### 3.3.3.6. Lepidoptera

As the butterfly diversity is considered in detail in the next two chapters this section addresses only the nocturnal flying lepidopterans (moths). A total of 11 families of moths comprising 206 individuals were collected from the study area. March and November were the most abundant months and May the least abundant month (Fig. 3.25; Table 3.7). Moths were abundant in the Northeast monsoon (Fig. 3.25). Pterophoridae, Lasiocampidae, Zygaenidae and Lymantridae have shown similarity in seasonality (Fig. 3.26).

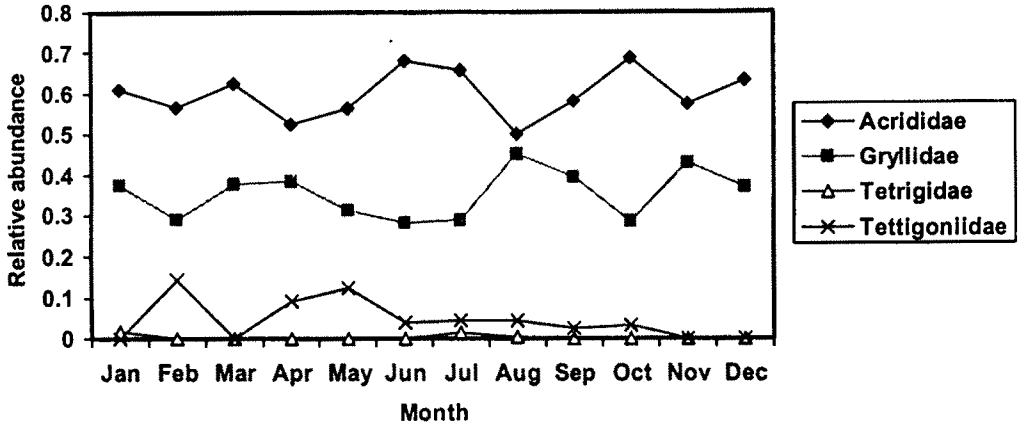



Figure 3.23. Monthly variations in relative abundance of major Orthopteran families.

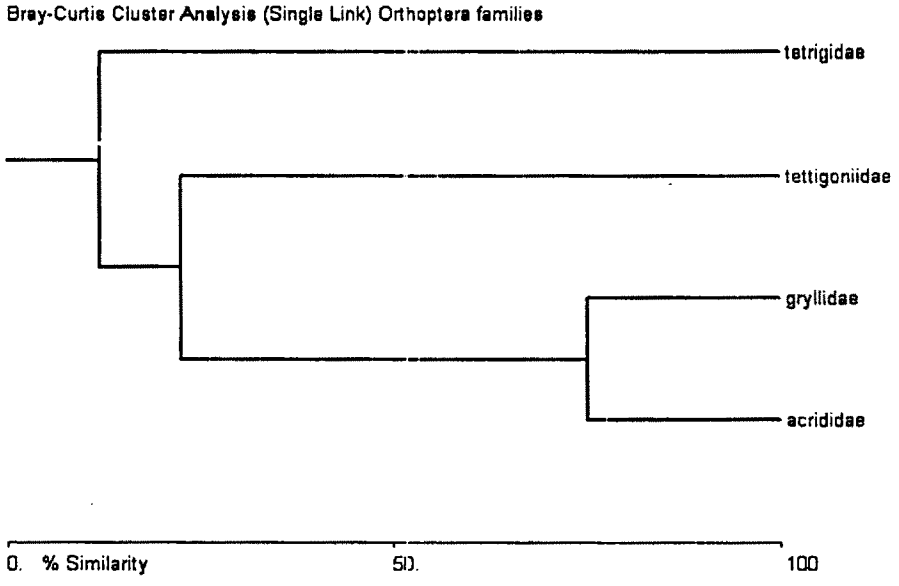



Figure 3.24. Dendrogram showing the Orthopteran families clustered based on seasonality.

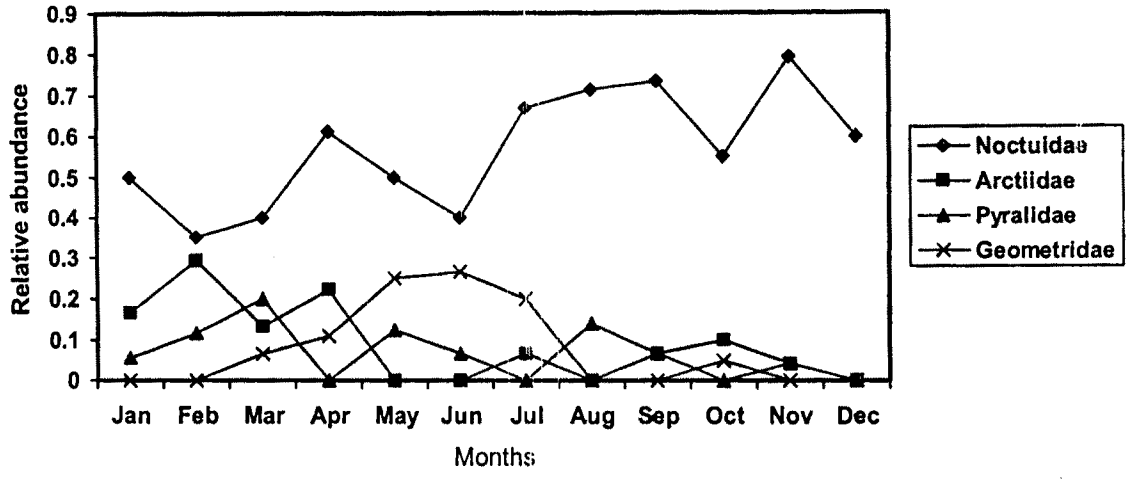



Figure 3.25. Monthly fluctuations in relative abundance of major families of nocturnal lepiodptera

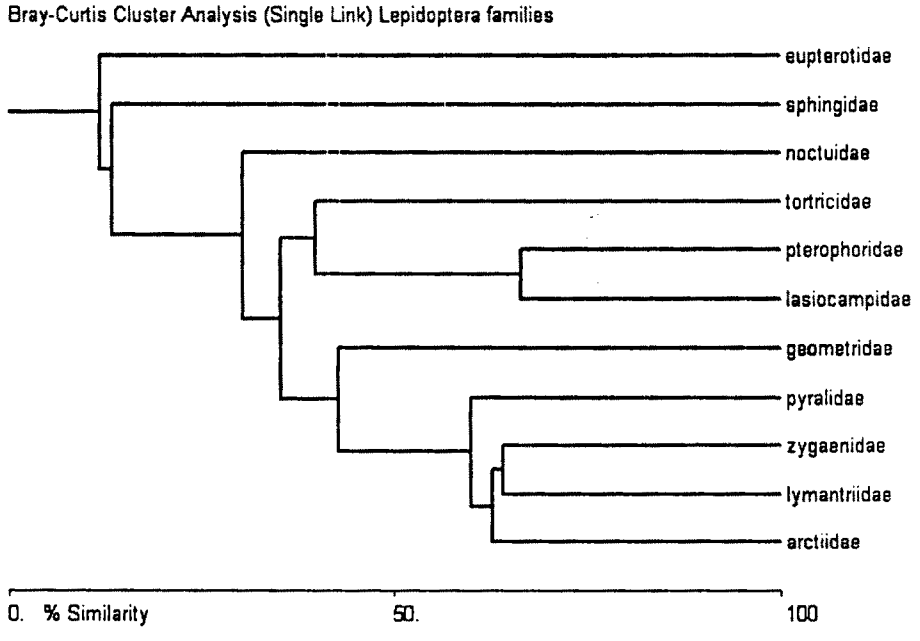



Figure 3. 26. Dendrogram showing nocturnal Lepidopteran families based on seasonality.

### 3.3.4. Alpha diversity

Alpha diversity measures such as species richness, two richness indices, two diversity indices, one evenness index and dominance indices were calculated and the results are shown in tables for each microhabitat and /or method separately.

Order level and family level indices were calculated for each method. The diversity of the samples significantly deviated between the active methods (beating sheet and sweeping) and passive methods (Light trap and pitfall) (Table 3.2 & 3.3). The passive methods are easy to perform in the field and hence the effort put in the overall study (in terms of the hours of insect collection) is more in the passive methods (Table 3.1). Though the effort and number of insects collected are more in passive methods, the diversity indices gave higher values for active methods. This emphasized the need for a combination of active and passive methods in the methodology package required for the study of overall insect diversity of an area.

### 3.3.5. Beta diversity

Beta diversity measures like Whittaker's index, Harrison index, Cody index, Jaccard similarity index, Sorenson similarity index, Morisita-Horn index of similarity and Mean Euclidean distance were calculated between the microhabitats / methods. Beating sheets and sweeping methods both capture insects affecting vegetation and these active collection methods show high similarity. As expected the greatest dissimilarity was exhibited between the ground dwelling insect community with nocturnal flying insect community (Table 3.4 & 3.5).

### 3.3.6. Patterns in total insects excluding Formicidae

Over dominance of one group of insects may alter the general trends of other insects in the simple statistical analysis hence an analysis was also executed after excluding. Formicidae. Figures 3.27 and 3.28 give the monthly abundance pattern and family diversity pattern of total insects with and without Formicidae. The figures clearly indicate the significance of ant community in relation to the abundance of other insects. A compensatory (negative) relationship was observed between the family richness of all the other families and abundance of Formicidae during many months.

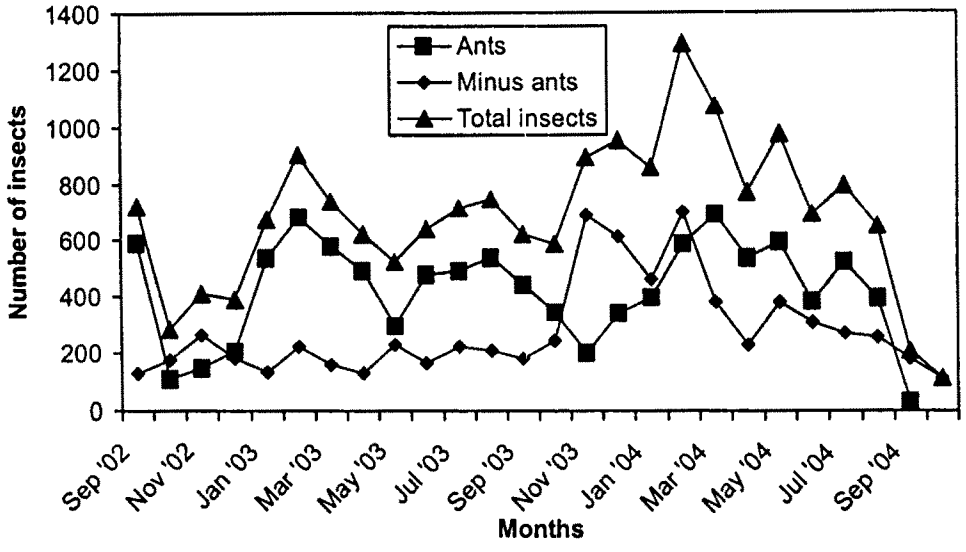



Figure 3.27. The monthly abundance variation of total insects, ants and total insects excluding ants.

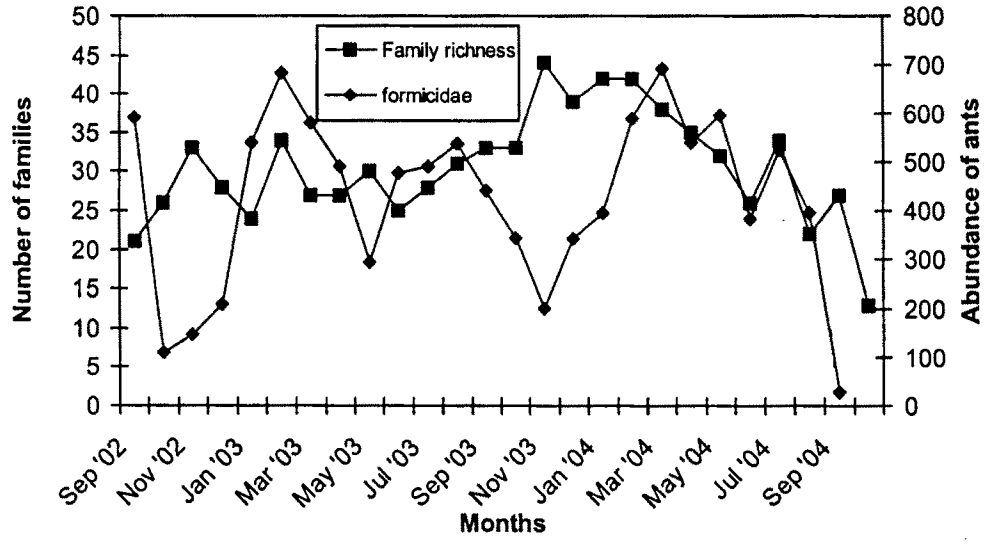



Figure 3.28. Monthly variation in number of families of total insects recorded and Formicidae (ants) abundance.

### 3.3.7. Climatic variables and major families

The Coleoptera, Diptera and Lepiodptera did not show a significant relation with the climatic variables. However, the Hemipteran abundance showed a negative correlation with the monthly mean wind speed (r = -0.648 p = 0.05), minimum temperature (r = -0.761 p = 0.05) and maximum temperature (r = -0.554 p = 0.05) (Table 3.6). The Hymenopteran abundance also showed a negative correlation with wind (r = -0.648 p = 0.05). Hymenoptera frequency was negatively correlated with the sunshine (r = -0.507 p = 0.05) and positively correlated with RH (r = 0.696 p = 0.05), minimum temperature (r = 0.552 p = 0.05) and rainy days ( r = 0.572 p = 0.05). The Orthopteran frequency (r = 0.718 p = 0.05) and abundance (r = 0.509 p = 0.05) were positively correlated with wind speed (Table 3.6).

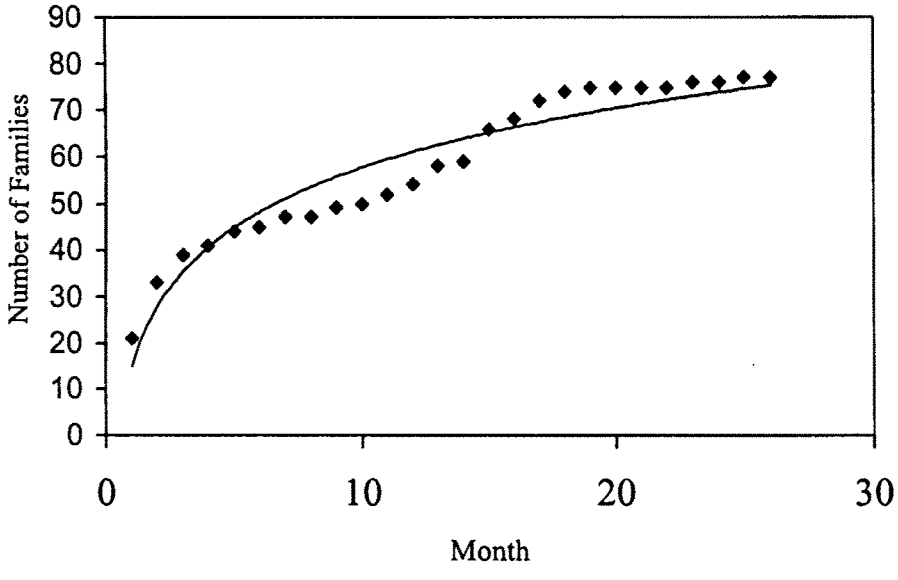



Figure 3.29. Family accumulation curve with respect to the effort of insect collection (total effort / month is the same for all months).

## 3.4. Discussion

Hymenopterans were the most abundant insects in Anaikatty hills. Arun, (2000) reported the similar result of ant abundance from the nearby moist deciduous forest of Siruvani. A similar report from dry deciduous forest of Bharatpur is also available (Vijayan, 1991). Although Hymenoptera was the abundant order, more families were recorded from Coleoptera .

Formicidae (ants) were more and other family representation was less during the summer season. The opposite trend, lower abundance of ants and other families were more during rainy seasons. It showed the effect of dominance of a particular group on the other members of a community.

The lead insect group was found to differ among microhabitats. The hymenopterans abundance in the ground is due to the Formicidae (ants). It could be due to the fact that ground is the main foraging area for many species of ants. Ants were also abundant in the trees. High involvement of ants in the collection of nectars and pollination (Kevan and Baker, 1983) makes the foliages and twigs as one of their major microhabitats. Many earlier reports explained that many plants mutually coevolved with ants (Bernays and Graham, 1988; Ananthakrishnan, 1992). The major herbivores such as Membracids and butterflies have mutual interactions with the ants. Hence, it could be concluded that ants movement is more in grounds and trees and hence ants abundance were more in ground and trees. Thus the trends and the patterns that emerge from the insect sampling have a definite reason that can be expected based on the natural history about the way nature works. It is showing insects' adaptability to specific variations in microhabitats.

The seasonality variation of insects differed among microhabitats. Although four microhabitats were studied, insects formed three clusters, such as vegetation insects (tree and shrubs insects), nocturnal flying insects and ground insects based on seasonality. The vegetation insects from trees and shrubs formed separate clusters and it could be due to

the similarity of microhabitat characteristics of these two. The composition of insect communities and the seasonality observed among and within the microhabitats showed the variations that can be ascribed to the microhabitat qualities as well as seasonal climate and their influence on insects.

The ground insects were least abundant during the rainy months. Inudation of insects during rain could be the reason. Ground insects were maximum in the months preceding rains. This observation also is significant in the light of known behaviour of ants that store food material for the rainy months (Sudd and Franks, 1987).

Vegetation insects were abundant in and around rainy months. The sprouting of leaf flush after the rains leads to increased population of vegetation insects. In Panamanian lowland forests the leaf production was found more at the beginning of wet season (May), during wet/dry season transition (December / January) and the smaller peak in the middle of the wet season (September), which was found correlated with the herbivores abundance (Aide, 1988).

Seasonality variations were recorded among families of same order as well as between the different places. Coleoptera, Hemiptera and Lepidoptera were recorded more in Winter and Notheast monsoon respectively. These are the major herbivorous insects; the effect of rain on the leaf flushing could be the reason for their abundance during monsoon seasons. Butterfield (1996) reported the impacts of microhabitat humidity and rainfall, which affect the Carabids distribution. Nocturnal Lepidopteran insects were the most abundant in the rainy cluster months. The observed trend is similar to the butterflies in the study area. All these variations among the insects indicate the variations in life history strategies in terms of the seasonality of their emergence to suit the availability of food and adapt to climatic conditions.

Some families within the same order show a compensatory relation or mutual exclusion in seasonality. Ths could be due to the competition working at the family level and the resultant family level niche segregation in insects. Hence, this indicates that a

family level identity is not a mere arbitrary classification and it has some ecological identity and plays a significant ecological role in ecosystems. However, the family level diversity pattern of insects did not show a correlation with vegetation parameters, which indicates that family level pattern, is not enough to study insect-plant specific relations of an area with special exception akin to the high specialist herbivores such as butterflies.

The effects of climatic variables on insects from many orders were differed and difficult to conclude. It could be attributed to the effect of climate on the insects could be both direct as well as indirect. In many cases combinations of factors are employed, producing flexibility and a better adjustment of reproduction to a variable and unpredictable environment (Wolda, 1987).

The 2-4mm (size class) insects were the body size of majority of insects in all the sampling methods. As most species of ants are of 2-4-size class, could be the reason for this size class (2-4mm) insects' abundance. Size class distribution of insects slightly differed among microhabitats. Sweeping and beating sheet captured larger sized insects. Smaller sized insects were more in pitfall. Luff (1996) reported that beetle size is an important factor that affected its capture rate. Insects captured in the Light trap were medium sized.

The insects collected through pitfall showed their specific identity with significant variation from the other methods in dendrogram. Among the other methods, sweeping and beating sheet collected more vegetation insects. Some of the nocturnal insects were also belong to the class herbivorous insects, hence they showed some similarity. Although, the variation in insect diversity captured in these collection methods could also be due to the microhabitat conditions, the capturing specificity of methods indicate their differed preferences. While, pitfall trap captured more number of insects, diversity of insects was more with the beating sheet. The present study has shown that the specificity of methods differed in capturing members of a particular family and order. The study also showed that sampled insects and size class of insects varied according to the time of operation of a specific method. Halsall and Wratten (1988) reported that the efficiency of pitfall trap varies in capturing seven different species of Carabids. A similar trend was reported by Gadagkar in 1989 and that gives greater weightage to the fact that the insect

study of a particular place should be planned with a package of methods that does justice to the majority of microhabitats available in that region. In addition, selection of methods should suit the objectives of the study also. For example, if the insect studies are needed to know the food availability of ground foraging insectivorous bird or animal the pitfall method alone seems to be sufficient to give a reasonable picture. However, to get overall insect diversity trends of an ecosystem a combination of a couple of active and passive methods are needed.

We have used two active methods and two passive methods, among which two methods captured nocturnal and crepuscular insects, and the other two captured diurnal insects. The effort in terms of hours sampled was also different; however, insect captured per hour is relatively uniform in all these methods. Moreover, the pitfall and beating sheet insects were relatively non-flying insects and lightrap methods captures the flying nocturnal insect. Sweeping collected more jumping insects. The result confirms four methods used in the study are a good package for the insect sampling for the biodiversity studies as well as rapid biodiversity assessment in forest habitats.

