STUDIES ON THE LEPIDOPTERA OF NELLIYAMPATHY FORESTS

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By

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CERTIFICATE

This is to certify that this thesis entitled "**Studies on the Lepidoptera of Nelliyampathy Forests**" is based on the original work done by Mr. Maheshkumar Madathil in partial fulfillment for the award of the degree of Doctor of Philosophy of the University of Calicut is a record of bonafide research work carried out by him under my direct supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.

28-11-2001

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DECLARATION

I hereby declare that this thesis is an authentic record of the work carried out by me under the supervision of Dr. George Mathew, Scientist, Entomology Division, Kerala Forest Research Institute, Peechi and no part of this has previously formed the basis for the award of any degree or diploma as stipulated in the statutes of Calicut University.

Peechi
21-11-2001

Maheshkumar Madathil

CONTENTS

DEDICATION

ACKNOWLEDGEMENTS i

LIST OF TABLES iii

LIST OF FIGURES v

LIST OF APPENDICES vi

LIST OF PLATES vii

Chapter I : INTRODUCTION 1

1.1. Butterflies and moths

1.2. Indicators

1.3. Objectives of work

Chapter 2 : REVIEW OF LITERATURE 6

2.1. Lepidopteran faunal studies

2.2. Insect species diversity studies

2.3. Impact of forest disturbance on insect diversity

Chapter 3 : STUDY AREA AND THE SAMPLING SITES 17

3.1. Study area

3.2. Sampling sites

Chapter 4 : MATERIALS AND METHODS 26

4.1. Sampling methods

4.1.1. Insect studies

4.1.2. Vegetation studies

4.2. Data analysis

4.2.1. Analysis of local distribution pattern of butterflies

4.2.2. Analysis of patterns of geographical distribution

4.2.3. Diversity studies

Chapter 5 : RESULTS AND DISCUSSION 36

5.1. Rhopaloceran fauna of Nelliyampathy

5.2. Local distribution pattern of butterflies

5.3. Community structure

5.4. Endemic butterflies

5.5. Heteroceran fauna of Nelliyampathy

5.6. Biogeography of moths of Nelliyampathy

5.7. Ecological diversity of moths

5.8. Seasonal patterns of moth fauna

5.9. Habitat preference of moths

5.10. Impact of plantation activities on moth diversity

Chapter 6 : SUMMARY 71

REFERENCES 75

APPENDICES 90

PLATES

Dedicated
to my
parents

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LIST OF TABLES

Table No.	Title	Pages
1	Species/ individual abundance of butterfly communities	39
3	A comparison of total number of species and endemics recorded from Western Ghats and Nelliyampathy	42
4	Number of moth species recorded under various families	43
5	Test of goodness of fit of truncated lognormal distribution at Site A	47
6	Test of goodness of fit of truncated lognormal distribution at Site D	48
7	Test of goodness of fit of truncated lognormal distribution at Site E	49
8	Test of goodness of fit of truncated lognormal distribution at Site F	50
9	Z –values for comparing the α of log series diversities of different sites	51
10	Shannon's diversity index for pooled data from each study sites	51
11	'*t*' values for comparing the Shannon diversity indices of the six study sites	52
12	Brillouin index calculated for various study sites	53
13	Evenness indices calculated for various sites	53
14	Sorenson index (C_N) of similarity of pairs of sites	54

Table No.	Title	Pages
15	Morisita – Horn index (C_{MH}) of similarity of pairs of sites	55
16	Shannon's diversity indices of month-wise data from different study sites	62
17	Richness index for various study sites	63
18	Shannon's diversity and evenness indices for family-wise data from different study sites	65
19	Characteristic of the vegetation in various sites	69
20	Insect and plant diversity pattern in various sites	69

10

LIST OF FIGURES

Figure No.	Title	Pages
1	Map of Nelliyampathy reserve forest showing the study site	18
2	Study site B in an evergreen forest patch with a light-trap in the center	24
3	Reverine study site C at Nelliyampathy	24
4	Site D in the edge of an undisturbed forest area	25
5	A cardamom plantation (site F) at Nelliyampathy. A portion of the light-trap can be seen in the foreground	25
6	Dendrogram derived in the classification of species according to their local distribution and abundance	
7	Proportional representation of butterfly families in different habitats	40
8	Dendrogram derived in the classification of species according to their geographical distributions.	
9	Comparison of Morisita index of different study sites	55
10	Rainfall (bars, in mm) and average temperature (dots, in °C) in Nelliaympathy	57
11	Monthly distribution of species and individual abundance for various study sites	59-60
12	Representation of species abundance in various families recorded from different study sites	66

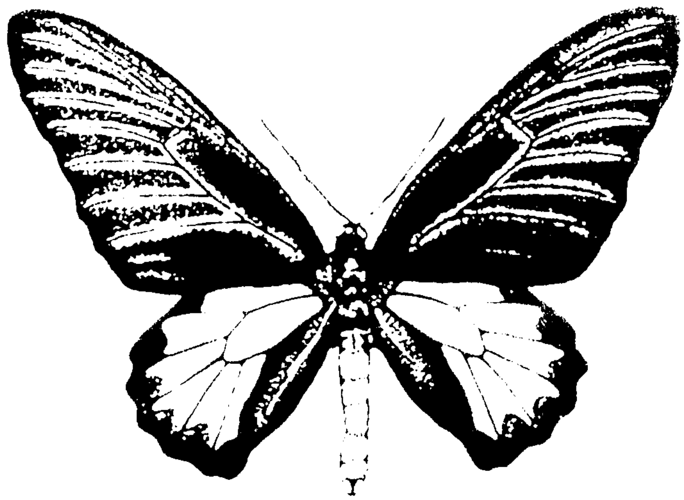
LIST OF APPENDICES

Appendix No.	Title	Pages
1	List of butterflies recorded from Nelliyampathy	90
2	List of butterflies with code no. for cross reference with figure 6	96
3	List of moths recorded from Nelliyampathy	99
4	List of primary areas used in the numerical analysis together with a list of species with code number for cross-reference with figure 8	106
5	List of plants recorded from the study area	111
6	List of Heteroceran pests of monoculture plantations recorded from various sites	113

12

LIST OF PLATES

Plates	Title
Plate I – III	Some butterflies recorded from Nelliyampathy
Plate IV – VII	Some moths recorded from Nelliyampathy



Chapter 1

INTRODUCTION

1. INTRODUCTION

Biodiversity, usually measured as simple species richness, has emerged recently as a matter of major conservation importance. The United Nations Conference on Environment and Development (UNCED) held in Rio de Janiero in June 1992 has already focused international concern on several issues including the conservation of biodiversity in forests.

The tropical rain forests which cover approximately 7% of the land surface of the earth are estimated to contain more than half of the species in the World's biota. Each year about 10,000 species of organisms are described as new and perhaps 3000 existing species are placed in synonymy, yet recent predictions (based on a world total of 5-10 millions) suggest that species extinction may approach 17,500 - 35,000 a year (Wilson, 1988). Tropical deforestation is the crucible of todays extinction crisis. About 16 million hectares of tropical forests are cleared annually and at this rate, at least 5-10% of tropical forest species face extinction in the next 30 years.

Invertebrates constitute at least 95% of the world's animal species (Southwood, 1978a). Conservation of invertebrates is coming to be recognised increasingly as a vital need for a sustainable world in view of the critical roles they play in most ecosystems, and their domination of organismal biodiversity. Invertebrates constitute the major or sole diet of many vertebrate species, ranging from fish and amphibians to bats and the largest whales. They also play key roles in many essential ecosystem functions such as herbivory, pollination, parasitism, predation and decomposition.

Of about 1.4 million species of invertebrates described so far, 0.75-1 million are insects (Wells *et al.,* 1983). WRI *et al.* (1992) estimated a world total of 751,000 described insect species. Forest is the main centre of insect diversity because of the variety of microhabitats and plant species. Due to deforestation and unhealthy forestry operations the insect life in the forest is fast becoming extinct even before we can understand their role in the ecosystem.

1.1. Butterflies and Moths

Insects which seem to have made their appearance around 360 million years ago are one of the most successful groups of animals on the earth. Butterflies and moths were among the last to arrive on the evolutionary scene around 160 million years ago, following the evolution of flowering plants. The present total number of described species reaches to 2,00,000, roughly half of which are macrolepidoptera and butterflies (Holloway, 1987). Heppner (1991) estimated 146,277 described species of Lepidoptera in the Oriental region.

Lepidopterans have a complete four-stage development or metamorphosis and are therefore called as holometabolous. The adults are characterised by their broad-scaled and typically patterned wings and the presence of a 'tongue' (haustellum or proboscis) which is often long and coiled, adapted for sucking liquid nourishment. The proboscis in the adult, as well as the powerful chewing equipment of the young larvae are designed for maximum nutritional benefit, mostly from plants. In most of the Lepidoptera, scales are also present on the head, thorax, abdomen and legs. It is the structure of these scales and the pigments they contain that are responsible for the extraordinary colours typical of butterflies and moths.

Larvae of most of the species feed on green plants and may consequently be in direct competition with man, requiring counter-measures and control. On the other hand some are beneficial, many are aesthetic and most, through their diversity and association with vegetation, may reflect the ecological stability of natural environments and persistence of their own populations.

India's diverse natural habitats have given rise to an amazing array of butterflies and moths in different shapes, sizes and colours. According to Varshney (1998), the number of lepidopteran species known from India reaches to 15,000, *ie.,* 10.52% of the world total. Gaonkar (1996) states that the butterfly fauna of the world comprises 16,823 species, of which 1,501 belongs to India.

As has been stated previously, forest is the main centre of species diversity. Typical climatic conditions and existence of a variety of native plant species have rendered the Western Ghats one of the most acceptable habitat for a variety of butterflies and moths. Occurrence of the largest Indian butterfly, the Southern Birdwing (*Troides minos* Cramer) and world's largest moth, the Atlas moth (*Attacus atlas*) reveals the rich faunal diversity of this most imposing mountain range of Indian subcontinent.

1.2. " Indicators "

In order to assess and to monitor the impact of disruption and modification of natural profile through our utilization and management of natural resources, it is often necessary to identify 'indicators' of change rather than the whole biota because of the immense diversity of life in most biotopes (Holloway & Stork, 1991).

Insects are important in the ecological functioning of natural ecosystems. They form important links in the food webs at lower trophic levels and any change in their composition is likely to affect the survival of higher groups of organisms in the ecosystem. Environmental perturbations impinge on their roles, and insects often respond to these perturbations in characteristic fashion, so that insects are useful objects of study in Environmental Impact Assessment (Rosenberg *et al.,* 1986).

A simpler, quicker and more readily repeatable approach using insects might be to use elements of the fauna that are easily sampled, widely distributed, diverse, show specificity to vegetation type and are sensitive to change. The ideal group should provide, for a given sampling effort, a high proportion of species that are frequent or common, rather than numerous species represented by one or a few individuals. Thus lepidopterans can be sampled in large numbers, are taxonomically well known and are relatively rapid to identify at least to a species complex. Use of Lepidoptera as indicator organisms has therefore become a precise tool in environmental monitoring and management.

1.3. Objectives of work

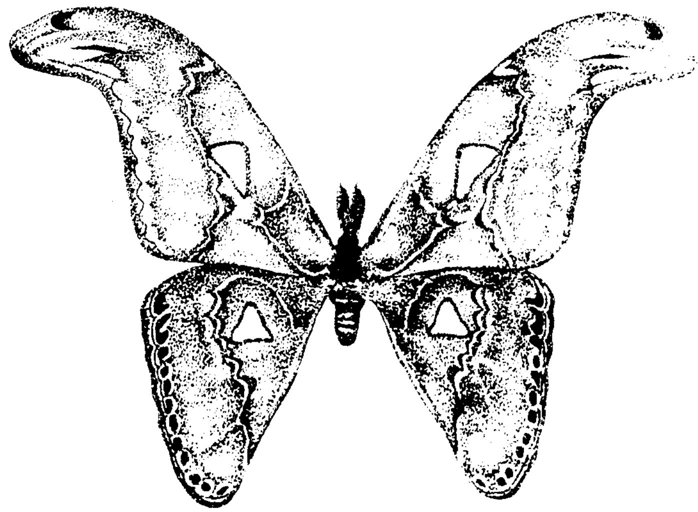
The Western Ghats is one of the 18 biodiversity 'hotspots' of the world. Because of its geographical location, stable geological history, equable climate, heavy rainfall and good soil conditions, it supports a variety of rich tropical forest ecosystems. Phytogeographically this area is very rich in palaeo endemic species which are botanically a 'relict' of an ancient and unique vegetation. Because of indiscriminate and unscientific exploitation of forests particularly for construction of hydro-electric projects, 'grow more food' programme for agriculture, rehabilitation of refugees, for raising monoculture plantations for selected industries etc., large chunks of these forests have been felled and these unique and fragile ecosystems which were once a treasure-house of rich and varied flora and fauna of the world is fast deteriorating and only very few patches of this ancient relicts are now available.

Nelliyampathy hills located in the Kerala part of Western Ghats, though subjected to extreme biotic influences as evidenced by the existence of Tea, Coffee, Rubber, Orange and Cardamom estates and plantations of Teak and Eucalyptus, still hold a few patches of rich and nearly undisturbed tropical evergreen forests sheltering unique flora and fauna.

Although a few attempts have been made in the past to document the insect fauna, no focussed effort has so far been made to study the Lepidopteran fauna there.

This study was undertaken with the following objectives :

- To study the Lepidopteran fauna of Nelliyampathy Reserve Forest of Western Ghats.
- To generate data on the species diversity of Lepidoptera in different habitats within Nelliyampathy Reserve Forest, and
- To gather information on the response of moths towards forest disturbance and conversion to plantations.



Chapter 2

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1. Lepidopteran faunal studies

Indian butterflies and moths reached the scientific community when Carl von Linnaeus published his tenth edition of 'Systema Naturae' in 1775. South Indian butterflies were described for the first time by J.C. Fabricius and Pieter Cramer (1775 onwards).

Horsfield (1828-'29) in the descriptive catalogue of the lepidopterous insects contained in the Museum of the East India Company described many Western Ghats species, including the biology of many species then known. Later, in 1858, Horsfield and Moore published another catalogue of lepidopterous insects in the Museum of East India Company with additions of species from the Western Ghats. Moore (1881) in 'Lepidoptera of Ceylon' described butterflies of Sri Lanka including species found in the W. Ghats.

Marshal and de Niceville (1883) published Butterflies of India, Burma and Ceylon, Vol. I, the very first systematic work to deal with the butterflies of the Indian region. de Niceville then published Vol. II and Vol. III in 1886 and 1890 respectively. These three volumes served as a descriptive hand book of all the known species of Rhopalocerous Lepidoptera inhabiting that region, with notes and illustrations on allied species occurring in the neighbouring countries along the border.

Ten volumes of ' Lepidoptera Indica' containing descriptions as well as information on the biology of all the species then known, including those of the Western Ghats was published by Moore and Swinhoe (1890, 1913)

Under the ' Fauna of British India ' series (Vol. I and Vol II), Bingham (1905, 1907) brought out excellent treatises on the Rhopaloceran insect life present in the country. Bell (1909-1927) published a series of papers in JBNHS, which contained the most detailed life history descriptions of the butterflies of Western Ghats. 'The identification of Indian Butterflies' by Evans (1932) contain the entire fauna of the region in a single volume. Peile (1937) in a Guide to Collecting Butterflies in India described about 600 species from the Indian region.

The study of butterflies has progressed largely since the publication of Bingham's work and, therefore, its revision became necessary, since too much additional information of the subject has been accumulated. One notable work in this regard was by Talbot (1939, 1947), 'The fauna of British India including Ceylon and Burma, Butterflies Vol I and Vol II'. Another notable work in a book form dealing with the majority of species found in the Western Ghats was by Wynter - Blyth (1957) - 'Butterflies of the Indian Region'. A fantastic work on butterflies containing excellent photographs is the 'Butterflies of the Oriental Region, Part I, II and III by D' Abrera (1982-'86). Ackery (1984) has given a classification of butterflies at the family level, which is widely followed.

Larsen (1987-'88) worked on the butterflies of Nilgiri mountains and published the most comprehensive study of 299 species found on the Nilgiri hills. Hauser et al. (1997) presented a compiled record of 625 butterfly species from the area of Kinabalu Park in Sabah, Malaysia, in a systematic arrangement which is a good reference regarding classification.

Records of Zoological Survey of India are other sources of reference regarding identification, description and geographical distribution of Indian butterflies. They include Varshney *et al.* (1981), Varshney (1983), Gupta and Shukla (1987) and Gupta and Shukla (1988). Revised nomenclature for taxa contained in Wynter-Blyth's book has been presented by Varshney (1979,1985). Descriptive catalogue of butterflies in the Madras Museum (Satyamurthi,1966), 'Field Guide on Some South- Indian Butterflies' (Gunathilagaraj *et al.,* 1998), Gay-Kehimkar and Punetha (1992) and Gaonkar (1996) are some recent works on Indian butterflies.

Besides the faunistic works mentioned above, numerous reports on the distribution, ecology and biology of Indian butterflies have also been published (Watson,1890; Fergusson,1891; Bell and Fletcher,1921; Yates, 1929; Fraser,1930; Ghosh *et.al.,* 1986; ZSI,1988; Elamon, 1993; Cherian, 1993; Gaonkar, 1996; Palot *et al.,* 1997 and Mathew,1990,1993,1998).

Pioneering works in the Heteroceran fauna of India includes 'Catalogue of lepidopterous insects', by Horsfield and Moore (1858), 'Lepidoptera of Ceylon' Vol. II & III by Moore and Swinhoe (1890-1913).

Hampson (1892-'96) published the 'Fauna of British India' Vol I - IV, which is the most remarkable work on the pyralid moths of India which was succeeded by Vol V on Sphingidae by Bell and Scott (1937).

Records of Zoological Survey of India by Arora and Gupta (1979), Arora and Chaudhury (1982), Arora (1983), contemporary treatment of moths of South East Asia by Barlow (1982), and checklists by Mathew (1990, 1993, 1995, 1998) are the other resources available on the faunal studies.

2.2. Insect species diversity studies

Apart from taxonomic studies, investigations have also been made on insect species assemblages in different habitats and an account of the pertinent studies with special reference to butterflies and moths are presented here.

Holloway and Jardine (1968) studied the distribution of butterflies, birds and bats in the Indo-Australian area, using numerical methods to assign primary areas to zoogeographic regions and to assign taxa to faunal elements. They also made an attempt to relate these classifications to the past geographical history of the area, and thereby to infer the past trends related to the spread and speciation in each group.

Holloway (1977) published the results of his Norfolk Island expedition in his book entitled "The Lepidoptera of Norfolk Island-their biogeography and ecology", wherein he presented a fascinating picture of the local distribution of the species, arrivals of vagrants, seasonal patterns and the response to variations in climatic conditions together with the systematic account of moth fauna based on the numerical analysis of the distribution of individuals amongst species and sampling areas.

In yet another book entitled " A survey of the Lepidoptera, biogeography and ecology of New Caledonia", Holloway (1979) gave an account of the geology, phytogeography and general zoogeography of New Caledonia as background for the Lepidopteran fauna and its biogeography. This work shows how quantitative sampling and numerical analysis contribute to resolve conservation problems.

Holloway (1987) also studied the macrolepidoptera diversity in the Indo-Australian tropics presenting data on the faunal richness as well as the proportional representation of various families. Both overall diversity and diversity of families declined with latitude. Measures of alpha-diversity from quantitative light-trap samples indicate that diversity within the tropics is often greatest at altitudes around 1000m.

Recent concurrent surveys including both invertebrate and vertebrate fauna and vascular flora in the Victorian Mallee by Yen *et al.* (1990) have provided data which forms the basis for investigation of the distribution of plant and animal assemblages for different taxonomic groups in 40 sites.

Raguso *et al.*(1990) studied the butterflies of the Tuxtlas Mts., Veracruz, Mexico and recorded 182 species and 212 species respectively from 2 different study sites. At both study sites seasonal patterns in species abundance was observed during periods of reduced precipitation. A comparison between the fauna of two sites revealed that a higher percentage of cosmopolitan species were present at the disturbed site.

The species number, the abundance per species and the body lengths of Arthropods foraging within the crown of *Argyrodendron actinophyllum* (Sterculiaceae), an overstorey rainforest tree from Australia, were investigated by interception trap sampling and restricted canopy fogging (Basset *et al.,* 1991). Emphasis was placed on the interpretation of trap data. This methodology is interpretive providing a proper understanding of arthropod community structure in rain forest.

The arthropod assemblages occurring in the canopies of tropical, subtropical and cool temperate sites have been sampled using a Pyrethrum Knockdown Technique (Kitching *et al.,* 1993). Sites were selected for study on the basis of canopy structure, tree species composition and accessibility. The purpose was to investigate differences in the frequency distribution of individuals among orders.

The bio-geographic and ecological profile of the Lepidopteran fauna of New Caledonia presented by Holloway (1993), contrasts the biodiversity of moth fauna there with that of neighbouring archipelagos and elsewhere in the Indo-Australian tropics. Variation in moth diversity in different vegetation types was examined. Attention was drawn to the unexpectedly low moth diversity associated with vegetation with high floristic endemism and diversity on ultrabasic rocks, suggested to be a result of adaptation of the flora to the unusual mineral regimes in soils on such rocks.

