SEASONALITY AND ABUNDANCE OF INSECTS WITH SPECIAL REFERENCE TO BUTTERFLIES (LEPIDOPTERA: RHOPALOCERA) IN A MOIST DECIDUOUS FOREST OF SIRUVANI, NILGIRI BIOSPHERE RESERVE, SOUTH INDIA

Thesis submitted to the

BHARATHIAR UNIVERSITY, COIMBATORE

for the

DEGREE OF DOCTOR OF PHILOSOPHY

in Zoology

by

P. R. ARUN, M.Sc.

SACON

Division of Avian Ecology
Salim Ali Centre for Ornithology and Natural History
Coimbatore - 641 108

April 2000

CERTIFICATE

This is to certify that the thesis, entitled "SEASONALITY AND ABUNDANCE OF INSECTS WITH SPECIAL REFERENCE TO BUTTERFLIES (LEPIDOPTERA: RHOPALOCERA) IN A MOIST DECIDUOUS FOREST OF SIRUVANI, NILGIRI BIOSPHERE RESERVE, SOUTH INDIA" is a record of original research work done by **Mr. P.R. Arun** in the Division of Avian Ecology, Sálim Ali Centre for Ornithology and Natural History, as a full time Research Scholar during the period of 1994 - 2000 under my guidance and supervision for the award of the Degree of Doctor of Philosophy in Zoology. I further certify that this research work has not previously formed the basis for the award of any other Degree or Diploma or Associateship or Fellowship or other similar title to any candidate of this or any other University.

Signature of the Guide

Dr. V.S. Vijayan
DIRECTOR,
Salim Ali Centre For Ornithology
and Natural History,
Anaikatty, Coimbatore-641108

Dr. V.S. Vijayan
DIRECTOR,
Salim Ali Centre For Ornithology
and Natural History,
Anaikatty, Coimbatore-641108

Countersigned

Head of the Department

DR. LALITHA VIJAYAN
PRINCIPAL SCIENTIST & HEAD
Division of Avian Ecology
Salim Ali Centre for Ornithology
and Natural History
Coimbatore - 641 108.

DECLARATION

I do hereby declare that the thesis entitled "**SEASONALITY AND ABUNDANCE OF INSECTS WITH SPECIAL REFERENCE TO BUTTERFLIES (LEPIDOPTERA: RHOPALOCERA) IN A MOIST DECIDUOUS FOREST OF SIRUVANI, NILGIRI BIOSPHERE RESERVE, SOUTH INDIA**" submitted to the Bharathiar University, Coimbatore, for the award of the Degree of Doctor of Philosophy in Zoology, is a record of original and independent research work done by me during 1994 - 2000 under the supervision and guidance of Dr. V.S. Vijayan, Director, Sálim Ali Centre for Ornithology and Natural History, Coimbatore, and it has not previously formed the basis for the award of any other Degree or Diploma or Associateship or Fellowship or other similar title to any candidate of this or any other University.

Signature of the Candidate

Countersigned

Head of the Department

DR. LALITHA VIJAYAN
PRINCIPAL SCIENTIST & HEAD
Division of Avian Ecology
Salim Ali Centre for Ornithology
and Natural History
Coimbatore - 641 108.

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SUMMARY

The present study describes the seasonal variations in the abundance of insect groups in a natural moist deciduous forest of Western ghats, South India. The study covers the seasonal abundance patterns of six major insect orders, namely Coleoptera, Lepidoptera, Hemiptera, Diptera, Orthoptera, and Hymenoptera and also the seasonality of 53 species of butterflies (Lepidoptera; Rhopalocera). The relationship of insect abundance with the prevailing abiotic and biotic conditions has been examined.

Three major sampling methods, namely sweep sampling, knockdown sampling and light trapping were used for the general insect sampling, while transect counting method was employed for the estimation of butterfly abundance. Other methods involving direct and indirect visual estimation of insect abundance employed in the field in an experimental basis for relatively shorter durations are also described.

An attempt was made to compare the efficiency of different sampling techniques. Among the three methods used for general insect abundance, the sweep samples showed the highest diversity, while the knock down samples yielded the highest abundance of insects in terms of numbers per sampling effort. The

composition of the insect groups was also different between the methods. The maximum abundant insect order was Diptera in the sweep samples, while it was Hymenoptera in the other two methods. The hierarchical order of abundance of various insect orders also varied among sampling methods.

Although, the abundance of insects was less in sweep sampling compared to that of knock down, an analysis of the actual area of foliage covered while sampling by both the methods shows that the abundance was more in the sweep samples. In effect it covered comparatively lesser area per sampling compared to knock down. The sweep samples appear to be representing both diversity and abundance of insects reasonably well compared to other methods.

The general insect abundance (all the insect groups together) was the highest during the south-west monsoon (June, July and August). While the abundance did vary significantly among the habitats, the pattern of seasonal fluctuation was significantly similar among the three different microhabitats. This indicates that, while the abundance of insects was very much dependent on the microenvironmental conditions, the seasonal fluctuation in the abundance was independent of the microhabitat conditions and was likely to be controlled by macroclimatic factors.

Abundance of each insect order is described in relation to each microhabitat and the seasons. Diptera, Hemiptera and Hymenoptera preferred to moist deciduous forest, while Coleoptera, Lepidoptera and Orthoptera did so to the riverine habitat. Coleoptera, Diptera, Hemiptera and Hymenoptera were more abundant in the south-west monsoon, while Lepidoptera and Orthoptera were abundant in winter.

The study reports 76 species of butterflies belonging to seven families in the moist deciduous forest. Out of these, seasonality patterns of 53 species were recorded. The butterfly population of the region showed high endemicity especially in the family Papilionidae. The most abundant family was the Pieridae followed by Lycaenidae, while Nymphalidae was the most diverse family with 22 species, followed by Papilionidae represented by 13 species. Highest abundance of butterflies during the study period was in November 1996 . The seasonality of abundance varied between the years. Generally, the most important factor that regulates the butterfly abundance in the study area was the abundance of flowers.

Effect of environmental factors on the abundance varied among the insect groups. Temperature had a major role in the seasonality of Diptera, while in Coleoptera it was rainfall, and in many butterflies, the flower abundance.

The study also reveals a significant relation between the insectivorous birds and the abundance of Orthoptera. It appears there is a covariation in the seasonal pattern of this insect order with that of the bird abundance without having a significant time lag, indicating an evolutionary race between the insectivorous birds and the insects. The success of the birds depending on how early and precisely they locate the insect abundance peaks in time and space, and the success of insects, on avoiding the bird abundance peaks, by constantly changing the abundance pattern in time.

CHAPTER I

INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

Biological system has a flexible characteristic of tuning itself to the ambient environment. Such changes could be behavioural (Youlatos 1998, Le Masurier 1994), genetical or physiological (Hazel and West 1996) and are among the major adaptations evolved during the course of organic evolution. These temporally recurring or resilient changes in the ecosystem processes are often referred to as seasonality. The seasonality studies in ecology focus on understanding the responses of ecosystem and its components to the cyclic changes in the environmental conditions, which are generally associated with the climate. These seasonal changes are predominant in invertebrates, especially insects, where an active system for regulating the body temperature is absent. Significant seasonality is exhibited by different taxa and communities of insects (Schowatter *et al.* 1988). The lower invertebrates with short life cycles consisting of two or more phases, and completed within an year, show an interesting aspect of seasonality known as seasonal incidence, in which different life history stages are adaptively timed in their occurrence in the seasonal time which is often crucial to their survival (Parker and Courtney 1983, Ezoe 1995).

1.2 SEASONALITY

Biological rhythms came into the attention of the scientific world only during the middle of the present century following the pioneering work on the circadian rhythms of vertebrates including human beings by Jurgan Aschoff, the founder of Chronobiology (Chandrashekaran 1998). Since then many studies have examined the seasonal rhythms of various organisms, such as plants (Prasad and Hegde 1986, Degreef *et al.* 1993), mammals (Wirminghaus and Perrin 1993, Peekelharing et al. 1998), bats (Milstead and Tinkle 1959) and Mites (Wilson and Morton 1993). Seasonality of arthropods has been widely studied by various authors especially that of terrestrial ones (Bushkirk and Bushkirk 1976, Reddy 1984, Moeed and Meads 1987, Basset 1991, Simandl 1993, Schowalter and Ganio 1998). The seasonality is an important aspect of the survival strategy of insects as well (Wolda 1978a, Wolda 1983, Frith and Frith 1985, Spitzer and Leps 1988, Wolda 1988 Spitzer *et al.* 1993, Ezhoe 1995, Novotny and Basset 1998).

However, the seasonal abundance of insect populations in natural conditions and its ecological significance are rather less explored. One of the reasons for the same may be that,such studies involve frequent sampling of insects using various sampling methods at regular intervals, which are often laborious and time consuming. Nevertheless, during the recent times, advanced techniques and even satellite imageries have come to the help of entomologists (Vasaenen and Helieoevaara 1994).