## 3.5. Summary

1. There is a significant variation in the insect community at family level in different microhabitats of the dry deciduous forest in the anaikatty hills.
2. Microclimatic variations are ascribed for such changes in insect community.
3. Seasonal fluctuations were recorded in insect groups; ground insects were abundant during summer while vegetation insects were so during rainy season.
4. Present work suggested that combination of day active (Sweeping and Beeting sheet) and night-operated (Pitfall and Light trap) methods are a good combination for the study of insect community.

Table 3.1. Proportional abundance (with in the order) of insects collected by different methods in Anaikatty hills. Major collections are highlighted indicating the effective methods.

| Order | Beating sheet | Light trap | Pitfall | Sweeping |
|---|---|---|---|---|
| Blattodea | **0.426** | 0.004 | **0.451** | 0.120 |
| Coleoptera | 0.146 | **0.643** | 0.158 | 0.053 |
| Collembola | 0.000 | 0.000 | **1.000** | 0.000 |
| Dermaptera | **0.636** | 0.000 | 0.364 | 0.000 |
| Diptera | 0.076 | **0.535** | 0.145 | 0.244 |
| Hemiptera | 0.243 | 0.221 | 0.115 | **0.421** |
| Hymenoptera | 0.058 | 0.006 | **0.895** | 0.042 |
| Isoptera | 0.000 | 0.000 | 1.000 | 0.000 |
| Lepidoptera | 0.044 | **0.825** | 0.053 | 0.078 |
| Mantodea | **0.621** | 0.035 | 0.103 | 0.241 |
| Neuroptera | **0.556** | 0.111 | 0.222 | 0.111 |
| Orthoptera | 0.189 | 0.004 | **0.311** | **0.497** |
| Phasmatodea | **0.957** | 0.000 | 0.000 | 0.044 |
| Thysanura | 0.000 | 0.000 | **1.000** | 0.000 |
| Total | 0.105 | 0.160 | **0.627** | 0.109 |
| Grand Total | 18.670 | 28.540 | 33.39 | 19.400 |
| Effort (hrs) | 96.000 | 144.000 | 384.000 | 96.000 |
| Number of insects / hr. | 19.450 | 19.820 | 29.130 | 20.210 |

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Table 3.2. Alpha diversity indices of insect orders for the four different insect collection methods.

| Indices | Beating sheet | Light trap | Pitfall | Sweeping | Total |
|---|---|---|---|---|---|
| Number of Order | 11 | 9 | 13 | 10 | 14 |
| Shannon Wiener | 1.6777 | 0.97116 | 0.68369 | 1.562 | 1.3306 |
| Simpson D | 4.4032 | 1.875 | 1.3588 | 4.0578 | 2.4835 |
| Margalef D | 1.3277 | 1.0055 | 1.2872 | 1.1888 | 1.3279 |
| Equitability J | 0.63573 | 0.36799 | 0.25907 | 0.59187 | 0.50419 |
| Berger Parker | 0.33048 | 0.71268 | 0.85562 | 0.34175 | 0.5992 |
| Mc Intosh D | 0.5354 | 0.27473 | 0.14347 | 0.51487 | 0.36818 |

Table 3.3. Alpha diversity indices of insect families for four different insect collection methods.

| Indices | Beating sheet | Light trap | Pitfall | Sweeping | Total |
|---|---|---|---|---|---|
| Number of Family. | 50 | 51 | 41 | 45 | 77 |
| Shannon Wiener | 2.6995 | 2.3918 | 0.78101 | 2.389 | 1.9447 |
| Simppson D | 7.2906 | 6.5459 | 1.3618 | 6.4193 | 2.7376 |
| Margalef D | 6.5055 | 6.2842 | 4.2907 | 5.8121 | 7.7633 |
| Equitability J | 0.62145 | 0.55062 | 0.1798 | 0.54998 | 0.44768 |
| Berger Parker | 0.32512 | 0.26034 | 0.85562 | 0.23351 | 0.59534 |
| Mc Intosh D | 0.64392 | 0.62038 | 0.14442 | 0.61881 | 0.39857 |

Table 3.4. The beta diversity indices of insect orders for four insect collection methods (1= Beating sheets; 2 = Light trap; 3 = Pitfall; 4 = sweeping)

| Methods | 1,2 | 1,3 | 1,4 | 2,3 | 2,4 | 3,4 |
|---|---|---|---|---|---|---|
| Whittaker's index | 0.1 | 0.17 | 0.05 | 0.18 | 0.05 | 0.22 |
| Harrison index | 0 | 0.08 | 0 | 0 | 0 | 0.08 |
| Cody index | -0.82 | -0.68 | -0.91 | -0.69 | -0.9 | -0.59 |
| Jaccard Similarity index | 0.82 | 0.71 | 0.91 | 0.69 | 0.9 | 0.64 |
| Sorenson similarity index | 0.45 | 0.42 | 0.48 | 0.41 | 0.47 | 0.39 |
| Sorenson quantitative similarity index | 0.79 | 0.29 | 0.98 | 0.41 | 0.81 | 0.3 |
| Morisita-Horn index | 0.44 | 0.14 | 0.82 | 0.04 | 0.24 | 0.1 |
| Mean Euclidean index | 513.39 | 2395.17 | 166.69 | 2675.35 | 634.24 | 2446.21 |

Table 3.5. The beta diversity indices of insect families for four insect collection methods (1= Beating sheets; 2 = Light trap; 3 = Pitfall; 4 = sweeping)

| Method | 1,2 | 1,3 | 1,4 | 2,3 | 2,4 | 3,4 |
|---|---|---|---|---|---|---|
| Whittaker's index | 0.37 | 0.27 | 0.18 | 0.39 | 0.35 | 0.26 |
| Harrison index | 0.35 | 0.16 | 0.12 | 0.25 | 0.27 | 0.2 |
| Cody index | -0.27 | -0.46 | -0.65 | -0.23 | -0.3 | -0.49 |
| Jaccard Similarity index | 0.46 | 0.57 | 0.7 | 0.44 | 0.48 | 0.59 |
| Sorenson similarity index | 0.32 | 0.36 | 0.41 | 0.3 | 0.32 | 0.37 |
| Sorenson quantitative similarity index | 0.79 | 0.29 | 0.98 | 0.41 | 0.81 | 0.3 |
| Morisita-Horn index | 0.23 | 0.13 | 0.73 | 0.01 | 0.12 | 0.09 |
| Mean Euclidean index | 138.57 | 1179.17 | 71.51 | 1200.53 | 157.78 | 1249.68 |

Table 3.6. Pearson correlation coefficients between insect abundance of major orders and climatic variables.

| Orders | Wind (km/hr.) | Sunshine (Hrs./day) | rh722 (%) | Max (°C) | Min (°C) | Rainfall (mm) | Rdays (No.) |
|---|---|---|---|---|---|---|---|
| Coleoptera | -0.1861 | -0.3128 | 0.4716 | -0.3494 | 0.0312 | 0.3438 | 0.3698 |
| Diptera | 0.2325 | -0.2023 | 0.1468 | -0.2583 | 0.0726 | 0.2425 | 0.2578 |
| Hemiptera | **-0.6484*** | -0.1175 | 0.49 | **-0.5538*** | **-0.7611**** | 0.0901 | -0.0454 |
| Hymenoptera | 0.2353 | -0.5068 | 0.148 | -0.1428 | 0.5514 | 0.4627 | 0.5719 |
| Orthoptera | **0.7184**** | -0.2938 | -0.466 | 0.1074 | 0.4747 | -0.1128 | -0.0069 |
| Lepidoptera | 0.038 | -0.1882 | -0.0924 | 0.009 | 0.1204 | 0.3055 | 0.2993 |

**Correlation is significant at the .01 level (2-tailed).
*Correlation is significant at the .05 level (2-tailed).

Table 3.7. Seasonal abundance of major insect orders

| Order | NE monsoon (%) | Summer (%) | SW monsoon (%) | Winter (%) |
|---|---|---|---|---|
| Coleoptera | 27 | 19 | 20 | **34** |
| Diptera | 28 | 7 | **33** | **32** |
| Hemiptera | **35** | 20 | 21 | 24 |
| Hymenoptera | 26 | 27 | 17 | **30** |
| Orthoptera | 26 | 23 | **35** | 16 |
| Lepidoptera | **29** | 27 | 25 | 19 |

Table 3.8. The Spearmann rank correlation between the monthly total insects, abundance and climatic variables

| Variables | Wind speed | Sunshine | RH | Max temp | Min temp | Rainfall | Rainy days |
|---|---|---|---|---|---|---|---|
| r value | -0.0457 | 0.4921 | -0.4705 | 0.3673 | -0.2556 | **-0.59** | **-0.64** |

# Chapter 4

## Species level patterns in butterfly community

### 4.1. Introduction

Species composition and species assemblages in a community are determined by the numerous internal and external factors (MacArthur, 1955; Cody and Diamond,1975). Members of locally coexisting species vary from place to place, local abundance of species fluctuates with time. Details of this variation and the factors producing them occupy a central place of ecological research (Cody and Diamond, 1975).

Interspecific interactions between populations frame the organisation of species diversity in a community (MacArthur, 1960). Life history strategies of the members of a community vary and each species adopts many strategies to tackle the competition (MacArthur, 1965). These strategies coincide with the abiotic factors, which affect the dynamics of the community structure and function at both spatial and temporal scales (MacArthur, 1964).

Butterflies are an excellent model sytem for studying community attributes. Survival strategies of the butterflies vary among species (Jones, 1987; Braby, 1995; Brakefield and Larsen, 1984). The environment of the butterfly determines the strategy it uses. K-selected butterflies generally have a single annual peak flying time, while the R-selected species have many peaks (Futuyma, 1976). Hence, the flying time varies between the species. Coevolution among species and coincident flying peaks remain major unresolved issues (Shapiro, 1975).

Many organisms that work as biotic factors also determine the butterfly diversity of an area. These biotic factors are the predators such as birds, reptiles, predatory insects and parasitoids (Ichneumonids). They may also have mutual interactions with other insects such as ants (Wynter-Blyth, 1957; Kunte, 2000).

Butterflies show a direct relationship with the plants (Chew, 1975; Ehrlich and Raven, 1964; Gratton and Denno, 2003). Seasonal variations of butterfly diversity are largely determined by the phenology of the larval and adult food plants (Gilbert and Singer, 1975; Cates, 1981). The synchronization is prominent between butterflies and plants (Jermy, 1984). Rodriguez *et. al.* (1994) and Moreira (2004) reported that the quantity and quality of the host plant influenced the adult body size of *Heliconius erato*.

The effect abiotic factors on the butterflies through the food plants were also subjected to many studies. Monthly variation of species composition and abundance of butterflies are influenced by abiotic factors such as temperature, relative humidity, sunlight and rainfall (Pivnick and McNeil, 1987; Pollard and Yates, 1993). Abiotic factors influence butterflies through egg development, larval development, feeding, reproduction and oviposition.

Souley (1986) has theorized that several local and regional level processes in the habitat qualities and climatic conditions predict the status of a species. Hence, the species that are rare in one area may be abundant in another area. Rarity of a species is recognised both by geographical distribution and local abundance. The seven forms of rarity considered in the literature (Rabinowitz *et. al.*, 1986) are significant in butterflies also.

The endemic species and restricted range species have high biological importance as they indicate the problems of the ecosystem through their vulnerability to extinction (Kumar *et. al.*, 2000). Besides focus on the attention of individual species, endemics and restricted range species richness can be an important criteria in prioritization of sites for conservation (Kershaw *et al.*, 1995).

Butterflies are relatively well studied taxa with respect to the taxonomic identity of the group. In India, butterfly studies started with the collection and checklisting (references in Goanker 1996; Singh and Pandey, 2004). Many studies reported the

butterfly species richness from protected areas such as National parks and Wildlife sanctuaries (Asaithambi *et al.*, 1995; Bhalodia *et al.*, 2002a,b,; Chandra *et. al.*, 2002; Thakur et. al., 2002; Mathew *et al.*, 2004a,b; Rao *et al.* 2004; Mathew and Binoy, 2002; Barua *et. al.*, 2004). Butterflies were also reported from major cities and districts by many researchers (Baskaran and Eswaran 2000, 2001, 2003; Kunte, 2000; Baskaran and Solaiappan, 2002; Raju *et. al.*, 2003; Chitra and Mahendran, 2003 Borkar and Komarpant, 2004). A few studies reported the butterflies from the institutional campus; Palot and Abdulrahman, 2002). Since the good field guides are available butterflies from many parts of the country are well documented. Most of the reports were from either one or two observations or many opportunistic visits to the study area. A year round planned study with detailed ecological questions is scandy. Although a good number of studies in the Nilgiri region focussed on listings of butterflies (Larsen 1987a,b, c, and 1988), there was relatively a few systematic year round butterfly study at the community level.

The present work attempted to study the butterfly community in the dry deciduous forest of Anaikatty hills with the objectives to (1) know the Community structure, Species composition and species assemblage of the butterflies, 2) explore the changes of community structure and attributes during various months and season, 3) study the internal and external factors affecting the community structure and to 4) determine the conservation importance of the area through butterfly community patterns.

## 4.2. Methodology

### 4.2.1. Data Collection

Transect walk method was followed for estimating the butterfly abundance following Pollard, (1977); Ishii (1993) and Natuhara *et al.* (1996). As suggested by Swengel (1977) a transect route of one km is generally used as a standard. Butterflies were counted 2.5m on both side and 5m in front of the observer. Butterfly transect count was done between 1100hrs and 0100hrs. Diurnal activity pattern of butterflies was also studied from March 2002 to May 2002 in 1 km transect from 0600hrs to 1800hrs at 1-

hour interval. The term, 'abundance' hereafter means the total number of butterflies encountered in the transects.

Four one-kilometer transects were laid in four sites of study area. Two transect counts were executed per transect in a month and totally eight transect counts were completed per month. Transect counts were avoided during rainy and windy days to avoid non regular conditions. Butterfly sampling was also avoided during the days when there were migrations of butterflies as it may distort the population of the resident butterflies. Hesperiids are crepuscular and hence to enable easy identification and these and lycaenids were captured using a butterfly net, identified and later released. Hence the data collected may have some bias against the hesperids. Evans (1932) and WynterBlyth (1957) were followed for the identification of butterflies. Butterflies of the area were categorized in to five families following Ackery (1996) and Goankar (1996).

The data was collected from March 2002 to February 2004. The climatic parameters such as temperature, humidity, wind, rainfall, number of rainy days and sunshine were recorded to study their effects on the population of butterflies.

### 4.2.2. Data Analysis

Butterfly species richness and abundance at the family level in various months during the study period were analysed. One-way analysis of variance and Pearson correlation were also used to analyse the monthly butterfly abundance pattern the relation among butterfly families and between the most abundant butterflies. The environmental variables and abundance were also analysed using the Pearson correlation and regression analysis. For analyzing the variation within and between sites, between seasons and years, alpha and beta diversities as suggested by Ludwig and Reynolds (1988) were adopted. The alpha diversity indices such as Species richness, Shannon Wiener, SimpsonD, MargalefD, EquitabilityJ, Berger Parker and McIntoshD were calculated for the transects. Beta diversity measures such as Whittaker's index, Harrison index, Cody index, Jaccard similarity index, Sorenson similarity index, Morisita-Horn index of similarity and Mean Euclidean distance were calculated between transects. The data were analysed using the statistical software, SPSS version 13.0. (SPSS Inc.).

## 4.3. Results

### 4.3.1. Species Composition and Assembly

In all, 94 species of butterflies were recorded in the study area (Appendix I). However, only 78 species of butterflies were recorded in transect counts. A total of 23325 butterflies were encountered through the 192 transect counts. Pieridae (54%) was the most abundant family followed by the Nymphalidae (33%), Papilionidae (10%), Lycaenidae (3%) and Hesperiidae (<1%) (Fig. 4.1) respectively. Nymphalidae (33%) was the most speciose family and followed by Lycaenidae (25%), Pieridae (22%), Papilionidae (15%) and Hesperiidae (5%) (Fig. 4.2).

### 4.3.2. Species diversity

Species richness and abundance did not show similar trends between families. Though Lycaenidae was the second speciose family it ranked only third in abundance. Hesperiidae has showed the same rank in species richness and abundance rank among the families. When compared with other families, Papilionidae showed a similar rank in species richness and abundance.

*Cepora nerissa* was the most abundant species of butterfly encounted (Fig. 4.3). Among the first ten abundant species, six species belonged to Pieridae; three were Nymphalidae and one Papilionidae. The overall butterfly abundance trend did show a lognormal distribution.

The species accumulation showed a slow but steady increase as the sample size increased and reaches asymptote around 12 months of sampling (Fig. 4.4).

Diversity indices values did not differ much among transects. However transect two recorded slightly greater evenness (Table 4.2). The transects one, two and three had similar variations (Table 4.3). The total butterflies encountered in transects both the years was almost same. Number of pierids wer high in transect three (Fig. 4.5).

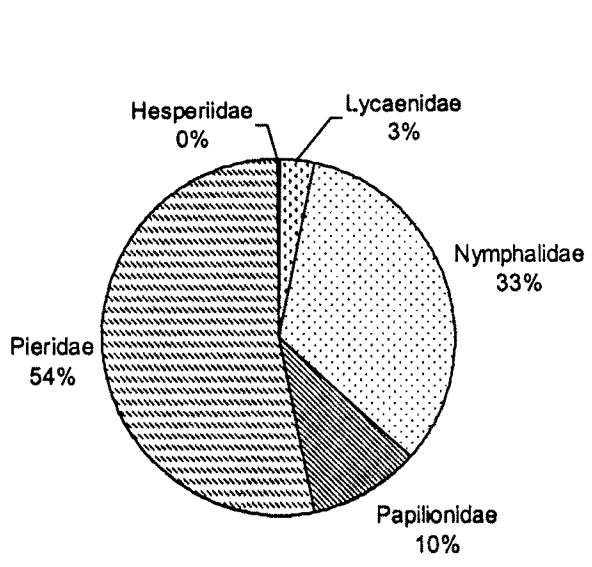



Figure 4.1. Percentage composition of abundance of five families of butterflies

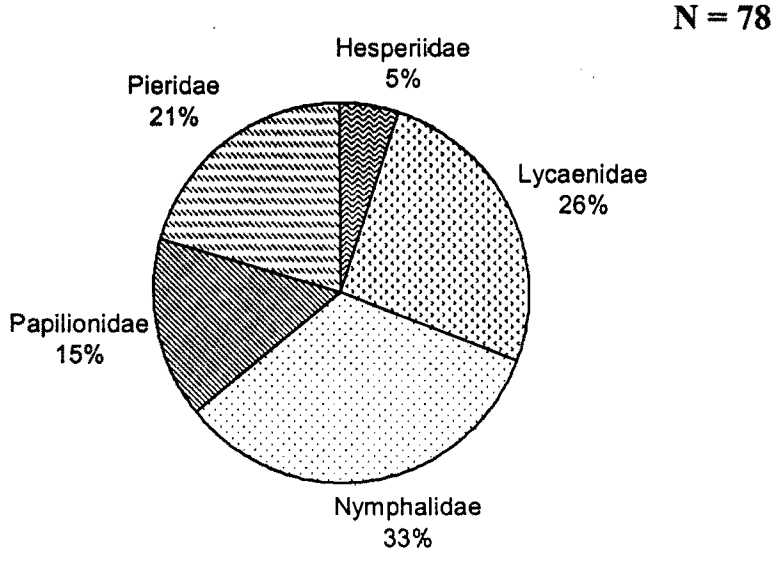



Figure 4.2. Percentage composition of species richness of five butterfly families.

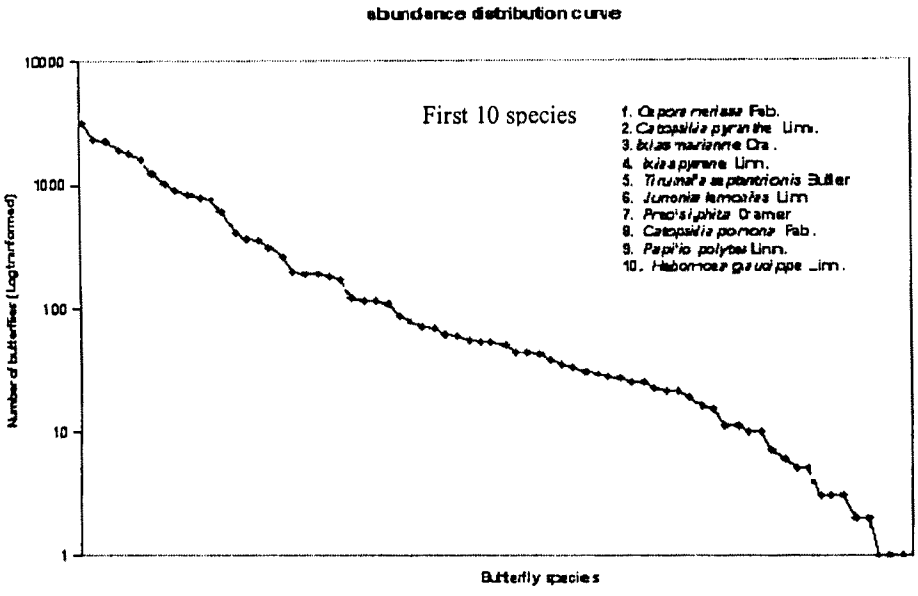



Figure 4.3. Dominance curve of butterflies recorded in Anaikatty hills.