Lin (1993) conducted light trap surveys of macroheterocerans at Meifeng, Nantou county, Taiwan. Based on data generated for 18 months of sampling, species – abundance relations were examined and several diversity indices were calculated. The relative abundance of trapped moth species fitted a lognormal model, which indicated that the moth community in that habitat was in stable equilibrium. There was also a significant relationship between members of moth community and such climatic factors as temperature and rainfall.

The butterfly community of the Tam Dao montane rain forest in northern Vietnam was described ecologically and biogeographically by Spitzer (1993). A negative correlation between the size of species, geographic range and maturity of the successional state of its preferred habitat was obtained. Within the forest, understorey species were mostly habitat specific and endemic while the canopy fauna tended to be much more heterogeneous and diverse.

Pollard and Yates (1993) in their book "Monitoring Butterflies for Ecology and Conservation" described one of the success stories of European ecology and conservation of the past two decades. Although essentially an account of the British Butterfly Monitoring Scheme, its scope ranges widely across the field of butterfly ecology, reflecting the diverse aspects of biology that the scheme has helped to elucidate.

Vane-Wright and Peggie (1994), based on a comprehensive checklist of the butterflies of Northern and Central Maluku, presented an estimate of butterfly species richness and endemism in this north-eastern region of Wallacea. A preliminary analysis of conservation priorities for the butterflies has also been presented.

In a study in Uttara Kannada in Karnataka, Gadagkar *et al. (1990)* assessed the species or taxonomic diversity of insects in reserve forests, disturbed forests, forest plantations and other similar habitats.

The study aimed at assessing the taxonomic diversity of different habitats resulted in 1789 species from 219 families belonging to 19 orders. Sampling was done using light traps, pitfall traps, netsweeps and scented traps. This study has shown that the diversity was high at intermediate levels of canopy cover. As the canopy opened up, more and more insects were found to colonize in the forest understorey.

An overall picture of the insect diversity in Indian forests is presented by Nair and Mathew (1993). As several forest habitats still remain unexplored, they insisted on infrastructure development for research on insect taxonomy to meet the needs of understanding and conserving biodiversity.

Quantitative data of the insect fauna of a natural scrub-jungle ecosystem at Nanmangalm Reserve Forest (Tamil Nadu) was assessed at the community level in relation to the seasonal changes in the habitat (Sanjayan *et al.,* 1995). A package of collection techniques involving light trap, scented trap, pitfall rap, sticky trap, sweep net and search out, was employed. A good correlation existed between the number of species and the member of individuals collected. A bimodal curve was obtained when the total insect abundance and species abundance were plotted against season with a small peak in February and a major in September. Coleopterans were found to be less affected by the high summer temperature of the forest.

Mathew *et al.* (1995) studied the insect species diversity with reference to moths in representative forest habitats in. the Silent Valley National Park. For sampling, a modified Pennsylvanian - type light trap, operated by a 6 V battery, with an automatic switching device to facilitate self operation of the trap at specified timings was used. Preliminary data suggested rich species diversity in well regenerative forests as compared to those subject to disturbances like incidence of fire. Sudheendrakumar *et al.* (2000) studied the habitat associations of 124 butterfly species in the Parambikulam Wildlife Sanctuary, Kerala, by analysing species records from five habitat types.

2.3. Impact of forest disturbance on insect diversity

Because of their abundance, species richness, ubiquitous occurrence and importance in the functioning of natural ecosystems, insects are widely used for monitoring landscape changes (Rosenberg, *et al.*, 1986). Insect diversity studies gained its present significance from its wide acceptance in EIA and conservation evaluation exercises to rank the particular site in relation to other sites in the region under consideration.

To categorise rainforests and monitoring changes in regeneration process, Holloway used lepidopterans which from a rich component of the rain forest fauna. Sampling of Lepidoptera is also fairly easy as large numbers can be collected in light traps. Samples were made quantitatively in 28 localities.

Holloway (1984), conducted a preliminary assessment on the distribution ecology and potential of larger moths as environmental indicators in Gunung Mulu National Park. In this five months survey with light traps, he had identified 6 families (Lymantriidae, Notodontidae, Arctiidae, Nolidae, Lasiocampidae, Geometridae and Drepanidae) and 2 subfamilies of Noctuidae (Hypeninae and

Cahlloephorinae) as potential biological indicators. Groups containing mobile species which appear to have high ecological amplitude are poor discriminates.

Holloway and Barlow (1992a) presented a profile of biological diversity in Malaysia using moths as an exemplar insect group. The effects of forestry practices and conversion to managed systems such as plantation or field crops were discussed. Loss of diversity is inevitable, but the effects vary ; in some instances recovery of diversity may be possible but it depends on the taxonomic group. Groups with a high degree of endemism and greater representation in lowland forest are most vulnerable to human disturbances. Certain groups with specialisation to open and disturbed habitats respond positively to human activities and are regarded as pests. Some other groups show exception to both these conditions and combine high endemism with high pest status.

While studying the response of some rain forest insect groups to logging and conversion to plantations, Holloway *et al.* (1992), used two insect groups having very different trophic requirements : moths, with floristically specific herbivory, and carrion beetles, exploiting resources of much more uniform quality over different forest systems. Moths show significant loss of diversity and taxonomic quality with disturbance and conversion to plantation. The beetles show much less change in diversity and faunistic composition.

To quantify the influence of altitude and anthropogenic disturbance on Lepidoptera diversity, Schulze and Fiedler (2000) conducted detailed studies in Mount Kinabalu (East Malaysia) in Northern Borneo. The diversity of butterflies was highest in the lowlands, whereas moth taxa (Sphingidae and Arctiidae) reaches its peak at mid elevations, butterfly diversity is found to decline strongly with human interference, while some moth taxa (Pyraloidea) persist even in heavily disturbed areas.

In northern Western Ghats, four tropical habitats with different disturbance levels were monitored for diversity and seasonal patterns in butterfly communities (Kunte, 1997). Species richness was highest in late monsoon and early winter. Fire played a significant role in determining species composition in five afflicted areas. Grazing had a major impact on species composition and favoured only those butterflies whose caterpillars fed on herbs.

In a study on patterns of butterfly, bird and tree diversity in the W. Ghats, natural vegetation types had relatively high diversities compared to human impacted vegetation types. Home gardens and paddy fields had very distinctive species composition (Kunte, 1999).

Impact of forest disturbance on insect species diversity was studied by Mathew *et al.* (1998) at four locations in the Kerala part of Western Ghats. Incidence of fire, plantation programmes as well as forest cutting for fodder and firewood were the major disturbance in these locations. Forest disturbance had an adverse effect on insect diversity as indicated by the reduction in the diversity indices obtained for the disturbed sites.

Mathew *et al.* (2000) studied the patterns of insect diversity in fire affected forests of Silent Valley National Park, Kerala. With regards to the patterns of species diversity, the fire affected areas showed reduction in the diversity.

Chapter 3

STUDY AREA AND THE SAMPLING SITES

3. STUDY AREA AND THE SAMPLING SITES

3.1. Study area

Location

The study was carried out in Nelliyampathy forests belonging to Nemmara Forest Division. This Division which was formed in 1958 comprises of 3 Forest Ranges namely Parambikulam, Nelliyampathy and Sungam. The tract dealt with (Figure 1) lies between 10^0 25′ and $30^0 30^{0}$′ North Latitude and 76^0 35′ and 76^0 40′ East Longitude. This forms the southern border of the Palghat gap of Western Ghats.

The name Nelliyampathy is supposed to have evolved from a tribal community 'Kadars' who had a hamjet or 'Pothi' near Nellikulam and the place 'Nelliampothi' might have changed to the present name.

The reserve forest patch of Nelliyampathy is boundered in the north by Kollengode Rajas forest, south by forests of Chalakudy Division, east by Parambikulam Wildlife Sanctuary and in the west by private forests of Nellikaledam and Puzhakkaledam.

Topography

Topographically the whole area is hilly in character. The Ghat forests are characteristically precipitous, consisting of many ridges and valleys, projecting their rocky apexes like the pyramids and presenting a sublime appearance. The Karapara Valley with the Thuthampara – Karapara ridge seperating them is a notable one. The Padagiri ridge running through the northern half of Nelliyampathy range is the main ridge in the Reserve Forest. The northern slopes of Padagiri hills extend up to the plains of Pothundy and Thiruvazhiod and consist of many major valleys of steep nature separated by subsidiary ridges taking off in different directions. The altitude of these hills varies from 40 metres to 1530 metres. The highest peak being the Padagiri ridge 5011' (1530.34 metres)..

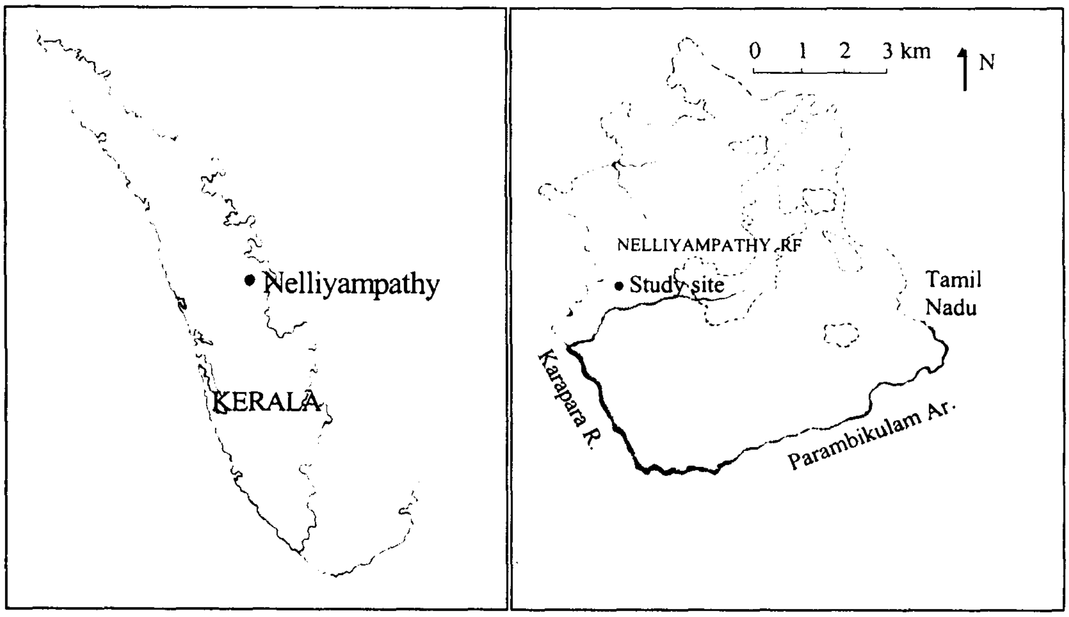


Fig.1. Map of Nelliyampathy reserve forest showing the study site

The main rivers that drain these forests are the Parambikulam river and Kuriarkutty river. These two main rivers join at Kuriarkutty and meets the Sholayar further down at Orukombankutty. Then there is the Karapara river originating from Karapara valley of Nelliyampathy and joins all the other rivers forming the main Chalakudy river.

Distribution and Area

Based on available records, Nemmara Division has a gross extent of 48,410.39 hectares of reserved forests out of which 1809. 008

hectares are under direct lease issued by the authorities with 20 estates in Nelliyampathy Range, for raising plantations of hill produce like cardamom, coffee and tea. In addition to the above, an area of 2147.47 hectares of forest was leased out before forest settlement. These areas continue to be treated as enclosures within the reserved forest under the Land Revenue Department.

Of the total 21993 hectares of land in the Nelliyampathy Range, 20005.177 hectares are under Nelliyampathy Reserve Forest. The total leased area under Nelliyampathy Reserve Forest is 3956.479 hectares. The remaining 16048.698 hectares comes under the reserve forest (Chandrasekharan, 1984).

Forest type

The forests of the Nemmara Division fall essentially under the 'Rain Forest' category. Major tracts of wet evergreen types of forest in Nemmara Division are found in Karapara and Thuthampara of Nelliyampathy Range. The forests are characterized by the presence of a relatively large number of lofty trees with extremely dense and even canopy. In Karapara – Thuthampara Valley, from the ground floor to the top storey, there is a chaotic mass of vegetation of all age gradation making it extremely difficult to identify the different species that lie in the different storeys of the forest. The total extent of evergreen forests in this Division is 9307.87 hectares. The general floristics of this type of forest is given below.

Vegetation

The major patches of forests in this region are of the wet evergreen type which are confined to higher elevations beyond 1000 m in rich humid valleys and banks of the river. Of the two such patches that still remain undisturbed, one is in the catchment of a tributory of Kuriarkutty river and the other along the southern and adjoining Sholayar Hydal Project (Chandrashekara *et al.*, 1998) According to Pascal (1988), *Cullenia exarillata - Mesua ferrea - Palaquium ellipticum* vegetation type is the most dominant along the medium elevation forests in the Western Ghats. Nelliyampathy forest comes under this category (Chandrashekara and Ramakrishnan, 1994).

The top canopy is very dense and the dominant species in the mature tree population are *Palaquium ellipticum, Cullenia exarillata, Mesua ferrea* and *Drypetes wightii.* The other common species include *Polyalthia coffeoides, Artocarpus heterophyllus, Syzygium laetum, Myristica dactyloides, Agrostistachys meeboldi, Ardicia pauciflora, Diospyros* sp., *Actinodaphnae bourdillonai* and *Heritiera papilio.*

The lower canopy consists of species like *Litsea floribunda, Canarium strictum, Elaeocarpus serratus, Mallotus philippensis, Aporusa lindliana* and *Holigarna arnottiana.*

These trees shelter a large number of epiphytic orchids, ferns and mosses which adds to the importance of the flora. The common undergrowth are *Saprosma fragrans, Schumannianthus virgatus, Pandanus thwaitesii, Strobilanthus* sp., *Solanum* sp., *Chromolaena odorata, Crotalaria* sp., *Amomum* sp., *Jasminum* sp., *Leea indica, Laportia crenulata, Eletteria cardamomum, Calamus* sp., *Glycosmis* sp. and *Centella asiatica* to mention a few.

In the undisturbed forest areas there is very good natural regeneration of *Dimocarpus longan, Litsea mysorensis, L. stocksii, Cinnamomum* *malabatrum, Cullenia exarillata, Drypetes wightii, Heritièra papilio, Meiogyne pannosa, Myristica dactyloides, Syzygium laetum* and *Psychotria* sp.

Climate and Rainfall

Climate is generally equable in the low lying areas and fairly cool at higher elevations. March, April and May are the hottest months of the year, the temperature raising upto 32° C, in low countries and even up to 27° C, higher up. During December, January and February, the temperature in the higher regions drops to 13° C.

The forests in Nemmara Division get the benefit of both the Southwest and Northeast monsoons. The average annual rainfall in this Division varies from 1270 mm in Thekkady forests to 3400 mm in the Nelliampathies. The southwest monsoon is active and lasts up to August. During September, the rainfall is comparatively low. The northeast monsoon generally breaks towards the middle of November. Generally the pre-monsoon shower occurs in May. Due to the elevation, the Nelliampathies get a larger incidence of rain from the southwest monsoon the precipitation being heaviest on the eastern and southeastern aspects of hill slopes.

3.2. Sampling sites

Six sampling sites selected for the survey represent diverse habitat types and were situated near Pothumala KFDC estate, at an elevation of approximately 1050 msl., within a radius of about 6 km.

Of these six study sites, three come under undisturbed forest (sites A,B and C), one in the forest edge (site D) and site E and F fall in monoculture plantations. Each site reflects different levels of vegetative distribution as given below :

Site A.

Dense forest with almost closed canopy. GBH of trees ranging between 200 and 400 cm. and are of approximately 35-40 m height. Understorey vegetation is much less, limited to tree saplings. The soil is humus rich and the atmosphere is cool, dark with reduced sunlight.

Site B

Typical evergreen patch with highly dense sapling population represented by secondary successional species in the girth class ranging from 10 cm to 30 cm open canopy resulted in lush forest with seedlings and shrubs (Figure 2).

Site C

River bank, lower to Aanakkayam, near Karapara (Figure 3). Vegetation is well represented with mature trees, saplings, seedlings, shrubs, herbs, grass and climbers.

Site D.

It is an edge of an undisturbed forest area lying adjacent to cardamom plantation (Figure 4). Few mature trees, saplings, seedlings, shrubs, climbers, cardamom plants, luxuriant grass and herbs forms the vegetation.

Site E

This site is a least managed coffee plantation. There were a few lofty trees in this area which provide shade. Herbs and grass present beside the paths. Prooning was not done during the study period.

Site F

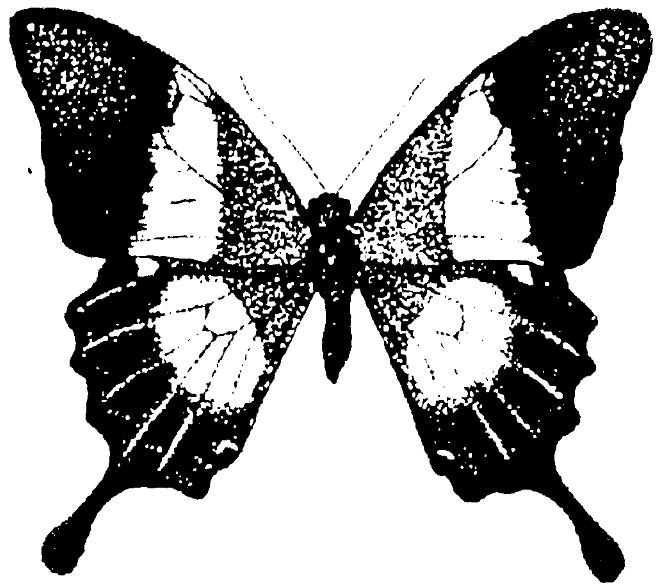
This site is within an intensively managed cardamom plantation (Figure 5). Weeding, mulching, soil working and irrigation were the common agricultural practices followed in the field. Insecticide application was not observed but limited use of inorganic fertilizers noticed. Trees remaining for shade regulation provided cool and humid atmosphere.

Fig. 2. Study site B in an evergreen forest patch with a light-trap in the centre

Fig. 3. Riverine study site C at Nelliyampathy

Fig. 4. Site D in the edge of an undisturbed forest area

Fig. 5. A cardamom plantation (site F) at Nelliyampathy. A portion of the light-trap can be seen in the foreground



Chapter 4

MATERIALS AND METHODS

4. MATERIALS AND METHODS

4.1. Sampling methods

4.1.1. Insect studies

Sampling strategy was aimed at making the methods quantitative and unbiased. Various techniques were employed for sampling towards different objectives.

Faunal studies

Rhopalocerans were collected using hand nets. Sweeps were done in different parts of the forest, mostly between 9.30 am and 12.30 pm when the butterflies are more active.

Heterocerans were collected by attracting them towards a light source. For this, light traps fitted with 8 watts U.V. tube were used. On certain occasions, an independent light source of 12 watts fluorescent tube was illuminated.

Standard methods suggested by Borror and Delong (1964) and Ghosh (1982) were used for pinning, spreading and drying of insects collected both through light trap and faunal surveys. Entomological pins of appropriate sizes were used for various specimens. Well dried insects were stored in air-tight insect storage boxes and kept in cabinets. The collection was properly curated. The identification of insects was done by comparing with the material available in the KFRI collections and by referring to literature (regarding classification of butterflies at the family level, present work is based on that of Ackery, 1984 given in New, 1997).

This study was confined mostly to macrolepidoptera and selected microlepidoptera viz., Pyralidae, Yponomeutidae and Tortricidae of microlepidoptera.

Diversity studies

Line transect method (Pollard, 1977 and 1982) was used to study the Rhopaloceran diversity. The transect was pre-planned and the length and route of the transect was fixed in each site. In this permanent line transect of 500 m, observations were taken in the morning between butterfly active hours, 9.30 am and 12.30 pm. The transect was covered in a slow but constant pace and on each consecutive visit, the direction of walking through the transect was reversed to reduce the bias related to peak time of butterfly activity. All individuals seen at all heights and distance from the transact were recorded in a specific data sheet from January 1995 to December 1995.

For uniform sampling of heterocerans, a battery operated light trap fitted with an automatic switching device to facilitate self operation at specified hours (Mathew and Rahamathulla, 1995) was used. The trap was operated in different study sites between 6.30 pm and 10.30 pm. The collecting chamber was provided with the killing agent, Benzene.

The study on the impact of forest disturbance on moth diversity was carried out in representative plots. At each site, four plots were laid out along a transect at fixed intervals. The plot size was fixed at

625 m^2 and the distance between the plots was 25 m. Light traps were operated in these plots.

Insects collected by the light trap were sorted out to species and each species was assigned with a code number. Number of individuals for each species was recorded on data sheets specifying study site, species code and the name of the family to which the specimen belonged.

4.1.2. Vegetation studies

Vegetation was studied with a view to generate base-line data on the floral elements to facilitate comparison of the relationship between the vegetation and insect community. Plants above 2 cm in diameter were enumerated in all the study plots (4 plots each of size 25 m X 25 m were taken within dense forest, forest edge and in cardamom plantation, to study the impact of disturbance on moth diversity). The diameter of small plants was measured at 6 cm from ground whereas in the case of tall plants, girth at breast height (gbh) was recorded. Based on this, plants were classified as mature trees (gbh more than 30.1 cm), saplings (gbh 10.1 to 30 cm), seedlings, shrubs, herbs and climbers (gbh <10 cm) (Chandrashekara and Ramakrishnan, 1994).