Holometabolous insects with a distinct larval stage in their life cycle, often have entirely different ecological requirements for the different life history stages. And hence, has different seasonality patterns for the larval and adult stages, which is an important ecological adaptation evolved inorder to avoid the intra-species competition between the adult and larvae for the resources and thereby to helping the long-term survival of the species.

Insects, being the most diverse among all groups of organisms, include diverse species adapted to various ecological conditions, which are reflected in the temporal aspects of their life-cycles as well. The duration of the life cycles is highly variable among different insects. In some Insects one generation takes a whole year to complete (univoltine species), while in some others it takes less than a year and there are species with two (bivoltine species) or more (multivoltine species) generations per year. On the contrary, there are species which take longer than a year to complete their life cycle. For instance, the *Cicada septemdecien* takes 17 years to complete its life-cycle, which is the longest reported among insects (Mani 1990). Hence, for a complete understanding of the seasonal patterns of insect abundance in the wild requires studies involving continuous long-term monitoring of insect populations. Most of the long-term monitoring studies on insect populations other than butterflies are carried out using only the light trap method, and are mostly done in the temperate countries (Wolda 1983, Holloway 1987). No such intensive long-term study on the seasonality of insect populations in the natural conditions has been reported from India so far.

1.3 FACTORS AFFECTING SEASONALITY

There are many biotic and abiotic factors which influence the seasonality of living organisms. Among them, temperature is one of the most important abiotic factors (Pollard 1988). Generally, the growth and development rates of insects are known to increase almost linearly with temperature till the optimum temperature. Insect predators and parasites also become more active at higher temperatures (Gilbert and Raworth 1996). Temperature tolerance varies much from species to species and hence, temperature fluctuations often affect the seasonality directly. Apart from its direct impact, it also affects the organisms indirectly, by causing changes in many other environmental factors. Rainfall, humidity and light are the three other important factors closely associated with the seasonality of organisms.

In the natural conditions these major factors often affect the abundance and diversity of organism indirectly (Janzen and Schoener 1968). The rainfall, for instance could determine the seasonality of plants (Borchert 1998) and hence, that of the folivorous insects indirectly. Apart from the major environmental factors, the seasonality of animals is reported to be regulated by many other factors such as, composition of trees in forest (Pekelharing *et al.* 1998). Other factors, such as age of the forest and size of the forest area may also affect seasonality, as it has been demonstrated in the case of birds in Hong Kong (Kwok and Corlett 1999).

Different authors have examined the role of various ecological factors associated with insect seasonality. The temperature and humidity have been established as the major factors regulating the insect abundance and seasonality in many of the studies (Subramanyam and Hagstrum 1993, Pollard and Moss 1995, Lale *et al.* 1996, Posonby and Copland 1996). The effect of temperature fluctuations on the rate of development of insects has been well studied in the past. For instance, the development times and temperature of 27 species of insects in captive conditions is described by Shu-Sheng *et al.* (1995). The variations in the diurnal surface temperatures affect the distribution and abundance of Alpine grasshoppers (Coxwell and Bock 1995). In the case of springtails, the soil humidity played only a minor role in their seasonality, while it was the life history phenomena that decided the patterns of seasonal fluctuations in the soil and litter collembolans

(Badejo and Straalen 1993). As it was observed in the present study also, distribution of rain is an important factor which controls the seasonal abundance of the insects (Wolda 1978a, Pollard 1988). The day length or photoperiod also has an important role in the insect seasonality (Danileviskii 1996). Studies from Russia on different insect species such as the heteropteran, *Pyrrhocoris apterus* (Saulich *et al.* 1994) and two species of lepidopterans *Dendrolimus pini* and *Dendrolimus sibiricus* (Gejspic 1965) have also emphasised the role of photoperiod on insect seasonality.

Other factors illustrated as being responsible for insect seasonality are floral species diversity (Sparks and Parish 1995), diet (Asad *et al.* 1997, Feeny 1970), predation by natural enemies (Basari *et al.* 1995, Gage *et al.* 1970) and shade (Sparks *et al.* 1996). In most cases a combination of different factors described above only can explain the phenomenon of insect seasonality. On the other hand, there have been studies describing the effect of insect population abundance on the abundance and biology of vertebrate predators which depend on insects such as birds (Turner and Mccarty 1998).

1.4 STUDIES ON INSECT SEASONALITY

Insect seasonality has been demonstrated in various parts of the world including the tropics (Wolda 1978a, 1978b & 1983, Spitzer 1983, Spitzer and Leps 1988, Spitzer *et al.* 1993). However, most of the insect seasonality studies are reported from abroad (Danilevskii, 1965, Mackay and Kalf 1969, Janzen 1973, Wolda 1978a, Erwin and Scott 1980, Parker and Courtney 1983, Spitzer 1983, Frith and Frith 1985, Paarman and Stork 1987, Moeed and Meads 1987, Chadee *et al.* 1992, Seal *et al.* 1992, Tobi *et al.*1992, Braby 1995a, Braby 1995b, Kato *et al.*1995, Novotny and Basset 1998, Schowalter and Ganio 1998). Various authors have demonstrated the seasonality of insect groups, such as caterpillars (Casey 1993), moths (Tobi *et al.*1992), collembola (Argyropoulou *et al.*1994, Badejo and Straalen 1993) and butterflies (Spitzer *et al.* 1993). Most of the seasonality studies are done on the economically important insect pest species such as mosquitoes (Chadee and Tikasingh 1992, Chadee *et al.* 1993, Chadee 1994), Cypress bark moth (Frankie and Koehler 1971), Wire worms (Seal *et al.* 1992) and Walnut husk fly (Kasana and AliNiazee 1996). The seasonality of the forest insect community had been studied in the Upland rainforests of Australia (Frith and Frith 1985).

However, the amount of present knowledge on the insects of the tropical forests is comparatively sparse than that of the temperate countries. The lack of scientific tradition and the moderate budgets are the two major causes attributed to this lack of knowledge (Gadagkar 1990). As far as the seasonality of insects are concerned there are only a few exclusive studies describing the seasonality of insects from Indian region (Mohandas and Narendran 1985, Veena Kumari *et al.* 1992, Narladkar *et al.* 1993, Agarwal *et al.* 1997, Kunte 1997), and most of these studies are on economically important species.

A recent study from India by Kunte (1997) has examined the seasonality of butterflies in the northern Western Ghats region of the country, which is probably the first of its kind reported from the Western Ghats. Records of the seasonal abundance of insects are available in many of the ecological studies especially ornithological studies reported from the region (Vijayan 1975, Gaston 1978, Shukkur 1978, Vijayan 1984, Vijayan 1991, Sundaramoorthy 1991). These studies attempted to establish the relationship between the breeding seasons of birds and the insect seasonality. The present study also was a part of a major Ornithological project wherein the insect seasonality had been studied to account the breeding seasonality of birds. The study was conducted, in a moist deciduous forest in the Southern India with the following specific objectives,

1.5 OBJECTIVES

I. find out the patterns of temporal fluctuations in insect abundance of a moist deciduous forest,

II. compare the seasonal patterns in the abundance of insects in different habitats,

III. evaluate the role of various ecological factors in regulating the insect abundance, and

IV. assess the seasonality of abundance and species composition of the butterfly fauna.

The study was conducted during the two year period from October 1994 to September 1996. The precise identification of all the insects met with was attempted up to the order level and the number of morphospecies (morphologically identifiable taxonomic units) encountered in each sample of various sampling methods was recorded. The butterflies (Lepidoptera: Rhopalocera) of all families except Hesperidae and Lycaenidae were identified up to the species level. No attempt was made to describe the seasonality of individual species, as the objective was to evaluate the general seasonality of insects in the area.

CHAPTER III

METHODOLOGY

3.1 INTRODUCTION

There are various methods for the sampling of insects from the wild and agricultural areas (Southwood 1971, Arnet and Jacques 1981, Cooper and Whitemore 1990, Diraviam and Uthamasamy 1992, Heinz et al. 1992). Many of them have become very popular. However, any single method among such popular methods as beat sheets, pitfall trapping and sweep net sampling have been found insufficient to sample the arthropods efficiently (Kharboutli and Mack 1993). The absence of a standard and widely accepted methodology for estimation of insect abundance is a seriously felt lacuna in the field of ecological entomology research especially in the natural forests of the tropical countries (Gadagkar *et al.* 1990). Methods involving poisonous chemical substances, such as chemical knock down method can efficiently extract insects from the vegetation (Erwin 1983). Nevertheless, it cannot be accepted for the long-term studies which involve repeated samplings from an area, since it would wipe out the insect fauna of the area, and cause serious damage to the entire ecosystem.

In the present study three major standard sampling techniques, as described by Southwood (1971) with slight modifications to suit the local environment were employed for the sampling of general insect abundance. Abundance of butterflies was estimated using the transect counting method (Pollard 1977, Ishii 1993).

The insects obtained in different sampling devices were collected, sorted according to the taxonomic group, the number of morpho species and abundance of each order were recorded and released back into the environment. Since different authors have followed slightly different classifications, for the purpose of sorting the insects, the Imm's classification was followed (Richards and Davies 1977).