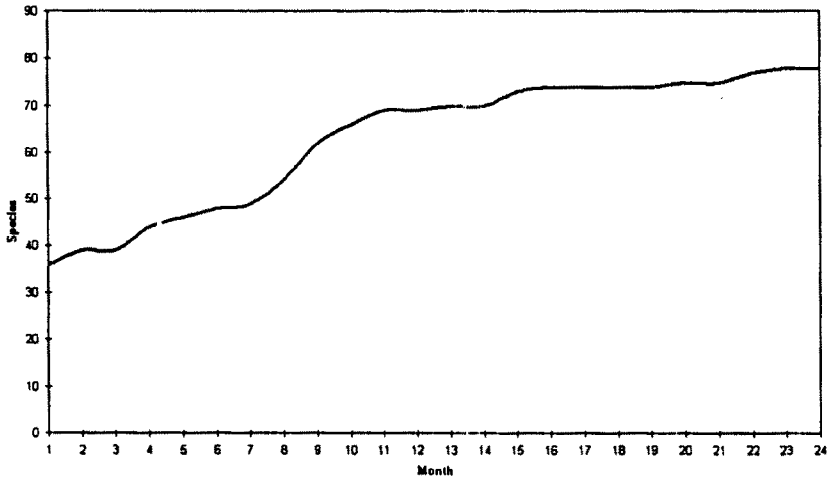



Figure 4.4. Species accumulation curve of butterflies during study period.

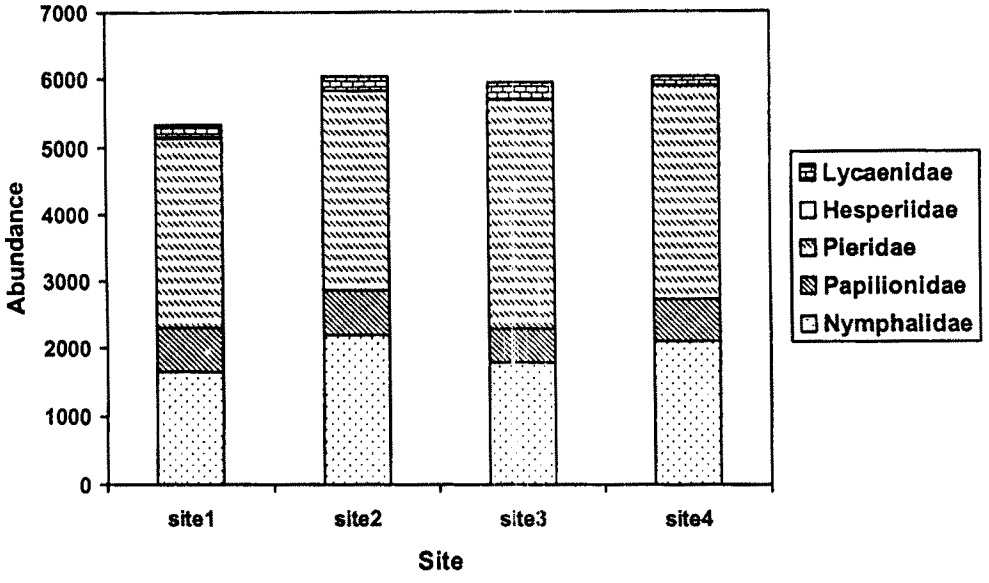



Figure 4.5. Composition and abundance of butterfly families in four different sites

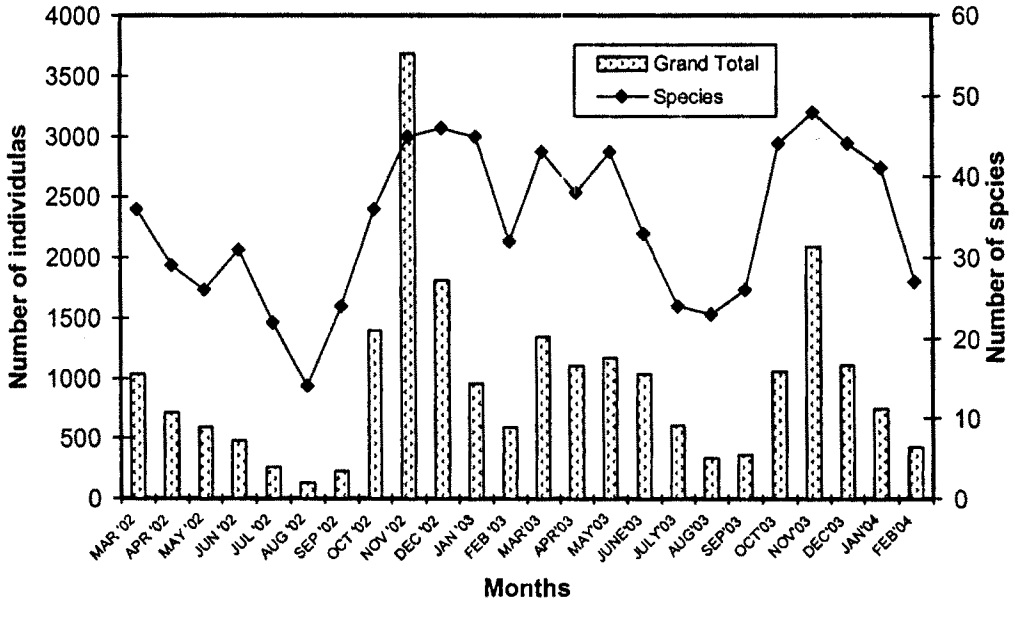



Figure 4.6. Monthly variations recorded in species richness and abundance of butterflies.

### 4.3.3. Seasonality of butterflies

Butterflies of the study area showed a bimodal annual seasonality with one peak abundance in March, April and May, and another one in October, November, and December (Fig. 4.6; Table 4.1). The butterfly migration was also observed during these months. November was the most abundant month for butterflies in Anaikatty hills. Butterfly abundance was less in August. Butterfly composition observed during study period were analysed by oneway ANOVA for dissimilarity. It showed significant variance ($F = 5.281$ $p = <0.001$) between the monthly observations.

Monthly relative abundance of butterflies at the family level showed significant variation. Pieridae and Nymphalidae showed inverse relation of abundance fluctuating across the year (Fig. 4.7). They were negatively correlated in monthly abundance ($r = -0.954$ $p = 0.01$) (Table 4.4). During April 02 and November 02, the Nymphalidae were more abundant than the Pieridae. Although the number was less, Papilionidae showed a similar pattern with respect to the peak abundance of Nymphalidae.

Abundance trend was analysed among the most abundant ten butterflies and they showed a clear variation in the monthly abundance pattern (ANOVA $F = 3.564$ $p= <0.001$). Frequency of encounter of abundant butterflies fluctuated significantly. The most abundant butterfly, *Cepora nerissa* was observed in 23 months. *Tirumala septentrionis*, that exhibited migration behaviour, were observed in 22 months.

Certain closely related butterflies have shown similar abundance pattern. *Ixias marianne* and *Ixias pyrene* showed significant positive correlation ($r = 0.687$ $P <0.01$). *Precis iphita* and *Precis lemonias* also correlated positively ($r = 0.463$ $p = 0.05$).

### 4.3.4. Pattern of butterfly abundance and climate

Butterfly species richness and abundance was greater during Northeast monsoon than Southwest monsoon. Seasonal occurrence was as follows: Northeast monsoon (38%) and followed by Summer (26%), Winter (24%) and Southwest monsoon (12%) (Fig. 4.8).

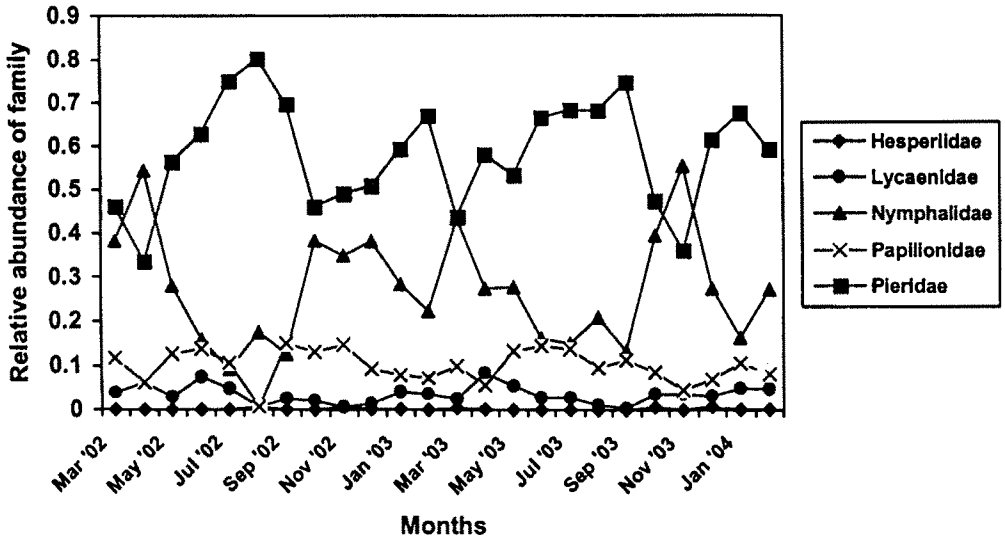



Figure 4.7. Fluctuations of relative abundance of butterfly families.

N = 23325

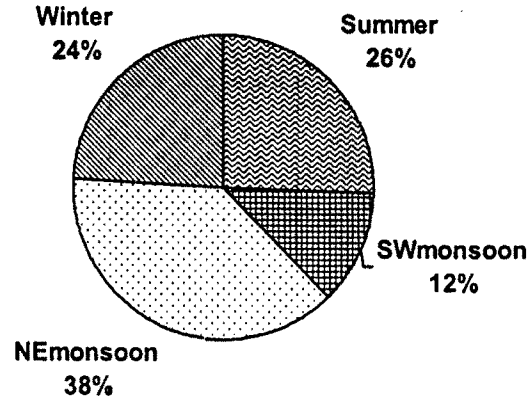



Figure 4.8. Abundance of butterflies observed during various seasons.

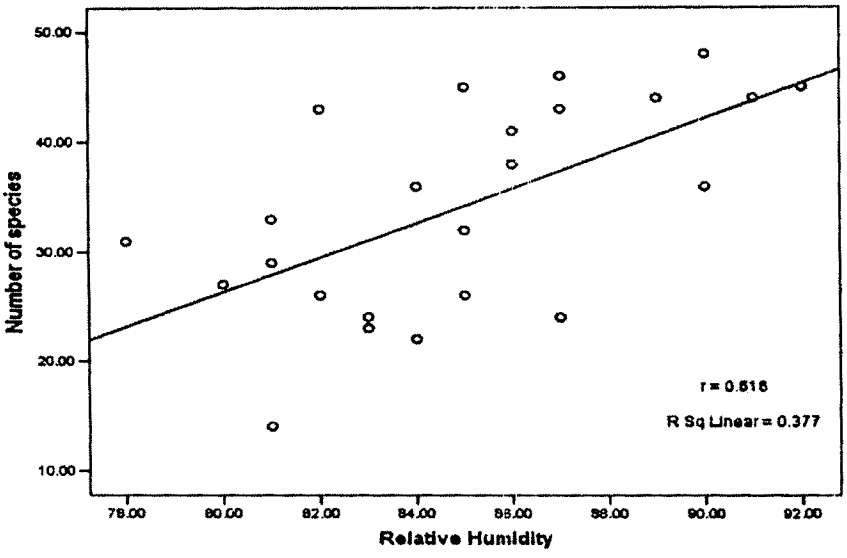



Figure 4.9. Relationship between the relative humidity and species richness of butterflies

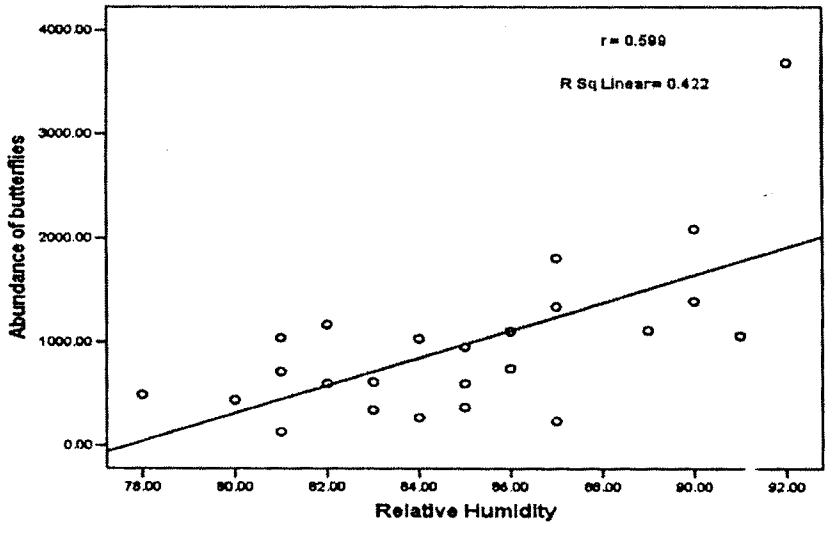



Figure 4.10. Relationship between the relative humidity and abundance of butterflies

Relation between the environmental factors and butterfly abundance was also analysed. Species richness showed a positive correlation with relative humidity ($r = 0.616$ $P = 0.01$) and abundance ($r = 0.599$ $p = 0.01$) (Fig. 4.9 & 4.10; Table 4.5). Rainfall did not show direct correlation with butterfly abundance of respective months. Nevertheless, the butterfly abundance followed the rainfall pattern (Fig. 4.11) with a one month time lag. Rainfall of the preceding months with the butterflies of the month showed a significant relation ($y = 12.509 + 448.55$ $R^2 = 0.728$) (Fig. 4.12). Monthly mean wind speed showed significant negative correlation ($R^2 = 0.57$) with butterfly diversity (Fig. 4.13).

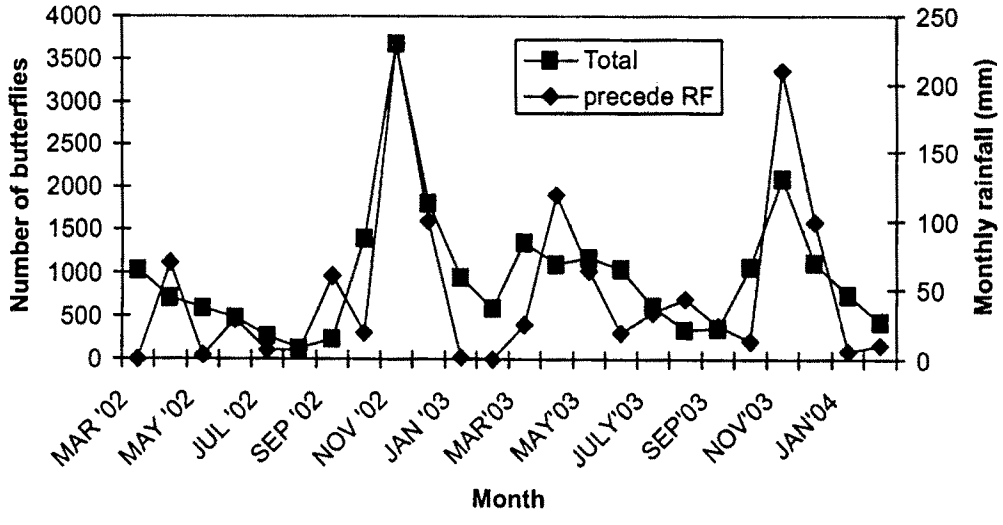



Fig. 4.11. Fluctuations in abundance of butterflies and preceeding month's rainfall.

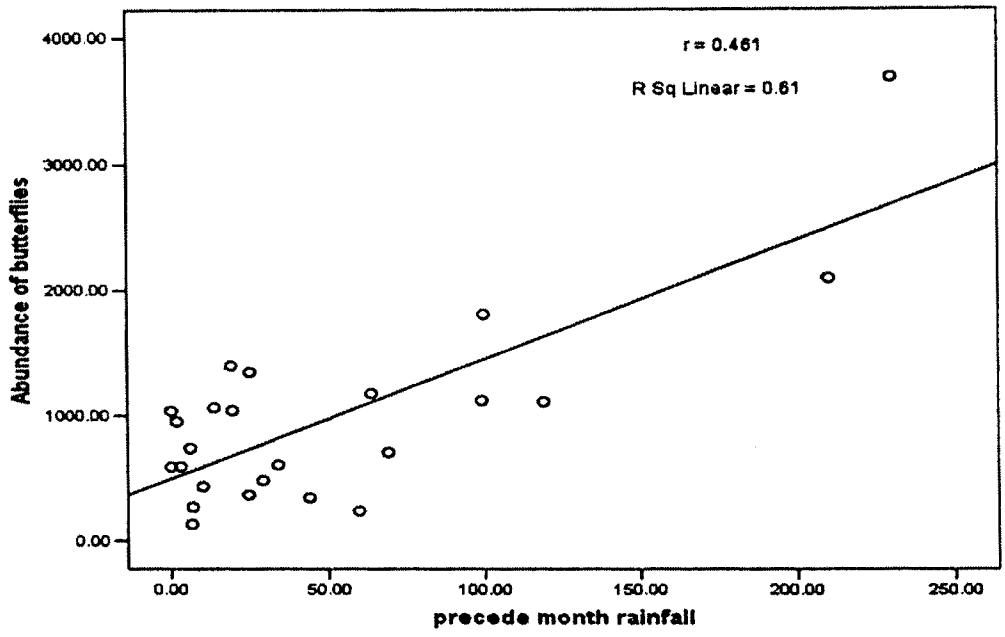



Figure 4.12. Relationship between the preceeding months rainfall and butterfly abundance

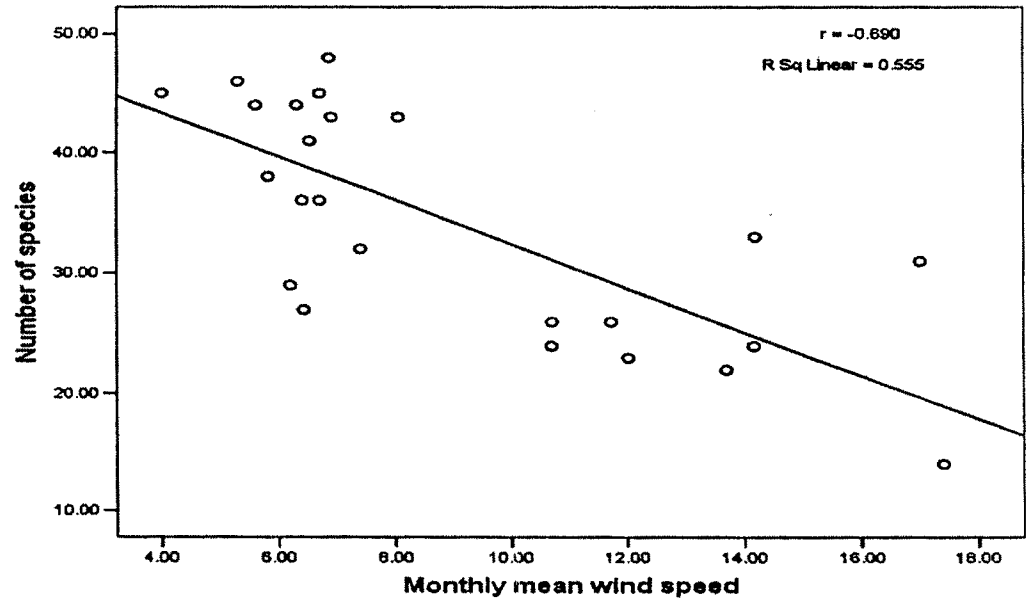



Figure. 4.13 Relationship between the the species richness of butterflies and mean monthly wind speed

### 4.3.5. Diurnal Activity pattern

Diurnal activity pattern of butterfly activity in a day was unimodal. It showed a peak between 1000hrs and 1400hrs (Fig. 15). Species such as *Pachliopta aristolochiae* Fab. *Pachliopta hector*, *Delias eucharis*, and some of the lycaenids (e.g., *Zizinia otis*) did not follow this pattern (Fig. 4.14).

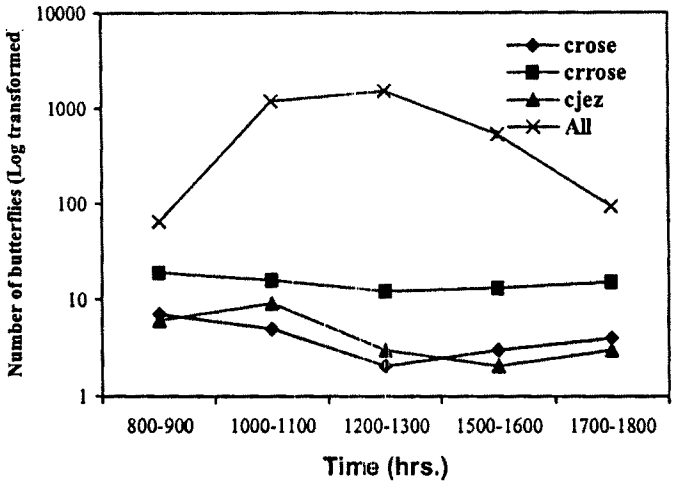
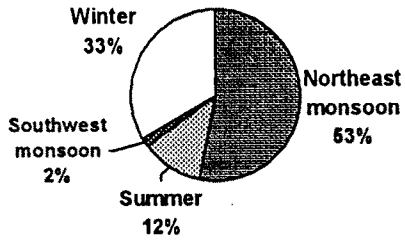



Figure 4.14. Diurnal activity pattern of butterflies. Crose = Common rose (*Pachliopta aristolochiae* Fab.); crrose = Crimson Rose (*Pachliopta hector*); cjez = CommonJezebal (*Delias eucharis* Drury). Others = All butterflies recorded including above three butterflies.