4.2. Data analysis

4.2.1. Analysis of local distribution pattern of butterflies

In the analysis, a simple coefficient estimating the overlap of distribution among samples (sites), between pairs of species was used, followed by cluster analysis to pick out groups of species with similar distributions. The coefficient of overlap is similar to the Bray and Curtis (1957) given in Ludwig and Reynolds (1988). The samples were normalized so as to express the numbers of each species as a proportion of the total sample.

BC-Group distances or Bray-Curtis dissimilarity index

This group is represented by a single index first introduced into the ecological literature by Bray and Curtis (1957). The first step is to compute the per cent similarity (*PS*) between sampling units (SU) *j* and *k* as

$$PS_{jk} = \left(\frac{2W}{A+B}\right)(100)$$

$$W = \sum_{i=1}^{s} \min(X_{ij} X_{ik})$$

$$A = \sum_{i=1}^{s} X_{ij} \text{ and } B = \sum_{i=1}^{s} X_{ik}$$

X_{ij} = abundance of i^{th} species in j^{th} SU

Thus *PS* between the j^{th} SU and k^{th} SU is a numerator of twise the sum of the minimum of the pair of observations X_{ij} and X_{ik} (shared species abundance between each pair of SUs) divided by a denominator of the total of all the species abundance for the two SUs.

The distance complement of *PS* is per cent dissimilarity (*PD*), which is computed as

$$PD = 100 - PS$$

PD may also be computed on a 0 -1 scale as $PD = 1 - \frac{2W}{(A+B)}$

4.2.2. Analysis of patterns of geographical distribution

A numerical analysis of patterns of geographical distribution was tried. The distribution data of moths amongst 26 primary areas were used to calculate the dissimilarity coefficients.

The coefficient is based on the overlap between each pair of species in terms of selected primary areas as in Holloway and Jardine (1968), Holloway (1973), Holloway (1977) and Holloway (1979).

The dissimilarity coefficient $= 1 - \frac{n}{N}$

Where '*n*' is the number of primary areas in which both species occurs and '*N*' is the number of primary areas in which either or both species occurs.

The matrix of dissimilarity coefficients is then subjected to cluster analysis.

4.2.3. Diversity studies

Whittaker (1972) distinguished three levels at which diversity can be studied: alpha (within-habitat), beta (between habitat) and gamma (study of the complex of habitats). In the present study α and β diversity were taken into account.

Alpha diversity (diversity within the site)

Diversity indices

Indices based on the proportional abundances of species, derived from information theory, such as Shannon diversity index ând Brillouin index were used. The number of species (species richness) in the community and their evenness in abundance are the two parameters that define these heterogeneity indices.

Distribution models

One of the ways of describing diversity in a community is through species abundance or distribution models (Fisher *et al.,* 1943). These models provide a sound basis for the examination of species diversity. A species abundance distribution utilises all the information gathered in a community and is the most complete mathematical description of the data (Magurran, 1988). Although species abundance data will frequently be described by one or more of a family of distributions (Pielou, 1975), diversity is usually examined in relation to four main models. These are geometric series, logarithmic series, truncated log normal series and broken stick models.

The frequency distribution of insects per collected species was studied for all the sites separately and one of the above four models which best describe the data was fitted.

α of log series

Log series α was computed by an iterative procedure using the equation

$$S = \alpha \log_e\left(1 - \frac{N}{\alpha}\right)$$

where S is the number of species in the sample, N is the number of individuals, and α is the index of diversity. The standard deviation of α is estimated as $\frac{\alpha}{-\log(1-X)}$ where $X = \frac{N}{N+\alpha}$

Using this standard deviation, significant differences in diversity between habitats were judged by *Z*-test.

Shannon diversity index

The Shannon index (Margalef, 1968) assumes that individuals are randomly sampled from an indefinitely large population (Pielou, 1975). The index also assumes that all species are represented in the sample. It can be calculated using the equation:

$$H' = -\sum p_i \ln p_i$$

where H' is the Shannon's index of species diversity and p_i is the proportion of individuals found in the i^{th} species.

A method using '*t*' - test was proposed by Hutcheson (1970) for comparing the diversity indices of two samples. It is given by the formula,

$$t = \frac{H_1' - H_2'}{\left(\mathrm{Var}(H') + \mathrm{Var}(H')\right)^{1/2}}$$

This follows a student '*t*' distribution with degrees of freedom ν which is given by the formula

$$\nu = \frac{\left(\mathrm{Var}(H_1') + \mathrm{Var}(H_2')\right)^2}{\frac{\left(\mathrm{Var}(H_1')\right)^2}{N_1} + \frac{\left(\mathrm{Var}(H_2')\right)^2}{N_2}}$$

where H_1' and H_2' are the diversity indices of sample 1 and sample 2, Var (H_1') and Var (H_2') are corresponding variances and N_1 and N_2 are the total number of individuals in samples 1 and 2 respectively.

The variance of H' (Magurran, 1988) can be calculated using the formula,

$$Var(H') = \frac{\sum p_i (\ln p_i)^2 - (\sum p_i \ln p_i)^2}{N} + \frac{S-1}{2N^2}$$

Shannon diversity index was calculated for both insect and vegetation data.

Brillouin diversity index

Due to unequal response to light, light- trapping cannot guarantee the randomness of a sample. Pielou (1969, 1975) strongly favours the use of Brillouin index (*HB*) in such circumstances. It is calculated as

$$HB = \frac{\ln N! - \sum \ln n!}{N}$$

where $N = \sum n_i$, N is the total number of individuals.

As this diversity is being calculated for a collection there is no significance test.

Species richness index

The number of species at a site, in a region or in a collection is called species richness. Menhinick's index of species richness (Whittaker, 1977):

$$D_{mn} = S/\sqrt{N}$$

where S is the number of species recorded and N is the total number of individuals summed over all species.

Evenness indices

Evenness indices which measure the evenness of species abundance, are complimentary to the diversity index concept as it indicates how the individuals of various species are distributed in the community.

Shannon's evenness index

Although as a heterogeneity measure, Shannon's diversity index takes into account the evenness of the abundance of species, it is possible to calculate a separate additional measure of evenness (*E*) using the formula (Pielou, 1975)

$$E = H'/\ln S$$

where *S* is the number of species recorded and *H'* is the Shannon diversity index.

Brillouin evenness index

Evenness (*E*) for the Brillouin diversity index is obtained from :

$$E = \frac{HB}{HB_{\max}}$$ where *HB* is Brillouin diversity index

HB_{max} is calculated as $HB_{\max} = \frac{1}{N}\ln\left(\frac{N!}{\{[N/S]!\}^{S-r}\{([N/S]+1)!\}^{r}}\right)$

and [*N*/*S*] = the integer of *N*/*S* and *r* = *N* - *S* [*N*/*S*]

Beta diversity (It measures the difference between sites)

Beta diversity is a measure of the replacement of species between different types of community or habitat. As such, it corresponds to the spatial contiguity of different communities or habitats (Halffter, 1998). The fewer the species that different communities or habitats share, the higher the β diversity will be. Taken together with measures of within habitat diversity, β diversity can be used to give the overall diversity of an area.

Similarity measures

Sorensen index

A version of the Sorensen measure modified by Bray and Curtis (1957) was used to study similarity for which the following formula was applied:

$$C_N = 2jN/(aN + bN)$$

where *aN* = the total number of individuals in Site A, *bN* = the total number of individuals in Site B, and *jN* = the sum of the lower of the two abundances recorded for species found in both sites.

Morisita – Horn index

A modified version of Morisita-Horn index (Wolda, 1983) was also calculated using the equation:

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

where *aN* = total number of individuals in Site A

bN = total number of individuals in Site B

an_i = number of individuals in the i^{th} species in Site A,

bn_i = number of individuals in the i^{th} species in Site B.

$$da = \frac{\sum an_i^2}{aN^2} \quad \text{and} \quad db = \frac{\sum bn_i^2}{bN^2}$$

Chapter 5

RESULTS AND DISCUSSION

5. RESULTS AND DISCUSSION

5.1. Rhopaloceran fauna of Nelliyampathy

Butterflies recorded from Nelliyampathy belonged to 5 families, 73 genera and 121 species (Appendix I). The family Nymphalidae with 54 species had the higher representation followed by Pieridae (23 species), Papilionidae (18 species), Lycaenidae (4 species) and Hesperiidae with 10 species (Plates I to III illustrates some species of significance recorded from the study area). Despite the moderate sampling effort at the area, all families except Lycaenidae and Hespriidae were recorded with high proportion of species expected from Western Ghats.

Eventhough Lycaenids and Hesperiids are common and abundant, they were seen less frequently due to their retiring habits and slow, jerky flights close to ground. The sombre colouring of Hesperiids also make them quite inconspicuous.

5.2. Local distribution pattern of butterflies

On account of the competition within and between species, the total mass of living organisms which can populate an ecosystem depends directly on the space available. The species diversity increases with the stability and maturity of the ecosystem.

The dependence of almost all Lepidoptera on plants for larval development is a known fact. Individual species show various levels of host specificity, from monophagy, through oligophagy, to limited polyphagy. Ehrlich and Raven (1965), in their classic paper on the correlation of butterflies and plants, suggested that mutual interactions of plants and phytophagous insects might be responsible for generating much of the species diversity of both groups. Although these are naive, extreme predictions, there are factors other than this, which are important in maintaining and generating butterfly faunal diversity. The presence of food plant is a necessary, but not a sufficient condition for the breeding presence of a butterfly. On the other hand, several butterflies may coexist where there is only one species of larval food plant. Thus food plant species diversity alone may be neither sufficient nor necessary for maintaining faunal diversity. In fact, an analysis of local distribution is essential to study the diversity as it serves to pinpoint major associations of species through similarities in their distributions and define the discontinuities separating these associations.

Terrestrial vegetation and their associated fauna are highly heterogeneous in response to irregularities in the physical environment. In such an environment, the faunal and floral communities will intermingle and overlap. Faunal groups often have an additional factor of the mobility of individuals.

In the analysis of local butterfly distribution based on line transect counts from three habitats, *viz.,* evergreen forest, forest edge and coffee plantation, a simple coefficient estimating the overlap of distribution among samples (sites), between pairs of species was used, followed by cluster analysis to pickout groups of species with similar distributions (Holloway, 1977). The dendrogram .obtained is given in Figure 6.

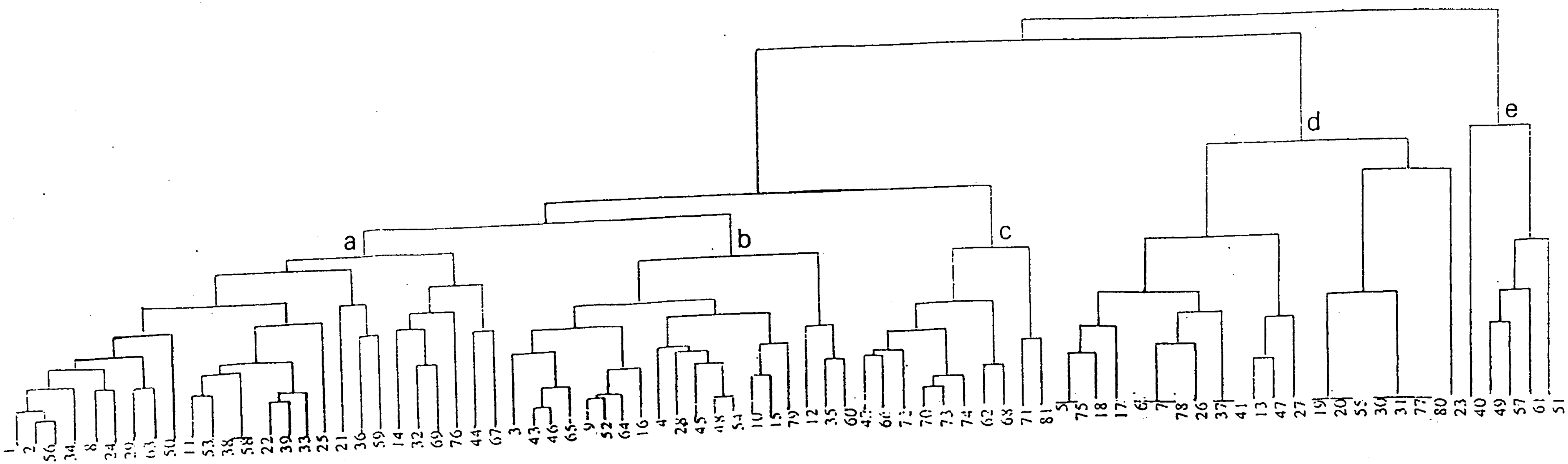
Major clusters obtained at levels 0.35 and 0.45 are numbered as a, b, c, d and e. The species numbered in the dendrogram is given in Appendix II for cross-reference.

Most of the species represented by cluster 'a', (1-67), are sun-loving and open habitat dwellers belonging to the Genera *Appias, Hypolimnas, Junonia* and *Neptis*. Butterflies like *Troides minos, Pachliopta aristolochiae, Papilio polytes, Graphium sarpedon* etc., begins to fly early in the morning and start feeding at the flowers. Thus, the butterflies under this cluster are those associated with the forest edge.

Powerful fliers and those which can survive in altered habitats are to be expected in plantations as this habitat is not much supportive regarding food resources. Cluster 'b', (3-60) demonstrates such a plantation association of butterfly species. Fast fliers such as *Papilio helenus, Papilio polymnestor, p. demoleus, P.paris, Graphium agamemnon* etc., are seen darting through the plantation, whereas, danaid butterflies are attracted to crotalaria plants beside the pavements, which serve as alkaloid source essential for the males to prime the pheromones.

In cluster d, (5-23), was highly significant in its unique species composition as it contained strictly habitat specific species that are found only in dense evergreen forests. Majority of the rare and endemic butterflies encountered in transect counts were confined to this association. *Papilio buddha, P. liomedon, P. dravidarum, P. pandiyana, Vanessa cardui, V. indica, Kaniska canace, Idea malabarica, Spindasis lohita, Talicada nyseus, Cethosia nietneri,*

Fig. 6. Dendrogram derived in the classification of species according to their local distribution and abundance.



Udaspes folus, Parthenos sylvia virens, Pathysa antiphates etc., are certain species referred with respect to this cluster.

Cluster 'c', (42-81), was formed by butterflies belonging to families Hesperidae, Lycaenidae and subfamily Satyrinae, constituting widely spread elements which clusters with forest edge, plantation and forest associations. The smallest combination of *Ariadne ariadnae, Pachliopta hector, Elymnias caudata, Euploea core and Leptosia nina* formed the cluster 'e'. These butterfly species can be expected in any of the associations mentioned above, as these are the most common species recorded for all the three sites.

5.3. Community structure

Eighty one species of butterflies were recorded in transect counts in dense forest, forest edge and plantation areas in the study site. The number of species and individual abundance for the three habitats are given in Table 1.

Table 1. Species/ individual abundance of butterfly communities

Family	Forest	Edge	Plantation
Papilionidae	17 (41)	16 (95)	13 (127)
Pieridae	10 (30)	15 (68)	9 (73)
Nymphalidae	34 (121)	29 (164)	26 (197)
Lycaenidae	7 (31)	7 (29)	4 (18)
Hesperiidae	7 (37)	4 (27)	5 (19)
Total	75 (260)	71 (383)	57 (434)

(Values in parenthesis indicate number of insects recorded)

Forest and forest edge were found to have approximately equal number of species whereas individual abundance showed great variation. The increase in butterfly abundance in the forest edge might be due to the availability of diverse habitats in this area. Not all species found in forest edge were open habitat specialists, but appeared to be forest gap specialists. Least species abundance was recorded in the plantation area compared to other two habitats because forest and edge with their higher structural diversity can definitely accommodate a variety of species having different niche requirements.

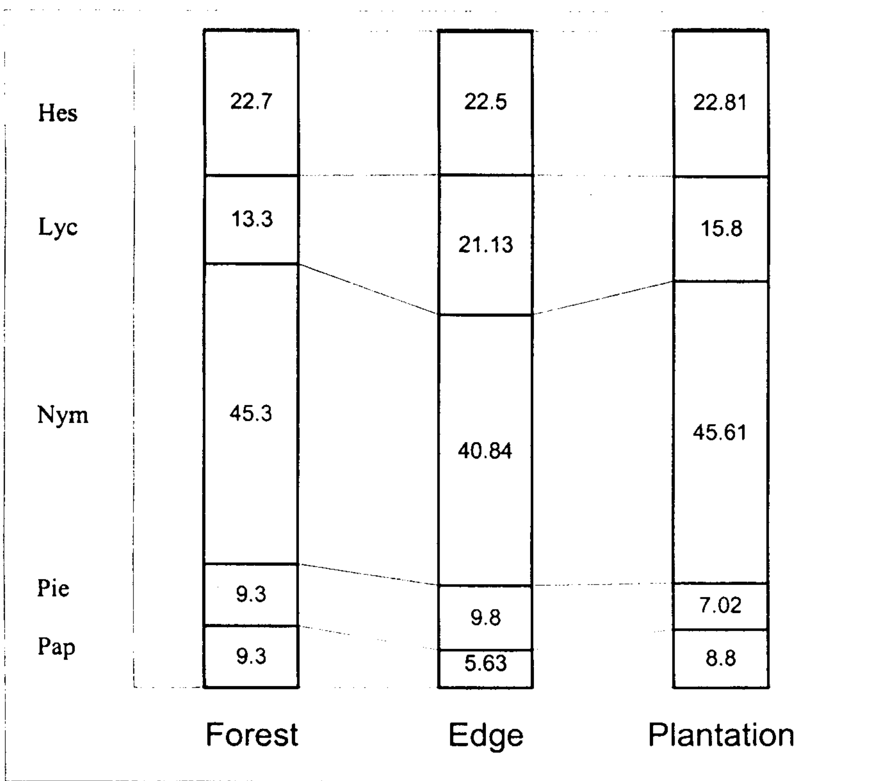


Fig. 7. Proportional representation of butterfly families in different habitats

With regard to the proportional distribution of butterfly families in different habitats, Pierids and Lycaenids were found to be more specific to the edge, while all the others preferred dense forest habitat (Figure 7).

5.4. Endemic butterflies

The endemic butterflies recorded from Nelliyampathy and those included in the Wildlife (Protection) Act of 1972 are listed in Appendix I. Seven species comes under Schedule I, 15 under Schedule II and 4 of Schedule IV have been recorded in the survey.

The number of species and endemics recorded at Western Ghats and Nelliyampathy along with corresponding percentages at Nelliyampathy to Western Ghats total are given in Table 3. Twenty one endemic species were recorded from Nelliyampathy which is 37% of the Western Ghats total. Comparatively high proportion of the papilionid and pierid species could be recorded here (95% and 69% of the W. Ghats total), whereas representation of other families was much lower. With regard to the proportion of endemic species recorded under various families, Papilionidae registered the highest value (87%) followed by Pieridae (50%). As with the case of species proportion, here also the other families stood far behind. It is noteworthy to mention here that *Idea malabarica* and *Parantica nilgiriensis* of the subfamily Danainae (Nymphalidae) are included in the 1994 IUCN Red list of threatened animals.

Table 3. A comparison of total number of species and endemics recorded from Western Ghats and Nelliyampathy.

Family / Subfamily	No. of species for W.Ghats	No.of species for Nelliyampathy	Proportion to W.Ghat total [%]	No. of endemic spp. in W.Ghats	No. of W.Ghat endemic spp. at Nelliyampathy	Proportion to W.Ghat endemic total [%]
Papilionidae	19	18	95%	8	7	87%
Pieridae						
Pierinae	24	17	71%	4	3	50%
Coliadinae	9	6	67%	2	-	-
Nymphalidae						
Danainae	10	9	90%	2	2	100%
Satyrinae	29	13	45%	13	4	31%
Morphinae	1	1	100%	1	1	100%
Nymphalinae	51	30	59%	4	2	50%
Charaxinae	5	1	20%	-	-	-
Lycaenidae						
Polyommatinae	50	11	22%	4	1	25%
Theclinae	45	4	9%	9	1	11%
Curetinae	3	1	33%	2	1	50%
Riodininae	1	-	-	-	-	-
Miletinae	2	-	-	-	-	-
Hesperiidae						
Pyrginae	18	6	33%	1	-	-
Hesperiinae	54	4	7%	11	-	-
Coeliadinae	9	-	-	-	-	-
Total	330	121	37%	61	22	36%

5.5. Heteroceran fauna of Nelliyampathy

Two hundred and four species of moths belonging to 151 genera and 14 families were recorded from Nelliyampathy (Appendix III) as detailed in Table 4 below (Plates IV to VII illustrates some species of significance recorded from the study area).

Table 4. Number of moth species recorded under various families

Family	No. species
Noctuidae	43
Lymantriidae	15
Eupterotidae	7
Arctiidae	24
Yponomeutidae	2
Tortricidae	2
Geometridae	43
Pyralidae	38
Amatidae	2
Notodontidae	4
Sphingidae	15
Saturniidae	5
Cossidae	2
Limacodidae	2

5.6. Biogeography of moths of Nelliyampathy

As Nelliyampathy is found well represented by a diverse heteroceran fauna, a numerical analysis of patterns of geographical distribution was tried.