The environmental factors monitored during the study were, minimum and maximum temperatures, relative humidity, rainfall, number of rainy days, the relative abundance of flowers, fruits and leaves, and bird abundance. The selected methods used for estimating the relative abundance of insects and to monitor the selected biotic and abiotic environmental factors during the study are described below.

3.2 INSECT SAMPLING METHODS

Four major sampling methods were used in the field for the regular sampling of insects, namely sweep net sampling, transect counting, mechanical knock down sampling, and light trapping. Apart from these, two other methods were also employed in the field for shorter durations, namely bark counting and indirect visual estimation of canopy insects.

3.2.1 Sweep sampling

Sweep sampling was done from the herb and shrub layers of the vegetation using a sweep net fitted with a cotton net having a mouth diameter of 40cm and an approximate mesh size of 2mm. This method is specially suited for sampling insects from ground layer vegetation. The sweeps were done during the morning hours while walking along the transect that passes through the three different habitat types present within the study area. One hundred sweeps each were taken randomly from each of the three habitats separately, thrice in a month. The approximate area of coverage per sweep was $0.8m^2$, and per sampling effort it was $80m^2$ (0.8×100). A unit sampling effort in this method was 100 sweeps per habitat. The insects collected in the sweeping net were temporarily anaesthetized by putting the tail end of the net along with the insect trapped, into a bottle containing a piece of cotton soaked in chloroform for approximately 20 seconds. The immobilized insects were recorded and then released back to the forest.

The major insect orders observed in the samples by this method were Coleoptera, Lepidoptera, Hemiptera, Diptera, Orthoptera and Hymenoptera. Its unsuitability to sample insects from the thorny, and thick bushes was the major limitation of this method.

3.2.2 Transect counting

Transect counting method was employed for estimating the relative abundance of butterflies in the area. The count was made during the morning hours while walking along a transect of one kilometre length. All the butterflies encountered on either sides and above the observer at an approximate distance of 5 meters were counted. Except when the observer was sure that the same individual once counted was encountered again, all the butterflies encountered at the specified distance from the observer were counted. The time of the count was fixed as between 09.30am and 10.30 am, based on the preliminary counts done at different times of the same day, which showed that this was the best time for counting. The transect used for the count was the road bisecting different habitats. The butterflies were identified up to the species level and representatives from each species was collected using a butterfly net whenever possible, to confirm the identification and to make a butterfly collection of the area. One transect count along the fixed transect route of 1km is considered as a unit sampling effort. The area covered during a transect count was approximately 50,000m^3, which is much higher compared to the area of coverage per sampling effort of the other methods.

The smaller butterflies, belonging to the Hesperidae and Lycaenidae were difficult to identify while they were on wings and hence, they could not be counted species-wise, instead their abundance was recorded family-wise. It may be noted that, since the count was made along an open area within the forest, which the butterflies prefer to the interior of the forest, butterfly counts give a rather magnified picture of the species abundance relative to the area covered.

The transect counting is the most popular and universally accepted method for monitoring butterfly population abundance. The reliability of this method for estimating and monitoring butterfly abundance has been tested and summarized elsewhere (Pollard 1977, Yamamoto 1988, Pollard and Yates 1993, Ishii 1993, Natuhara *et al.* 1996).

3.2.3 Knock down sampling

Mechanical knockdown of the insects inhabiting the shrubs were made using a bamboo pole and the insects were collected on a tray (1m x 1m, made of thick white cloth with steel frame). The tray was placed under the bush or thicket selected for sampling and the bush was beaten thoroughly with a bamboo pole. For uniformity, 10 beats were made as a standard for each sample. The insects collected on the tray were identified, counted and released back. This method was employed randomly in the moist deciduous habitat for sampling the less mobile and weak flying forms of insects which are mostly shade loving. The unit sampling effort of this sampling method involved 10 samples at randomly selected spots in the moist deciduous forest. The monthly samples consisted of three such sampling efforts, ie. 30 samples.

Majority of insects obtained by this method belonged to the orders Coleoptera, Lepidoptera, Hemiptera, and Hymenoptera. Major limitation of this sampling method was, its inefficiency to sample active flying insects and the insects of herb layers.

3.2.4 Light trapping

A fabricated light trap based on the design of Mathew (1990) was employed for the purpose of sampling the nocturnal insect abundance. The light source used in the trap was a fluorescent tube, powered by a 12 watt battery. A fluorescent tube was preferred to bulb type light sources because of the uniform emission of light to all the sides of the trap. The insects attracted towards the light were collected in the collecting chamber of the trap, where the insects were immobilized with chloroform vapour. Since keeping the light trap on for longer periods may lead to gradual reduction in the efficiency of the trap due to the accumulation of insects within the collection chamber (Trematorra *et al.* 1996), the trap was operated only for two hours during the early night hours. Moreover, longer duration trapping may also adversely affect the insect fauna of the area.

It was operated only once in ten days. The unit sampling effort of the light trap sampling was two hours of trapping in the early night hours.

There are various factors affecting the catch size in a light trap. According to Bowden (1982), the catch size is related to the intensity of the light used and the background illumination by the relation,

$$\textbf{Catch} = \mathbf{k} \times \sqrt{(\mathbf{w}/\mathbf{I})}$$

Where, **k** = a constant

w = the trap illumination and

I = the background illumination.

Hence, at constant trap illumination the catch size is inversely proportional to the background illumination.

In the present study there were three factors that would have probably affected the background illumination, and thereby the efficiency of the light trap during the trap nights. Firstly, the vegetation present around and atop the trap which resulted in lesser area of catchment, secondly the lights that were present in the nearby human settlements and in the water purification plant run by the Tamilnadu Water supply and Drainage Board, and finally, the moonlit nights which enhanced the background illumination. Although the effect of lights from the settlements and the water purification plant might have caused a reduction in the total catch size obtained in the light trap, it may have had a little effect on the temporal patterns in the relative abundance of different insect groups trapped, as these factors remained almost constant throughout the sampling period. The variations in the background illumination was also kept to the minimum by avoiding the moonlit and overcast nights. However, the changes in the vegetation cover around the trap changed seasonally, resulting in a higher catchment area during the summer, when the foliage around the trap site was less dense compared to other seasons.

The light trap is a special sampling device for the sampling of nocturnal flying invertebrates. The major orders of insects collected in this trap were Lepidoptera (Moths), Coleoptera, Isoptera and Hymenoptera.

3.2.5 Other methods

Apart from the four major sampling methods described above, two more methods, namely bark counting and canopy counting were also tried in the field for shorter durations for estimating insects.

The bark counting method was employed during the first year of the study on an experimental basis for estimating the insects dwelling on superficial bark tissue of trees . The counting was done on different types of barks, by marking two areas of 30cm x 30cm each on opposite sides of the tree trunk at breast height. 10 minutes were spent on each of the two marked areas for recording the insects encountered. Three major types of barks were identified, namely very rough (eg: bark of *Grewia tiliaefolia*) moderately rough (eg: bark of *Terminalia paniculata* and *Dalbergia latifolia*) and smooth (eg: bark of *Bombax malabarica* and *Eucalyptus sp.*). This method was used only from November 1994 to January 1996 and was not continued during the remaining period of study, since the insects obtained by this method was negligibly low compared to other methods. For realistic estimations of the bark insect abundance, the bark needs to be chiselled out and examined thoroughly. The method was useful only for sampling superficial bark insects which dwell on the surface as well as the shallow crevices of the bark which could be explored with the naked eyes. Those which inhabit deeper layers of bark tissue could not be counted.

Tree canopies of the tropical forests host the most diverse and probably the least explored biotic frontier (Jansen 1976, Erwin 1983, Schowalter *et al.*1988, Basset 1991, Simandi 1993). The only widely followed methodology for the canopy insect sampling is the canopy fogging (Erwin and Scott 1980), which cannot be employed for the regular seasonal sampling of the insect fauna to study the seasonal fluctuation in abundance. For estimating the relative changes in the abundance levels of the canopy arthropods, an indirect method of estimation based on the insect herbivory on the canopy layer of the forest was attempted during the second year of study. The percentage of leaf damage caused on the canopy as a result of the insect herbivory was estimated by direct observation using a pair of binoculars from three different observation points in each of the three habitats. An area of the canopy with around 100 relatively younger leaves was observed closely through the binoculars and the proportion of leaf damage was recorded as percentage of the total leaf area. Three such areas were focused from each observation point and the average of these nine observations was taken as an indirect estimate of the canopy insect abundance. This method was employed in the field once in every month during the second year. However, the sample sizes being too less, the data from this method was not used for the analysis.

3.3 COMPARISON OF DIFFERENT SAMPLING METHODS

The samples obtained by three major sampling methods showed much variation in the composition and abundance of insect orders. The maximum insect abundance per sampling effort was recorded in the knock down sampling (55%) followed by sweep sampling (23%) and light trapping (22%)(figure 3.1). The monthly data on the insect abundance obtained from three different general sampling methods (light trap, knock down and transect counting) showed no correlation between them, confirming the assumption that each method was biased for certain insect groups. The order of abundance of different insect groups differed among sampling methods. Hymenoptera and Coleoptera dominated the knock down and light trap samples, while Diptera dominated the sweep samples (table 3.1).