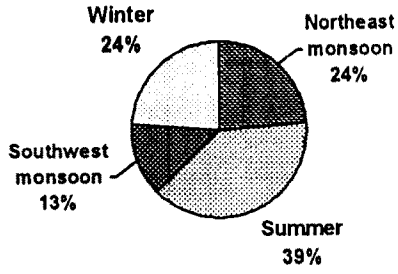
### 4.3.6. Trends of populations within families

#### 4.3.6.1. Family: Papilionidae

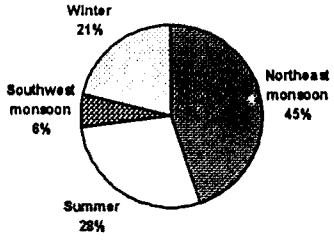
Two thousand four hundred and thirty seven pailionid butterflies belonging to 12 species were recorded during the two years. Papilionids of the study area represented 63 per cent of those encountered in the Western Ghats. Abundance was greater in the Northeast monsoon (41%) followed by summer (24%), Winter (20%) and Southwest monsoon (15%) (Fig. 4.15). Unlike pierids and nymphalids, these butterflies showed a relatively similar abundance pattern all round the year, though a distinct peak was observed during November of the first year of the study period (Fig. 4.16).



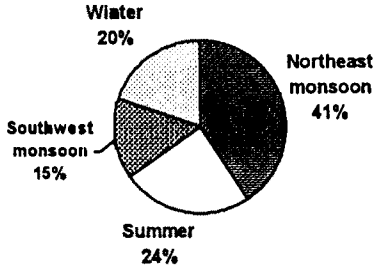

Hesperiids



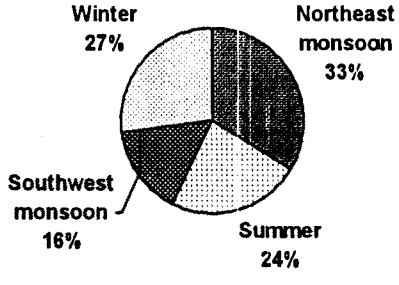

Lycaenidae




Nymphalidae (N = 7735)

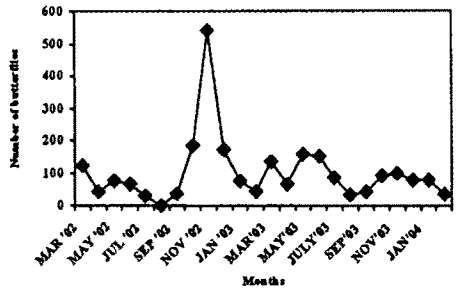



Papilionidae (N = 2437)

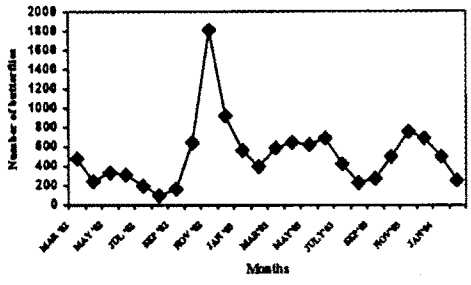



Pieridae (N =12353)

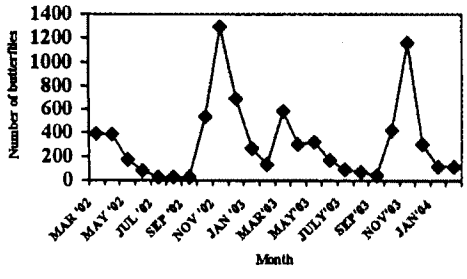
Figure 4.17. Seasonal abundance variations of butterfly families



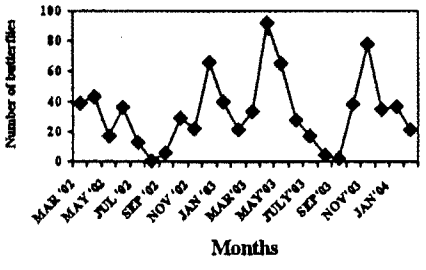

Pieridae



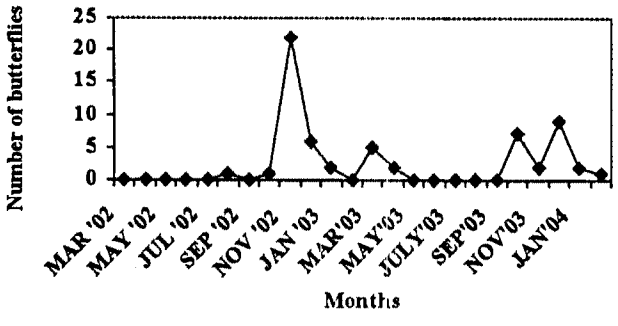

Papilionidae




Nymphalidae




Lycaenidae




Hesperiidae

Figure. 4.18. Fluctuations in monthly abundance of different butterfly families

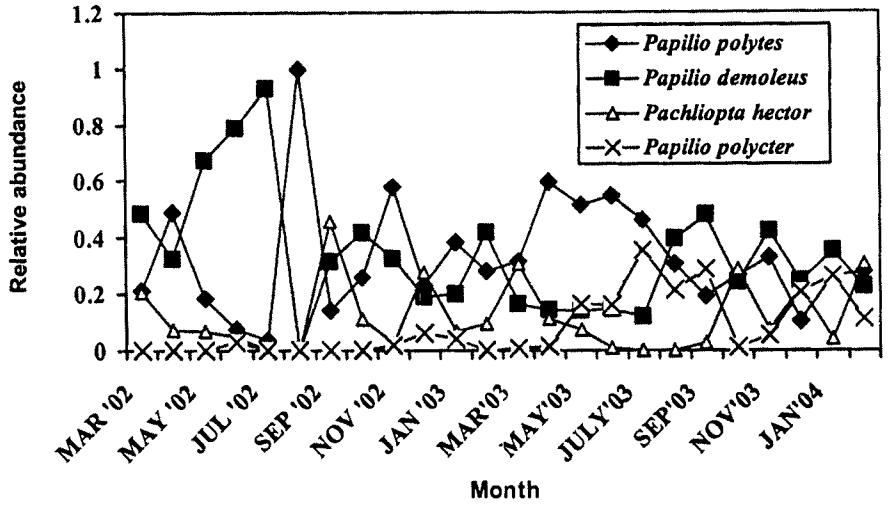



Figure 4.19. Monthly fluctuations in relative abundance of common papilionids

Among the most common papilionids, *Papilio polytes* was negatively correlated with *Papilio demoleus* ($r = -0.681$ $p < 0.01$) in their seasonal abundance (Fig. 4.17). Though the other common butterflies showed variations in seasonality they were not significant.

#### 4.3.6.2. Family: Nymphalidae

A total of 7735 nymphalid butterflies belonging to 26 species were recorded during this study. The species recorded represented 27 per cent of those encountered in Western Ghats. Butterflies were abundant during the Northeast monsoon (45%) followed by Summer (28%), Winter (21%) and Southwest monsoon (6%) (Fig. 4.15). These butterflies showed a bimodal seasonality with peaks in March and November (Fig. 4.16).

Among the most common four nymphalid butterflies, the abundance of *Tirumala septentrionis* was negatively correlated with the other three dominant butterflies such as *Precis lemonias* ($r = -0.516$ $p = 0.01$), *Precis iphita* ($r = -0.512$ $p = 0.05$) and *Ypthima baldus* ($r = -0.666$ $p < 0.01$) (Fig. 4.18). The pansies, *Junonia lemonias* and *Precis iphita* did not show any significant correlation between themselves.

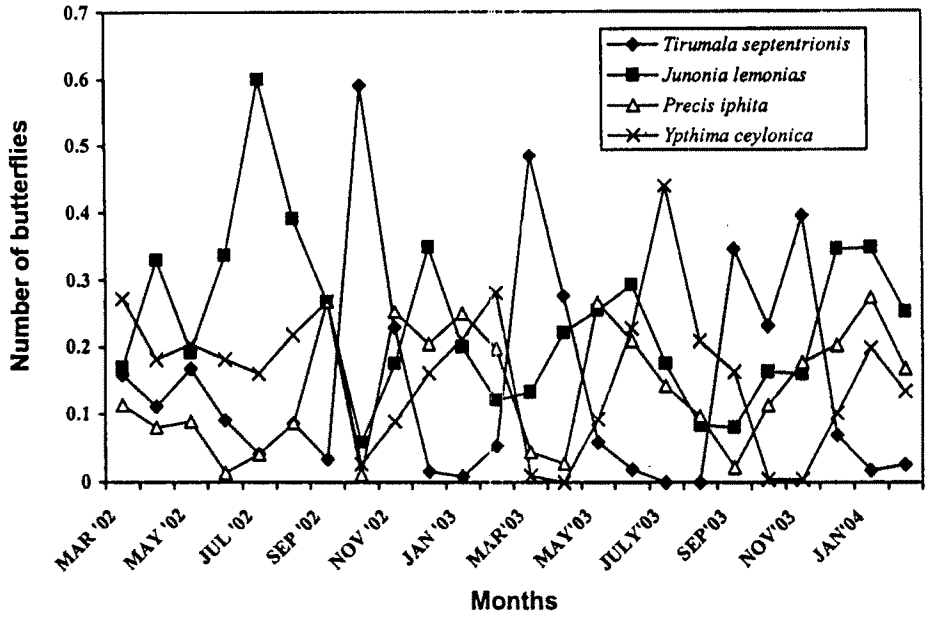



Figure 4.18. Monthly fluctuations in relative abundance of common nymphalids

#### 4.3.6.3. Family: Pieridae

With the record of Pieridae 12353 individuals during this study pierids were numerically abundant in the area. There were 16 species of pierids observed from the area. The species represented 42 per cent of Western Ghats pierid butterflies. These butterflies were also abundant in the Northeast monsoon (33%) and it was followed by winter (27%), summer (24%) and southwest monsoon (16%) (Fig. 4.15). The primary peak of their abundance was observed during November, secondary one between March and June. August was the least abundant month for pierid butterflies (Fig. 4.16). While papilionids showed a similar in seasonal populations, pierid showed a bloom-and-crash pattern in population trend with respect to seasons.

Each butterfly showed specific trends of abundance round the year. *Cepora nerissa*, dominant butterfly of the area, was negatively correlated with *Ixias marianne* ($r = -0.737$ $p < 0.01$) and *Ixias pyrene* ($r = -0.689$ $p < 0.01$) (Fig. 4.19). The abundance of *Ixias marianne* and *Ixias pyrene* were correlated positively ($r = 0.615$ $p < 0.001$).

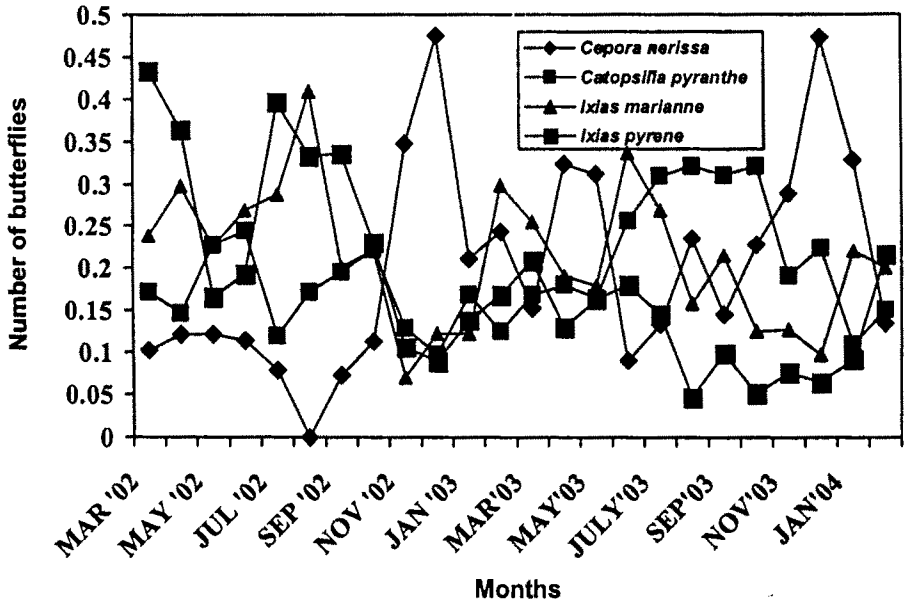



Figure 4.19. Monthly fluctuations in relative abundance of common Pierids

#### 4.3.6.4. Family: Lycaenidae

A total of 740 individuals belonging to 22 species of lycaenids were recorded. The count number of species represented 20 per cent of lycaenids recorded from Western Ghats. Unlike other families of butterflies, these were more abundant in the summer (39%) and it was followed by Northeast monsoon, Summer (24% each) and Southwest

monsoon (13%) (Fig. 4.17). The Lycaenidae also showed a bimodal seasonality with peaks during April and November and least abundant was during August.

Among the dominant lycaenids *Zizinia otis* was negatively correlated with the *Jamides celeno*(r = -0.446 p = 0.05). Relative abundance of other dominant butterflies didn't show any significant relation of among them.

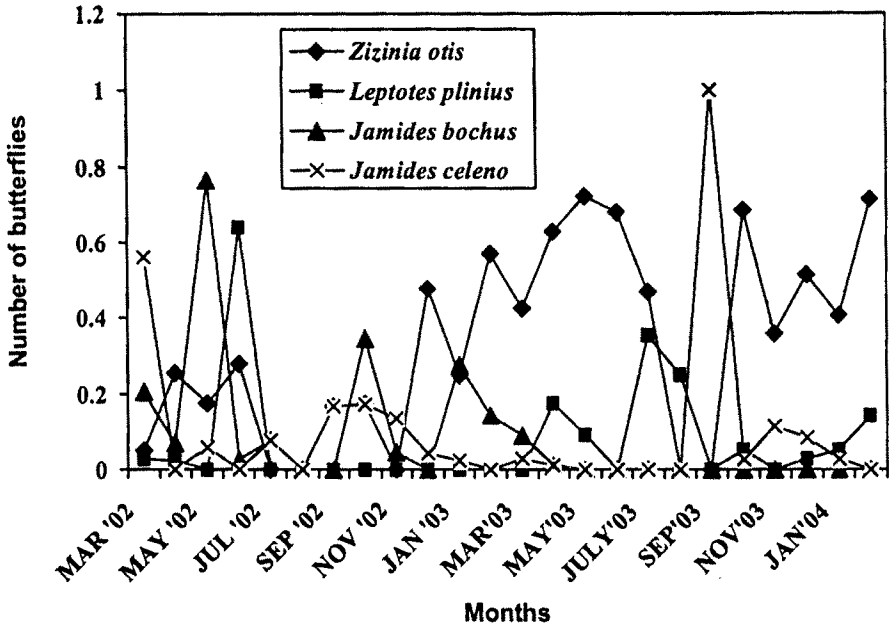



Figure 4.23. Monthly fluctuations in relative abundance of common Hesperiids

### 4.3.6.5. Family : Hesperiidae

A total of sixty butterflies of 5 species were recorded during 192 transect counts. The species recorded represent only 5 per cent of hesperiids reported in Western Ghats. Hespriids were abundant during Northeast monsoon (53%) and it was followed by Winter (33%), Summer (12%) and Southwest monsoon (12%) (Fig. 4.15). November was the

most abundant month for Hesperiids although a minor peak was observed in March (Fig. 4.16).

Among these butterflies, any significant relation in seasonal population trends between them was noticeable (Fig. 4.20). It may be due to the data being biased against the Hesperiids and less species of Hesperiids recorded in the study when compared to other families.

### 4.3.7. Nesting of birds and butterflies

Butterfly abundance coincided with the breeding season of birds with a one-month time lag (Fig. 4.22). Breeding activity of birds was more in March and October months. However, the butterfly abundance was more during March, April, November and December. The breeding activities of dominant birds' activity highly correlated with the butterfly abundance (Table 4.6).

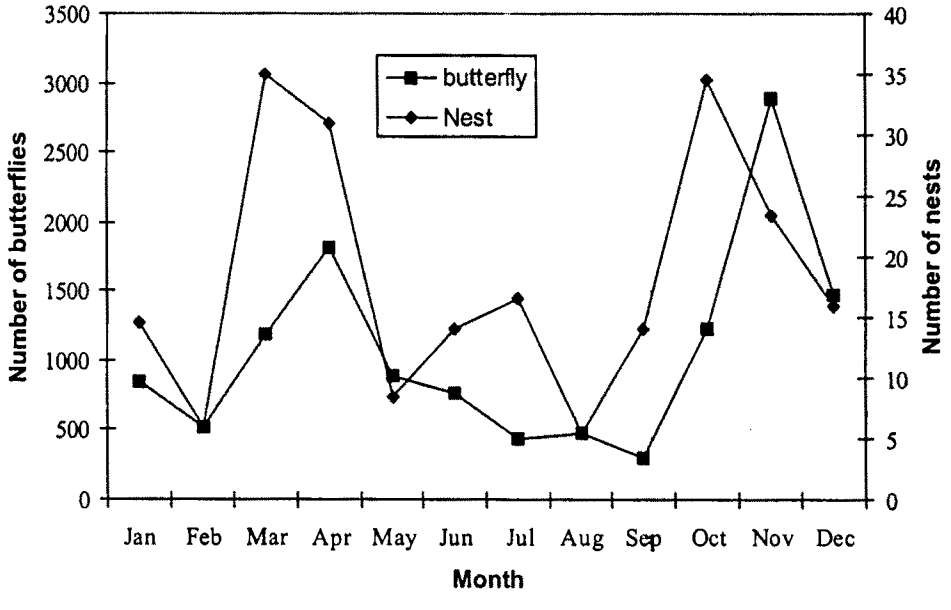



Figure 4.24. Seasonality variations of butterfly abundance and bird nest abundance observed in the study area.

## 4.4. Discussion

The observed pattern, Nymphalidae representing the maximum species and Pieridae representing maximum number of butterflies, is similar to report of the region. Arun (2000) and Mathew and Rahamathulla (1993) reported a similar trend from Siruvani and Silent Valley respectively. More number of butterflies was observed per transect count (120 / transect) in the study area compared to the studies in wet evergreen forest (71/transect) of Siruvani hills (Arun, 2000). The greater diversity in moderately disturbed forest areas could be attributed to the more availability of microhabitats and vegetation associated with disturbance (Bowmann *et. al.,* 1990; Thomas, 1991; Spitzer *et. al.,* 1993;). Devy and Davidar (2001) opined that more butterfly diversity in secondary forests could be due to richer availability of nectar resources.

Ehrlich and Raven (1964) brought out the coevolution of butterflies and their food plants. Extraordinary dominance of Pierids in this landscape could be due to the dominance of their larval food plants in the region. Vegetation analysis has brought out the dominant plants in the study area belongs to Caesalpinanceae, Caparidaecese and most of them are food plants of pierid butterlifes. Balasubramanian *et al.* (2001) also reported the dominance of the pierid food plants belonging to the genus *Capparis*, *Cassia*, *Bauhinia* and *Albizia* in the study area.

Butterflies have shown a unimodal pattern of diurnal activity with the peak between 1000hrs and 1400hrs. The nectar availability is high prior to and during noon hours as reported by Willmer (1983) and Kevan and Baker (1983). It might also be a strategy by butterflies to escape from the predators. The predation is more on the butterflies during morning before butterflies are able fly (Kingslover, 1987). The diurnal activity pattern of butterflies is strongly influenced by prevailing physical factors such as air temperature and light intensity (Taylor, 1963; Saunders, 1977; Pivnick and McNeil, 1987). Nectar availability is also influenced by temperature and light intensity (Kevan and Baker, 1983). Hence the diurnal activity pattern recorded in the study could be a strategy to get maximum food and predator avoidance.

Heighest butterfly diversity was recorded during Northeast monsoon. Southwest monsoon was recorded as the lean season for the butterflies. Kunte (1997) reported a similar pattern that butterfly species richness was higher in early winter (October and November) in northern Western Ghats. However, the present result is different from Arun's (2000) report from nearby Siruvni hill reported the highest butterfly abundance in Southwest monsoon and followed by Winter, Northeast monsoon and Summer respectively in the area which gets rain during the South west monsoon. As the study area falls inside rain shadow area of Western Ghats with the Northeast monsoon as the wet season for the region hence this pattern is to be expected.

Butterflies of the study area followed by a bimodal seasonality with one peak in March, April, May and another one in October, November, and December when the rainfall of the area was observed to be more. Butterfly population followed the rainfall pattern with a lag of one month. The heavy rainfall of a month created new flush of leaves and it resulted sudden hike in butterfly emergence in the subsequent months. Insect emergence in response to rainfall and their increase in abundance as the rainy season progress were reported earlier (Wolda, 1978b; Murali and Sukumar, 1993;). Kunte (1997) has reported that lycaenid populations showed rapid increase at the time when the plants were in suitable phenophase for growth of the caterpillar. Rainy season also provides floral richness and plant species (Raju *et. al.,* 2004). This indicates that larval food availability exerts the primary influence on the population dynamics of butterflies.

Bird diversity of the area showed a similar seasonality (Nirmala, 2002). Breeding activity of birds did not show any significant relation with the seasonal trend in total insect abundance of the area. Howeover, preceeding month's breeding activity of birds was found to correlate with butterfly abundance of the month. Selection of the breeding season by birds appears to be influenced more by abundance of specific insects such as butterflies than all insects. Increased abundance of soft bodied insects such as butterflies during breeding period could be advantageous for birds to support the the feeble digestive ability of chicks.

Butterfly abundance showed a negative correlation with mean monthly wind speed and this suggests that the butterflies do not prefer to emerge during windy months. Studies in Prairies of Iowa also showed that wind speed and direction influences the behaviour of butterflies (Ries and Debinski 2001).