The distribution data of 150 moth species collected from the study area were recorded from the literature (Hampson,1892-1896; Beeson,1941; Bhattacherjee and Gupta,1969; Laithwaite *et.al.,* 1975; Wiltshire, 1976; Arora and Gupta, 1979; Arora and Chaudhury, 1982; Barlow,1982; Arora, 1983; Sevastopulo, 1986; Carter, 1992 and Shubhalaxmi and Chaturvedi,1999). The distribution data thus gathered suggested affinities with 26 seperate geographic locations. These 26 primary areas were then used to calculate the dissimilarity coefficients (method is discussed in Chapter 4).

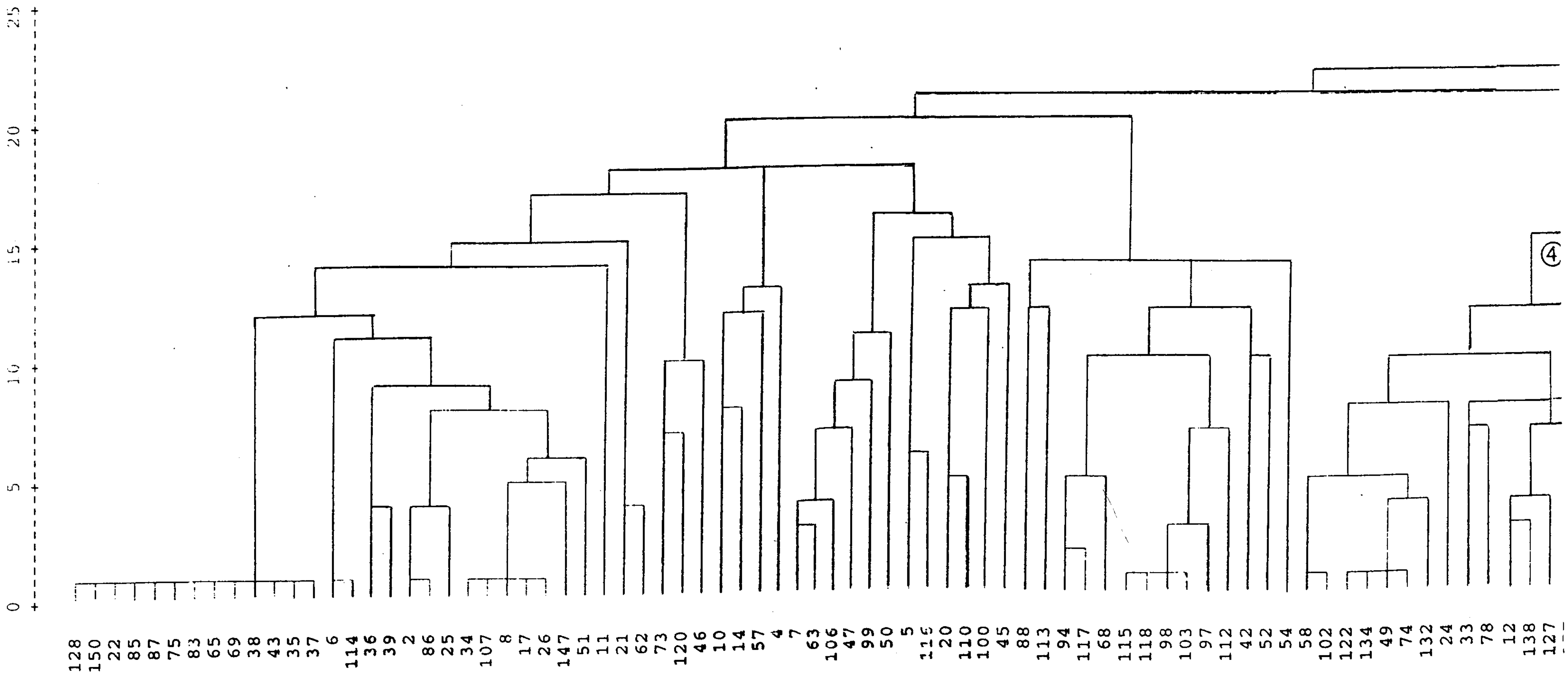
The matrix of dissimilarity coefficients was subjected to cluster analysis and the pattern of clustering is summarized in the dendrogram in Figure 8. The primary areas used in the numerical analysis together with the list of species numbered as in Figure 8 to facilitate cross reference is given in Appendix IV. It produced many clusters that appeared over a narrow range of dissimilarity values and fused together at a barely greater level. Even a glance of the dendrogram clearly illustrates the wide- ranging geographical affinity of moth fauna present here.

The largest cluster '1' obtained at a dissimilarity level of 10 and clusters '2' and '3' comprise species showing affinity to major zoogeographical regions. In cluster 1, species 15 to 77 (*Petelia medardaria, Cnaphalocrocis medinalis, Dichocrocis evaxalis* etc.), having least dissimilarity shows affinity to Indo Australian region in their distribution.

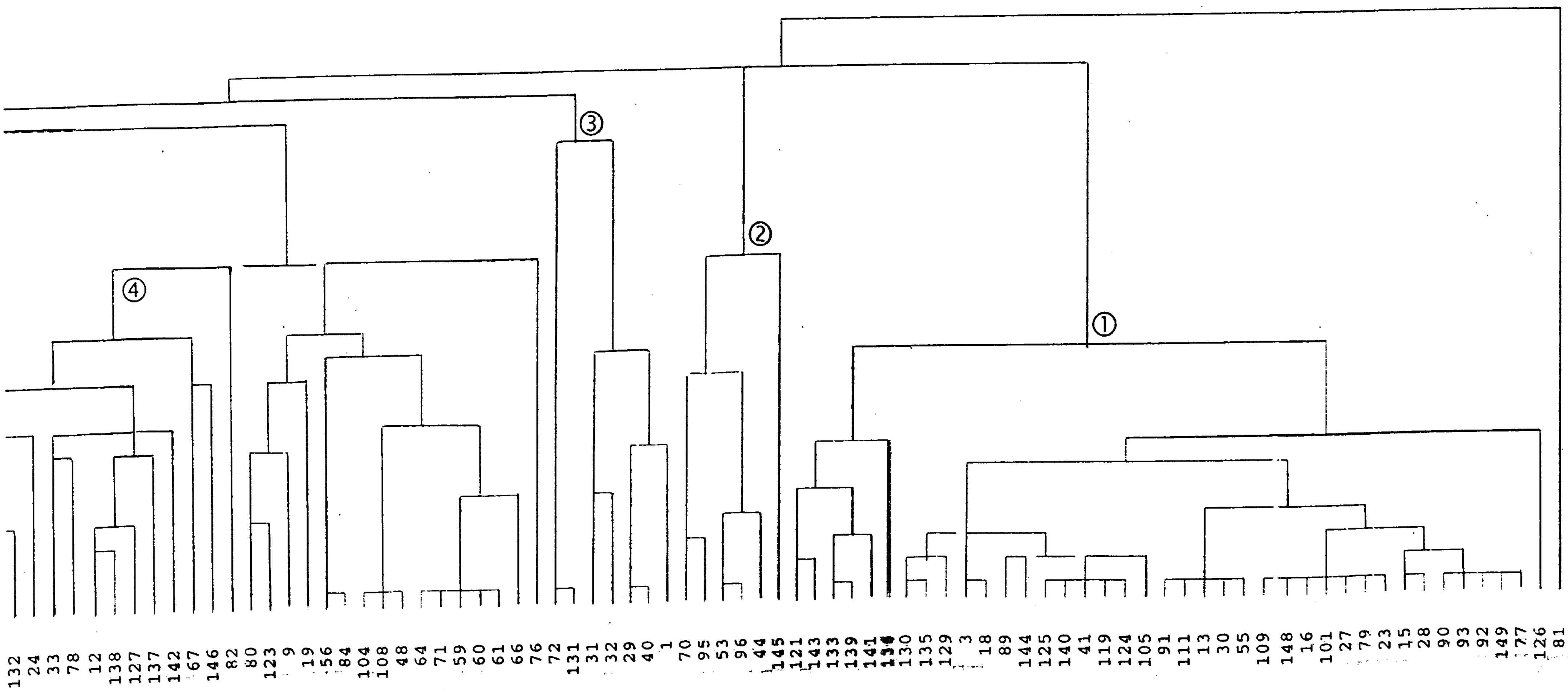
In cluster '1' species 121 to 136 were found to be restricted to Oriental tropics to Sundaland, whereas clusters 2 and 3 were strictly of Oriental affinity.

area were recorded from the literature (Hampson,1892-1896; Beeson,1941; Bhattacherjee and Gupta,1969; Laithwaite *et.al.*, 1975; Wiltshire, 1976; Arora and Gupta, 1979; Arora and Chaudhury, 1982;

Fig. 8. Dendrogram derived in the c



ved in the classification of species according to their geographical distributions.



At this same level of resemblance, species 109 to 23 shows affinity to Ethiopian region which included *Nyctipao macrops, Prodenia litura, Ophideres fullonica, Pingasa ruginaria* and *Marasmia trapezalis. Laphygma exigua, Thyas hunesta, Diasemia litterata* and *Nymphula crisonalis* (91-55) are universally distributed.

Palaearctic affinity of the moth fauna was represented by the cluster (130-105). This included *Callopistria rivularis, Eilema tetragona, Miresa argentifera, Eumelia rosalia, Rhodogastria astreas, Lymantria ampla, Utethesia pulchellale, Euproctis spp. Ourapteryx marginata* and *Boarmia infixaria*.

All other clusters formed at the 'cut-off ' distance of 10 are associations of species distributed among various primary areas in the Ethiopian, Oriental and Australian regions. Most of them are not significant regarding the geographical affinity. Species 128-37, which form a cluster with least dissimilarity represents fauna confined to India, Sri Lanka and Burma. Cluster '4' formed at level 15 by the species 58-82 are striking for its Malayan affinity. This includes 18 species such as *Phalera procera, Tarsolepis rufobrunnea malayana, Oxyambulyx pryeri, Marumba dyras, Macroglossa aquila, Theretra nessus, Loepa sikkima, Cricula trifenestrata, Attacus atlas, Actias maenas, Actias selenae* and *Oxyambulyx subocellata*.

5.7. Ecological diversity of moths

Biodiversity, the variety of life, is distributed heterogeneously across the earth. It is a well accepted fact that some areas or habitats are much richer in species than others. Recent advances and interest in biodiversity monitoring using quantitative sampling techniques elate the importance of the study of distribution of abundance amongst species to species richness. This leads to the formulation of various indices of diversity to derive numerical values from quantitative samples, which can be interpreted in terms of various environmental factors.

Alpha-diversity: the species / abundance relationship

Species / abundance relationship in the six study sites at Nelliyampathy have been described using distribution models and various diversity indices such as α of log series, Brillouin index and Shannon index.

Distribution models

The frequency distribution of insects per collected species for the various localities and the best fitted model are discussed below:

Site A

Truncated log normal distribution was best fitted to the data gathered from site A. The observed and expected number of species was compared using χ^2 goodness of fit test to see whether the observed distribution of species fits well with the truncated log normal distribution. As the calculated value of χ^2_2 = 4.30 is less than the table value $\chi^2_{(2,0.05)}$ = 5.991, there exists no significant difference between the observed and expected distribution. This indicates that the distribution pattern of species follows truncated log normal distribution. Class behind veil is with an expected value of 36.2 (Table.5), shows the presence of species which were not sampled in the study.

Table 5. Test of goodness of fit of truncated lognormal distribution at Site A

Class	Upper class boundary	Observed species (O)	Expected species (E)	χ^2 $\frac{(O-E)^2}{E}$
Behind veil line	0.5	-	36.20	-
1	2.5	44	38.73	0.72
2	4.5	13	21.18	3.16
3	8.5	16	15.36	0.03
4	16.5	13	10.96	0.38
5	∞	4	3.78	0.01
			$\Sigma\chi^2$	4.30

Critical value of $\chi^2_{(2,0.05)}$ = 5.991

Site B

The data from site B did not follow the above pattern of species distribution and since there were only three classes, truncated log normal model could not be applied. As the number of species was high, geometric series was also unfit. The total number of species recorded from this site was 170, whereas the number of individuals was only 369. The highest value of evenness index (0.97) for this site is a better estimate as far as the habitat quality is concerned (Table 13). The inefficiency of the data to fit into distribution model may be due to reduced number of sampling attempts.

Site C

In this case too, distribution models were not suitable. The higher values of richness and evenness index (Table 17 and Table 13 respectively) show the habitat suitability which in turn signifies the insufficiency of data gathered.

Site D

Truncated log normal distribution was fitted to the data from this site. The observed and expected numbers of species was compared using χ^2 goodness of fit test. As there was no significant difference between observed and expected distributions, it is inferred that the pattern of species distribution follows truncated log normal model (Table 6). Log normal distribution pattern indicate the existence of a large, mature and varied natural community. Number of expected species behind the veil line was high (Table 6) indicating the presence of large number of rare species in the area and some of which were not covered in the survey.

Table 6. Test of goodness of fit of truncated lognormal distribution at Site D

Class	Upper class boundary	Observed species (O)	Expected species (E)	χ^2 $\frac{(O-E)^2}{E}$
Behind veil line	0.5	-	36.2	-
1	2.5	45	41.57	0.28
2	4.5	11	11.57	0.03
3	8.5	7	8.27	0.20
4	16.5	1	5.01	3.20
5	32.5	5	2.31	3.15
6	∞	1	1.26	0.05
			$\Sigma\chi^2$	6.91

Critical value of $\chi^2_{(3,0.05)}$ = 7.815

Site E

A truncated log normal distribution was fitted to the data. The observed and expected number of species was compared using χ^2 goodness of fit test. The test showed no significant difference between the observed and theoretical distribution because the calculated value ($\Sigma\chi^2 = 0.44$) was less than the critical value ($\chi^2_{(1,0.05)} \doteq 3.84$). This implies the distribution pattern of the species follows truncated log normal distribution (Table 7).

Table 7.Test of goodness of fit of truncated lognormal distribution at Site E

Class	**Upper class boundary**	**Observed species (O)**	**Expected species (E)**	χ^2 $\frac{(O-E)^2}{E}$
Behind veil line	0.5	-	15.91	-
1	2.5	55	52.15	0.15
2	4.5	13	13.69	0.03
3	8.5	6	7.20	0.20
4	16.5	2	2.39	0.06
			$\Sigma\chi^2$	0.44

Critical value of $\chi^2_{(1,0.05)}$ = 3.841

Site F

The data of this site was best fitted for truncated log normal distribution. No significant difference was observed when observed and expected number of species were compared using χ^2 goodness of fit test. The calculated value for χ^2 was less than the critical value (Table 8). So the community is expected to have large number of rare species and the behind veil line value of expected species insists on more sampling.

Table. 8. Test of goodness of fit of truncated lognormal distribution at Site F

Class	Upper class boundary	Observed species (O)	Expected species (E)	χ^2 $\frac{(O-E)^2}{E}$
Behind veil line	0.5	-	22.08	-
1	2.5	55	51.50	0.24
2	4.5	9	13.16	1.31
3	8.5	8	7.51	0.03
4	16.5	4	2.91	0.41
			$\Sigma\chi^2$	1.99

Critical value of $\chi^2_{(1,0.05)}$ = 3.841

α of log series

The log series index (α) was computed for all the six sites. The significant differences in diversity between habitats as judged by Z - test is given in Table 9 which shows that there exist no significant differences in the diversities of site B and C and site E and F. Site B (low canopy with high understorey vegetation) and site C (river bank) are much similar habitats regarding the distribution of vegetation and indices of richness and evenness of insect community (Table 16 and Table 13 respectively). Site E and F belongs to monoculture plantations and from both habitats same number of species were recorded, (76). Species abundance also showed much similarity in these sites. Significant difference in diversity was observed in all the other pairs of sites.

Table 9. Z –values for comparing the α of log series diversities of different sites.

Site	A	B	C	D	E	F
A						
B	11.37					
C	10.85	0.21(ns)				
D	3.37	-9.80	-9.42			
E	5.82	-7.05	-6.90	7.10		
F	5.60	-7.45	-7.28	6.97	-0.43(ns)	

Shannon index

Shannon's diversity index calculated for the pooled data from each site is given in Table 10. The highest diversity was for site B which could be probably due to the varied habitat conditions there. The site D, although situated in the forest edge, recorded only minimum value. Even though this area contained maximum number of individuals (except site A), evenness index came down to the least, 0.76, which inversely affected the diversity index.

Table10. Shannon's diversity index for pooled data from each study sites

Study sites	A	B	C	D	E	F
Shannon's diversity index	4.11	4.96	4.84	3.22	4.13	3.99

In the 't' test diversity of Site A and E, and Site A and F were found to be non significant (Table 11). The similarity in diversity might be due to the peculiarity of the habitats. At all the three sites, top canopy was dense with less understorey vegetation (A), while the

Coffee (E) and Cardamom plantations (P) were almost devoid of undergrowth. The closed canopy of site A and the almost open canopy with managed monoculture nature of sites E and F inversely affects the growth of understorey vegetation, which in turn reduces insect diversity. For all the other pairs, diversity was highly significant. High plant diversity in these sites provides for greater vegetation stratification that leads to niche space for different populations. It also diversifies the feeding specialisation of insects, ultimately results in high diversity.

Table 11. '*t*' values for comparing the Shannon diversity indices of the six study sites.

Site	A	B	C	D	E	F
A		-21.23	-17.30	-10.97	-0.54(ns)	1.88(ns)
B			-4.55	-23.48	21.59	17.95
C				-21.49	17.41	15.25
D					-11.43	-8.67
E						2.35

Brillouin index

When the randomness of a sample cannot be guaranteed, as for instance during light trapping (Southwood, 1978) where different species of insects are differentially attracted to light, Pielou (1969, 1975) suggested Brillouin index as the appropriate information index. Brillouin indices calculated for the different study sites is given in Table 12. Like that of Shannon's index (Table10), here also Site B with moderately open canopy and high secondary successional vegetation recorded maximum diversity. Minimum value obtained was for site D.

Table 12. Brillouin index calculated for various study sites

Study sites	**A**	**B**	**C**	**D**	**E**	**F**
Brillouin index (HB)	3.79	4.39	4.23	2.97	3.63	3.52

Evenness or equitability index

The equitability indices for Shannon diversity index and Brillouin diversity index calculated for the various study sites is given in Table 13.

Table13. Evenness indices calculated for various sites

Study sites	**A**	**B**	**C**	**D**	**E**	**F**
Shannon index	0.91	0.97	0.96	0.76	0.95	0.92
Brillouin index	0.92	0.97	0.97	0.76	0.96	0.92

Evenness for both the indices disclose its maximum to site B and site C and minimum for site D. High equitability refers to the occupation of all available habitats by maximum number of individuals possible.

The result signifies the importance of mature and diverse community present in site B and C. Site D located in the forest edge which register second maximum individual abundance has only least number of species. The openness of the habitat and unique vegetation sustains only a few populations and that might be sampled in abundance.

β or Differentiation diversity

The Sorenson index and Morisita-Horn index which were used to study the similarity of pairs of sites in terms of species abundances (quantitative data) are given below:

Sorenson index (quantitative data)

The similarity of pairs of sites measured using the above index is given in Table14. The index was highest for site E and F, 0.61 (cardamom and coffee plantations) and site B and C, 0.52 (low canopy with understorey vegetation and river bank). This indicates the similarity of ecological requirements that these pairs of sites provides for different species.

Table 14. Sorenson index (C_N) of similarity of pairs of sites.

Sites	A	B	C	D	E	F
A		0.34	0.21	0.19	0.07	0.07
B			0.52	0.11	0.21	0.19
C				0.10	0.36	0.29
D					0.03	0.03
E						0.61
F						

Morisita - Horn index (quantitative data)

This index which is, strongly influenced by species richness and sample size is given in Table15. Sites B & C and Sites E & F recorded the highest similarity, 56% and 50% respectively. This supports the finding that there exists no significant difference in the species diversities of sites B & C and E & F.

Table 15. Morisita – Horn index (C_{MH}) of similarity of pairs of sites.

Sites	A	B	C	D	E	F
A		0.33	0.29	0.14	0.22	0.12
B			0.56	0.08	0.31	0.27
C				0.18	0.37	0.25
D					0.15	0.08
E						0.50
F						

A dendrogram representing β diversity obtained through cluster analysis using Morisita index is given in Figure 9. It clearly confirms the findings obtained above.

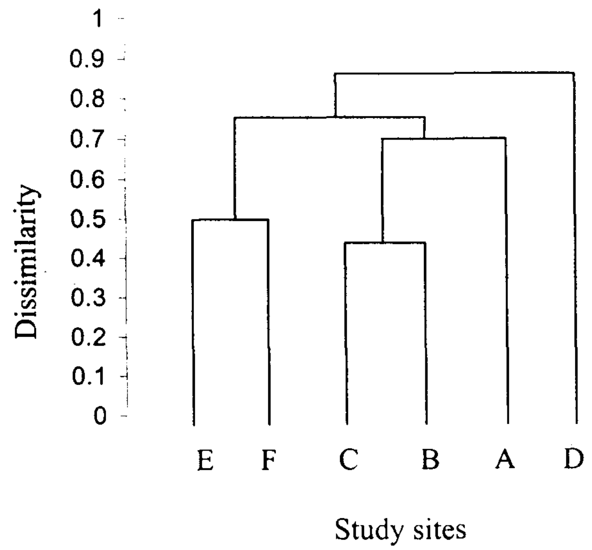


Fig. 9. Comparison of Morisita index of different study sites

5.8. Seasonal patterns of moth fauna

Nineteen months light trap survey of moths of quantitative nature has provided good data for studying general seasonal patterns for the various species and also modification in these patterns due to changing physical environment. Climatic variations can act both directly on insect populations through the tolerance, or lack of it, of individuals to extreme temperature, humidity, insulation and so on, and indirectly through the effect of these variations on the condition of vegetation such as its production of new growth, leaf fall, flowering and fruiting (Holloway, 1984).