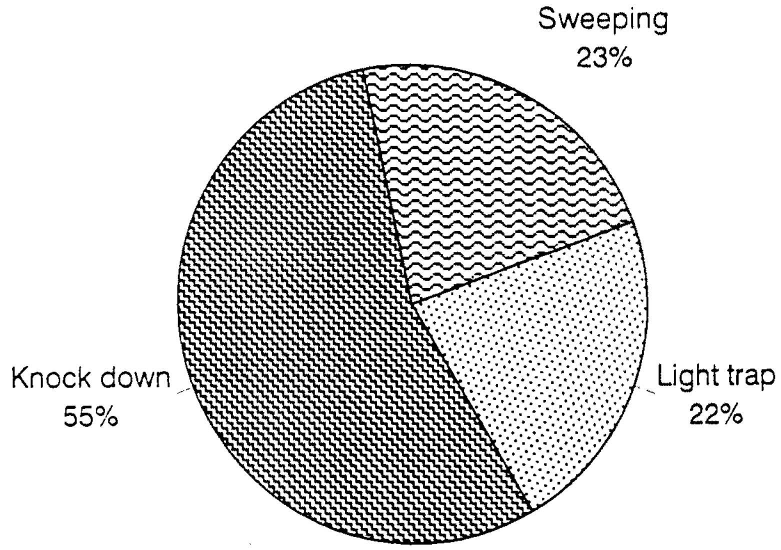

Figure 3.1 Percentage contribution by different sampling methods to the total insects sampled

Method	Insect group	Mean abundance	Range		Std. Dev
			Minimum	Maximum	
Knock-down sampling	Coleoptera	52.78	25.00	101.00	24.51
	Dictyoptera	22.17	3.00	53.00	12.87
	Hemiptera	42.78	8.00	96.00	23.45
	Hymenoptera	104.61	50.00	195.00	35.90
	Lepidoptera	46.65	5.00	158.00	43.39
	Orthoptera	28.78	6.00	72.00	15.81
	Miscellaneous	98.74	3.00	219.00	54.29
Light trapping	Coleoptera	34.19	8.00	100.00	25.82
	Dermaptera	3.06	0.00	20.25	4.39
	Diptera	7.88	0.00	54.00	13.09
	Hemiptera	13.97	2.00	31.00	7.83
	Hymenoptera	38.11	6.00	125.00	38.82
	Isoptera	9.69	0.00	57.00	16.53
	Lepidoptera	33.75	12.00	85.00	18.89
	Orthoptera	3.58	0.00	8.25	2.36
	Miscellaneous	14.27	0.00	41.50	10.57
Sweep sampling	Coleoptera	12.86	2.25	34.00	9.39
	Diptera	47.82	1.50	220.00	54.33
	Hemiptera	15.94	4.50	43.50	9.12
	Hymenoptera	24.19	9.75	55.00	12.80
	Lepidoptera	21.58	1.50	58.50	20.26
	Orthoptera	23.89	0.00	77.25	16.67
	Miscellaneous	15.84	0.00	66.00	13.49

Table 3.1 Mean monthly abundance (per three sampling efforts) of insect orders in different sampling methods

April and July during the first year and April and June during the second year showed the peak abundance of insects in the light trap, while it was in December and June during the first year and November and March during the second year in the knock down sampling. January, June and August had the peak in sweep samples (Figure 3.2). Proportions of different insect orders in the samples of different methods varied remarkably (Figure 3.3). Seasonal

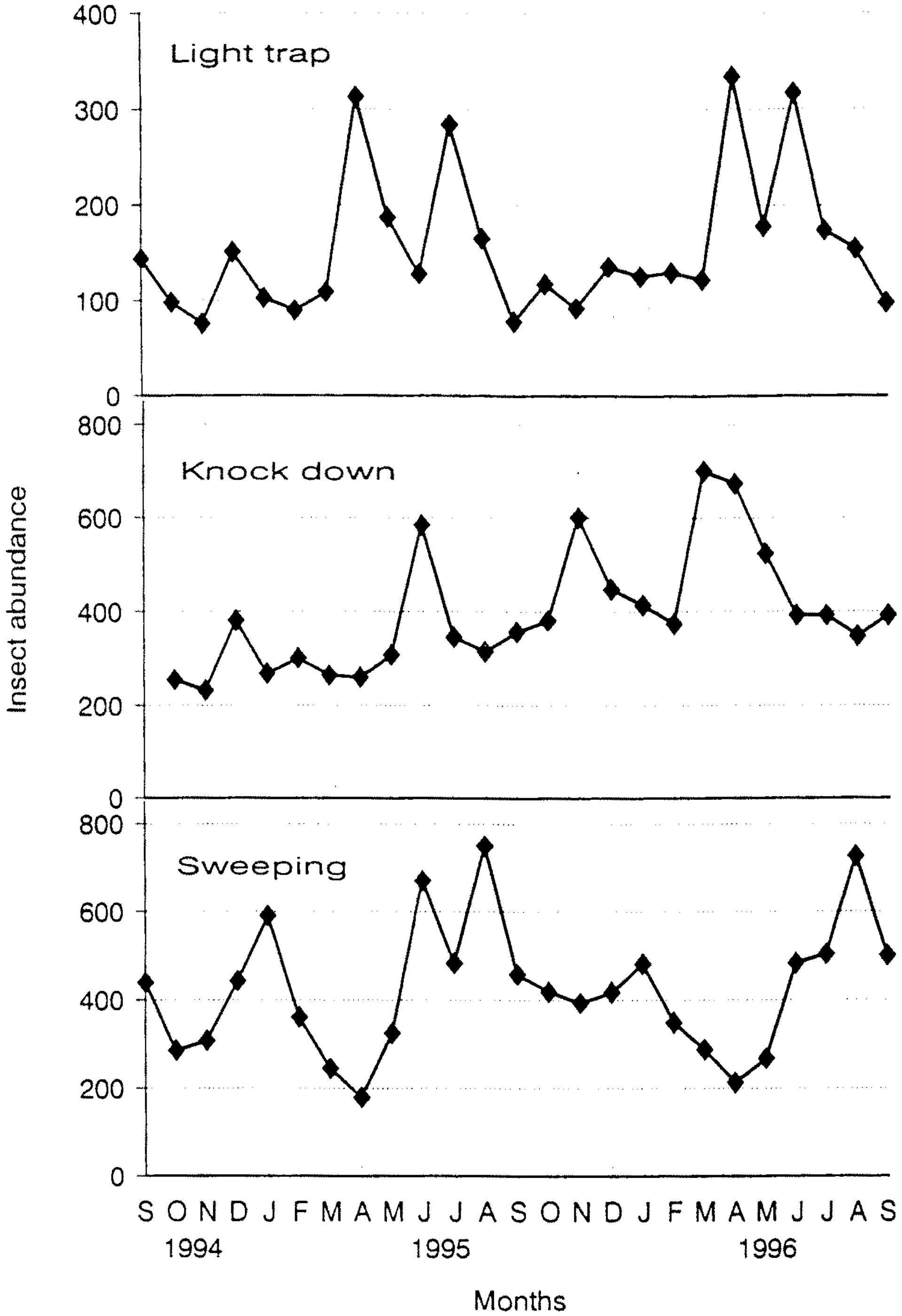

Figure 3.2 Temporal fluctuations in insect abundance recorded by three different sampling methods