The compensatory relationship in seasonality was observed among species under same families. It could be due to significant niche separation of congeneral species to facilitate the coexistence. Similar trends were observed in insects of families of the same orders in chapter3. Segregation of the preferred season among the coexisting members of the same community highlights how adaptations to seasonal changes similar way both in the higher taxonomic level and at the species level.

Anaikatty harbours nine endemic species of butterflies. While some of them are restricted to South India, other ranges the entire Indian Subcontinent. Three Schedule I species, Seven Schedule II species and one Schedule IV species of Wildlife Protection Act, 1972 were also observed from the Anaikatty hills (Appendix 1).

### 4.5. Summary

1. Butterfly community in the Anaikatty hills are numerically dominated by pierids; mainly because of the abundance of host plants.
2. There is a bimodal seasonality pattern in the butterflies which is related to the rainfall with the peak in a month's time lag.
3. Monthly mean wind speed showed a negative correlation with the butterfly diversity and the high wind speed could affect the flight and emergence pattern of butterflies.
4. The seasonal segregation among butterflies at family level as well as species level could be because of their variation in resource utilization pattern.
5. Anaikatty hills harbour significant proportion of the butterflies of Western Ghats; many of which are endemic and protected species.

Table 4.1. Seasonal abundance of various butterfly families. (values are in percentage)

| Family | Winter | Summer | Northeast monsoon | Southwest monsoon |
|---|---|---|---|---|
| Papilionidae (N = 2437) | 20 | 24 | 41 | 15 |
| Pieridae (N = 12353) | 27 | 24 | 34 | 16 |
| Nymphalidae (N = 7735) | 21 | 28 | 45 | 6 |
| Lycaenidae (N = 740) | 24 | 39 | 24 | 13 |
| Hesperiidae (N = 60) | 33 | 12 | 53 | 2 |

Table 4.2. Alpha diversity of butterflies for four different transects.

| Indices | Site 1 | Site 2 | Site 3 | Site 4 | Total |
|---|---|---|---|---|---|
| Grand Total | 5337 | 6029 | 5939 | 6020 | 23325 |
| Average | 68.423 | 77.295 | 76.141 | 77.179 | 299.038 |
| SD | 136.879 | 155.811 | 168.92 | 174.285 | 611.017 |
| Species Richness | 67 | 64 | 66 | 61 | 78 |
| Margalef's index | 7.6901 | 7.2378 | 7.4805 | 6.8943 | 7.6561 |
| Simpson index | 0.9367 | 0.9359 | 0.925 | 0.9228 | 0.9344 |
| Shannon index | 3.1284 | 3.099 | 3.0248 | 2.9516 | 3.0943 |
| Evennes index | 0.6918 | 0.7036 | 0.648 | 0.6768 | 0.6904 |

Table 4.3. Beta diversity indices of butterflies for four different sites

| Sites | 1,2 | 1,3 | 1,4 | 2,3 | 2,4 | 3,4 |
|---|---|---|---|---|---|---|
| Whittaker's index | 0.09 | 0.1 | 0.15 | 0.12 | 0.11 | 0.12 |
| Cody index | -0.82 | -0.79 | -0.7 | -0.76 | -0.79 | -0.76 |
| Jaccard Similarity index | 0.84 | 0.81 | 0.74 | 0.79 | 0.81 | 0.78 |
| Sorenson similarity index | 0.46 | 0.45 | 0.43 | 0.44 | 0.45 | 0.44 |
| Morisita-Horn index | 0.52 | 0.62 | 0.38 | 0.41 | 0.39 | 0.45 |
| Mean Euclidean distance | 261.35 | 255.13 | 411.42 | 312.48 | 413.96 | 414.88 |

Table 4.4. Pearson correlation coefficient among the seasonality of different butterfly families

| Family | Pieridae | Papilionidae | Nymphalidae | Lycaenidae | Hesperiidae |
|---|---|---|---|---|---|
| Pieridae | 1. | – | – | – | – |
| Papilionidae | 0.058 | 1. | – | – | – |
| Nymphalidae | -0.954** | -0.316 | 1. | – | – |
| Lycaenidae | -0.183 | -0.103 | 0.052 | 1. | – |
| Hesperiidae | -0.023 | -0.438* | 0.171 | -0.280 | 1. |

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 4.5. Pearson correlation coefficient between the butterfly species richness abundance, and climatic factors

| Factors | Species | Total |
|---|---|---|
| Wind (km./hr.) | -0.690* | -0.659* |
| Sunshine (hr./day) | 0.019 | -0.182 |
| RH (%) | 0.616** | 0.599** |
| Maxi temp (°C) | -0.439* | -0.335 |
| Min Temp (°C) | -0.486* | -0.250 |
| Rainfall (mm/month) | 0.137 | 0.386 |
| Rainy days (No.) | 0.145 | 0.374 |

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 4.6. Correlation coefficients of three common breeding bird species nest abundances with the total insects and butterflies of the study area (* p = 0.05).

| Bird Species | Previous month nest abundance | | Same month nest abundance | |
|---|---|---|---|---|
| | Butterfly | Total Insect | Butterfly | Total Insect |
| Jungle Babbler *Turdoides striatus* | 0.02 | 0.43 | **0.57*** | -0.12 |
| Purple Rumped Sunbird *Nectarinia zeylonica* | -0.03 | 0.20 | **0.73*** | 0.12 |
| Yellow Eyed Babbler *Chrysomma sinense* | **0.63*** | -0.41 | 0.06 | -0.56 |

* Correlation is significant at the 0.05 level (2-tailed)

# Chapter 5

# Aggregation of Butterflies

## 5.1. Introduction

For many reasons ethologists have focused relatively little attention on the ecological implications of their data and theories, and ecologists too have incorporated only a few results of investigation of animal behaviours into their theories and interpretations about ecology. Orians (2000) stressed the research needs about the role of any behaviour on population and community structure of a species.

In many populations, overall density alone cannot be helpful in understanding the long-term trend of a population. Hence, there is an increasing recognition that we must understand the clumped and other pattern of spatial distribution of species also to understand their population dynamics. As we give more attention to such distribution patterns, it is natural that search will also go on for specific secondary parameters such as food, parasite incidence, and predator abundance that causes the distribution of a species.

Aggregation, clumping together of individuals of the species for various reasons, has been observed in many groups of organisms such as insects, fishes, reptiles, birds and mammals (Hassel and May, 1974; Hastings, 1978; Hassel *et. al.*, 1985; Niwa, 1994). Aggregation of individuals of a species occur for getting food, mate, and to utilize the favourable time and space. Since aggregation is a product of individual movements, theories that relate aggregation with population dynamics hold the promise of viewing population ecology through behavioural ecology.

Species composition and cause of aggregation have been studied in diverse groups of insects. However, most of the studies have explored single species aggregation

and the causative factors. Aggregation of members of several species has been reported by studies about insect host-parasite and parasitoid (Hassel and May. 1974).

Although many observations were recorded regarding lepidopteran aggregations, studies of butterfly aggregation are scarce with some exception such as Monarch butterfly, *Danaus plexippus* (Gleddinning and Brower, 1990). Climatic parameters, food, parasitic incidence have been identified as the major factors determining the monarch migration (Altizer *et. al.*, 2000). However, butterfly migration was less studied in the tropics (Dingle, 1996). The present work is focussed on the aggregations of butterfly during two important behaviours of butterflies namely mud puddling and migration.

Earlier aggregation studies were focussed on the factors governing (Adler, (1982; Adler and Pearson. 1982; Boggs and Jackson, 1991), the aggregations and the modulation of aggregations with regard to the stimulus as in the case of mud-puddling butterflies . The variation of aggregation characteristics among butterflies are also not very clear. Hence, the present study aims to explore the following general questions.

1. How does species composition vary in aggregation?
2. What are relations fo aggregating butterflies with the regular and resident butterfly community of the area?
3. What are the habitat factors influencing these aggregation behaviours?
4. How does this aggregation behaviour vary among the different families of butterflies?

Mud-puddling and migration were studied to answer the above-mentioned general questions. Habitat qualities such as aggregation site availability and vegetation characteristics of the migratory path were also detailed. The species characters such as sex ratio of a species were studied. The overall butterfly population monitoring data, detailed in the previous chapter was compared to know the trend of the effect of aggregation on the overall butterfly population. The methodology has been discussed in each section.

## 5.2. MUD-PUDDLING

### 5.2.1. Introduction

The aggregation of a large number of butterflies on the soil to collect the minerals such as sodium and calcium is called as mud puddling (Boggs and Jackson, 1991; Haribal, 1992) (Plate 3.1). Minerals and nutrients procured during mud-puddling are essential for their flight and reproduction. Male butterflies require minerals for the long distance flight to find food and mate. Moreover, females need large quantity of minerals for egg development. However, Only male butterflies (98%) involve in the mud-puddling (Kunte, 2000). The reproductive fitness of males is influenced by mud-puddling behaviour because female butterflies select the male harbouring high quantity of minerals for mating. Hence, mud-puddling behaviours have been found to play an influential role on population dynamics of butterflies through the sexual selection (Kunte, 2000). It was also reported that mud-puddling site work as a substitute to nectar foraging during the natural catastrophes such as drought (Launer, *et. al.*, 1993)

### 5.2.2. Method

Wet and riverine areas were searched for mud-puddling. The transect path was three km in length in the stream sites of the area. Transects were monitored monthly between February 2002 and August 2003. However a few mud-puddling aggregations were also recorded and included from the four butterfly population monitoring transects detailed in chapter 4. As the butterfly population in the region and mud puddling were more in the April, November and December, transects count in stream was executed bimonthly. Samples of 30 individuals of the most common mud-puddling butterflies were captured by hand net to check their sex.

Species diversity of mud-puddling butterflies was recorded. Data was analyzed to identify the dominant species among groups and the interspecific association. Mud-puddling butterfly diversity and species assemblages were compared with the overall butterfly population of the area.

## 5.2.3. Result

### 5.2.3.1. Species Composition

Totally 337 groups of mud-puddlling aggregations were recorded. These constituded 19988 individuals of 54 species. The maximum number of species belonged to the family Nymphalidae followed by the Lycaenids. Abundance of butterflies vacillated between one and 6253 (Table 5.2). Frequency of observation of a butterfly species among the 337 observed aggregations ranged from one to 201. The *Cepora nerissa* was the most frequent (201 groups) followed by *Ixias pyrene* (Fig. 5.1).

Figure 5.2. shows the dominance curve of mud-puddling butterflies in the study area. The *Catopsilia pomona* was the most abundant butterfly in mud-puddling (6253 individuals). *Cepora nerissa, Papilio polytes, Ixias pyrene* and *Papilio demoleus* were the other most abundant butterflies of the mud-puddling aggregations of Anaikatty hills.

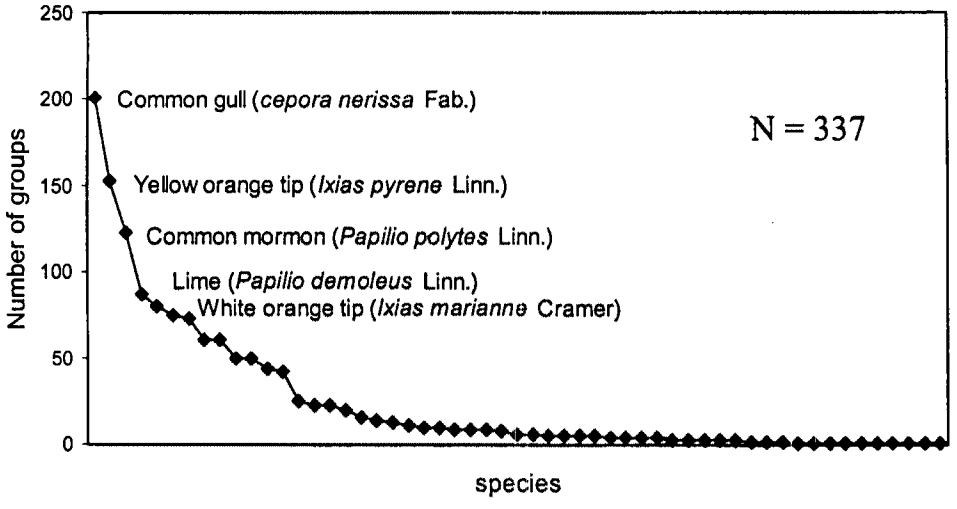



Figure 5.1. Frequency of occurrence of mud-puddling butterfly species in 337 groups.

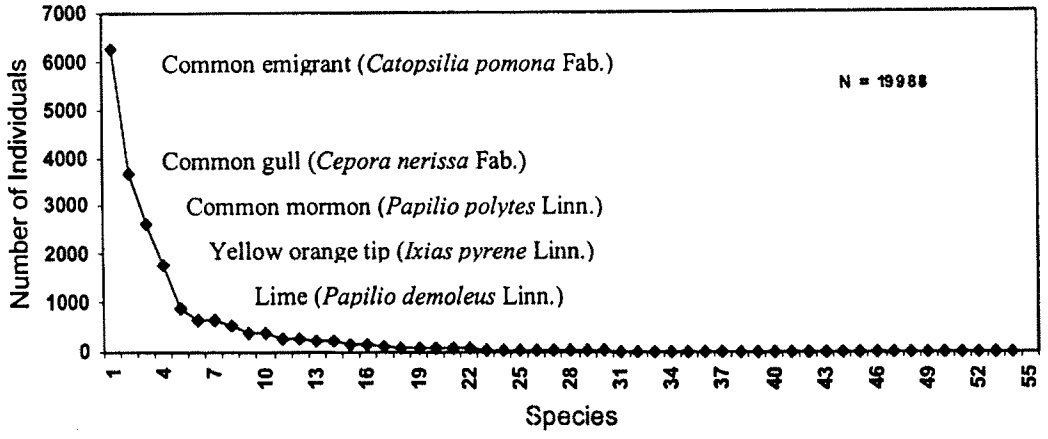



Figure 5.2. Dominance curve of mud-puddling butterflies in the Anaikatty hills

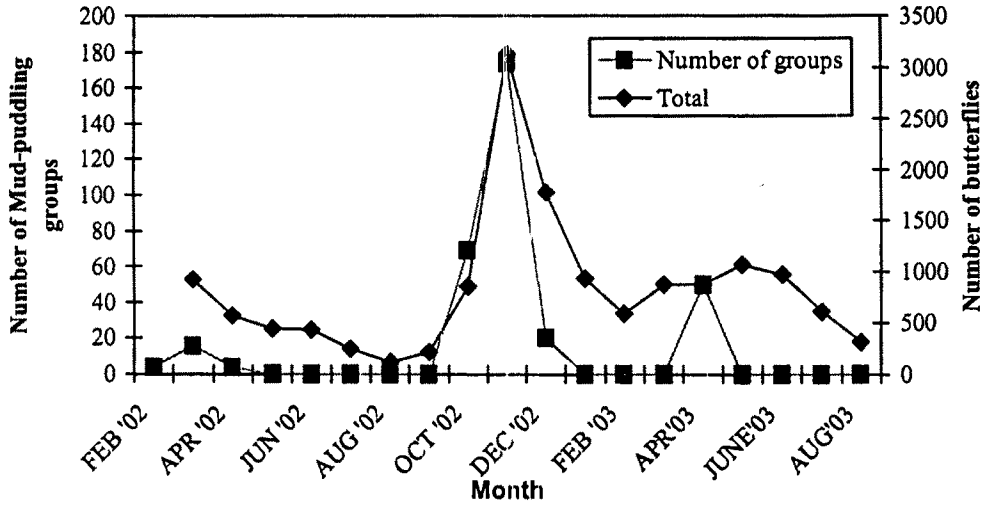



Figure 5.3. Monthly fluctuations in mud-puddling groups recorded and butterfly abundance recorded in the transect counts at the study area.

### 5.2.3.2. Seasonality

Mud-puddling groups reached maximum proportions during rainy months such as March - May and October-December (Fig. 5.3). Of the 337 groups studied, about 100 groups were observed in the first and second weeks of November after a week of continuous rain.

### 5.2.3.3. Effects on Butterfly Community

The species composition and diversity pattern of the overall regular resident butterflies in the area and the those of the mud-puddlers alone were similar. The number of butterflies encountered in mud-puddling was far greater than sum total of all individuals encountered continuously through transects for two years (Table 5.1). In addition, Mud-puddling behaviour was recorded more during March-April and October-November.

### 5.2.3.4. Group size variation

The cluster of the mud-puddling aggregations differed between three and 625 individuals. Figure 5.4 shows the group size distribution of aggregations. It followed an unimodal curve with the maximum of four-species-aggregation (77 groups). Another interesting observation was that in many cases species of similar sized butterflies observed as mud-puddling together.

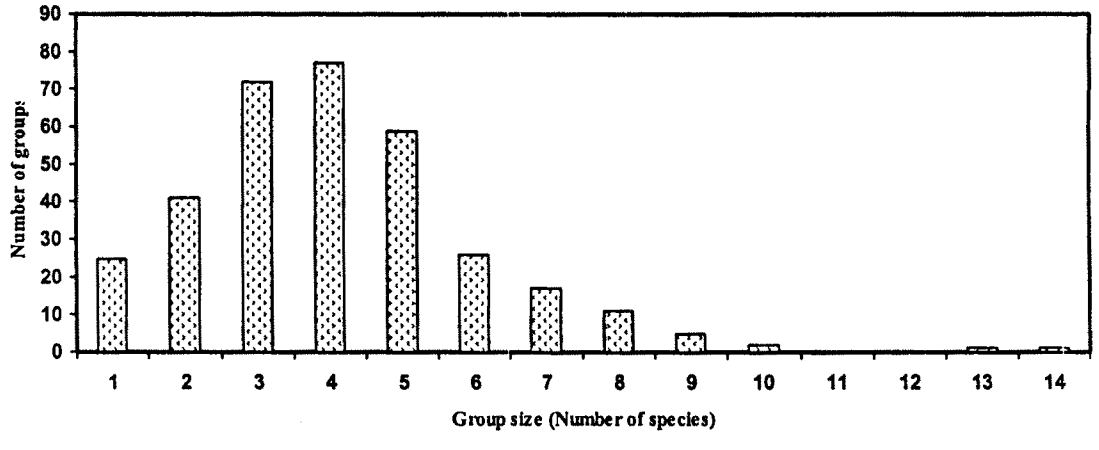



Figure 5.4. Group size distribution of butterflies aggregations in mud-puddling in the study area.

## 5.3. MIGRATION

Migration has an important role in dispersal especially with respect to invertebrates. It also encourages out-breeding of the species and helps them avoid unfavourable climatic conditions. Migration of the butterflies in India has so far not been critically studied. In a strict sense, the term migration is referred as a two-way journey undertaken by the animals from feeding ground to breeding ground and vice versa. The definition for migration with respect to butterfly does not follow the classic two-way pattern. A generation travels only one direction and individuals traveling in the opposite direction belong usually to the succeeding generation (Williams, 1930).

### 5.3.1. Butterfly migration in India

Migration of butterflies has been reported from many places in India. Ten species of butterflies have been regarded as common migratory butterflies in India although a total of 36 species are reported in migration from here. The annual butterfly migration in southern India is larger and more regular unlike in northern India where it occurs occasionally (Williams 1938; Reuben 1961; Larsen, 1978; Chaturvedi, 1993; and Bharos 2000). Butterfly migration in the Nilgiri Mountains and Palni hills were monitored and reported in earlier days (Williams 1938; Larsen 1978, 1987). The Dark blue tiger (*Tirumala septentrionis*), Blue tiger (*Tirumala limniace*), Common Indian crow (*Euploea core*), Double branded crow (*Euploea limniace*) Common emigrant (*Catopsilia pomona*) and Common albatross (*Appias albina*) are the widespread migrating butterflies in Nilgiris (Evershed 1910; Larsen 1978; Williams 1938). Migration of butterflies occurs in October -November and April-May (Williams 1930, 1938).

The ecological significance of this phenomenon is also less understood. The direction and migratory path of butterflies were reported occasionally as a passing reference. Since, butterflies change the direction of movement according to local climatic and geographical circumstances (Spieth and Kascuba-Holtgrave, 1996), year round continuous monitoring is required to know the regional migration direction and migratory

path and frequency. Effect of the landscape characteristics on butterfly migration is also unexplored so far. Information about the aggregation sites of the migrating butterflies at a regional level is also scanty and is important to understand the riddles of this phenomenon.

## 5.3.2. Methods

### 5.3.2.1. Butterfly count

The number of migratory butterflies crossing a particular spot with in ten minutes was counted using a tally counter (Toshiba, Taiwan). Butterflies crossing approximately 10X10m area were recorded in open clearings. However, in forested areas, the pollard transect method was followed. The approximate height of the flight was also recorded.

### 5.3.2.2. Migratory path and direction

The direction of migration was observed in various points in the area. Then the migratory path of butterflies was marked in 1km transect units. The larger group of moving butterflies was followed to trace its path. The topography of the migratory path was also recorded. The migratory path was drawn using the GIS software viz., Map Info. Migratory butterflies were found feeding on nectar from the flowers. Another interesting observation was the high incidences of mud-puddling of *Catopsilia pomona* during migration. The details of the feeding while migrations were recorded in detail.

### 5.3.2.3. Aggregation sites

Physiognomical and geographical characters of large aggeragtions of migrating butterflies were noted. The proportion of each species in a migrating group was also estimated.

### 5.3.2.4. Sex ratio and wing damage pattern

To identify the sex and extent of damage to wings, butterflies were caught using a hand net. The sex ratio was calculated and wing damage taken as an indirect measure to assess the age and distance travelled (Kunte, 2000).