Population fluctuation of these highly mobile insects inferred from quantitative data obtained from light trap surveys should take into account the air temperature, flight range of insect, effect of wind and moonlight.

Monthwise data collected for different study sites were first subjected to a '*t*' test in order to find whether any significant difference exists in the distribution of both number of species and individuals in the sample. In all the sites except sites E and F, calculated value of χ^2 was greater than the table value. It indicates that the number of species or individuals observed in different months were not uniform. In sites E and F, located in coffee and cardamom χ^2_{18} plantations respectively, the calculated values of χ^2 were less than the table value =28.9, for both the distribution of number of species and number of individuals. Hence in the above two cases, species / abundance distribution were uniform in different months. This might be due to the peculiarity of the habitat itself. Monoculture plantation can support only certain specific groups of insects. Part of the insects caught in the light trap might include transient individuals having nearby home ranges. This is because of the openness of the habitat and increased light penetration. These factors may probably cause such a uniform species / abundance distribution in different months.

For recording the seasonal abundance of moth species and individuals a tentative classification of the calendar year was made into three seasons based on temperature and rainfall. They are , (1) Summer – January to April , (2) Rainy – May to August, (3) Winter – September to December.

In all study sites the number of species and individuals were found to be higher in months from May to December (rainy and winter seasons) and lower in January to April (summer). The incidence of precipitation was found to be inversely proportional to atmospheric temperature or in otherwords, the rainy months were with minimum temperature (Figure 10).

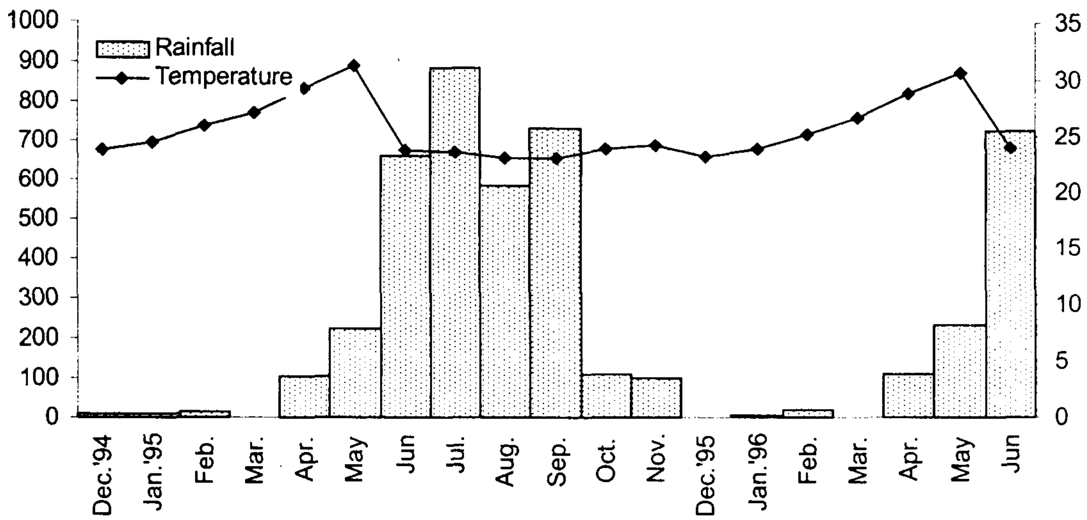


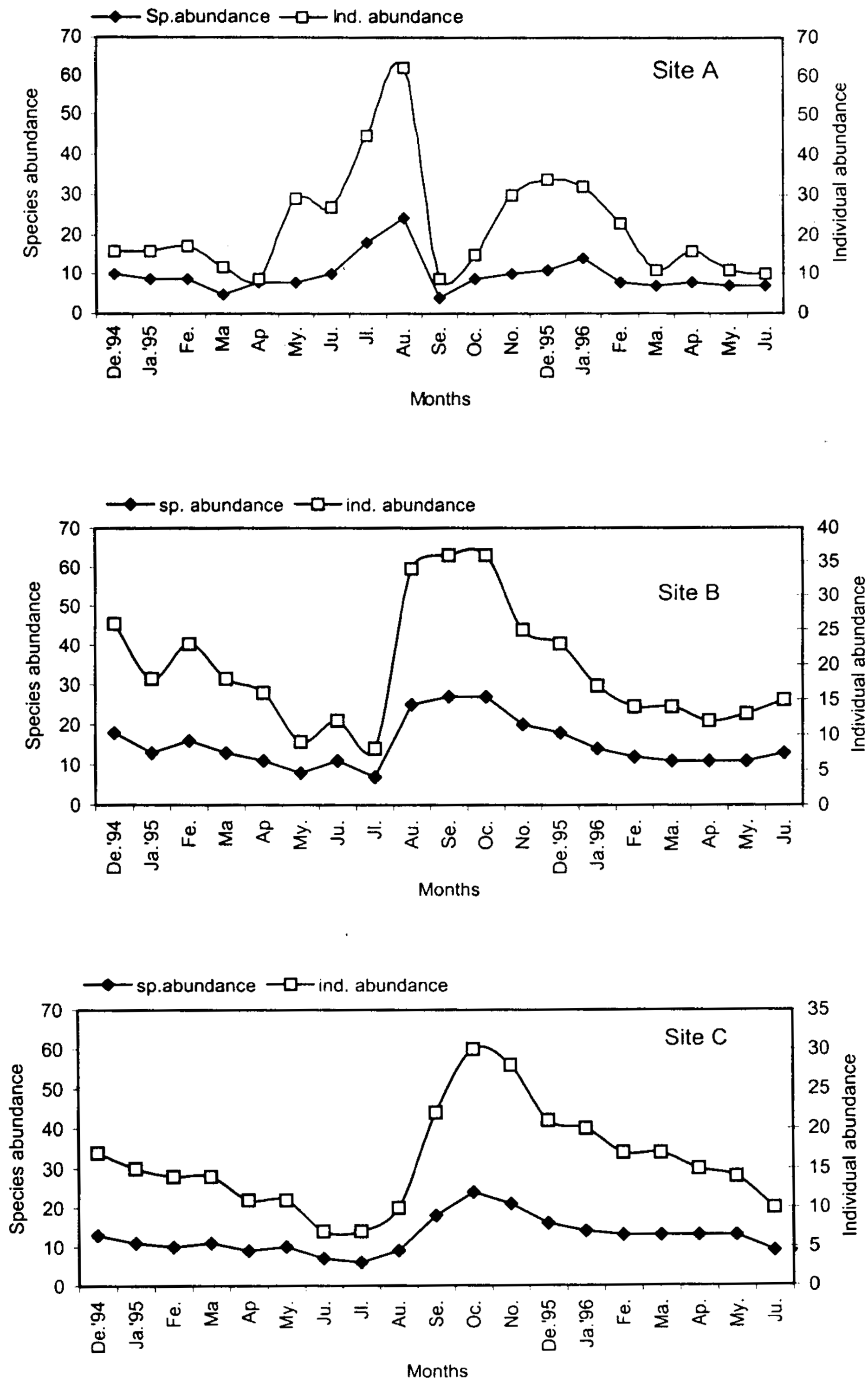
Fig. 10 Rainfall (bars, in mm) and average temperature (dots, in °C) in Nelliaympathy

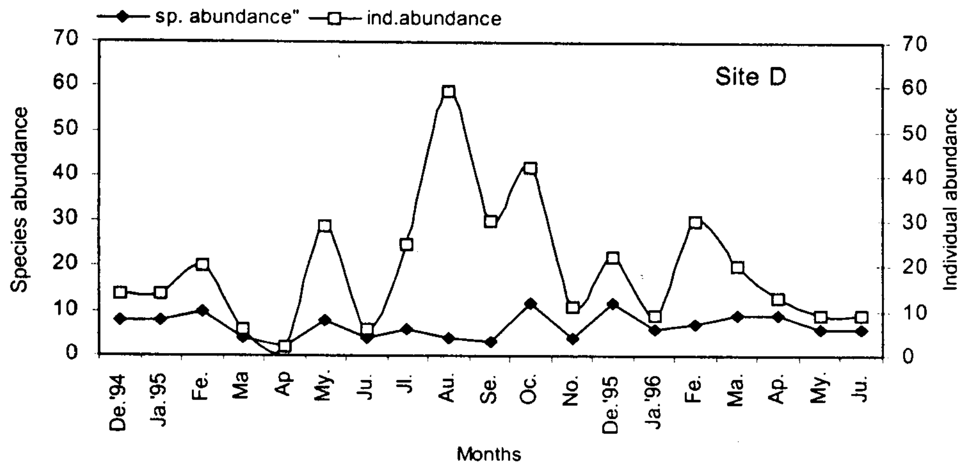
Species and individual abundance plotted against months for every site is given in Figure 11. Both values are seen declining from February to May which may be due to the dry conditions with the onset of summer. The curve formed by accumulated individual abundance shows the peakedness in mid-rainy and mid-winter seasons, *i.e.* July to October. Fairly medium level of precipitation and temperature in these months might be the reason for this insect abundance. In this period, August with a mean temperature of 23° C and precipitation 584 mm was recorded with highest accumulated abundance of 185 individuals.

Quantification of diversity addresses two statistical properties common to any mixture of different objects. One is the distribution of objects and the other is their relative abundance. To see the monthly variation in occurrence of species and the relative abundance of individuals among them, diversity indices were calculated. Values obtained for Shannon's diversity index for each month is given in Table16. Eventhough the readings are seen fluctuating among different months, a marked increase was observed in mid-rainy and mid-winter seasons which was expected to provide the most suitable physical environment for moths.

Life cycles of moths are highly correlated with seasons, as the variations in physical environment has much effect on their survival. So the seasonality in occurrence and increased frequency of observation in certain months are expected. *Pericallia ricini*, *Dudusa nobilis* and *Cusiala raptaria* were frequent in early rainy months of June and July whereas *Hyposidra talaca*, *Eupterote fabia*, *Lymantria ampla* and *Marumba indicus* were recorded maximum in their emergence period from late rainy season to early winter, August to

Fig. 11 Monthly distribution of species and individual abundance for various study sites





sp. abundance"
ind.abundance
Site D
Species abundance
Individual abundance
Months
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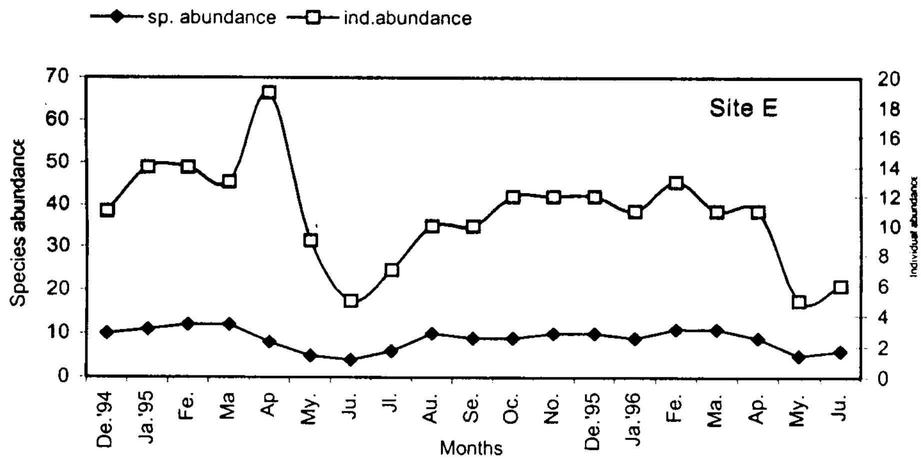

sp. abundance
ind.abundance
Site E
Species abundance
Individual abundance
Months
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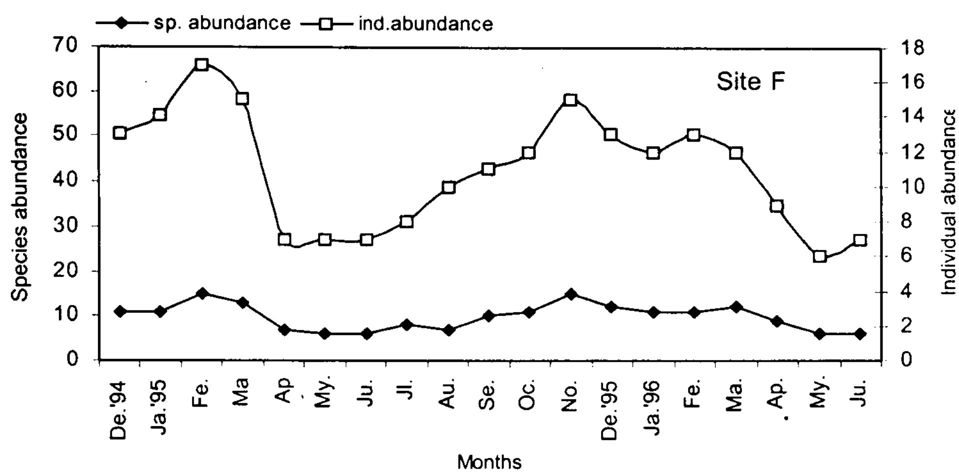


sp. abundance
ind.abundance
Site F
Species abundance
Individual abundance
Months
De.'94 Ja.'95 Fe. Ma Ap My. Ju. Jl. Au. Se. Oc. No. De.'95 Ja.'96 Fe. Ma. Ap. My. Ju.

October. Certain species were found to be active in mid-summer months of March and April such as *Sylepta derogata*, *Sylepta balteata*, *Lygropia orbinusalis, Carea subtilis* and *Eupterote testacea*. An Arctiid moth, *Diacrisia obliqua* was found totally absent from the scene during November to February as that was their pupal hibernation period. Some species were seen in almost all months as they have several generations (4-6) a year, eg: *Argina argus*, *A.cribaria, A. syringa*, *Dasychira grotei*, *D. mendosa*, *Achaea janata*, *Prodenia litura*, *Lygropia orbinusalis*, *Acherontia styx*, *A. lachesis*, *Macroglossa aquilla* etc. *Achaea janata*, which usually prefers open habitat, though seen in all months was particularly abundant in monsoon, possibly due to the luxuriant vegetation during that season.

Table 16. Shannon's diversity indices of month-wise data from different study sites.

	Dec' 94	Jan '95	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec'95	Jan'96	Feb	Mar	Apr	May	Jun
A	2.19	2.13	1.87	1.54	2.04	1.93	2.22	2.80	3.07	1.21	2.03	2.01	2.13	2.52	2.01	1.85	1.84	1.89	1.83
B	2.76	2.45	2.69	2.43	2.31	2.04	2.37	1.91	3.10	3.16	3.20	2.92	2.81	2.59	2.44	2.34	2.37	2.35	2.52
C	2.51	2.30	2.20	2.34	2.14	2.27	1.94	1.75	2.16	2.81	3.11	2.92	2.59	2.55	2.48	2.42	2.52	2.54	2.16
D	2.01	1.91	2.04	1.33	-	1.80	1.24	1.24	0.94	0.98	2.03	1.12	2.26	1.68	1.61	1.78	2.09	1.58	1.68
E	2.27	2.30	2.44	2.46	2.04	1.47	1.33	1.75	2.30	2.16	2.09	2.21	2.25	2.09	2.35	2.40	2.34	1.61	1.79
F	2.35	2.30	2.67	2.52	1.94	1.75	1.75	2.80	1.75	2.27	2.37	2.71	2.46	2.37	2.31	2.48	2.20	1.80	1.75

5.9. Habitat preference of moths

Moths in their larval stage are mainly foliage feeding. Plant feeding insect group that exhibit specificity along floristic lines will be likely to provide a much more precise profile of diversity, reflecting general patterns of both flora and fauna, though the correlation is not without exceptions (Holloway, 1984).

From various sites, 207 species belonging to 13 families and 1864 individuals were recorded. Sites B and C had maximum number of species and thus registered highest richness index value (Table17). Eventhough reported with least number of species, site D stood second to site A in individual abundance. Sites B and C in the evergreen forest, with high undergrowth, limited sunlight and humid atmosphere helps to flourish insect life. Such a habitat can provide niche space for diverse species which eventually results in high species richness. Peculiar vegetation and more open habitat with direct sunlight in site D or forest edge supported only limited species.

Table 17. Richness index for various study sites.

Study site	Number of species	Number of individuals	Species richness index
A	90	424	4.37
B	170	369	8.85
C	153	300	8.83
D	70	370	3.64
E	76	193	5.47
F	76	208	5.27

Data transformed to family-wise distribution of species for every site was analysed using a '*t*' test to find whether any significant difference exist between sites with regard to number of species and individuals among various families. In all cases calculated value of χ^2 was greater than the corresponding tabular values. It discloses that either the number of species or the number of individuals found in different families were not uniformly distributed.

The proportion of families in various sites are given in Figure 12. Forest sites such as A, B and C were seen effectively supporting arboreal feeding insect families such as Geometridae, Lymantriidae, Saturnidae and Cossidae whereas disturbed forest sites such as D,E and F promoted herbaceous feeding families, Noctuidae and Pyralidae. Eupterotidae almost entirely restricted to forest understorey were found to be represented by sites B, C, E & F.

Shannon's diversity indices and evenness values were computed for family-wise data and are shown in Table 18. Highest values of both indices for the families Geometridae, Lymantriidae and Saturnidae were reported for sites A, B and C. Family Notodontidae with arboreal feeding larvae was recorded only for site B which reveals the habitat specificity of the taxa. Forest edge was with Noctuidae, Pyralidae and Arctiidae on top. Almost all major families were competently represented by sites in plantations. The openness of the habitat and increased penetration of light used in the trap might be the reason for this phenomenon. Moths from the neighbouring forest area have probably flown into the plantation and augmented the intrinsic diversity. Majority of Sphingids, except Macroglossinae were uncommon in open habitats and plantations. The high mobility of these insects will justify their significant presence in sites E and F. At the same time habitat preference of a pest species, *Atteva fabriciella* of family Yponomeutidae, with index values for only these two sites was a good indicator.

Table.18 Shannon's diversity and evenness indices for family-wise data from different study sites.