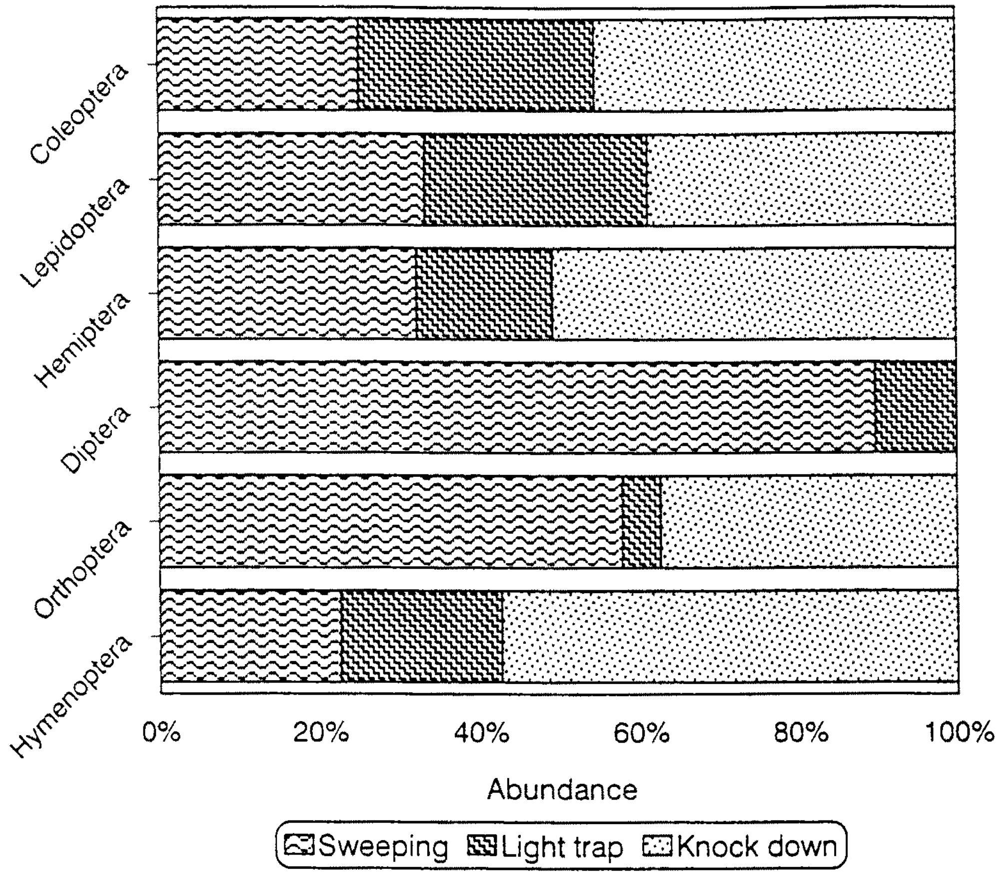

Figure 3.3 Percentage contribution of different sampling methods to the overall abundance of major insect orders

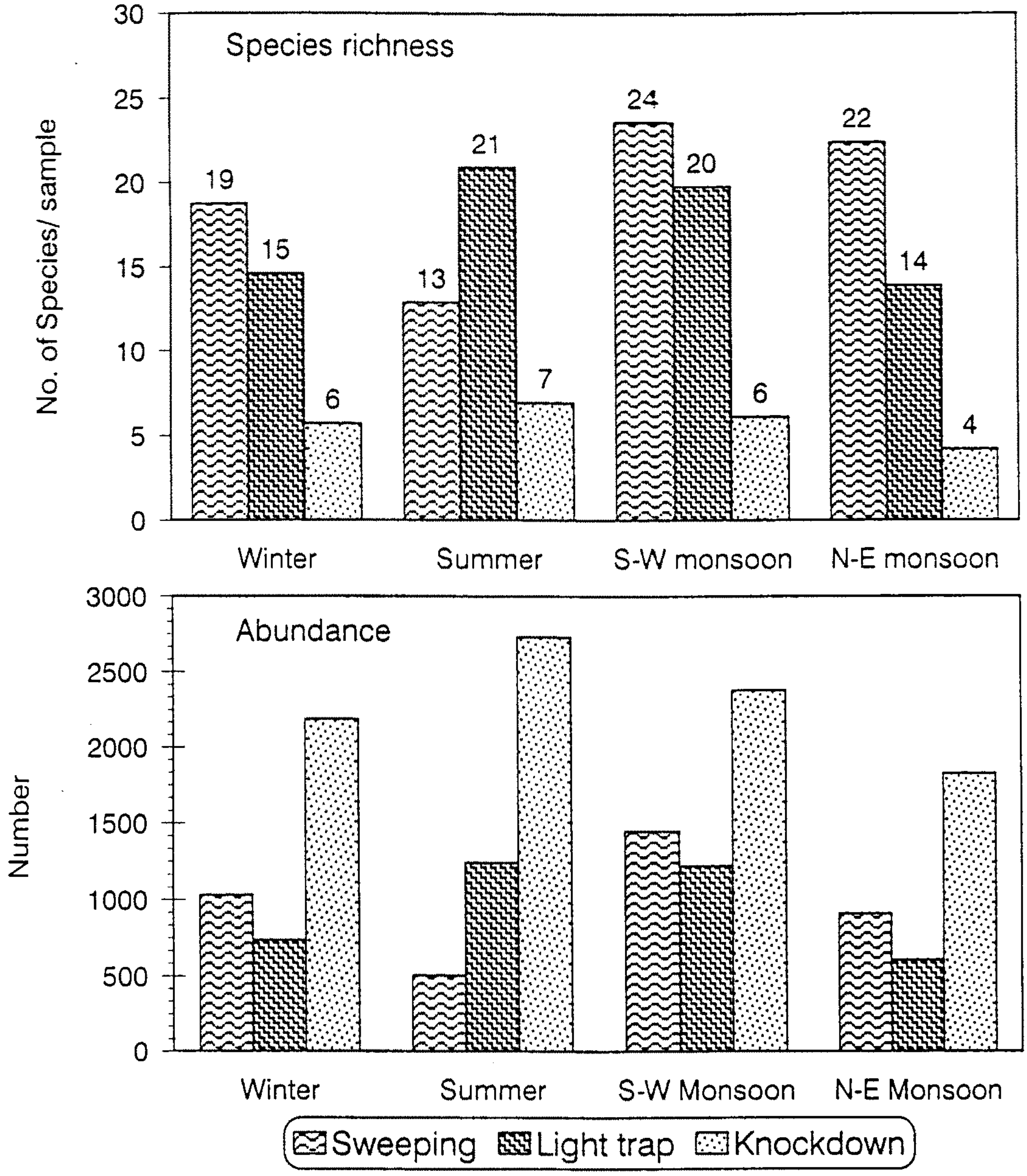

Figure 3.4 Seasonal fluctuation in the abundance and species richness of of insects observed in three different sampling methods

fluctuations in the abundance also varied among sampling methods (figure 3.4). Light trapping and knock down sampling had more similar relative proportions of different insect groups ($r_s = 0.86$; $P = 0.014$).

The Friedman two way analysis and Kendall's coefficient of concordance were used for testing the consistency of the abundance hierarchy observed between different sampling methods. Accordingly, there is a significant consistency of abundance hierarchy among the four sampling methods ($w = 0.51$, $\chi^2 = 35.35$, $P < 0.001$). The highest mean rank was obtained for the knock down samples, followed by transect counting and light trap samples (table 3.2).

The percentage variation from the mean monthly abundance was used for comparing the amount of monthly fluctuations in the insect abundance in the samples of different methods. The percentage variation in the abundance over the months from the mean was calculated for each method using the following formula,

$$Percentage\ variation = \left(\frac{Standard\ deviation}{Mean}\right) \times 100.$$

The highest monthly variation in abundance (49%), was observed in the transect counting method which was used for estimating butterfly abundance, closely followed by the light trapping method (48%), indicating a greater amount of fluctuation in the abundance of insects in these methods than the other two methods (table 3.2). Knock down sampling showed the least variation among the methods with the standard deviation being 33.9% from the mean.

A major portion of the light trap catches consisted of coleopterans and hymenopterans and hence, the total coleopteran and hymenopteran abundance was significantly correlated with the total insect abundance recorded using light trap ($r = 0.74$, $P < 0.001$). The light trap samples recorded a significant difference in insect abundance among the four seasons (Kruskal Wallis one way anova, $\chi^2 = 11.91$, $P = 0.007$). There was a significant difference between the insect abundance of the two study years as well (Kruskal Wallis one way anova, $\chi^2 = 5.88$, $P = 0.01$).

	Methods			
	Light Trap	Knock down	Transect count	Sweeping
Mean abundance/month	158.70	396.00	195.80	419.80
Standard deviation	76.70	134.10	96.40	152.90
(STD/mean)	0.50	0.30	0.50	0.40
% variation from mean	48.30	33.90	49.20	36.40
Mean rank of abundance	1.87	3.87	2.22	2.04
Kendall's W = 0.5123 , Chi-Square = 35.35 , D.F = 3 , Sig: P < 0.001				

Table 3.2 Comparison of insect abundance data from different sampling techniques.

3.3.1 Variation of insect community in samples of different methods

Proportion of insect groups in samples varied among methods (Figure 3.3 and table 3.1). Certain insect orders were observed only in particular sampling methods. For instance, the isoptera was recorded only in the light trapping, while dictyoptera was present only in the knock down samples. Diptera, which was present in the other methods was absent in the knock down samples. Hymenoptera was the most dominant insect order in knock down and light trap samples, where as diptera was the most abundant order in the sweep samples. High proportions of Coleoptera and lepidoptera along with hymenoptera were a distinguishing feature of the light trap samples.

The insect abundance recorded in sweep sampling method behaved differently from the other two methods. The insect abundance data from various sampling techniques were tested for a significant hierarchy of abundance among the insect orders using Kendall's coefficient of concordance. The mean ranks obtained for different insect orders and the Kendall's coefficient of concordance values in the insect samples of different sampling methods and total insect population (obtained from the pooled data from the three methods) are given in table 3.3.