In the present study, a simple method was used to study the wing damage pattern during the 2005 migration. Butterflies were ranked from 0 to 5 according to the extent of damage (Plate 3.2). Rank one was assigned if damage was wast in the sub-marginal area of a fore wing or hind wing. If the damage was present in both wings, rank two was allocated. One more rank was added if the damage present up to the post discal area from the margin. If the damage was present in both discal areas it was given rank four. The maximum rank, five, was allotted if the damage is present beyond the post discal area.

### 5.3.3. Result

### 5.3.3.1. Diversity of migratory butterflies

*Tirumala septentrionis*, *Tirumala limniace*, *Euploea core*, *Euploea sylvester*, *Papilio demoleus*, *Appias albina* and *Catopsilia pomona* were observed to migrate through the Anaikatty hills.

Butterfly population during migratory and non migratory days of the same season were different. The mean abundance was 295.09 individuals per ten minutes during migratory days whereas 49.91 individuals during the nonmigratory days. Observations were recorded over a period of 960 minutes. This shows a six times greater abundance during migratory days (29329 individuals) than during non-migratory days (4971 individuals) (Table 5.3).

### 5.3.3.2. Seasonality

Migration of butterflies was recorded during March, April, July, October, November and December. The direction of migration was from Southeast to Northwest except in July 2004 when it was in the opposite direction (Northeast to Southwest).

### 5.3.3.3. Effects on Butterfly Community

Abundance of migratory butterflies was observed as high during migrating months although the transect count was executed in the non-migratory days (Fig. 5.5). The abundance of the local population of migratory butterflies showed profound increase and the abundance trend of butterflies was similar to other butterfly abundances ($r = 0.500$ $p = 0.05$) of the area. However, migratory butterflies were the most abundant immediately after the rainy months and other butterflies follow it.

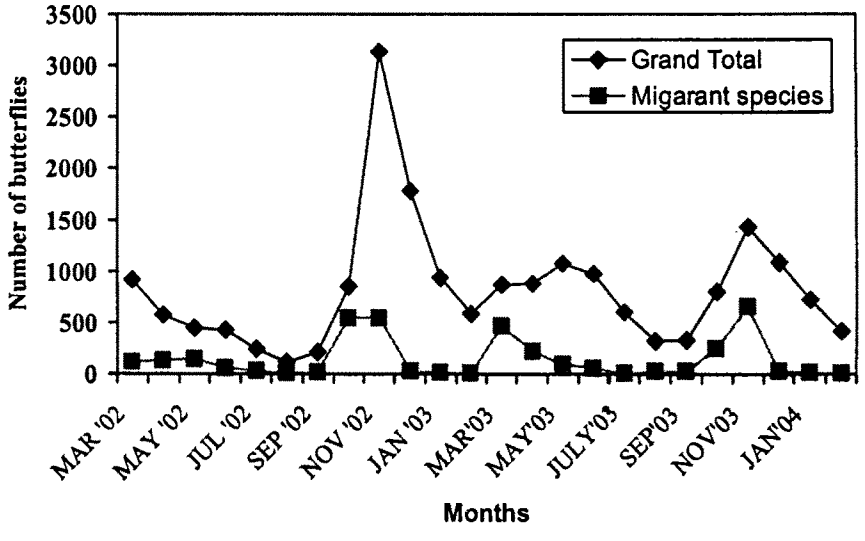



Figure 5.5. Fluctuations in abundance of five migratory butterflies and total butterflies recorded in transect counts during the study period.



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### 5.3.3.4. Factors regulating the migration

**Habitat qualities**

**a). Aggregation sites**

Thirty-six butterfly aggregation sites in both migratory and non-migratory period were observed in several parts of NBR such as Anaikatty hills, Kotagiri hills and Velliangiri hills. The most common plants species observed in the aggregation sites were *Bamboosa, Lantana camera, Ocimum* sp., and *Terminalia arjuna* (Fig. 5.6) (Plate 3.5). The sites chosen by butterflies for aggregation were shady, humid and protected from the strong winds. Off 40 aggregation sites recorded significant proportion were near water sources and in wind protected area (Fig. 5.7).

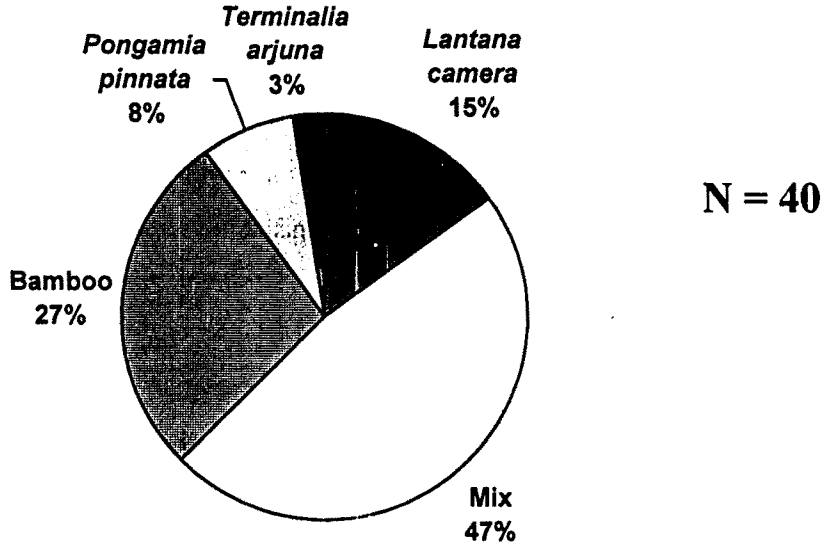


Figure 5.6. Percentage composition of plants in which migratory butterflies were observed resting in aggregations.

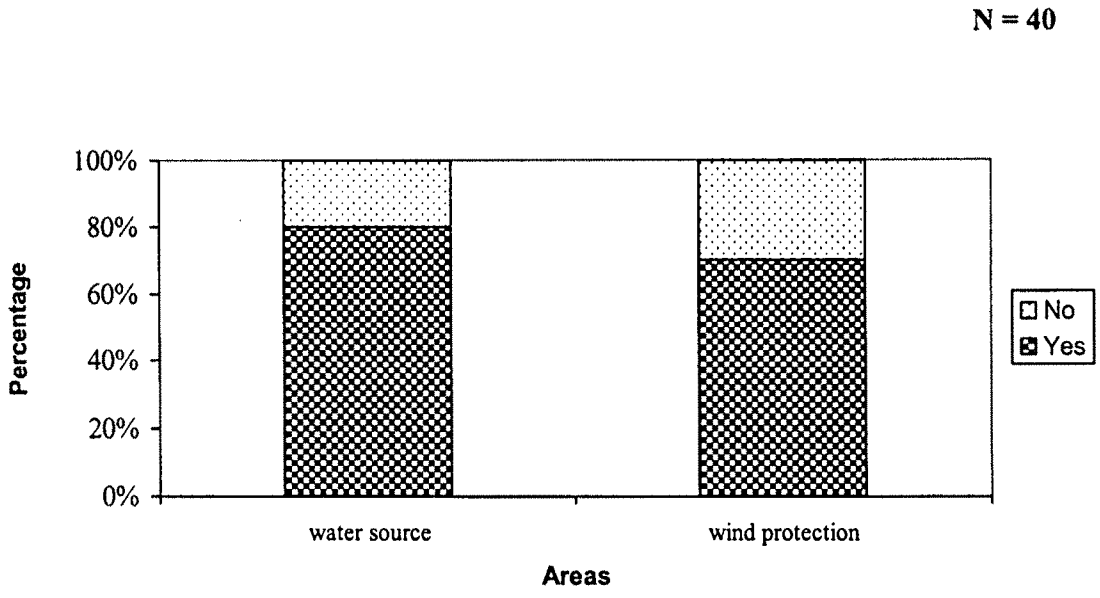


Figure 5.7. Water source and wind protection Characteristics of aggregation sites

**b) The migratory path and source area**

The migratory paths of the butterflies from Kotagiri hills to Velliangiri hills through Anaikatty hills was traced with frequent visits and through the help of local informants (Plate 3.3). The migration direction was downward from the upper Nilgiris. Butterflies were found to follow the valleys of the area for migration. Five distinct valleys that connect the upper Nilgiris with the plains facing the study area are shown in (Plate 3.4). The valleys are Moyyar, Kothagiri, Conoor, Pillur, Manjur and Silent Valley. We had recorded migration in all the valleys. The width of the groups of migrating butterflies extended to more than a kilometer. Though the direction of migration was specific, changes in direction were noticed especially at Kongarathan peak, where they tended to travel around the peak and not over.

Migrating butterflies were seen to feed on nectar of *Lantana camera*, *Todalia asiatica* and *Acacia canescens*. These observations were found all along the migratory

path particularly in open areas. Many long distance migrants have to refuel repeatedly during the migration (Hadenstrom, 2003). Velliangiri hills were observed to serve as source areas for production of large number of larva of Lepidoptera in general and for migratory butterflies particularly. We recorded the thousands of simultaneous pupa and larvae from the Velliangiri hills (Plate 3.6). Migration probably ended at the foothills of Velliangiri hills as was evident from the subsequent boom in caterpillar population of the migrating species during the subsequent months.

**c). Sexual variation in ratio and Wing damage**

The sex ratio of the migrating population was not 1:1. The sex ratio difference was significant in the migrating species such as *Tirumala septentrionis* ($X_1^2 = 4.35$ $p < 0.05$), *Euploea core* ($X_1^2 = 5.24$ $p < 0.05$) and *Euploea sylvester* ($X_1^2 = 47.09$ $p < 0.005$) (Table 5.4). There was a propensity towards a greater female population in *Catopsilia pomona, Tirumala septentrionis* and *Euploea core*. However, it was otherwise in *Euploea sylvester, Papilio demoleus and Appias albina*.

Wing damage pattern showed that males had more damaged wings than females (Table 5.5).

**d) Predation**

Asian Paradise flycatcher (*Terpsiphone paradisi*) and Black Drango (*Dicrurus macrocerus*) were observed feeding the migrating butterflies.

**5.3.3.5. Danainae and Pieridae Migrations**

The pierid butterfly, *Catopsilia pomona* was observed to migrate as a single species. Where as the danainae butterflies migrated as a more than one species group with *Tirumala septentrionis, Tirumala limniace, Euploea core* and *Euploea sylvester*. Moreover, *Tirumala septentrionis* has been found influencing the overall migratory butterflies population trend (Figure 5.8). While pierid butterflies were engaged in mud-puddling behavior, the danaids were aggregating on uprooted plants of *Lantana* and

*Todalia. Catopsilia pomona* was recorded in greater frequency of more than 75 groups with 6253 individuals in mud-puddling during their peak migratory days.

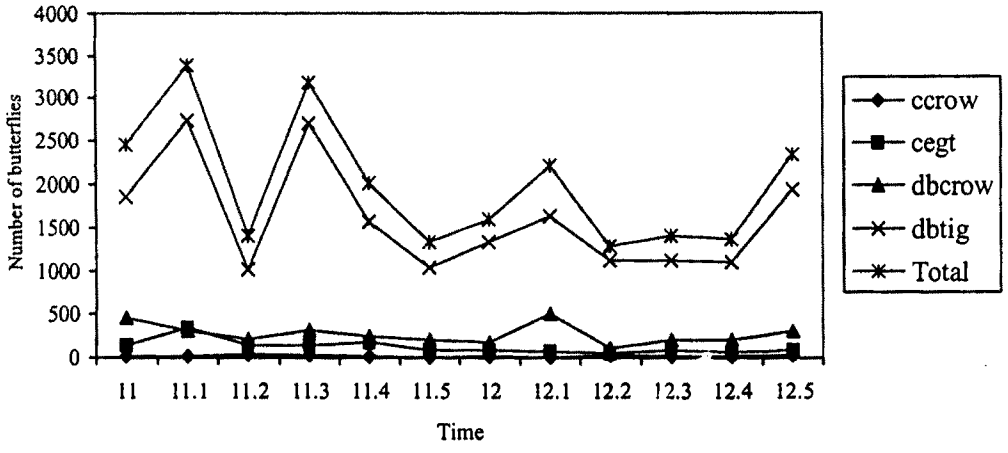


Figure 5.8. Abundance trend of the migratory butterflies and comparison with the total migratory butterflies (ccrow = *Euploea core*, cegt = *Catopsilia Pomona*, dbcrow = *Euploea sylvestor*, dbtig = *Tirumala septentrionis*)

## 5.4. Discussion

The mud-puddling groups were more during the butterfly abundant months. Mud-puddling incidences coincided with the butterfly abundance period of the area. Though not conclusively, the present study also support the available hypothesis that mud-puddling site work as an alternative foraging areas and works as a measure of competition exclusion between the males and females (Boggs and Jackson, 1991).

Migrating butterflies and the period of migration observed in the Anaikatty hills augment with the earlier reports in Nilgiris (Evershed 1910; Larsen 1978; Williams 1938).

Pierids were the most abundant mud-puddlers. It could be due to the Pierid dominance in butterfly community as reported in chapter 4. As peak mud-puddling coincided with a spurst in the pierid population it could be attributed to the fact that the behaviour might be an alternate food source. However all the mudpuddlers were young males. Similar reports were made earlier (Adler 1982; Alder and Pearson 1982; and Boggs and Jackson 1991).

Butterflies selected humid, shady and wind protected such as hill slope for aggregation, which is similar to the observations in Monarch butterflies (Dingle, 1996).

Predation by birds such as Asian Paradise flycatcher (*Terpsiphone paradisi*) and Black Drongo (*Dicrurus macrocerus*) were recorded. Similar observation was reported in Monarch butterflies also. Glendinning and Brower, (1990) have reported predation of winter aggregating Monarch butterflies by mice and the populations of four sympatric species of mice have been influenced by monarch butterfly aggregation.

Migratory butterflies were found to change the direction of migration according to local barriers such as mountain peaks. Spieth and Kaschuba-Holtgrave (1996) reported that butterflies change migratory path according to the local circumstances. However the present study recorded that mountain peaks also act as major barrier during the migration.

Migrating butterflies were observed to feed on nectar of *Lantana camera*, *Todalia asiatica* and *Acacia canescens*. Brower (1995) reported that butterflies feed while migration to increase energy storage required for flight. The long-distance migrant has to refuel repeatedly during the migration; although it slowdown their overall rate of travel (Handerstorn, 2003)

Male migratory butterflies had more damaged wings than females. Kunte (2000) explained that butterfly wing damage is an indirect measure of the age of the butterflies and the distance they traveled. It may be assumed that the males may have traveled larger

distances for finding a mate. And it supports the protandry mechanisms that reported in many species.

The irregular sex ratio may be a strategy to escape from predation and parasitization. Parasitization by protozoa was observed more in crowded population such as Monarch butterfly (Altizer et al., 2000).

The sex ratio of the migrating butterflies was not 1:1. The heavy deviation towards male butterflies in the present study could be due to the following reasons. Only males could have initiated migration themselves to migrate first and hence is the congregation of males were more in number. Secondly, the emergence of males some time before the female (protandry) could be a reason and it increases the mating chances of males (Wiklund and Fagerstorm, 1977; Zonneveld, 1996). Ehrlich *et. al.*, (1984) reported that the sex ratio in *Euphydryas editha* skewed towards male and they opined that the observation could be due to higher pre-adult mortality in females, emigration of female and possibly higher adult mortality. The earlier studies reported protandry as well as protogyny (female emergence earlier) in butterflies. Prokopy and Roitberg (2001) reported sex ratio difference in many species of non social insects aggregated in mating sites and feeding sites.

### 5.4.1. Mud-pudddling and Migration Vs Resident Butterfly community

Aggregation of butterflies for migration as well as mud-puddling were observed during the rainy months when butterfly abundance was also in peak. We could infer that the favourable climatic conditions and the resultant boom in population necessitate the mud-puddling and migration in the butterfly community of the area. Similar results of migration and aggregation of insects on plants were reported earlier. It is an excellent example of the behavioural responses to population dynamics and activity of the seasonal tropical forest.

Group size of butterflies in mud-puddling and migration varied in different parts of the area. As suggested earlier, butterfly community of the whole area should be considered as one unit for the conservation action. Mud-puddling and migratory butterflies give insights to the population dynamics and regulating factors and hence help in developing a conservation action plan.

As there is no non resident species involved in migration, it did not affect the species richness of the butterfly community. Hence there may not be competetion by migratory species for space and food with other resident species. It could be due to the food specialization observed in the world of butterflies.

### 5.4.2. Limitation and the way ahead

The present work brought up many baseline informations for future studies. Since the butterfly migration occurs in a short period of one or two weeks, most of the data about the migration such as migratory path, aggregation site and height of migration were more of qualitative in nature. To study the overall migratory patterns and process in the study area and Nilgiris it needs more indepth studies with co-ordinated effort and that falls outside the scope of this thesis.

The present study brought out some interesting lacunae in the knowledge of mud-puddling and migratory aggregations of butterflies. a) Migratory and non-migratory populations of butterflies need to be studied separately to understand butterfly diversity and dynamics of populations at the local and regional levels. b) Anthropogenic pressure on the migratory path and the aggregating places need to be studied. c) More aggregation site and source areas in the Western Ghats need to be mapped and protected.

## 5.4. Summary

1. Pierid butterflies were more abundant in the mud-puddling, reflecting their numerical abundance in the Anaikatty hills.
2. Young males were abundant in the mud-puddling butterflies.
3. Butterfly community of the area as well as in the mud-puddling was almost similar.
4. There is a significant correlation between the butterfly population abundance of the area and mud-puddling incidences.
5. The present work strengthern the hypothesis that mud-puddling sites might be alternative sources for butterflies to avoid competition.
6. Butterfly migrates in and through the study area during March, April, July, October, November and December.
7. However, such migration of butterflies did not affect the butterfly diversity of the area.
8. Direction of migration changes at local level, but the particular direction was maintained at the regional level.
9. The sex ratio of the migrating butterflies deviates from 1:1.
10. Nymphalids migarate along with other species, while pierids does so alone.
11. The migratory pierids aggregate in mud-puddling while nymphalids do so on the roots of uprooted plants.
12. The migratory butterflies used the bamboos and stream sites; wind protected areas; as aggregation sites.
13. The number of butterflies recorded in mud-puddling was more than that the total transect counts, although mud-puddling was recorded only in a few months.
14. The protection of sites used for mud-puddling and aggregation of migratory butterflies are important for the conservation of butterflies.
15. Since there are specific locations for mud-puddling, breeding and also migaratory route, conservation of the butterfly requires protection for the entire area.