	AMA	ARC	LYM	NOC	PYR	GEO	EUP	SPH	SAT	NOT	LIMA	YPO	COS
A		2.20 (0.81)	2.18 (0.85)	3.17 (0.91)	1.45 (0.81)	2.10 (0.84)		1.56 (0.75)	0.69 (1.0)				
B	2.60 (0.96)		2.70 (0.95)	3.66 (0.97)	2.77 (0.96)	3.63 (0.96)		2.43 (0.95)	1.50 (0.93)	0.69 (1.00)	1.81 (0.93)		0.64 (0.92)
C	0.38 (0.54)	2.75 (0.95)	2.45 (0.90)	3.50 (0.96)	3.31 (0.95)	3.31 (0.98)		2.51 (0.95)	0.96 (0.88)				
D	0.58 (0.83)	1.95 (0.69)	1.21 (0.58)	2.90 (0.90)	1.84 (0.88)	1.61 (0.90)		1.04 (0.75)					
E	0.56 (0.81)	2.03 (0.97)	1.73 (0.83)	2.61 (0.92)	2.36 (0.98)	2.46 (0.96)	1.79 (0.92)	1.75 (0.98)	0.56 (0.81)			0.56 (0.81)	
F	0.60 (0.86)	2.08 (0.95)	1.82 (0.79)	2.65 (0.98)	2.08 (0.87)	2.09 (0.84)	1.42 (0.73)	1.56 (0.87)	0.41 (0.59)			0.35 (6.50)	

AMA – AMATIDAE

ARC – ARCTIIDAE

LYM – LYMANTRIIDAE

NOC – NOCTUIDAE

PYR – PYRALIDAE

GEO - GEOMETRIDAE

EUP- EUPTEROTIDAE

SPH – SPHINGIDAE

SAT – SATURNIIDAE

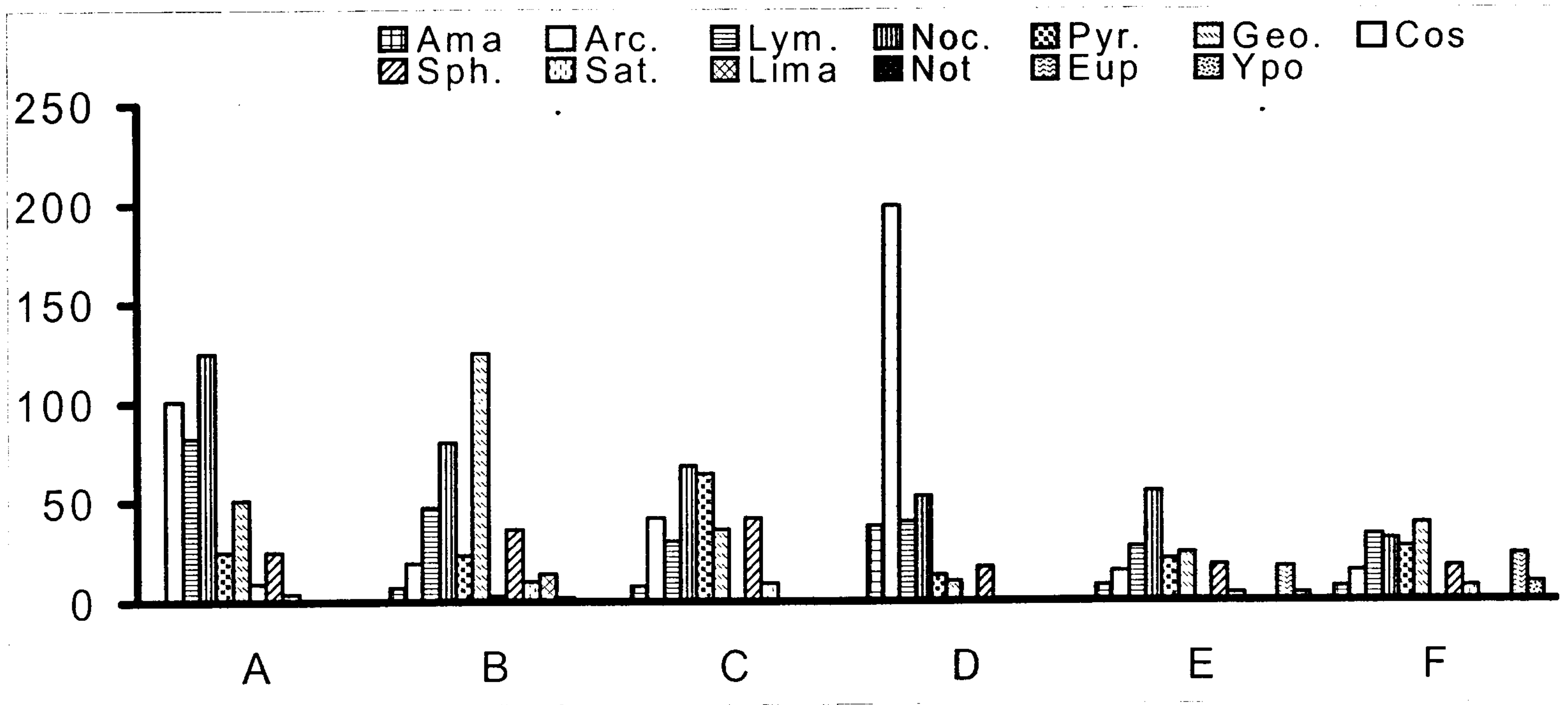
NOT – NOTODONTIDAE

LIM – LIMACODIDAE

YPO – YPONOMEUTIDAE

COS - COSSIDAE

Fig 12. Representation of species abundance in various families recorded from different study sites



5.10. Impact of plantation activities on moth diversity

Loss of diversity is inevitable during conversion to managed systems such as plantation or field crop. Plantations show a differential erosion of diversity in the smaller taxonomic group, an erosion that proceeds further with conversion to open habitat. Ultimately the fauna of such systems becomes limited to an association of open habitat specialists to low diversity (Holloway, 1987; Holloway *et al.* 1990). At the same time, in some instances recovery of diversity may be possible, eg:- logging cycles in natural forests (Holloway, 1992).

It is likely that most higher taxa of tropical plants support at least some tightly associated and coevolved insect groups (Gilbert *et al.* 1975). When considering the diversity of vegetation as an environment supporting insect life, it is important to consider both structural and floristic diversity to estimate the number of potential niches a vegetation type may present for exploitation by animals (Southwood *et al.* 1979; Lawton, 1978).

In order to see the impact of plantation activities on moth diversity, both vegetation and insect diversities of undisturbed forest and managed systems were correlated. For this purpose, from the total six study sites of Nelliyampathy, three were selected. They were site B (low canopy with high understorey vegetation), Site D (forest edge) and site F (cardamom plantation).

A total of 50 plant species were recorded from different sites (Appendix V). In site B, of 32 species registered, 24 were represented as mature trees, 20 as saplings and 19 as seedlings. Herbs and shrubs were sparse. Out of 42 species present in site D, 27 were represented as mature trees, 20 as seedlings and 12 as saplings whereas those of site F were divided among mature trees, saplings and seedlings with 17, 7 and 9 species respectively (Table 19).

The overall pattern of plant and insect diversity in various sites are given in Table 20. Shannon diversity indices were calculated for both flora (except cardamom plants) and fauna. The result shows that both plant and insect diversity indices were higher for forest site (B). This may probably be due to the presence of appropriate host plants and suitable climatic conditions there. Eventhough recorded with least plant diversity, plantation represented comparatively higher insect diversity than forest edge. The influx of insects from the adjacent forest patches might be the reason for this rarity.

The diversity indices and proportional representation of various families (Figure 12) show that plantation system support a much lower moth diversity than dense forest, although the pattern was confused by inclusion of a component of secondary forest fauna. This may be probably due to the location of the plantation in the vicinity of the forest. The above mentioned component of secondary forest fauna should be identified and segregated to yield a more clear impression of the ability of floristically impoverished plantation to support diversity in herbivorous insects.

Table. 19. Characteristic of the vegetation in various sites

Study site	Mature trees	Tree saplings	Tree seedlings	Shrub	Herb	Total	Shannon diversity index
B	24 (265)	20 (201)	19 (364)	4 (63)	2 (271)	32 (1164)	2.92
D	27 (120)	12 (39)	20 (200)	4 (88)	3 (205)	42 (652)	2.85
F	17 (74)	7 (12)	9 (45)	-	-	19 (131)	2.68

(values given in parenthesis indicate number of plants)

Table. 20. Insect and plant diversity pattern in various sites

Study site	Plant diversity	Plant species	Plant number	Insect diversity	Insect species	Insect number
B	2.92	32	1164	4.96	170	369
D	2.85	42	652	3.22	70	370
F	2.68	19	131	3.99	76	208

When we look into the overall moth diversity of these sites, some groups with endemism and high representation in forest area such as Geometridae, which are most vulnerable to human disturbance, have high potential for loss of diversity, including extinction. At the other extreme are groups such as Noctuidae and Arctiidae with many geographically widespread taxa with specialism to open and disturbed habitats. These include many taxa that respond positively to human activities and are regarded as pests. Appendix III gives a list of general Heteroceran pests of agricultural crops recorded from various sites. The family Limacodidae, represented in evergreen forest site, combining high endemism with high pest status is an exceptional case. The fern feeding noctuid genus *Callopistria* is common in forest site than plantation. Species of open habitats, with herb feeding larvae are most numerous in plantation sites such as members of the genus *Athetis, Mocis, Mythimna, Eupterote, Euproctis, Spodoptera, Chalciope* etc. Most of the major Heteroceran pests of monocultures are recorded from the plantation site (Appendix VI). Some of the species are present in forest edge samples which is of course, adjacent to the plantation area. A diverse community of moth taxa belonging to Pyralidae and Geometridae persist in heavily disturbed area of plantation due to the secondary forest patches remaining in their vicinity.

Chapter 6

SUMMARY

6. SUMMARY

Thesis configuration

The thesis is composed of seven chapters. Chapter 1 gives an introduction to the topic whereas Chapter 2 reviews the available literature pertaining to Lepidopteran fauna and diversity studies. Chapter 3 describes the study area and sampling sites in the context of location, topography, climate and vegetation etc. Chapter 4 broadly discusses methods related to sampling and statistical analysis.

In the 5th chapter on results and discussion, rhopaloceran fauna, local distribution pattern and endemism are given prior to heteroceran fauna, the biogeographical affinities, ecological diversity, seasonal patterns, habitat preference, and the impact of forest disturbance. The last chapter contains a summary of the findings.

Highlights of the study

A study in Nelliyampathy forests was conducted on the Lepidopteran fauna to generate data on the species diversity in different habitats and to gather information on the response of moths towards forest disturbance and conversion to plantations.

Of the six study sites selected, three were in undisturbed forest (sites A, B and C), and the remaining in the disturbed zone representing various levels of perturbations *ie.*, the forest edge (site D) and monoculture plantations of coffee and cardamom (sites E and F) respectively.

Rhopaloceran faunal survey based on sighting and sampling by net-sweeps has resulted in recording 121 species belonging to 73 genera under 5 families. Heterocerans were collected by setting up light traps. Two hundred and four species of moths belonging to 151 genera under 14 families were recorded.

Of the various butterflies recorded, 22 were endemic to the Western Ghats which represents 56% of the Western Ghats total. The families Papilionidae and Pieridae were recorded with high proportion, 95% and 70% respectively. Of the total, 26 species were of protected status (included in the Wildlife (Protection) Act of 1972).

Analysis of local distribution pattern of butterflies revealed three major associations of species. While sun-loving and open habitat dwellers were seen associated with the forest edge, powerful fliers and those which can survive in altered habitats were found in plantation areas. Forest association was highly significant in its unique species composition as most of them were strictly habitat specific and found only in dense evergreen forests. Majority of the rare and endemic butterflies encountered were also confined to this group.

Community structure of butterflies revealed high species richness in dense forest habitat compared to forest edge and plantations. Proportional distribution of butterfly families showed that pierids were more specific to forest edge whereas all others preferred dense forest habitat.

Biogeography of moths was studied by numerical analysis of patterns of geographical distribution. Faunal elements were derived for a sample of 150 moth species and their zoogeographical affinities were studied. While 7 species were found to have close affinity to Indo-Australian region, 7 were strictly of Ethiopian, 13 Palaearctic and 18 species with Malayan affinity.

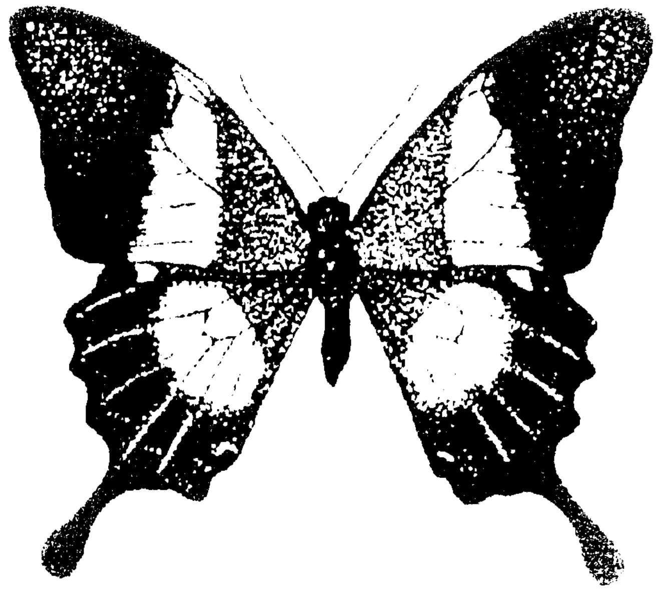
Ecological diversity of moths in different habitats was studied using light trap sampling and the data was analysed using various statistical methods. Even though the undisturbed forest sites were found supporting a much diverse natural community, the distribution model fitted has indicated the need for more surveys. Greater vegetation stratification in site B (evergreen forest) which diversifies the feeding specialism in turn has led to high diversity. Plantation sites which could support only specific groups of insects was recorded with least diversity index.

Studies on the habitat preference of moths have shown that while the undisturbed sites supported arboreal feeding families such as Geometridae, Lymantriidae, Saturniidae and Cossidae, the disturbed sites promoted herbaceous feeding families like Noctuidae and Pyralidae.

When observing seasonal patterns of moth fauna, both individual and species abundance recorded peakedness in mid-rainy and mid-winter seasons. Both values were seen declining with the onset of summer, due to the dry conditions. Life cycles of moths were found to be highly correlated with seasons, as the variation in physical environment has much effect on their survival.

In order to see the impact of plantation activities on moth diversity, both vegetation and insect diversities of forest and managed systems was correlated. The results show that both plant and insect diversities recorded for 'dense forest' site was higher. Species with high endemism, most vulnerable to human disturbance and high potential for loss of diversity were found to be well represented in this region, while species that are geographically wide spread (including pests) and those specialised to open and disturbed habitats were represented in forest edges and plantations.

This study has unveiled the rich lepidopteran species diversity of Nelliyampathy Reserve Forest and the utmost conservational importance of this area. The plantations in this area showed a differential erosion of diversity in the smaller taxonomic groups. Often the loss of diversity is omitted from the economic equations produced by agronomists when weighing up the pros and cons of various agricultural schemes. The agronomists must be encouraged to take note of the value of biodiveristy when advising on the economic advantages of different plantation schemes. Sustainable utilization of forest resources with least disturbance on the existing reserve forests could be the future mode of forestry practices in this area of rich biological diversity.



Chapter 7

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Appendix I. List of butterflies recorded from Nelliyampathy

ORDER : LEPIDOPTERA

Suborder : Rhopalocera

Family : Papilionidae

Subfamily : Papilioninae

Tribe : Troidini

Troides minos Cramer*
Pachliopta aristolochiae Linnaeus
P. hector Linnaeus* **
P. pandiyana Moore*

Tribe : Graphiini

Graphium sarpedon teredon Felder
G. agamemnon agamemnon Linnaeus
G. doson doson Felder
Pathysa antiphates (Fabricius)

Tribe : Papilionini

Chilasa clytia Linnaeus**
Papilio polytes thesus Cramer
P. polytes romulus Cramer
P. demoleus demoleus Linnaeus
P. paris tamilana Moore
P. liomedon Moore* **
P. helenus Linnaeus
P. polymnestor parinda Moore*
P. buddha Westwood* **
P. dravidarum Wood-Mason*

Family : Pieridae

Subfamily : Pierinae

Delias eucharis Drury*
Cepora nadina Moore**
C. nerissa Fabricius
Hebomoia glaucippe (Linnaeus)

Appias libythea Fabricius**
A. albina darada (C.Felder & R. Felder)**
A. indra Moore**
A. wardii (Moore)* **
A. lyncida (Cramer)**
Appias sp. (Hubner)
Leptosia nina Fabricius
Ixias marianne (Cramer)
I. pyrene Linnaeus
Colotis danae Fabricius
Anaphaeis Belenois aurota (Fabricius)
Pareronia ceylanica Felder*
P. valeria (Cramer)

Subfamily : Coliadinae

Catopsilia florella (Fabricius)
C. pomona Fabricius
C. pyranthe (Linnaeus)
Eurema laeta Boisduval
E hecabe Linnaeus
E,blanda silhetana (Wallace)

Family : Nymphalidae

Subfamily : Danainae

Tribe :Danaini

Tirumala limniace leopardus Butler
T.septentrionis dravidarum Fruhstorfer
Parantica aglea Stoll
P. nilgiriensis Moore*
Danaus genutia genutia Cramer
D. chrysippus (Linnaeus)

Tribe : Euploeini

Idea malabarica malabarica Moore*
Euploea core Cramer**
E. klugii kollari Felder & Felder**

Subfamily : Satyrinae

Mycalesis anaxias Hewitson**
M. perseus Fabricius
M. igilia Fabricius*
M. patnia Moore*
Lethe europa Fabricius**
L. neelgheriensis Guerin
Ypthima ceylonica Hewitson*
Y.hubneri Kirby
Ypthima ? chenu ? Guerin
Elymnias caudata Butler
Zipoetis saitis Hewitson* **
Melanitis leda Linnaeus
M. phedima varaha Moore

Subfamily : Morphinae

Tribe : Amathusini

Discophora lepida lepida Moore* **

Subfamily : Nymphalinae

Tribe : Heliconiini

Subtribe : Argynniti

Cupha erymanthis maja Fruhstorfer
Cirrochroa thais thais Fabricius*
Phalanta phalantha Drury

Subtribe : Heliconiiti

Cethosia nietneri Felder*
Vindula erota soloma de Niceville

Subtribe : Acraeiniti

Acraea violae (Fabricius)

Tribe : Nymphalini

Kaniska canace haronica Moore
Junonia stygia
J. lemonias vaisya Fruhstorfer
J. iphita pluvialis Fruhstorfer
J. heirta Fabricius
J. atlites Linnaeus
J. almana Linnaeus

Hypolimnas bolina Linnaeus
H. misippus Linnaeus**
Cynthia cardui Linnaeus
V. indica nubicola Fruhstorfer
Tribe : Cyrestini

Cyrestis thyodamas ganescha Kollar

Tribe : Limenitidini

Subtribe : Limenitiditi

Moduza procris Cramer
Athyma ranga (Moore)**
A. nefte ? inara Doubleday
Neptis hylas varmona Moore
N. perius perinus Fruhstorfer
Pantoporia ? sandaka davidsoni Eliot

Subtribe : Partheniti

Parthenos sylvia virens Moore**

Subtribe : Bibliniti

Ariadne merione Cramer
A. ariadne indica Moore

Subtribe : Adoliaditi

Tanaecia lepidea (Butler)**
Euthalia lubentina (Cramer)**
E.aconthea Fruhstorfer

Subfamily : Charaxinae

Tribe : Charaxini

Polyura sp. Billberg

Family : Lycaenidae

Subfamily : Polyommatinae

Tribe : Polyommatini

Castalius rosimon (Fabricius)**
Caleta caleta Hewitson
Celastrina lavendularis Moore
Chilades pandava
Euchrysops cnejus (Fabricius)**
Catochrysops strabo (Fabricius)
Jamides alecto (Felder)
J. celeno aelianus Fabricius
Udara akasa Horsfield*
Thalicada nyseus (Guerin)
Megisba malaya (Moore)

Subfamily : Theclinae

Tribe : Aphnaeini

Spindasis lohita Himalayanus (Moore)**
S. schistacea Moore*

Tribe : Cheritrini

Cheritra freja (Fabricius)

Tribe : Horagini

Rathinda amor Fabricius

Sub family : Curetinae

Curetis thetis Drury*

Family : Hesperiidae

Sub family : Pyrginae

Celaenorrhinus leucocera (Kollar)
C. ambareesa (Moore)
Tagiades litigiosa Moschler
T. japetus (Stoll)
Udaspes folus Cramer
Coladenia dan (Fabricius)

Sub family : Hesperiinae

Iambrix salsala (Moore)
Potanthus pava pava Fruhstorfer
Pelopidas mathias Fabricius
Telicota ancilla bambusae Moore

* Western Ghat endemics recorded for Nelliyampathy
** Butterflies recorded at Nelliyampathy included in the Wildlife (Protection) Act, 1972

Appendix II. List of butterflies with code number for cross-reference with figure 6

Name	Code No.
Chilasa clytia Linnaeus	1
Troides minos Cramer	2
Appias sp. (Hubner)	56
Hypolimnas misippus Linnaeus	34
Graphium sarpedon teredon Felder	8
Junonia almana Linnaeus	24
Euploea klugii kollari Felder & Felder	29
Mycalesis perseus Fabricius	63
Appias indra Moore	50
Pachliopta aristolochiae *Linnaeus*	11
Appias albina darada Felder & Felder	53
Junonia stygia	38
Appias lyncida (Cramer)	58
Appias libythea Fabricius	22
Junonia lemonias vaisya Fruhstorfer	39
Hypolimnas bolina Linnaeus	33
Junonia atlites Linnaeus	25
Cyrestis thyodamas ganescha Kollar	21
Neptis perius perinus Fruhstorfer	36
Appias wardi (Moore)	59
Papilio polytes thesus Cramer	14
Ariadne merione Cramer	32
Celaenorrhinus ambareesa (Moore)	69
Cheritra freja (Fabricius)	76
Parantica nilgiriensis Moore	44
Melanitis leda Linnaeus	67
Papilio helenus Linnaeus	3
Parantica aglea Stoll	43
Danaus chrysippus (Linnaeus)	46
Catopsilia pyranthe (Linnaeus)	65
Graphium agamemnon agamemnon Linnaeus	9
Catopsilia pomona Fabricius	52
Tirumala septentrionis dravidarum Fruhstorfer	64

Papilio paris tamilana Moore	16
Papilio polymnestor parinda Moore	4
Pareronia ceylanica Felder	28
*Danaus genutia genutia Crame*r	45
Delias eucharis Drury	48
Eurema laeta Boisduval	54
Graphium doson doson Felder	10
Papilio. demoleus demoleus Linnaeus	15
Euchrysops cnejus (Fabricius)	79
Junonia heirta Fabricius	12
Neptis hylas varmona Moore	35
Eurema blanda silhetana (Wallace)	60
Ypthima ceylonica Hewitson	42
Zipoetis saitis Hewitson	66
Tagiades japetus (Stoll)	72
Tagiades litigiosa Moschler	70
Castalius rosimon (Fabricius)	73
Caleta caleta Hewitson	74
Mycalesis anaxias Hewitson	62
Celaenorrhinus leucocera (Kollar)	68
lambrix salsala (Moore)	71
Acraea violae (Fabricius)	81
Papilio buddha Westwood	5
Thalicada nyseus (Guerin)	75
Parthenos sylvia virens Moore	18
Pathysa antiphates (Fabricius)	17
Papilio liomedon Moore	6
Papilio dravidarum Wood-Mason	7
Spindasis lohita Himalayanus (Moore)	78
Cirrochroa thais thais Fabricius	26
Kaniska canace haronica Moore	37
Tirumala limniace leopardus Butler	41
Pachliopta pandiyana Moore	13
Idea malabarica malabarica Moore	47
Phalanta phalantha Drury	27.
Tanaecia lepidea (Butler)	19
Cupha erymanthis maja Fruhstorfer	20

Hebomoia glaucippe (Linnaeus)	55
Cynthia cardui Linnaeus	30
Vanessa indica nubicola Fruhstorfer	31
Jamides alecto (Felder)	77
Udaspes folus Cramer	80
Cethosia nietneri Felder	23
Ariadne ariadne indica Moore	40
Pachliopta hector Linnaeus	49
Euploea core Cramer	57
Leptosia nina Fabricius	61
Elymnias caudata Butler	51

Appendix III. List of moths recorded from Nelliampathy

HETEROCERA

NOCTUIDAE

Achaea janata Fabricius*
Agrotis sp.
Anomis figlina Butler
Anomis flava (Fabricius)
Anua coronata Fabricius
Arcte modesta Van der Hoev
Athetis renalis Moore
Callopistria rivularis Walker
Carea subtilis Walker
Chalciope hyppasia Cramer
Chasmina rejecta Fabricius
Dierna strigata Moore
Elygea materna (Linnaeus)
Ercheia cyllaria
Erebus caprimulgus Fabricius
Erebus ephesperis
Ericeia inangulata Guenee
Hulodes caranea Cramer
Ischyja inferna Cramer
Laphygma exigua Hampson*
Melipotis cyllaria Cramer
Mocis frugalis Fabricius
Mythimna vittata Hampson
Nyctipao macrops Linnaeus
Ophideres fullonica Linnaeus*
Ophideres materna Linnaeus*
Ophiusa dotata Fabricius
Othreis ancilla Cramer
Oxyodes scrobiculata Fabricius

Parallelia joviana Stoll
Parallelia crameri Moore
Prodenia litura Fabricius*
Pterogonia cardinalis
Raparna undulata Moore
Rhynchina curvilinea Hampson
Speiredonia retorta Cramer
Speiredonia suffusoma Guenee
Sphetta apicalis Walker
Spodoptera litura (Fabricius)*
Spodoptera mauritia Boisduval*
Tiracola plagiata Walker
Thyas hunesta
Westermannia superba Hubner

LYMANTRIIDAE

Aroa plana Walker
Cispia charma Swinhoe
Dasychira mendosa Hubner
Dasychira cerigoides Walker
Dasychira bhana Moore
Dasychira grotei Moore
Euproctis fraterna Moore*
Euproctis bigutta Walker
Euproctis scintillans Walker*
Euproctis luteifascia Hampson
Euproctis sp.
Lymantria todara Moore
Lymantria ampla Walker
Penicillifera sp.
Redoa sp.