Insect orders	Mean abundance ranks			
	Light trap	Knock down	Sweeping	Total
Coleoptera	7.42	4.41	2.81	6.89
Lepidoptera	7.71	3.59	3.73	7.57
Hemiptera	5.56	3.48	3.52	5.57
Dermaptera	2.63	-	-	1.61
Diptera	3.44	-	5.25	6.17
Orthoptera	2.92	2.48	4.48	5.74
Hymenoptera	7.15	6.17	4.58	9.11
Isoptera	3.19	-	-	1.70
Dictyoptera	-	2.04	-	2.78
Kendall's W	0.57	0.54	0.14	0.756
Chi - square	109.43	73.83	20.68	156.4918
D.F	8	6	6	9
Significance	P < 0.001	P < 0.001	P = 0.002	P < 0.001

Table 3.3 Mean abundance ranks obtained for different insect orders in different sampling methods.

The significant values of Kendall's coefficient of concordance in all the sampling techniques revealed a significant unique abundance hierarchy among the different insect groups within each of the insect samples from the three sampling methods. The abundance hierarchy obtained by the mean ranking was Diptera > Hymenoptera > Orthoptera > Lepidoptera > Hemiptera > Coleoptera in sweep sampling method, while it was Lepidoptera > Coleoptera > Hymenoptera > Hemiptera > Diptera > Isoptera > Orthoptera > Dermaptera in light trapping , and Hymenoptera > Coleoptera > Lepidoptera > Hemiptera > Orthoptera > Dictyoptera in knock down method. Although, these significant hierarchical patterns in the abundance of insect orders in each method was not in the same order as it was observed in the overall insects sampled by each of these methods (figure 3.3), indicating that, each insect order had a differential preference towards different sampling methods, these methods could be used for monitoring the temporal patterns in the abundance of insects.

The results clearly showed that the rank order of abundance of different insect orders obtained in each of the three different sampling methods did not change significantly during the study period. Hence, in spite of the seasonal difference in the abundance levels of different insect groups, the samples of each sampling method was found to maintain a significantly similar relative proportions of various insect orders.

3.4 ENVIRONMENTAL FACTORS

Various selected biotic and abiotic environmental factors such as plant phenology and meteorological factors were monitored during the study in order to find out the role of these factors in the seasonality of insects.

3.4.1 Plant Phenology

Phenology of plants were monitored at fortnightly intervals by stratified sampling which involved estimation of the phenology of different species of plants. Eight major species of plants of the under story vegetation were selected for monitoring phenology. An approximate proportion of flowers, fruits and leaves observed on each species was recorded. The different growth phases (young, mature and dry) of each of these three phenological events were also separately recorded. The total proportion of different phenological events from eight species of plants is used as an index of plant phenology of the area. Data on the phenology was systematically collected during the second year of the study (1995-96).

3.4.2 Rainfall and number of rainy days

The rainfall data for the study period and previous years were collected from the office of Tamil Nadu Water supply and Drainage Board (TWAD). The rain-guage from which the data were recorded was situated right inside the study site. The rainfall data were recorded daily. The number of days in which it rained in the area was also recorded regularly from the office of TWAD.

3.4.3 Relative humidity

Relative humidity of the atmosphere (in %) was measured daily at 10 am and at 5 pm using a hair hygrometer. The average of these two readings were taken as an index of the relative humidity content in the atmosphere on that day. The average of daily readings was used for the monthly estimates. Humidity data were recorded during the last 18 months of the study.

3.4.4 Temperature

A maximum - minimum thermometer was used for recording the highest and lowest temperatures of each day. The maximum and minimum temperature readings were averaged for each month to find the mean daily maximum and minimum temperature during the month. The average of mean temperatures of the days during a month was taken as the monthly temperature. Temperature data were recorded during the last 18 months of the study.

3.4.5 Abundance of birds

Monthly data on total bird abundance and insectivorous bird abundance collected from the same area during the same period by Vijayan *et al.*, (in press) and are used for comparing the insect abundance with that of the bird abundance of the area. The data on the bird abundance was collected using the variable width line transect method.

CHAPTER IV

GENERAL INSECT SEASONALITY

4.1 INTRODUCTION

The seasonal fluctuations in the abundance of insect populations in relation to the environmental conditions have been reported elsewhere. Daniel and Myers (1995) observed that the temperatures during the larval feeding time was one of the key factors in deciding the outbreaks of forest tent caterpillar (*Malacosoma disstria* Hbn.) in forests of the Ontario province in Canada. Studies from Russia (Gejspic 1965, Danilevskii 1965, Saulich *et al.* 1994) and Japan (Yoshio and Ishii 1994) have highlighted the importance of light regime and temperature on the development and seasonality of insects. However, often the wether variables alone did not explain the details of insect population dynamics (Daniel and Myers 1995, Berryman 1996).

The biotic environment too does play an important role in the seasonality of organisms. For instance, the Predator - prey cycles have an important role in the abundance and seasonality of vertebrates (Erlinge *et al.* 1984, Korpimaki 1994) and arthropods (Gunnarsson 1996). According to Berryman (1996), six to eleven year cycles of many forest lepidopterans are caused by delayed negative feed back with insect parasitoids. Concentration in spring feeding by caterpillars of *Operophtera brumata* and other species of Lepidoptera on Oak trees in England is related to the seasonal changes in the texture and chemical composition of the leaves (Feeny 1970).

However, most such studies are focused on the seasonal aspects of a few selected species of insects. No study on the overall insect seasonality, with the various biotic and abiotic factors affecting it, has been reported from the forests of India. However, insects being a stable diet of most birds, many of the ecological studies on birds have documented the insect abundance of different forest areas (Vijayan 1975, Shukkur 1978, Vijayan 1985, Sundaramoorthy 1991). However, these studies merely reported the abundance of different insect groups during the study period, and no attempt had been made to find its relationship with the environmental factors.

Insect fauna showed temporal and spatial variations in abundance. While the fluctuations in the relative abundance were more pronounced in certain insect orders like Diptera, it was less so in some insect orders like Hemiptera. An attempt has been made in this chapter to bring out the variations in insect seasonality patterns among the habitats, the overall abundance and seasonality of the general insect fauna of the area and the role of selected biotic and abiotic factors on the abundance of insects.

4.2 METHODS

The general insect abundance was estimated using three different sampling methods, namely sweeping (SW), mechanical knock down (KD) and light trapping (LT). The pooled data obtained from these three methods were used as a measure of insect abundance in the selected moist deciduous forest. Two other habitats, namely teak plantation and riverine habitat were sampled exclusively by the sweep sampling. For the purpose of comparisons the insects obtained per sampling effort is used as a unit. One sampling effort involved 100 sweeps in the case of sweep sampling, two hours of trapping in the early night hours in the case of light trapping, and ten samples in the case of knock down sampling. The monthly insect abundance data from each method are derived from three such sampling efforts at an approximate interval of ten days between the samplings. Relatively larger forms of insects which measured roughly over 2mm in length and could be easily distinguished with the naked eye only were recorded during the sampling procedures. Those smaller than 2mm were ignored, as most times they required microscopic analysis for confirming the identity, which was not feasible in this kind of study. The data set used for analysis consisted of data from 24 months of sweeping and light trap sampling and 23 months data of knock down sampling. The meteorological data were collected from the study site regularly. The phenology of selected major herb and shrub species were recorded quantitatively, using stratified random sampling method. For details see chapter III.

Four seasons, namely winter, summer, south-west monsoon and north-east monsoon were distinguished, based on the local climatic factors such as rainfall and temperature. Details of the climatic conditions during different seasons are given in chapter III.

4.3 DATA ANALYSIS

Mainly nonparametric tests were used for the data analysis (Siegel and Castellan 1988). The following major statistical tests were employed in analysing the data using the SPSS (SPSS for MS windows, Release 6 and 7.5) statistical package.

The Hierarchical Cluster Analysis using average linkage between groups with the Pearson correlation as the measure of distance was used to classify and cluster the monthly insect abundance data. The Multivariate Analysis of Variance and the Kruskal- Wallis one way ANOVA were used to test the significance of difference in insect abundance between the habitats, seasons and years. The Friedmans Two Way ANOVA and Kendall's Coefficient of Concordance were used to test the significance of the rank order of abundance between variables. The Pearson and Spearman Correlation Coefficients were calculated to estimate the covariations shown by two variables directly or with a time lag. The linear multiple regression was used to examine the relationship between insect abundance and environmental factors.

4.4 RESULTS

Of the 29 orders of insects under the Class Insecta (Richards and Davies 1977), the following 13 major orders were encountered during the various sampling procedures employed in the field. Coleoptera (beetles), Lepidoptera (butterflies and moths), Hemiptera (bugs), Diptera (flies, mosquitoes), Orthoptera (grasshoppers), Hymenoptera (ants, bees, wasps), Isoptera (termites), Dictyoptera (Cockroaches), Odonata (dragon flies, damsel flies), Collembola (spring tails), Embioptera (web spinners), Phasmida (leaf insects), Ephemeroptera (mayflies), Mecoptera (scorpion flies) Neuroptera, Plecoptera and Dermaptera. Out of these, the first six orders were relatively more abundant in the study area than the others, and hence were selected for detailed study. Apart from these, three other orders, namely Isoptera, Dermaptera and Dictyoptera were recorded in significant proportions in two sampling methods (Isoptera and Dermaptera in Light trap and Dictyoptera in the Knock down). Insects belonging to all other orders were insignificant in numbers and were recorded as miscellaneous along with those with uncertain identity.