Table 5.1. Comparison of species richness and abundance recorded in mud-puddling and transect counts of butterflies (Two years transect count data)

| S.No | Family | Species Richness | | Abundance | |
|---|---|---|---|---|---|
| | | **Mud-puddling** | **Total Butterfly** | **Mud-puddling** | **Total Butterfly** |
| 1. | Nymphalidae | 19 (35) | 26 (33) | 1589 (8) | 7735 (33) |
| 2. | Lycaenidae | 13 (24) | 20 (26) | 687 (3) | 740 (3) |
| 3. | Pieridae | 11 (20) | 16 (21) | 13829 (70) | 12353 (54) |
| 4. | Papilionidae | 9 (17) | 12 (15) | 3846 (19) | 2437 (10) |
| 5. | Hesperiidae | 2 (4) | 4 (5) | 37 (<1) | 60 (<1) |
| | Total | **54** | **78** | **19988** | **23325** |

- **Percentage values with in parenthesis**

Table 5.2. Butterfly species recorded in mud-puddling.

| Common name | Scientific name | Average |
|---|---|---|
| Three-spot grass yellow | *Eurema blanda* Bois. | 9.900 |
| Pale 4-line blue | *Nacaduba hermus nabo* Fruh. | 9.000 |
| Baronet | *Euthalia nais* Fors. | 2.333 |
| Brown awl | *Badamia exclamationis* Fab. | 6.200 |
| Common blue bottle | *Graphium sarpedon* Linn. | 4.260 |
| Blue mormon | *Papilio polymnestor* Cramer. | 3.500 |
| Blue pasny | *Junonia orithya* Linn. | 1.000 |
| Common albatross | *Appias albina* Bois. | 8.836 |
| Common beak | *Libythia lepita* Moore | 1.900 |
| Common banded peacock | *Papilio crino* Fab. | 1.273 |
| Common castor | *Ariadne merione* Cramer | 2.000 |
| Common cerulean | *Jamides celeno* Cramer | 1.750 |
| Common crow | *Euploea core* Cramer | 2.957 |
| Common emigrant | *Catopsilia pomona* Fab. | 83.373 |
| Common gull | *Cepora nerissa* Fab. | 18.199 |
| Common grass yellow | *Eurema hecabe* Linn. | 2.750 |
| Chocolate pansy | *Precis iphita* Cramer | 8.803 |
| Common leopard | *Phalanta phalantha* Drury | 6.810 |
| Common mormon | *Papilio polytes* Linn. | 21.333 |
| Common nawab | *Polyura athamas* Drury | 4.929 |
| Common pierrot | *Castalius rosimon* Fab. | 4.167 |
| Crimson tip | *Colotis danae* Fab. | 1.000 |
| Common sailor | *Neptis hylas* Moore | 1.200 |
| Double branded crow | *Euploea sylvester* Fab. | 2.667 |
| Dark blue tiger | *Tirumala septentrionis* Butler | 6.800 |
| Dark cerulean | *Jamides bochus* Cramer | 3.111 |
| Danaid egg fly | *Hypolimnas misippus* Linn. | 3.308 |
| Dark grass blue | *Zizeeria karsandra* Moore | 2.000 |
| Gram blue | *Euchrysops cnejus* Fab. | 30.000 |
| Great eggfly | *Hypolimnas bolina* Linn. | 1.222 |
| Great orange tip | *Hebomoea glaucippe* Linn. | 5.341 |
| Indian skipper | *Spialia galba* Fab. | 1.200 |
| Lemon emigrant | *Catopsilia crocale* Cramer | 1.500 |
| Lesser grass blue | *Zizinia otis* Fab. | 11.160 |
| Lime butterfly | *Papilio demoleus* Linn. | 10.023 |
| Lemon pansy | *Junonia lemonias* Linn. | 7.480 |
| Malabar banded peacock | *Papilio budha* West. | 2.000 |
| Mottled emigrant | *Catopsilia pyranthe* Linn. | 6.607 |
| Pea blue | *Lampides boeticus* Linn. | 5.500 |
| Pale grass blue | *Pseudozizeeria maha* Kollar | 11.000 |
| Pioneer | *Anaphaeis aurota* Fab. | 20.500 |

Table 5.2. contd....

| Common name | Scientific name | Average |
|---|---|---|
| Plain tiger | *Danaus chrysippus* Linn. | 2.000 |
| Red helen | *Papilio helenus* Linn. | 1.000 |
| Rounded pierrot | *Tarucus nara* Kollar | 9.000 |
| Red pierrot | *Talicades nyseus* Gue.-Men. | 1.000 |
| Rustic | *Cupha erymantis* Drury | 1.000 |
| Spot sword tail | *Graphium nomius* Esper. | 3.478 |
| Striped tiger | *Danaus genutia* Cramer | 1.000 |
| Tiny grass blue | *Zizula hylax* Fab. | 10.063 |
| Tailed jay | *Graphium agamemnon* Linn. | 2.000 |
| White four ring | *Ypthima ceylonica* Hewit. | 2.667 |
| White orange tip | *Ixias marianne* Cramer | 8.325 |
| Yellow orange tip | *Ixias pyrene* Linn. | 11.588 |
| Yellow pansy | *Junonia hierta* Fab. | 2.000 |
| Zebra blue | *Leptotes plinius* Fab. | 7.556 |

Table 5.3. Comparison of the diversity of butterflies during migration and non-migratory period (the comparison executed for 96 ten minutes counts).

| S. No. | Characters | Non migratory | | Migratory | |
|---|---|---|---|---|---|
| | | Species Richness | Abundance | Species Richness | Abundance |
| 1. | Min | 5 | 7 | 3 | 12 |
| 2. | Max | 18 | 157 | 22 | 2670 |
| 3. | Mean | 11.25 | 49.91 | 11.35 | 295.09 |
| 4. | SD | 3.17 | 32.65 | 3.98 | 574.44 |
| 5. | CV | 0.28 | 0.65 | 0.35 | 1.95 |
| 6. | Total | 53 | 4791 | 53 | 28329 |

Table 5.4. Sex ratio of migrating butterflies

| S. No | Species | Male | Female | Total | Male : female (%) | Chi square Value |
|---|---|---|---|---|---|---|
| 1. | *Tirumala septentrionis* | 141 | 226 | 367 | 38: 62 | $X^2_1 = 19.69$ $p < 0.005$ |
| 2. | *Euploea core* | 113 | 179 | 292 | 39 : 61 | $X^2_1 = 14.92$ $p < 0.005$ |
| 3. | *Euploea sylvester* | 236 | 48 | 284 | 83 :17 | $X^2_1 = 124.45$ $p < 0.005$ |
| 4 | *Tirumala limniace* | 116 | 54 | 170 | 68 : 32 | $X^2_1 = 22.61$ $p < 0.005$ |
| 5 | *Papilio demoleus* | 538 | 42 | 580 | 93 : 7 | $X^2_1 = 424.16$ $p < 0.005$ |
| 6 | *Catopsilia pomona* | 118 | 362 | 480 | 25 : 75 | $X^2_1 = 124.03$ $p < 0.005$ |
| 7 | *Appias albina* | 73 | 47 | 120 | 61 : 39 | $X^2_1 = 5.63$ $p = 0.05$ |

Table 5.5. Comparison of wing damage pattern variation between males and females among common migratory butterflies. The rank 0, the minimum rank, was given to no damage. Maximum rank, 5, was given to more damaged butterflies (for more detatils see Plate 1.)

| Species | Sex | Damage Rank | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | |
| *Tirumala septentrionis* | Female | 51 | 27 | 53 | 19 | 13 | 3 | 166 |
| | Male | 12 | 25 | 35 | 22 | 15 | 9 | 118 |
| *Tirumala limniace* | Female | 18 | 30 | 9 | 4 | 1 | 2 | 64 |
| | Male | 10 | 22 | 47 | 13 | 11 | 11 | 114 |
| *Euploea core* | Female | 15 | 14 | 37 | 28 | 18 | 5 | 117 |
| | Male | 19 | 26 | 14 | 7 | 5 | 2 | 73 |
| *Euploea sylvester* | Female | 3 | 7 | 6 | 4 | 1 | 0 | 21 |
| | Male | 46 | 54 | 44 | 30 | 12 | 5 | 191 |
| *Papilio demoleus* | Female | 3 | 5 | 10 | 14 | 6 | 4 | 42 |
| | Male | 64 | 143 | 124 | 107 | 74 | 26 | 538 |
| *Catopsilia pomona* | Female | 107 | 83 | 81 | 63 | 18 | 10 | 362 |
| | Male | 16 | 25 | 27 | 22 | 17 | 11 | 118 |
| *Appias albina* | Female | 17 | 14 | 10 | 3 | 2 | 1 | 47 |
| | Male | 30 | 18 | 12 | 8 | 3 | 2 | 73 |

Plate 3.1. Mud-puddling behaviour of butterflies

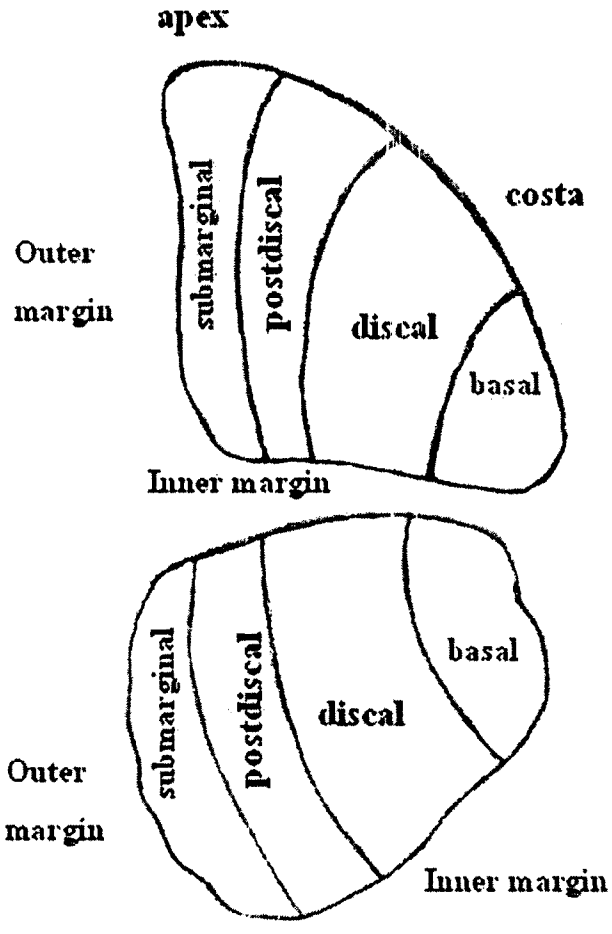


**Plate** 3.2. Different parts of the butterfly wings. Rank 1 was given to the butterflies having the damage in submarginal area and rank two was given f the damage reached post discal area. If the damage present both the fore wings and hind wings then the rank will be doubled as three and four. The damage thet are more than post discal area (or) reached discal area, brought maximum rank i.e., five.

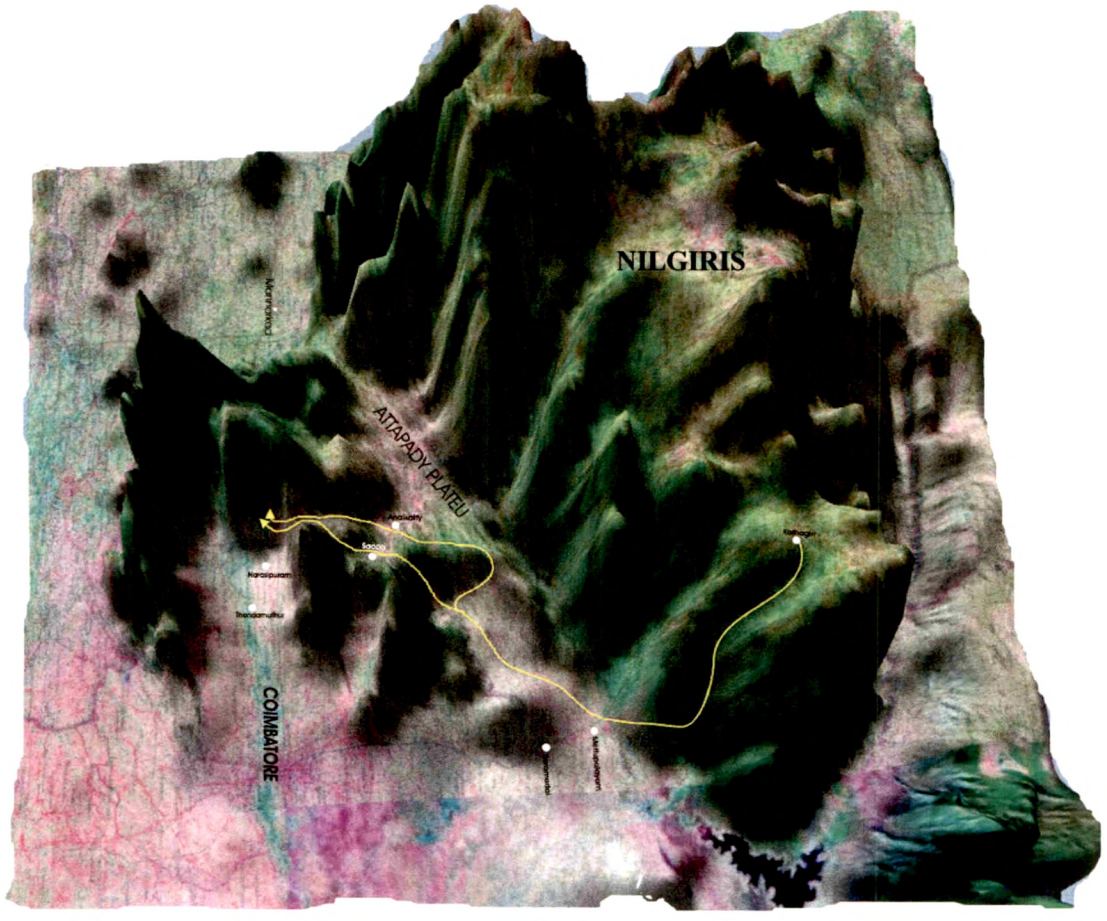


Plate 3.3. Three dimensional view of Nilgiris and the migratory path of butterflies recorded from Kotagiri to Velliangiri hills

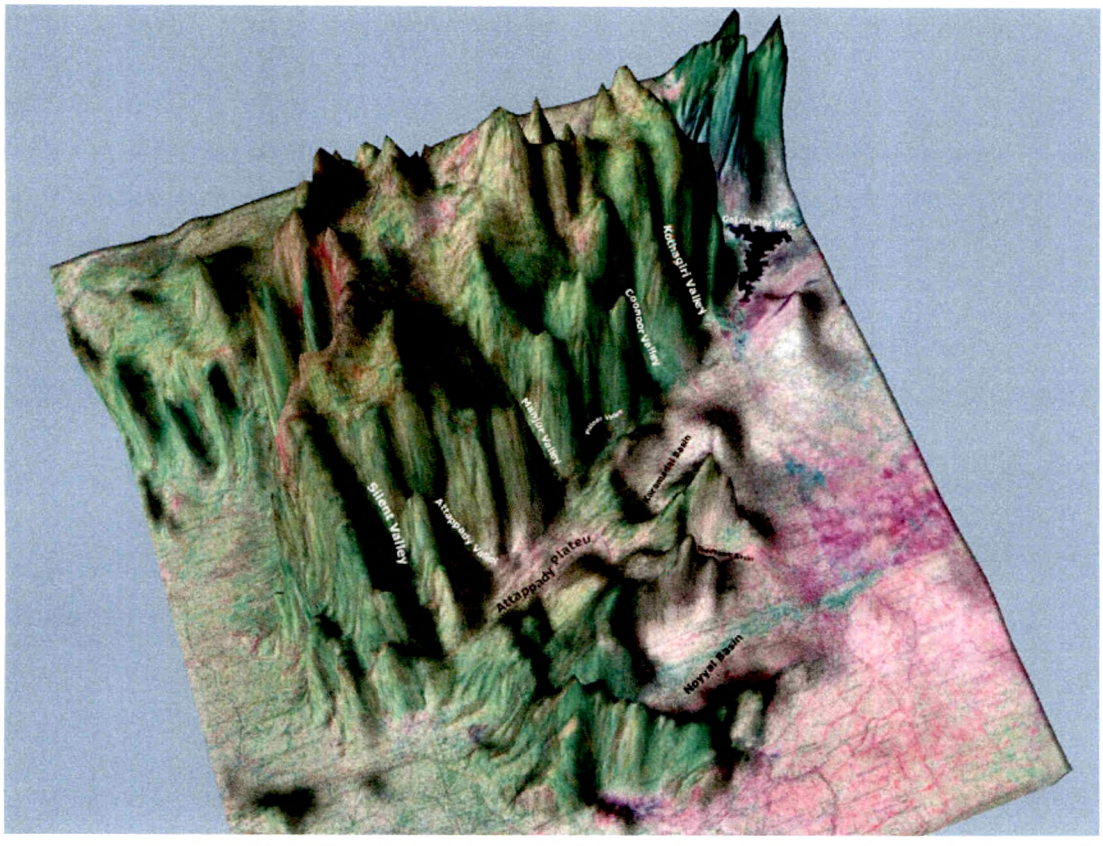


Plate 3.4. Valleys of Nilgiris. Butterflies migration observed in all the valleys except Silent Valley

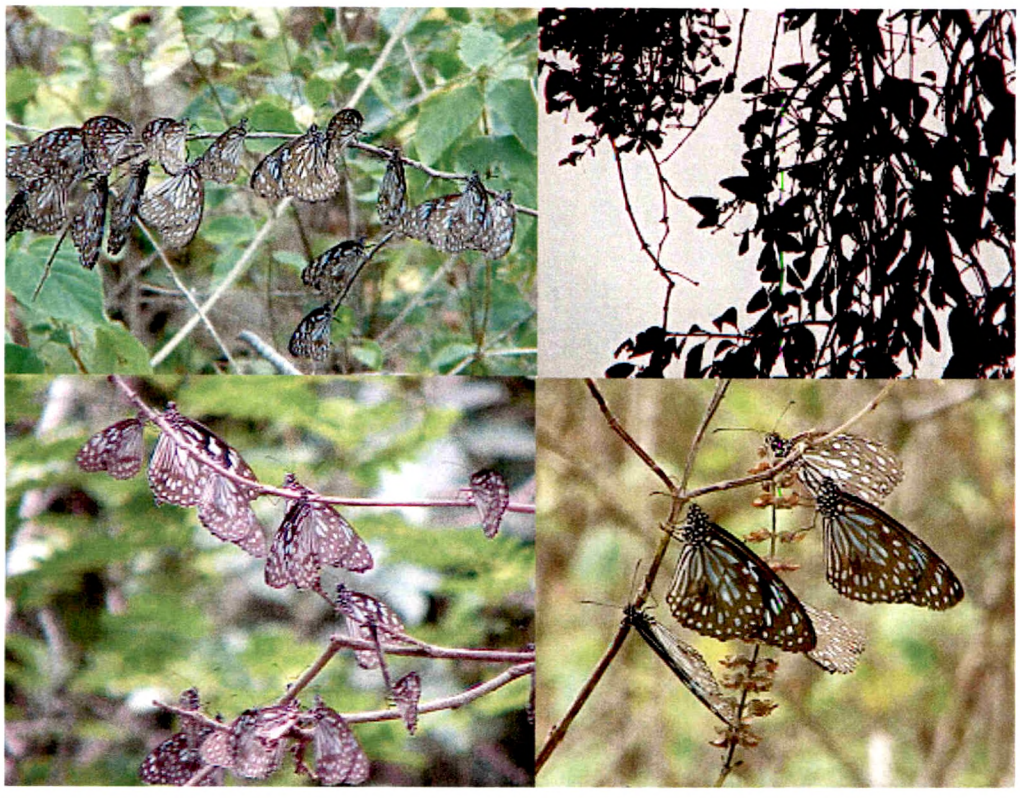

Plate 3.5. Aggregation of butterflies

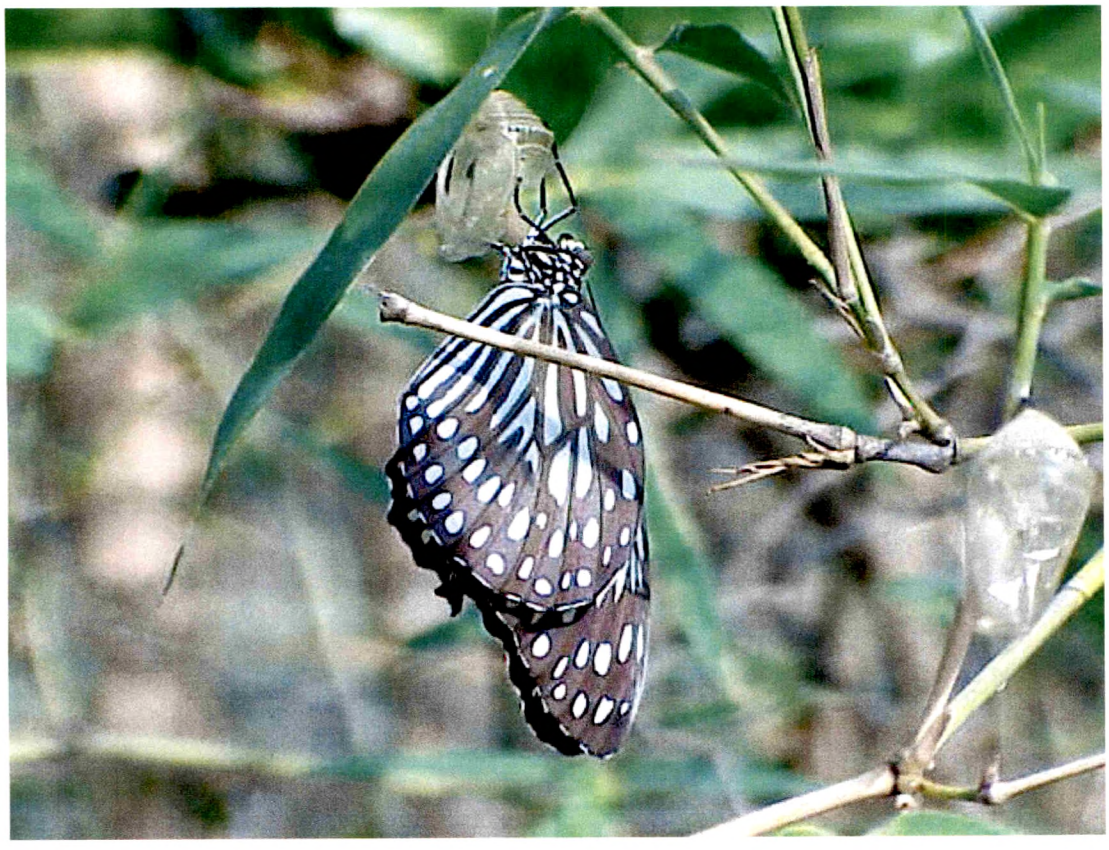

Plate 3.6. *Tirumala septentrionis* Pupa and emergence of adult.