EUPTEROTIDAE

Eupterote testacea Walker

Eupterote hibisci Fabricius
Eupterote flavida Moore
Eupterote mollis Moore
Eupterote canaraica
Eupterote fabia Cramer
Eupterote cardamomi L

ARCTIIDAE

Argina syringa Cramer*
Argina argus Kollar*
Argina cribaria Clerck*
Asura conferta Walker
Asura obsoleta Moore
Asura rubricosa Moore
Asura sp.
Asota producta Butler
Asota plana Walker
Chionaema peregrina Walker
Cyana sp.
Diacrisia obliqua Walker*
Eilema tetragona Walker
Eligma narcissus Cramer
Estigmene perotetti
Hypsa alciphron Cramer
Nyctemera coleta Cramer
Neochera dominia Cramer
Paraona splendens Bulter
Paraplastis hampsoni Swinhoe
Pericallia ricini Fabricius*
Rhodogastria astreas Drury
Spilosoma sp.
Utethesia pulchellale Walker*

YPONOMEUTIDAE

Atteva fabriciella Swed
Hilarographa caminodes

TORTRICIDAE

Adoxophyes revoluta Meyrick
Olethreutes paragramma Meyrick

GEOMETRIDAE

Abraxas sp.nr. latizonata Hampson
Abraxas poliaraia Swinhoe
Abraxas poliostrota
Agathia laetata Fabricius
Agathia lycaenaria Kollar
Amblychia angeronaria Guenee
Anisodes denticulate
Anisozyga sp.
Aplochlora vivilaca Walker
Boarmia infixaria Walker
Borbacha sp.nr. pardonica Guenee
Buzura suppressaria Walker
Cleora alienaria Walker
Cusiala raptaria Walker
Ecliptopera dissecta Moore
Ectropis breta Swinhoe
Elphos brabanti Thierry-Mieg
Epiplema quadricaudata Walker
Eumelea rosalia Cramer
Eumelea aureliata Guenee
Gnamptoloma aventiaria Guenee
Heterostegane subtessellata Walker
Hypomecis pallida Hampson
Hypomecis sp.
Hyposidra talaca Walker

Lomographa simpliciaria Walker
Luxiaria hypaphanes Hampson
Medasina dissimilis Moore
Naxa textilis Walker
Ourapteryx marginata Hampson
Petelia medardaria Herrich- Schaffer
Pingasa chlora Cramer
Pingasa ruginaria Guenee
Prasinocyma sp.
Racotis boarmiaria Guenee
Racotis inconclusa Walker
Ruttellerona cessaria Walker
Scopula opicata (Fabricius)
Semiothisa khasiana Moore
Semiothisa fasciata Fabricius
Semiothisa eleonora Stoll
Semiothisa emersaria Walker
Thalassodes sp.

PYRALIDAE

Acigona sp.
Agathodes ostentalis Hubner
Botyodes asialis Guenee
Cnaphalocrocis medinalis Guenee
Diasemia litterata Scop
Dichocrocis evaxalis Walker
Dichocrocis plutusalis Walker
Dichocrocis punctiferalis Walker
Eutectona macheralis Walker
Galleria mellonella Linnaeus
Glyphodes bicolor Swinson
Glyphodes laticostalis Guenee
Glyphodes vertumnalis Guenee
Glyphodes glauculalis Guenee*

Glyphodes indica Saunders
Glyphodes itysalis Walker
Glyphodes marginata Hampson
Herculia marthalis Walker
Isocentris filalis Guenee
Lepyrodes geometralis Guenee
Loxostege sp.
Lygropia amyntusalis Walker
Lygropia orbinusalis Walker
Marasmia trapezalis Guenee*
Myleopsis sp.
Nacoleia diemenalis Guenee*
Nymphula crisonalis Walker
Omphisa repetitalis Snell
Polygrammodes spilosomoides Moore
Pygospila tyres Cramer
Pyrausta signatalis Walker
Scirpophaga sp.
Sylepta arctalis Guenee
Sylepta balteata Fabricius
Sylepta derogata Fabricius*
Sylepta tibialis Moore
Terastia egialealis Walker
Vitessa suradeva Moore

AMATIDAE

Eressa confinis Walker
Syntomis extensa Walker

NOTODONTIDAE

Dudusa nobilis Walker
Phalera procera Felder
Tarsolepis rufobrunnea malayana
Nakamura

SPHINGIDAE

Acherontia lachesis Fabricius
*Acherontia styx**
Agrius convolvuli Linnaeus
Acosmeryx socrates Boisduval
Compsogene panopus Cramer
Daphnis hypothous Cramer
Hippotion boerhaviae Fabricius
Megacorma obliqua Walker
Macroglossa aquila Boisduval
Marumba dyras
Oxyambulyx subocellata Felder
Oxyambulyx pryeri Distant
Theretra latreillei Macleay
Theretra boisduvali Bugnion
Theretra nessus Drury

SATURNIIDAE

Attacus atlas *Linnaeus*
Actias maenas Doubleday
Actias selenae Hubner
Cricula trifenestrata Helfer
Loepa sikkima Moore

COSSIDAE

Alcterogystia cadambae Moore
Xyleutes strix

LIMACODIDAE

Miresa argentifera Walker
Susica himalayana Holloway

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* General heteroceran pests of agricultural crops recorded from various study sites.

Appendix IV. List of primary areas used in the numerical analysis together with a list of species with code number for cross-reference with figure 8

Africa	Java
Madagascar	Bali
Arabia	Lombok
Japan	Sumbawa
China	Timor
Bhutan	Moluccas
Taiwan	Ceram
India & Sri Lanka	Sulawesi
Burma	Philippines
Thailand	Australia
Malaya	New Guinea
Sumatra	Solomon
Borneo•	Fiji

Name	Code No.
Compsogene panopus Cramer	128
Ophiusa dotata Fabricius	150
Parallelia crameri Moore	22
Semiothisa emersaria Walker	85
Callopistria rivularis Walker	87
Medasina dissimilis Moore	75
Semiothisa fasciata Fabricius	83
Ectropis breta Swinhoe	65
Eumelea aureliata Guenee	69
Argina syringa *Cramer*	38
Asura conferta Walker	43
Euproctis fraterna *Moore*	35
Euproctis scintillans *Walker*	37 ·
Carea subtilis Walker	6
Pyrausta signatalis Walker	114

Tiracola plagiata Walker	36
Eupterote testacea Walker	39
Anomis flava (Fabricius)	2
Agathia lycaenaria Kollar	86
Speiredonia retorta Cramer	25
Dasychira grotei Moore	34
Lygropia amyntusalis Walker	107
Elygea materna (Linnaeus)	8
Ophideres materna *Linnaeus*	17
Speiredonia suffusoma Guenee	26
Anua coronata Fabricius	147
Neochera dominia Cramer	51
Ericeia inangulata Guenee	11
Parallelia joviana Stoll	21
Buzura suppressaria Walker	62
Lomographa simpliciaria Walker	73
Vitessa suradeva Moore	120
Hyposidra talaca Walker	46
Westermannia superba Hubner	10
Achaea janata Fabricius	14
Agathia laetata Fabricius	57
Athetis renalis Moore	4
Chalciope hyppasia Cramer	7
Cleora alienaria Walker	63
Lepyrodes geometralis Guenee	106
Chionaema peregrina Walker	47
Glyphodes vertumnalis Guenee	99
Eligma narcissus Cramer	50
Eutectona macheralis Walker	5
Sylepta balteata Fabricius	116
Oxyodes scrobiculata Fabricius	20
Nacoleia diemenalis Guenee	110
Glyphodes glauculalis Guenee	100
Asota producta Butler	45
Agathodes ostentalis Hubner	88
Pygospila tyres Cramer	113
Dichocrocis punctiferalis Walker	94

Sylepta derogata Fabricius	117
Pericallia ricini Fabricius	68
Sylepta arctalis Guenee	115
Sylepta tibialis Moore	118
Glyphodes laticostalis Guenee	98
Glyphodes marginata Hampson	103
Glyphodes bicolor Swinson	97
Omphisa repetitalis Snell	112
Argina cribaria Clerck	42
Dasychira mendosa Hubner	52
Asura obsoleta Moore	54
Amblychia angeronaria Guenee	58
Glyphodes itysalis Walker	102
Phalera procera Felder	122
Oxyambulyx pryeri Distant	134
Megacorma obliqua Walker	49
Actias maenas Doubleday	74
Marumba dyras	132
Pterogonia cardinalis	24
Dasychira cerigoides Walker	33
Actias selenae Hubner	78
Tarsolepis rufobrunnea malayana Nakamura	12
Macroglossa aquila Boisduval	138
Theretra boisduvali Bugnion	127
Theretra nessus Drury	137
Loepa sikkima Moore	142
Epiplema quadricaudata Walker	67
Attacus atlas *Linnaeus*	146
Oxyambulyx subocellata Felder	82
Racotis inconclusa Walker	80
Ischyja inferna Cramer	123
Erebus caprimulgus Fabricius	9
Othreis ancilla Cramer	19
Abraxas sp.nr. latizonata Hampson	56
Semiothisa eleonora Stoll	84
Herculia marthalis Walker	104
Lygropia orbinusalis Walker	108

Diacrisia obliqua Walker	48
Ecliptopera dissecta Moore	64
Heterostegane subtessellata Walker	71
Anisodes denticulata	59
Cusiala raptaria Walker	60
Borbacha sp.nr. pardonica Guenee	61
Elphos brabanti Thierry-Mieg	66
Naxa textilis Walker	76
Hippotion boerhaviae Fabricius	72
Theretra latreillei Macleay	131
Daphnis hypothous Cramer	31
Arcte modesta Van der Hoev	32
Spodoptera litura (Fabricius)	29
Botyodes asialis Guenee	40
Hulodes caranea Cramer	1
Acherontia styx	70
Luxiaria hypaphanes Hampson	95
Argina argus Kollar	53
Terastia egialealis Walker	96
Acherontia lachesis Fabricius	44
Isocentris filalis Guenee	145
Dudusa nobilis Walker	121
Cricula trifenestrata Helfer	143
Semiothisa khasiana Moore	133
Susica himalayana Holloway	139
Pingasa chlora	141
Acosmeryx socrates Boisduval	136
Euproctis luteifascia Hampson	130
Eilema tetragona Walker	135
Estigmene perotetti	129
Utethesia pulchellale Walker	3
Euproctis bigutta Walker	18
Lymantria ampla	89
Ourapteryx marginata Hampson	144
Gnamptoloma aventiaria Guenee	125
Boarmia infixaria Walker	140
Eumelea rosalia Cramer	41

Galleria mellonella Linnaeus	119
Rhodogastria astreas Drury	124
Miresa argentifera Walker	105
Diasemia litterata Scop	91
Nymphula crisonalis Walker	111
Laphygma exigua Hampson	13
Thyas hunesta	30
Nyctemera coleta Cramer	85
Marasmia trapezalis Guenee	109
Ercheia cyllaria	148
Nyctipao macrops Linnaeus	16
Glyphodes indica Saunders	101
Ophideres fullonica Linnaeus	27
Pingasa ruginaria Guenee	79
Prodenia litura Fabricius	23
Mocis frugalis Fabricius	15
Spodoptera mauritia Boisduval	28
Cnaphalocrocis medinalis Guenee	90
Dichocrocis plutusalis Walker	93
Dichocrocis evaxalis Walker	92
Xyleutes strix	149
Petelia medardaria Herrich- Schaffer	77
Agrius convolvuli Linnaeus	126
Ruttellerona cessaria Walker	81

Appendix V. **List of plants recorded from the study area**

Aglaia lawii (Wt.) Sald.

Aglaia sp.

Agrostistachys meeboldii Pax & Hoffm.

Albizia chinensis (Osb.) Merr.

Ardisia pauciflora Heyne ex Wall.

Artocarpus heterophyllus Lamk.

Bischofia javanica Bl.

Canarium strictum Roxb.

Celtis sp.

Cullenia exarillata Robyns

Dimocarpus longan Lour.

Diospyros sp.

Drypetes elata Bedd.

Drypetes oblongifolia (Bedd.) *Airy Shaw*

Emblica officinalis Gaertn.

Erythrina sp.

Ficus sp.

Garcinia morella (Gaertn.) Desr.

Gomphandra coriacea Wt.

Haldina cordifolia (Roxb.) Ridsd.

Heritiera papilio Bedd.

Holigarna arnottiana Hk.f.

Laportea crenulata (Roxb.) Gaud.

Litsea floribunda (Bl.) Gamble

L.laevigata (Nees) Gamble

Macaranga indica Wt.

M.peltata (Roxb.) M.A.

Mastixia arborea (Wt.) Bedd. ssp.arborea

Meiogyne sp.

Meliosma pinnata (Roxb.) Maxim.

Mesua ferrea auct.non Lin.

Myristica dactyloides Gaertn.

Neolitsea sp.

Olea dioica Roxb.

Palaquium ellipticum (Dalz.) Engl.

Pinanga dicksonii (Roxb.) Blume

Polyalthia coffeoides (Thw.) Benth.ex Hk.f. & Thoms.

Scolopia crenata (Wt. & Arn.) Clos.

Syzygium cumini (Lin.) *Skeels*

Trema orientalis (Lin.) Bl.

Vernonia arborea Ham.

Walsura trifolia (Juss.) Harms

Shrubs

Chromolaena odorata (Lin.) King & Robins.

Saprosma fragrans Bedd.

Schumannianthus sp. *virgatus (Roxb.)* Rolfe.

Solanum sp.

Herbs

Blumea sp.

Bolbytis sp.

Centella asiatica (Lin.) *Urban*

Synedrella nodiflora (Lin.) Gaertn.

Appendix VI. List of Heteroceran pests of monoculture plantations recorded from various sites

TEA

Lymantridae

Dasychira mendosa Hubner – Defoliator

Geometridae

Buzura suppressaria Walker – Tea looper

CARDAMOM

Pyralidae

Dichocrocis punctiferalis Walker – Attack pods and seeds

Eupterotidae

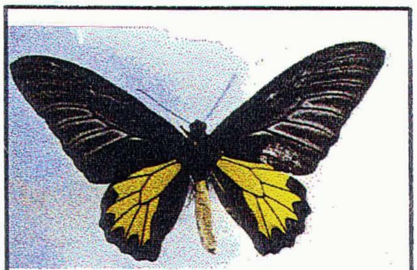
Eupterote testacea Walker *Eupterote cardamomi* *Eupterote canaraica* *Eupterote fabia* Cramer	Cardamom defoliators

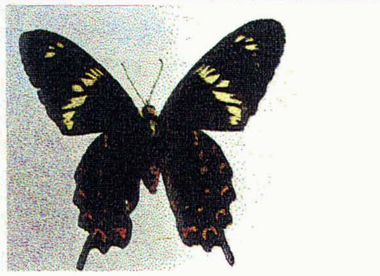
COFFEE

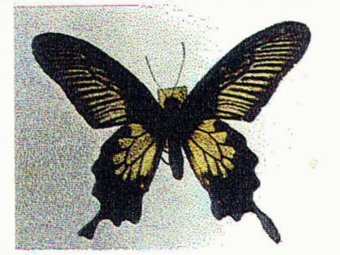
Family : Eupterotidae

Eupterote canaraica *Eupterote fabia* Cramer	Coffee defoliators

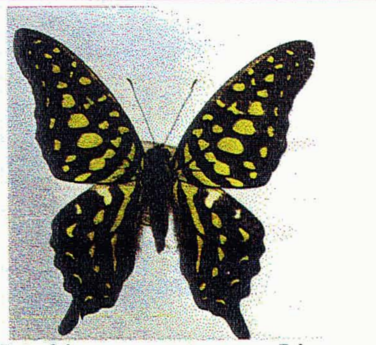
Plate I. Some butterflies recorded from Nelliyampathy

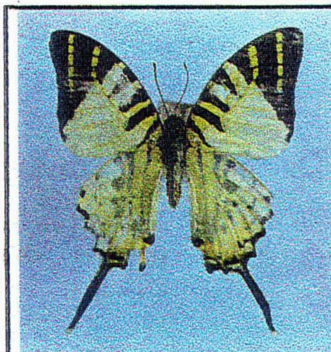

Troides minos Cramer

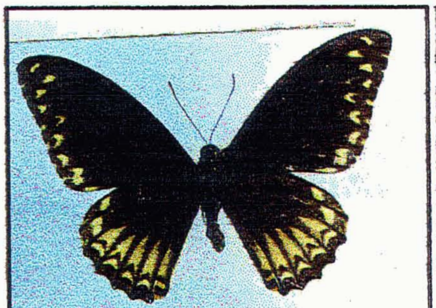

Pachliopta hector Linnaeus

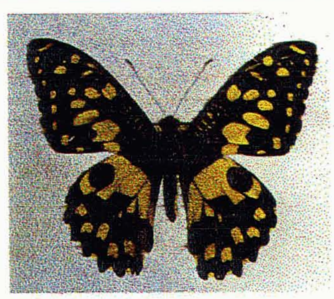

Pachliopata pandiyana Moore

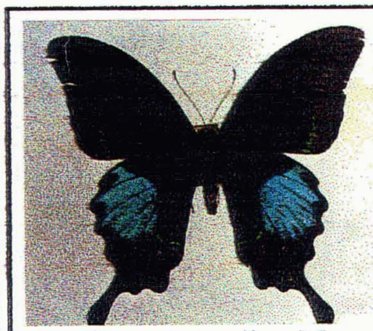

Graphium sarpedon teredon Felder


Graphium. agamemnon Linnaeus

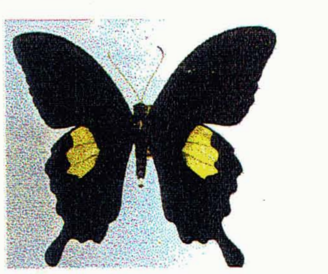

Pathysa antiphates (Fabricius)


Chilasa clytia Linnaeus


Papilio demoleus Linnaeus


Papilio paris tamilana Moore


Papilio liomedon Moore


Papilio helenus Linnaeus

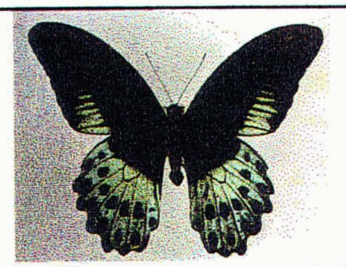
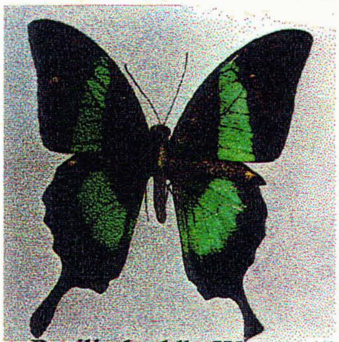
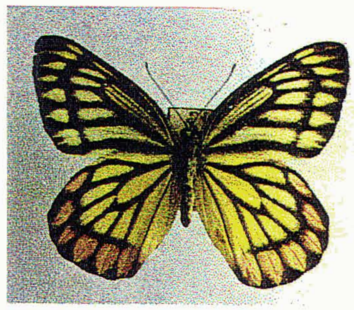