4.4.1 Community composition

The general insect abundance from the pooled data of three sampling methods shows that the maximum abundant insect order in the study area was Hymenoptera which was responsible for 23% of the total insect abundance

(Figure 4.1). The contribution of other insect groups was; Lepidoptera 16%, Coleoptera 15%, Diptera 13%, Orthoptera 11%, Hemiptera 11% and Miscellaneous insects 11%. This hierarchy of abundance (Hymenoptera > Lepidoptera > Coleoptera > Diptera > Orthoptera > Hemiptera) among the insect groups was statistically significant (Kendall's W = 0.345, $P < 0.0001$) in the monthly data set. Seasonality of different insect orders are described in the chapter IV.

The seasonal abundance of the insects obtained in the study area may be compared with a similar insect abundance study reported from three different habitats at Keoladeo National Park, Rajasthan, India (Vijayan 1991). There too the first three most abundant orders were the same (Hymenoptera, Diptera and Coleoptera) as observed in the present study. However, in most of the years the most abundant insect group recorded at Keoladeo study was the coleopterans unlike here, where the maximum abundant group was the Hymenoptera in both the years of study. The major peaks in insect abundance observed were around the September in both the studies. Excepting this similarity in the highest abundant period of the year, the seasonal abundance patterns and the percentage abundance of insect groups in the general insect community were different in Keoladeo National Park from that of the present study. This difference in seasonality and composition of insect fauna between the two areas were obviously because of the difference in the environmental conditions between the two regions.

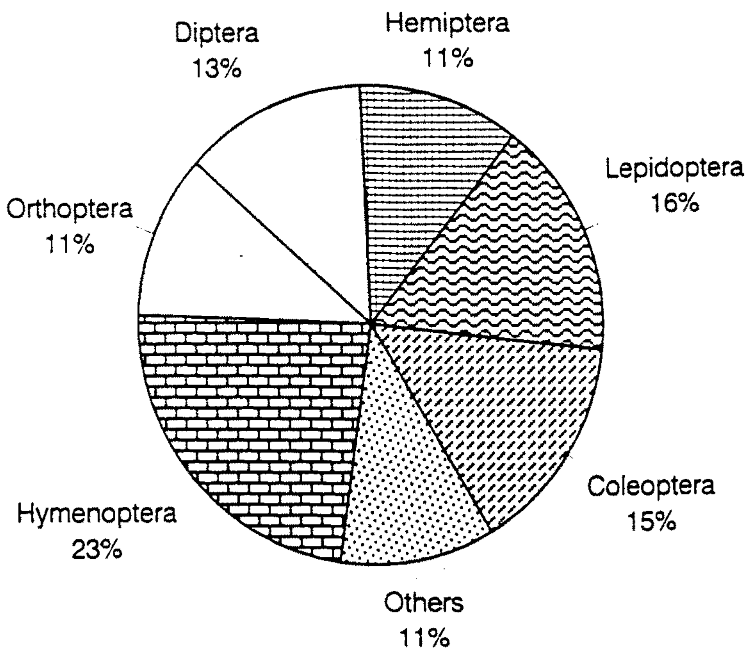

Figure 4.1 Percentage composition of the general insect community

4.4.2 Seasonal abundance

The over all insect abundance fluctuated much, but showed a slight upward trend from 1994 to 1996. The peak abundance was in June during 1994-95 and in April during 1995-96. The lowest insect abundance levels recorded were in September, March and February during 1994, 1995 and 1996 respectively (Figure 4.2). Insect abundance was maximum during the south-west monsoon which accounted for 30% of the total abundance and minimum during the north-east monsoon (20% of total). Summer and winter contributed 27% and 23% of the total insect abundance respectively (Figure 4.3).

Generally the insect abundance peaks are closely associated with the major monsoon season of the area. A higher abundance of insects during the monsoon season has been reported from the tropical dry evergreen forest of Point Calimere (Vijayan 1975) and moist deciduous forest of Thekkady (Vijayan 1984) of South India.

The seasonal abundance patterns were compared among nine insect orders using the hierarchical cluster analysis to distinguish the orders with similar patterns (Figure 4.4). Lepidoptera and Orthoptera showed highest similarity in their seasonal abundance pattern. This may, probably, be an indication of broadly similar requirements of environmental conditions by these orders. Another common characteristic of these two orders is that both are important

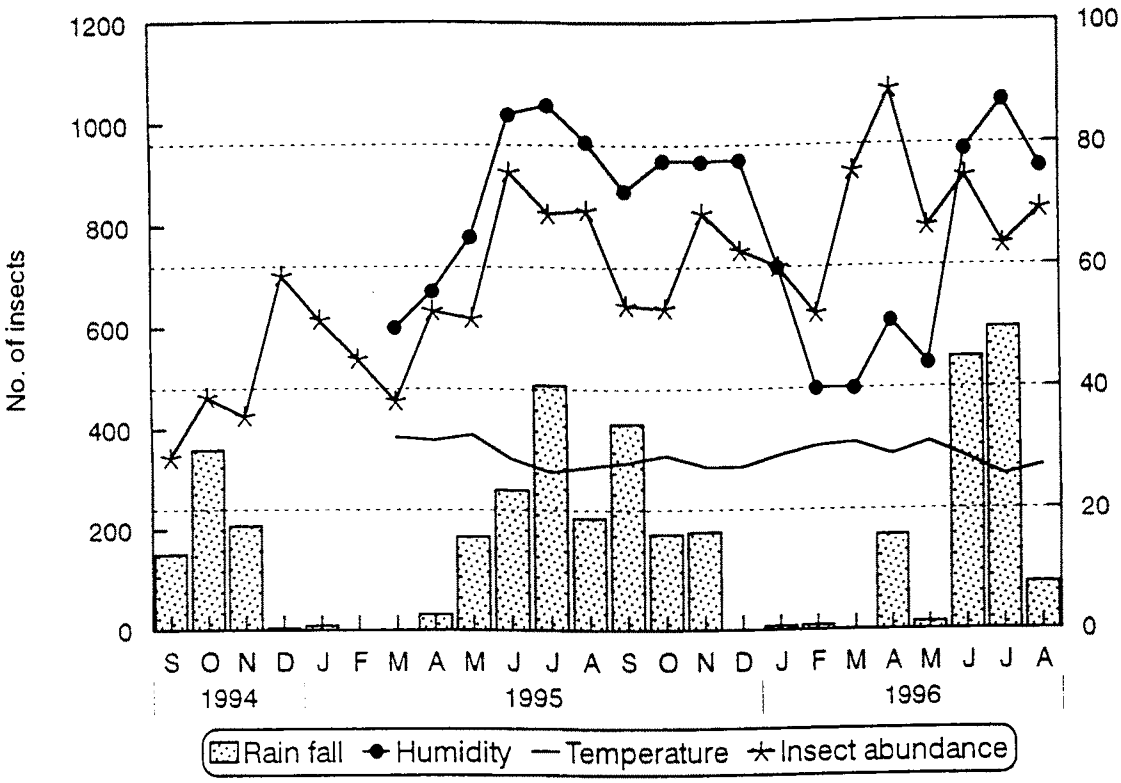

Figure 4.2 Monthly fluctuations in the insect abundance and abiotic factors.

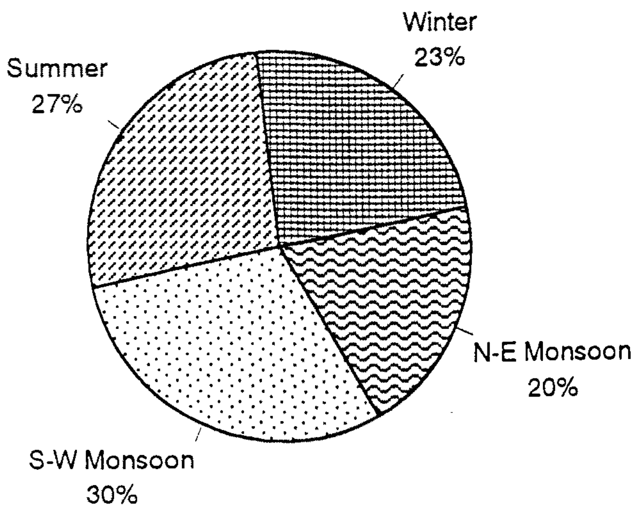

Figure 4.3 Insect abundance in various seasons (in %)

food sources of birds. A similar seasonal abundance pattern may enable them to tackle the predation pressure more efficiently. Hymenoptera and Coleoptera were the other two orders that showed similar seasonal abundance patterns.

```
                         Rescaled Distance Cluster Combine

                  0         5        10        15        20        25
                  +---------+---------+---------+---------+---------+

Lepidoptera    -+-----------+
Orthoptera     -+           +---------------------------------------+
Miscellaneous  -------------+                                       |
Coleoptera     --------+-----------+                                |
Hymenoptera    --------+           +--------------------+           |
Hemiptera      --------------------+                    +-----------+
Diptera        -----------------------------------------+
```

Figure 4.4 Dendrogram showing similarities in seasonality among the insect groups (Pearson correlation measure and average linkage between groups are used for the classification).