# Appendices

Appendix 1. Plants recorded in the four transects of the study area.

| Name of the Species | Site 1 | Site 2 | Site 3 | site 4 | Frequency |
|---|---|---|---|---|---|
| *Abutilon indicum* | - | + | - | + | 2 |
| *Acacia canescens* | + | + | - | + | 3 |
| *Acacia leucophloea* | - | + | - | - | 1 |
| *Acacia planifrons* | - | - | - | + | 1 |
| *Acacia polycantha* | - | - | - | + | 1 |
| *Acalypha fruticosa* | + | + | + | + | 4 |
| *Aerva lanata* | - | + | - | - | 1 |
| *Ageratum sp* | + | + | + | + | 4 |
| *Albizia amara* | + | + | + | + | 4 |
| *Albizia lebbeck* | - | - | - | + | 1 |
| *Alphonsea sclerocarpa* | + | + | - | - | 2 |
| *Amorphophalus sylvaticus* | - | - | - | + | 1 |
| *Argeria pomacea* | - | - | + | - | 1 |
| *Aristida depressa* | + | - | + | - | 2 |
| *Asystasia gangetica* | + | + | - | + | 3 |
| *Atlantia racemosa* | + | + | - | + | 3 |
| *Azadirachta indica* | - | - | + | - | 1 |
| *Azima tetracantha* | + | + | + | + | 4 |
| *Bambusa bamboos* | - | - | - | + | 1 |
| *Barleria acuminata* | + | + | - | + | 3 |
| *Bauhinia racemosa* | - | + | - | - | 1 |
| *Blepharis maderaspatensis* | + | + | + | + | + |
| *Bombax ceiba* | + | - | - | - | 1 |
| *Breynia vitis-idaea* | + | + | + | + | 4 |
| *Calotropis gigantea* | - | - | + | - | 1 |
| *Cansjera rheedi* | + | + | - | - | 2 |
| *Canthium dicoccum* | + | + | + | + | 4 |
| *Canthium parviflorum* | - | + | - | + | 2 |
| *Capparis grandiflora* | + | + | + | + | 4 |
| *Capparis grandis* | + | + | - | + | 3 |
| *Capparis roxburghii* | - | + | - | + | 2 |
| *Capparis sepiaria* | + | + | + | + | 4 |
| *Carissa spinarum* | + | + | + | + | 4 |

| *Cassia auriculata* | - | - | + | - | 1 |
|---|---|---|---|---|---|
| *Cassia occidentalis* | - | - | + | + | 2 |
| Name of the Species | Site 1 | Site 2 | Site 3 | site 4 | Frequency |
| *Cassia siamea* | - | - | - | + | 1 |
| *Cassine glauca* | + | - | + | + | 3 |
| *Casssia fistula* | - | - | + | - | 1 |
| *Celtis philippensis* | + | + | - | - | 2 |
| *Chloroxylon swietenia* | + | + | + | + | 4 |
| *Chromaelaena odorata* | + | - | + | + | 3 |
| *Cissus quadrangularis* | + | + | + | + | 4 |
| *Clausena dentata* | + | + | + | + | 4 |
| *Clitoria Sp.* | + | + | + | + | 4 |
| *Coccinia indica* | + | - | - | - | 1 |
| *Commiphora caudata* | + | - | - | - | 1 |
| *Cordia monoica* | + | + | - | + | 3 |
| *Crossandra infundibuliformis* | + | + | + | + | 4 |
| *Croton bonblandianum* | - | - | + | + | 2 |
| *Dichrostachys cinerea* | - | + | + | + | 3 |
| *Dioscorea oppositifolia* | + | - | + | + | 3 |
| *Dioscorea pentaphylla* | + | + | - | + | 3 |
| *Diospyros montana* | + | + | + | - | 3 |
| *Diospyros ovalifolia* | - | + | - | - | 1 |
| *Dipteracanthus patulus* | + | + | + | + | 4 |
| *Dodonaea viscosa* | - | - | + | - | 1 |
| *Dalbergia paniculata* | + | - | - | - | 1 |
| *Ehretia ovalifolia* | + | + | + | + | 4 |
| *Erumanalangi* | - | + | - | - | 1 |
| *Euphorbia antiquorum* | - | + | + | + | 3 |
| *Evolvulus alsinoides* | + | + | + | + | 4 |
| *Ficus racemosa* | + | + | + | + | 4 |
| *Fimbrystylis ovata* | + | + | + | + | 4 |
| *Flacourtia indica* | - | + | + | - | 2 |
| *Gloriosa superba* | + | - | - | + | 2 |
| *Glycosmis mauritiana* | - | - | + | - | 1 |
| *Grewia bracteata* | + | + | + | - | 3 |
| *Grewia flavescens* | + | - | + | - | 2 |
| *Grewia oppositifolia* | + | + | + | + | 4 |
| *Grewia villosa* | + | + | + | - | 3 |
| *Gymnema sylvestre* | + | + | + | + | 4 |
| *Gyrocarpus americanus* | + | + | - | - | 2 |

| *Hemionitis arifolia* | + | - | - | - | 1 |
|---|---|---|---|---|---|
| *Hibiscus lunariifolius* | + | + | - | + | 3 |
| Name of the Species | Site 1 | Site 2 | Site 3 | site 4 | Frequency |
| *Ichnocarpus frutescens* | + | - | - | - | 1 |
| *Ipomoea pes-capre* | - | + | + | + | 3 |
| *Ipomoea Sp.* | - | - | + | - | 1 |
| *Ipomoea obscura* | + | + | + | - | 3 |
| *Ixora pavetta* | + | + | + | - | 3 |
| *Jasminum auriculatum* | + | + | + | + | 4 |
| *Justicia tranquebariensis* | + | + | + | + | 4 |
| *Kakavirisi** | + | + | - | + | 3 |
| *Lantana camara* | + | + | + | + | 4 |
| *Lantana wightiana* | + | + | + | + | 4 |
| *Leucas aspera* | + | - | + | - | 2 |
| *Leucas urticifolia* | - | - | + | - | 1 |
| *Liemanitis** | + | + | - | - | 2 |
| *Limonia alata* | + | + | + | + | 4 |
| *Loeseneriella obtusifolia* | - | - | - | + | 1 |
| *Maba buxifolia* | + | + | + | + | 4 |
| *Manilkara roxburghiana* | - | + | - | - | 1 |
| *Maytenus emarginata* | + | - | + | + | 3 |
| *Maytenus heyneana* | - | + | + | + | 3 |
| *Mukia maderaspatana* | - | + | - | - | 1 |
| *Mundulea sericea* | + | + | + | - | 3 |
| *Murraya paniculata* | - | + | - | + | 2 |
| *Ocimum canum* | + | + | + | + | 4 |
| *Opuntia dillenii* | + | + | + | + | 4 |
| *Orthoisphon rubicandus* | + | + | + | + | 4 |
| *Oxalis corniculata* | + | - | + | + | 3 |
| *Pachygone ovata* | + | + | + | - | 3 |
| *Panicum trypheron* | + | + | + | + | 4 |
| *Parthenium hysterophorus* | + | + | + | + | 4 |
| *Pattai** | - | + | - | - | 1 |
| *Pavetta indica* | + | + | + | + | 4 |
| *Pavonia odorata* | + | + | + | + | 4 |
| *Pavonia zeylanica* | - | - | - | + | 1 |
| *Phyllanthus amarus* | - | + | + | - | 2 |
| *Phyllanthus polyphyllus* | + | + | + | + | 4 |
| *Polycarpaea corymbosa* | - | - | + | - | 1 |
| *Polygonum chinensis* | + | + | - | + | 3 |

| | | | | | |
|---|---|---|---|---|---|
| *Pongamia pinnata* | - | - | + | - | 1 |
| *Premna latifolia* | - | - | - | + | 1 |
| Name of the Species | Site 1 | Site 2 | Site 3 | site 4 | Frequency |
| *Premna tomentosa* | + | - | + | - | 2 |
| *Priva cordifolia* | + | - | + | - | 2 |
| *Prosopis juliflora* | - | - | - | + | 1 |
| *Pseudarthria viscida* | + | + | + | + | 4 |
| *Pterolobium hexapetalum* | + | + | + | + | 4 |
| *Randia dumetorum* | - | + | + | + | 3 |
| *Randia malabarica* | + | + | - | + | 3 |
| *Sadakasangu** | - | + | + | - | 2 |
| *Santalum album* | - | - | + | + | 2 |
| *Sapindus emarginatus* | + | - | - | - | 1 |
| *Scutia myrtina* | + | + | + | + | 4 |
| *Secemone emetica* | + | + | + | + | 4 |
| *Securinega leucopyrus* | + | + | + | + | 4 |
| *Sida acuta* | + | + | + | + | 4 |
| *Sida cordifolia* | + | + | + | + | 4 |
| *Stenosiphonium cordifloium* | + | + | - | + | 3 |
| *Strebulas asper* | - | - | - | + | 1 |
| *Tephrosia purpurea* | - | - | + | - | 1 |
| *Tephrosia Sp* | - | - | + | + | 2 |
| *Toddalia asiatica* | + | + | + | + | 4 |
| *Tribulus subramanii* | - | - | + | - | 1 |
| *Unidentified* | + | - | - | + | 2 |
| *Urimili** | + | + | - | - | 2 |
| *Ziziphus oenoplia* | + | + | + | + | 4 |

* Vernacular name

Appendix 2. Families of insects collected through four methods from Anaikatty hills

| Family | Beating | Light trap | pitfall | Sweeping |
|---|---|---|---|---|
| Acrididae | 16.03 | 0.50 | 7.85 | 75.63 |
| Agromyzidae | 16.67 | 83.33 | - | - |
| Anthrophoridae | 100.00 | - | - | - |
| Aphididae | - | - | 100.00 | - |
| Apidae | 20.00 | - | - | 80.00 |
| Arctiidae | 4.76 | 80.95 | - | 14.29 |
| Ascalaphidae | - | 100.00 | - | - |
| Asilidae | 5.56 | 68.52 | 3.70 | 22.22 |
| Blattidae | 42.61 | 0.35 | 45.07 | 11.97 |
| Bostrichidae | 75.00 | - | - | 25.00 |
| Braconidae | 4.55 | 59.09 | - | 36.36 |
| Bruchidae | 68.42 | - | 3.95 | 27.63 |
| Buprestidae | 35.09 | - | 1.75 | 63.16 |
| Calliphoridae | - | - | - | 100.00 |
| Cantharidae | - | 33.33 | - | 66.67 |
| Carabidae | - | 35.66 | 64.34 | - |
| Cecidomyiidae | - | 100.00 | - | - |
| Cerambycidae | 54.00 | 16.00 | 6.00 | 24.00 |
| Cercopidae | 25.00 | 50.00 | - | 25.00 |
| Chalcididae | - | 100.00 | - | - |
| Chrysomelidae | 19.50 | 73.93 | 0.30 | 6.27 |
| Chrysopidae | - | - | - | 100.00 |
| Cicadellidae | 14.09 | 44.55 | 15.00 | 26.36 |
| Cicindelidae | 65.71 | 20.00 | 2.86 | 11.43 |
| Cleridae | 100.00 | - | - | - |
| Coccinellidae | 53.49 | 25.58 | 4.65 | 16.28 |
| Coreidae | 20.61 | 8.18 | 6.97 | 64.24 |
| Cucujidae | 100.00 | - | - | - |
| Culicidae | - | 25.00 | 75.00 | - |
| Curculionidae | 75.86 | 13.79 | 2.30 | 8.05 |

| Family | Beating | Light trap | pitfall | Sweeping |
|---|---|---|---|---|
| Cydnidae | 25.00 | 50.00 | 12.50 | 12.50 |
| Dermestidae | 100.00 | - | - | - |
| Dytiscidae | - | 100.00 | - | - |
| Elateridae | 43.59 | 28.21 | 25.64 | 2.56 |
| Erotylidae | - | - | - | 100.00 |
| Eupterotidae | - | 100.00 | - | - |
| Evaniidae | - | 44.44 | - | 55.56 |
| Forficulidae | 63.64 | - | 36.36 | - |
| Formicidae | 5.71 | 0.26 | 90.08 | 3.94 |
| Fulgoridae | 40.35 | 36.84 | 3.51 | 19.30 |
| Geometridae | - | 78.57 | 7.14 | 14.29 |
| Gryllidae | 19.61 | 0.28 | 73.20 | 6.91 |
| Ichneumonidae | - | 100.00 | - | - |
| Lampyridae | 60.00 | 40.00 | - | - |
| Lasiocampidae | - | 100.00 | - | - |
| Lepismatidae | - | - | 100.00 | - |
| Lygaeidae | 17.54 | - | 19.30 | 63.16 |
| Lymantriidae | 7.14 | 92.86 | - | - |
| Mantidae | 62.07 | 3.45 | 10.34 | 24.14 |
| Megachilidae | 60.00 | - | - | 40.00 |
| Membracidae | 24.32 | 13.51 | 43.24 | 18.92 |
| Muscidae | 13.29 | 1.27 | 32.91 | 52.53 |
| Mutillidae | - | 100.00 | - | - |
| Myrmeleontidae | 71.43 | - | 28.57 | - |
| Neanuridae | - | - | 100.00 | - |
| Noctuidae | 5.13 | 76.92 | 8.55 | 9.40 |
| Pentatomidae | 30.72 | 44.88 | 1.81 | 22.59 |
| Phasmatidae | 95.65 | - | - | 4.35 |
| Pterophoridae | - | 100.00 | - | - |
| Pyralidae | - | 100.00 | - | - |
| Pyrrhocoridae | 40.24 | 8.54 | 10.98 | 40.24 |
| Reduviidae | 18.18 | 3.90 | 70.13 | 7.79 |
| Scarabaeidae | 3.19 | 91.04 | 4.98 | 0.80 |

| Family | Beating | Light trap | pitfall | Sweeping |
|---|---|---|---|---|
| Scoliidae | - | 100.00 | - | - |
| Scutelleridae | 62.50 | - | 12.50 | 25.00 |
| Sphingidae | 100.00 | - | - | - |
| Staphylinidae | 0.24 | 76.21 | 22.83 | 0.72 |
| Tabanidae | 8.33 | 64.58 | 6.25 | 20.83 |
| Tenebrionidae | 62.50 | 37.50 | - | - |
| Tenthredinidae | - | 100.00 | - | - |
| Termitidae | - | - | 100.00 | - |
| Tetrigidae | 25.00 | - | - | 75.00 |
| Tettigoniidae | 50.00 | - | 4.35 | 45.65 |
| Tingidae | 66.67 | - | 4.76 | 28.57 |
| Togossitidae | - | - | 100.00 | - |
| Tortricidae | - | 100.00 | - | - |
| Zygaenidae | - | 100.00 | - | - |
| Grand Total | 10.46 | 15.99 | 62.68 | 10.87 |

Appendix 3. Butterflies recorded from the Anaikatty hills

| Sl No | Common Name | Scientific Name | Endemism* | WPA, 1972** |
|---|---|---|---|---|
| **Family:** | **PAPILIONIDAE** | | | |
| 1 | Tailed Jay | *Graphium agamemnon* Linnaeus | | |
| 2 | Spot Sword tail | *Graphium nomiuus* Esper | | |
| 3 | Common Bluebottle | *Graphium sarppedon* Linnaeus | | |
| 4 | Common Rose | *Pachliopta aristolochiae* Fabricius | | |
| 5 | Crimson Rose | *Pachliopta hector* Linnaeus | SI, SL | Sch I |
| 6 | Malabar Banded Peacock | *Papilio buddha* Westwood | WG | Sch II |
| 7 | Common Mime | *Papilio clytia* Linn. | | Sch I |
| 8 | Lime Butterfly | *Papilio demoleusl* Linnaeus | | |
| 9 | Red Helen | *Papilio helenus* Linnaeus | | |
| 10 | Blue Mormon | *Papilio polymnestor* Cramer | SL, PI | |
| 11 | Common Mormon | *Papilio polytes* Linnaeus | | |
| 12 | Common Banded Peacock | *Papilio Sp.* | PI, SL | |
| 13 | Southern Bird Wing | *Troides minos* Cramer | SI, WG | |
| 14 | Malabar Raven | *Papilio dravidarum Wood-Mason* | WG | |
| 15 | Common Jay | *Zetides doson* (C& R Felder) | | |
| **Family:** | **PIERIDAE** | | | |
| 16 | pioneer or Caper White | *Anaphaeis aurota* Fabricius | | |
| 17 | Common Albatross | *Appias albina* Boisduval | | |
| 18 | Chocolate Albatross | *Appias lyncida* Cra. | | Sch II |
| 19 | Small or Little Orange Tip | *Calotis etrida* Boisduval | | |
| 20 | Common Emigrant | *Catopsilia pomona* Fabricius | | |
| 21 | Mottled Emigrant | *Catopsilia pyranthe* Linnaeus | | |
| 22 | Common Gull | *Cepora nerissa* Fabricius | | Sch II |
| 23 | Crimson Tip | *Colotis danae* Fabricius | | |
| 24 | Common Jezebel | *Delias eucharis* Drury | | |
| 25 | Three-spot Grass Yellow | *Eurema blanda* Boisduval | | |
| 26 | Common Grass Yellow | *Eurema hecabe* Linnaeus | | |
| 27 | Great Orange Tip | *Hebomoea glaucippe* Linaeus | | |
| 28 | White Orange Tip | *Ixias marianne* Cramer | | |
| 29 | Yellow Orange Tip | *Ixias pyrene* Linnaeus | | |
| 30 | Psyche | *Leptis nina* Fabricius | | |
| 31 | Common Wanderer | *Pareronia valeria* Cramer | | |
| **Family:** | **NYMPHALIDAE** | | | |
| 32 | Tawny Coster | *Acraea violae* Fabricius | | |
| 33 | Common castor | *Ariadne merione* Cramer | | |
| 34 | Black Rajah | *Charaxes dolon* Fab. | | |
| 35 | Tamil Yeoman | *Cirrochora thais* Fabricius | SI, SL | |
| 36 | Rustic | *Cupha erymanthis* Drury | | |
| 37 | Painteed Lady | *Cynthia cardui* Linnaeus | | |

| Sl No | Common Name | Scientific Name | Endemism* | WPA, 1972** |
|---|---|---|---|---|
| 38 | Common Map | *Cyrestis thyodamas* Boisduval | | |
| 39 | Plain Tiger | *Danaus chrysippus* Linnaeus | | |
| 40 | Striped or Common Tiger | *Danaus genutia* Cramer | | |
| 41 | Palmfly | *Elymnias hypermenstra* Linnaeus | | |
| 42 | Common Indian Crow | *Euploea core* Cramer | | Sch IV |
| 43 | Double-banded Crow | *Euploea sylvester* Fabricius | | |
| 44 | Baronet | *Euthalia nais* Forster | | |
| 45 | Great Eggfly | *Hypolimnas bolina* Linnaeus | | |
| 46 | Danaid Eggfly | *Hypolimnas misippus* Linnaeus | | Sch I & II |
| 47 | Peacock Pansy | *Junonia almana* Linnaeus | | |
| 48 | Yellow Pansy | *Junonia hierta* Fabricius | | |
| 49 | Lemon Pansy | *Junonia lemonias* Linnaeus | | |
| 50 | Blue Pansy | *Junonia orithya* Linnaeus | | |
| 51 | Common Beak | *Libythea lepita* Moore | | Sch II |
| 52 | Common Evening Brown | *Melanitis leda* Linnaeus | | |
| 53 | Gladeye Bushbrown | *Mycalesis patnia* Moore | | |
| 54 | Common Bushbrown | *Mycalesis perseus* Fab. | | |
| 55 | Common Sailor | *Neptis hylas* Moore | | |
| 56 | Common Lascar | *Pantoporia hordonia* Stoll | | |
| 57 | Nilgiri Tiger | *Parantica aglea* Stoll | SI | |
| 58 | Clipper | *Parthenos sylvia* Cramer | | Sch II |
| 59 | Common Leopard | *Phalanta phalanda* Drury | | |
| 60 | Common Nawab | *Polyura athamas* Drury | | |
| 61 | Chocolate Pansy | *Precis iphita* Cramer | | |
| 62 | Blue tiger | *Tirumala limniace* Cramer | | |
| 63 | Dark Blue Tiger | *Tirumala septentrionis* Butler | | |
| 64 | Common Four Ring | *Ypthima baldus* Fabricius | | |
| 65 | White Four-ring | *Ypthima ceylonica* Hewitson | | |
| Family: | LYCAENIDAE | | | |
| 66 | Indian Oakblue | *Amblypodia alemon* | | |
| 67 | Common Pierrot | *Castalius rosimon* Fabricius | | |
| 68 | Lime blue | *Chilades laius* Stoll | | |
| 69 | Plains Cupid | *Chilades pandava* Horsfield | | |
| 70 | Banded Blue Pierrot | *Discolampa ethion Hewitson* | | |
| 71 | Gram Blue | *Euchrysops cnejus* Fabricius | | Sch II |
| 72 | Grass Jewel | *Freyeria trochylus* Freyer | | |
| 73 | Metallic Cerulean | *Jamides alecto* Felder | | |
| 74 | Dark Cerulean | *Jamides bochus* Cramer | | |
| 75 | Common Cerulean | *Jamides celeno* Cramer | | |
| 76 | Pea Blue | *Lampides boeticus* Linnaeus | | |
| 77 | Zebra Blue | *Leptotes plinius* Fabricius | | |

| Sl No | Common Name | Scientific Name | Endemism* | WPA, 1972** |
|---|---|---|---|---|
| 78 | Yam fly | *Loxura atymnuscontinentalis* Fruhstorfer | | |
| 79 | Quaker | *Neopithecops zalmora* Butler | | |
| 81 | Monkey Puzzle | *Rathinda amor* (Fabricius) | | |
| 82 | Common Silverline | *Spindasis vulcanus* Fabricius | IS | |
| 83 | Rounded Pierrot | *Tarucus nara* Kollar | | |
| 84 | Red Pierrot | *Telicada nyseus* GuerinMeneville | | |
| 85 | Dark Grass Blue | *Zizeeria karsandra* Moore | | |
| 86 | Lesser Grass Blue | *Zizinia otis* Fabricius | | |
| 87 | Tiny Grass Blue | *Zizula hylax* Fabricius | | |
| **Family:** | **HESPERIIDAE** | | | |
| 88 | Brown Awl | *Badamia exclamationis* Fabricius | | |
| 89 | Common Banded Awl | *Hasora chromus Cramer* | | |
| 90 | White Banded Awl | *Hasora taminatus Hubner* | | |
| 91 | Chestnut Bob | *Iambrix salsala* Moore | | |
| 92 | Fulvous Pied Flat | *Pseudocoladenia dan* Fabricius | | |
| 93 | Indian Skipper | *Spialia galba* Fabricius | | |
| 94 | Suffused Snow Flat | *Tagiades gana Moore* | | |

* SI - South India; WG - Western Ghats; PI - Peninsular India; IS – Indian Sub continet; SL – Sri Lanka

** WPA – Wild Life Protection Act, 1972; Sch – Schedule I, II, IV

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