Papilio. polymnestor parinda Moore

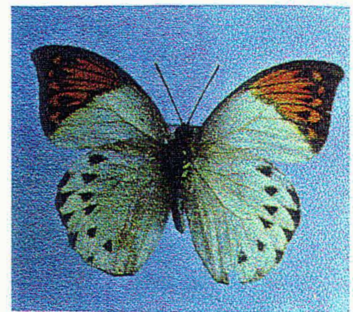
Plate II



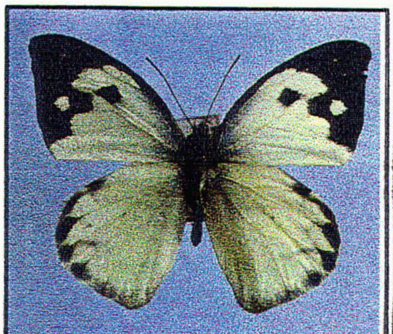
Papilio buddha Westwood



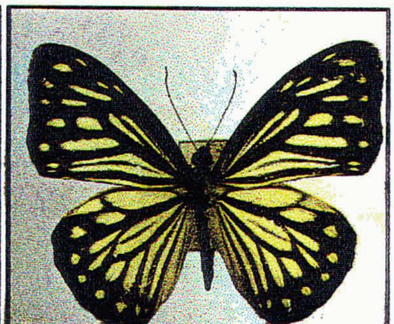
Delias eucharis Drury



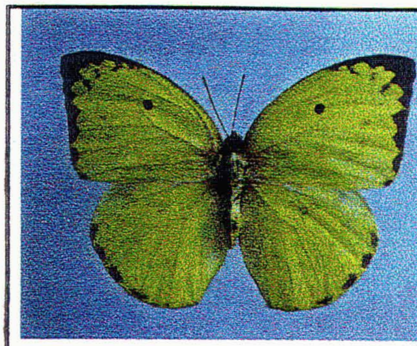
Hebomoia glaucippe (Linnaeus)



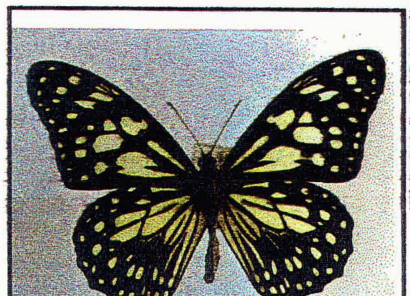
Appias sp. (Hubner)



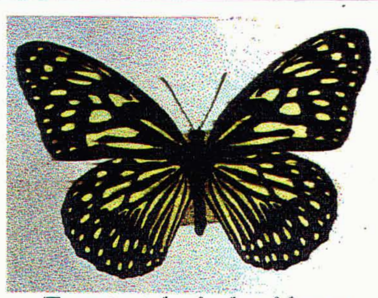
Pareronia ceylanica Felder



Crocale pomona Fabricius

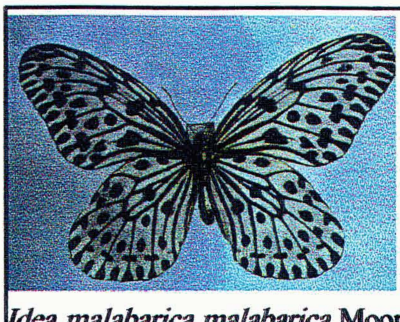


Tirumala limniace leopardus Butler



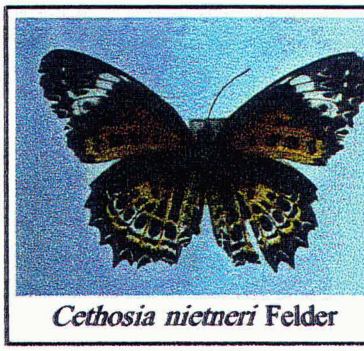
T. septentrionis dravidarum Fruhstorfer

Parantica nilgiriensis Moore



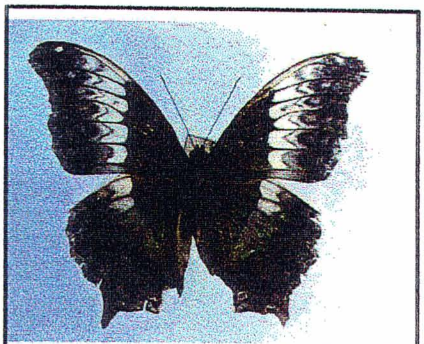
Idea malabarica malabarica Moore

Melanitis leda Linnaeus

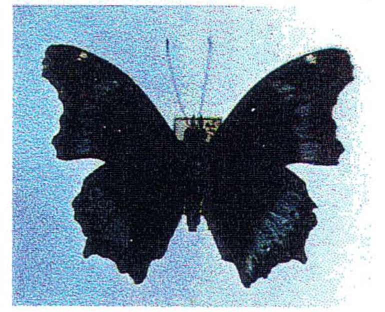


Cethosia nietneri Felder

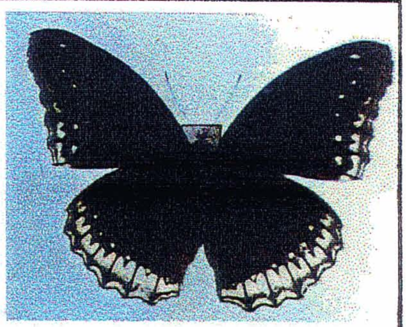
Plate III



Vindula erota soloma de Niceville



Kaniska canace haronica Moore

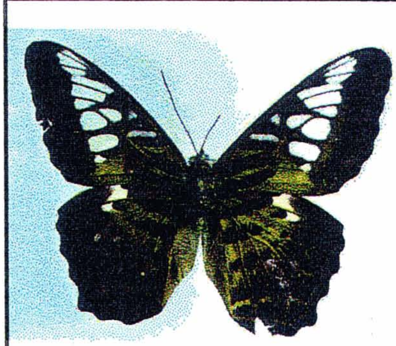


Hypolimnas misippus Linnaeus

Junonia heirta Fabricius

Cyrestis thyodamas ganescha Kollar

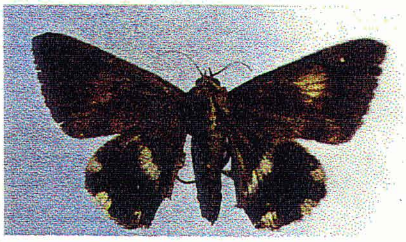
A thyma nefte? inara Doubleday



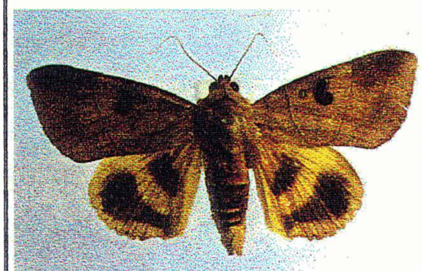
Parthenos sylvia virens Moore

Polyura sp. Billberg

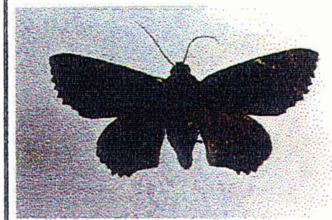
Plate IV. Some moths recorded from Nelliyampathy



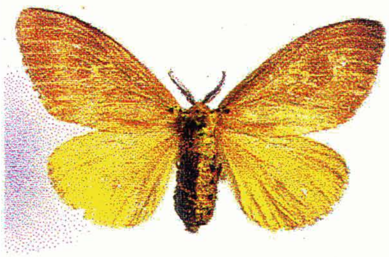
Achaea janata Fabricius



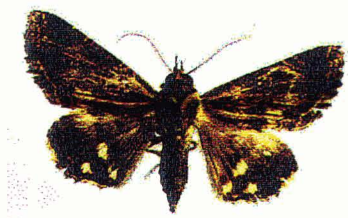
Anua coronata Fabricius



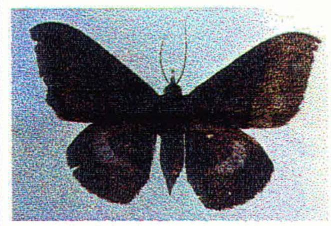
Arcte modesta Van der Hoev



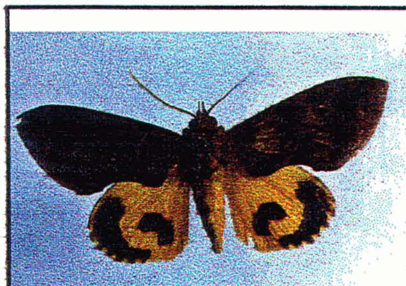
Elygea materna (Linnaeus)



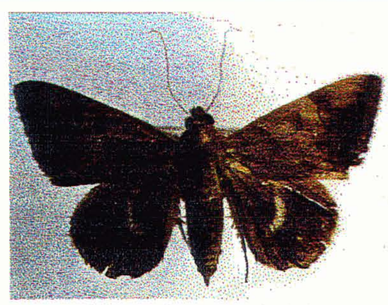
Ercheia cyllaria



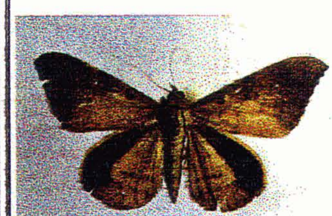
Ischyja inferna Cramer



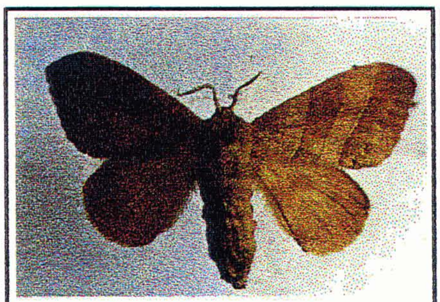
Ophideres fullonica Linnaeus



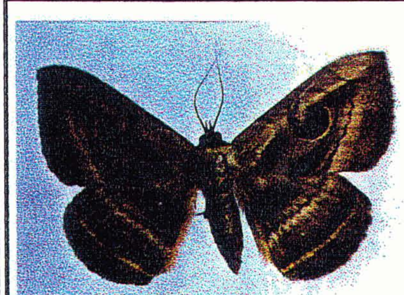
Ophiusa dotata Fabricius



Oxyodes scrobiculata Fabricius



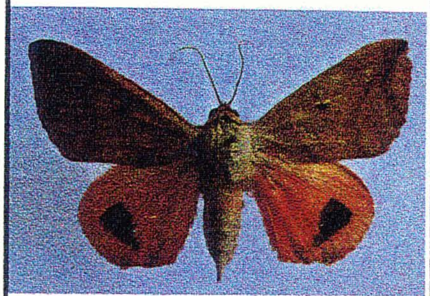
Rhynchina curvilinea Hampson



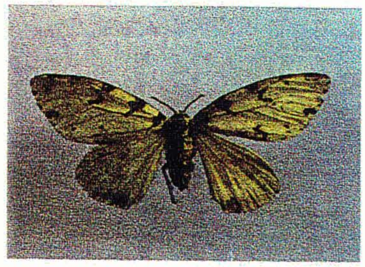
Speiredonia retorta Cramer

Tiracola plagiata Walker

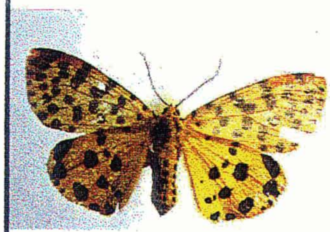
Plate V



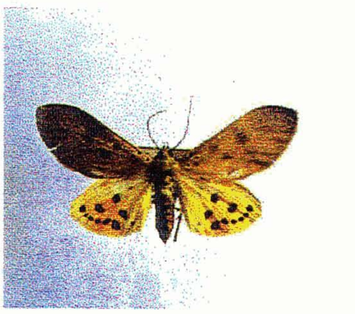
Thyas hunesta



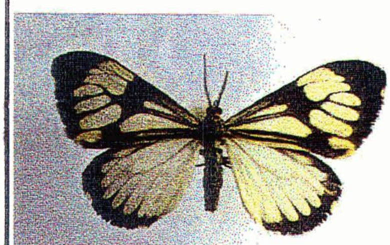
Lymantria todara Moore



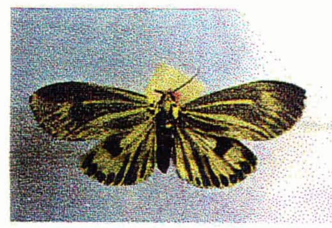
Argina cribaria Clerck



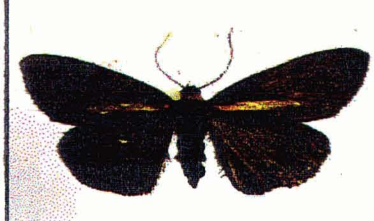
Hypsa alciphron Cramer



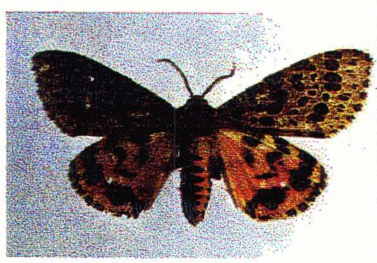
Nyctemera coleta Cramer



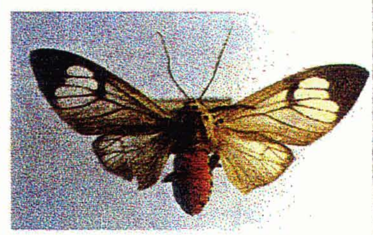
Neochera dominia Cramer



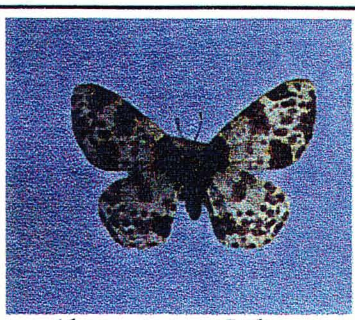
Paraona splendens Butler



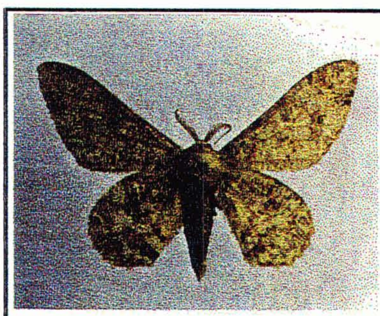
Pericallia ricini Fabricius



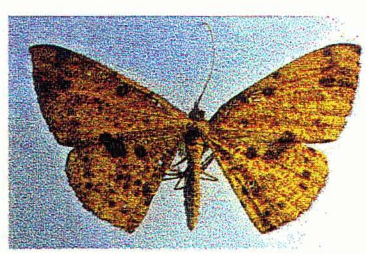
Rhodogastria astreas Drury



Abraxas sp. nr. latizonata Hampson

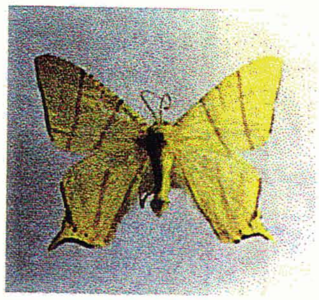


Bazura suppressaria Walker



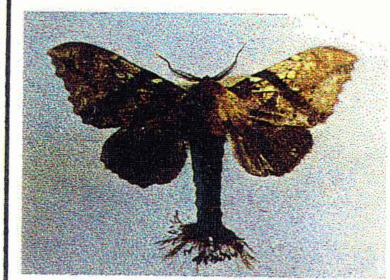
Eumelea rosalia Cramer

Plate VI

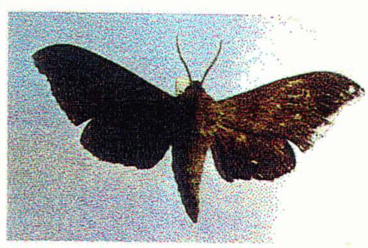


Ourapteryx marginata Hampson

Pygospila tyres Cramer

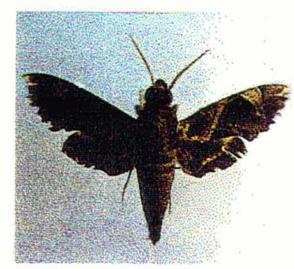


Dudusa nobilis Walker

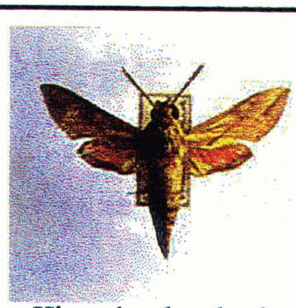


Acosmeryx socrates Boisduval

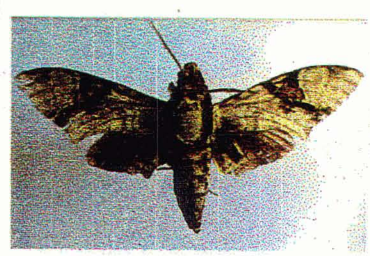
Compsogene panopus Cramer



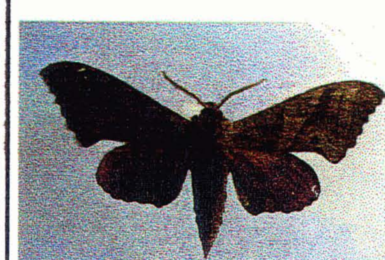
Daphnis hypothous Cramer



Hippotion boerhaviae Fabricius

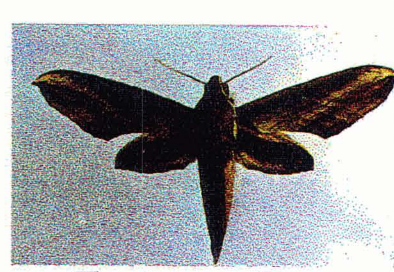


Megacorma obliqua Walker



Marumba dyras

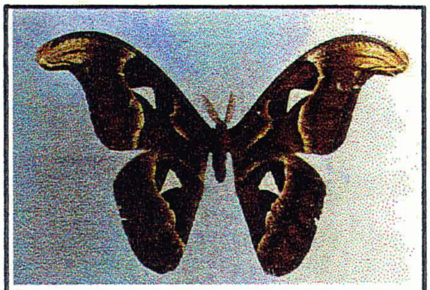
Oxyambulyx pryeri Distant



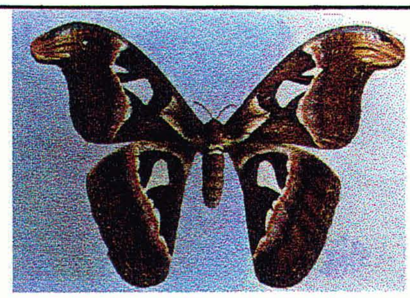
Theretra nessus Drury

Xyleutes Strix

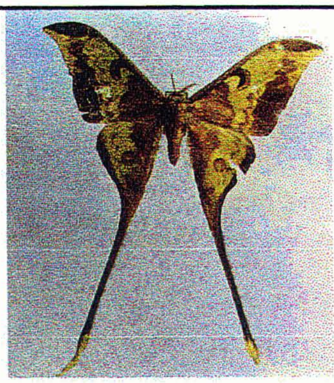
Plate VII



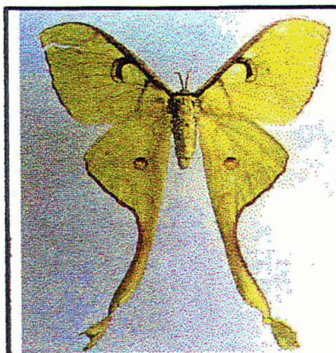
♂ *Attacus atlas* Linnaeus



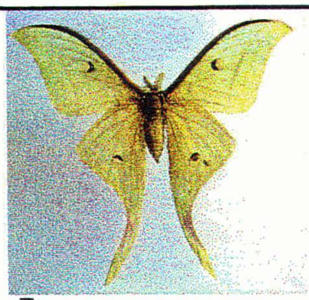
♀ *Attacus atlas* Linnaeus



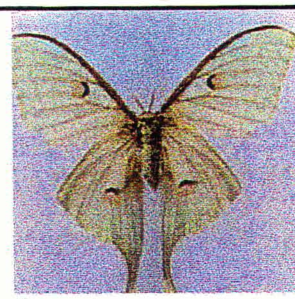
♂ *Actias maenas* Doubleday



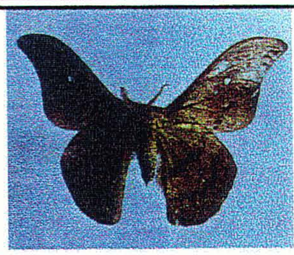
♀ *Actias maenas* Doubleday



♂ *Actias selenae* Hubner



♀ *Actias selenae* Hubner



♂ *Cricula trifenestrata* Helfer

♀ *Cricula trifenestrata* Helfer

Loepa sikkima Moore