4.4.3 Role of ecological factors

Among the five environmental parameters, namely rainfall, number of rainy days, maximum temperature, minimum temperature and relative humidity, monitored during the study, only the minimum temperature showed a significant negative correlation with the monthly fluctuations in insect abundance ($r = -0.66$; $P = 0.03$). The total insect abundance had a significant cross correlation with the rainfall at a lag of 3 months ($r = 0.55$, Standard Error = 0.22). Biotic factors such as relative abundances of flowers, flower buds and young leaves did not show any direct significant correlation (table 4.1). The relationship of insect abundance with the environmental factors was calculated using the multiple linear regression (Table 4.2, Figure 4.5)

Variables	Correlation coefficients (r)	Significance level (P =)
Insects	1.000	-
Rain fall	0.190	0.373
No. of rainy days	0.158	0.462
Relative Humidity	0.170	0.500
Maximum temperature	-0.250	0.317
Minimum temperature	-0.515	0.029*
Flower	-0.307	0.359
Flower bud	-0.493	0.123
Young leaves	-0.030	0.931
Bird abundance	-0.189	0.377
Insectivorous bird abundance	-0.190	0.374

Table 4.1 Pearson correlation coefficients between insect abundance and environmental variables. * = Significant at 5% level

A linear association was observed when the standardised predicted values of insect abundance using the regression equation was plotted against the observed values of insect abundance of the corresponding months (Figure 4.5). It may be noted that no single environmental factor, except the temperature, was found to play a key role in regulating the insect abundance. It was a combination of many factors that decide the abundance.

Variables in the equation	Slope (B)	Standard Error
Bird (insectivorous) abundance	-0.31	6.97
Monthly Rainfall in mm	0.04	1.14
Number of Rainy days	45.27	52.83
Relative Humidity (%)	-1.1	7.3
Maximum Temperature (°C)	54.31	51.23
Minimum temperature (°C)	137.3	121.08
Flower abundance (%)	69.04	43.41
Flower bud abundance (%)	-17.43	10.44
Young leaf abundance (%)	1.52	31.21
Constant = -4860.42		4451.09

Table 4.2 Result of the regression analysis of insect abundance against the environmental factors (R= 0.947).

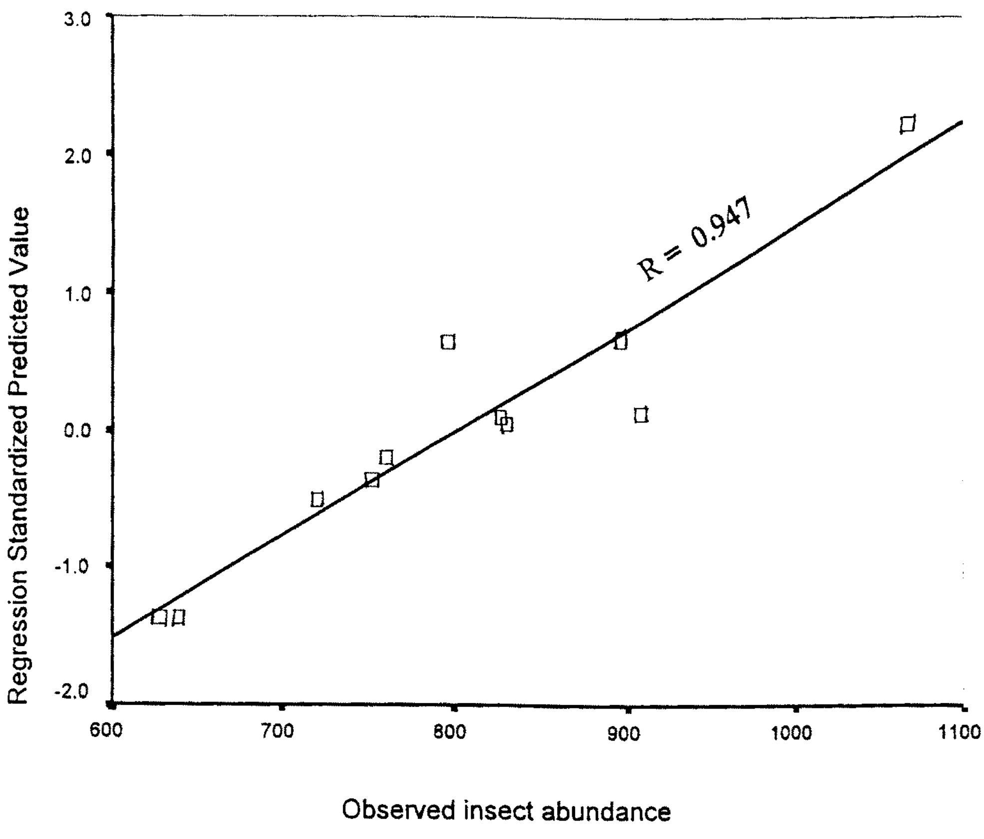

Figure 4.5 Scatter plot of observed insect abundance against the standardised predicted values of insect abundance based on environmental factors (regression)

4.4.4 Inter-habitat comparison

The habitat-wise data on insect abundance showed a similar pattern of seasonal fluctuation in all the three habitats. Invariably in all habitats south-west monsoon was the most preferred season followed by winter, north-east monsoon and summer (Table 4.3). The hierarchical cluster analysis using the average linkage between the composition of the insect samples of various habitats and seasons, using correlation as the distance measure, revealed that the effect of seasons was more prominent than that of the habitats on the insect community composition. The analysis yielded two major clusters. One representing the wet season (North-east and South-west monsoon), and the other dry season (winter and summer) samples (Figure 4.6). However, the wet season samples were more closely clustered compared to the dry season. Within each of these two major clusters, minor clustering was observed between the community composition of the same season, irrespective of the habitats. This seasonal clustering was more distinct in wet than in the dry season. Among the habitats, moist deciduous and teak plantation habitats were highly similar in both the wet seasons, while the riverine and teak plantation in summer and, riverine and moist deciduous in winter were the other similar habitats in terms of composition of insects. The highest similarity in community composition observed was between the south-west monsoon samples of moist deciduous and teak plantation habitats.

Although all the three habitats showed a similar pattern of fluctuation in insect abundance, there was significant difference in the insect abundance among these habitats in all seasons. Generally the moist deciduous habitat was the most preferred habitat with maximum abundance of insects, closely followed

```
                       Rescaled Distance Cluster Combine

                     0         5        10        15        20        25
                     +---------+---------+---------+---------+---------+
S-W   (MD)           ----
S-W   (TP)           -+ +--------+
N-E   (RI)           ---+        +------+
S-W   (RI)           -----------+      +------------------------------+
N-E   (MD)           -----------------+                               I
N-E   (TP)           ------                                           +-+
WINTER (MD)          -----------------+                               I I
WINTER (RI)          ----              +------------------------------+ I
WINTER (TP)          -----------------+                                 I
SUMMER (RI)          ---------------+---------------------+             I
SUMMER (TP)          ---------------+                     +-------------+
SUMMER (MD)          -------------------------------------+

          S-W South-West Monsoon; N-E North-East Monsoon;
     MD Moist deciduous;   RI  Riverine;   TP  Teak plantation
```

Figure 4.6 Dendrogram showing similarity between the insect community composition in different habitats and seasons

by the riverine habitat (Figure 4.7). The teak plantation was the least preferred habitat with comparatively very low insect abundance during all the seasons.

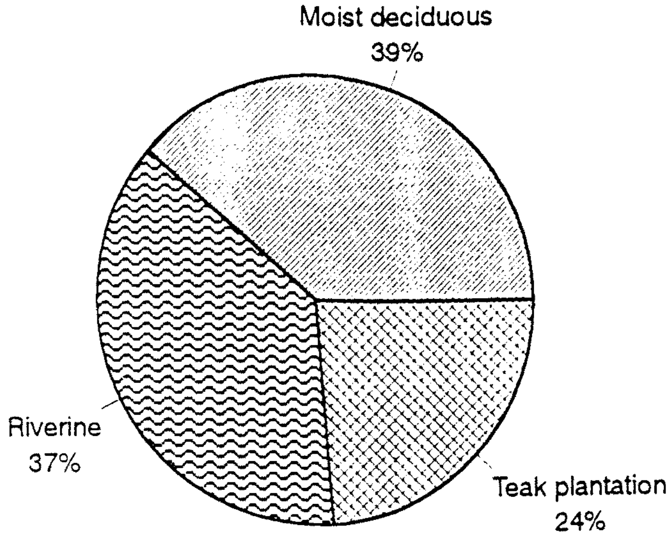

Figure 4.7 Insect abundance in various habitats (in %)

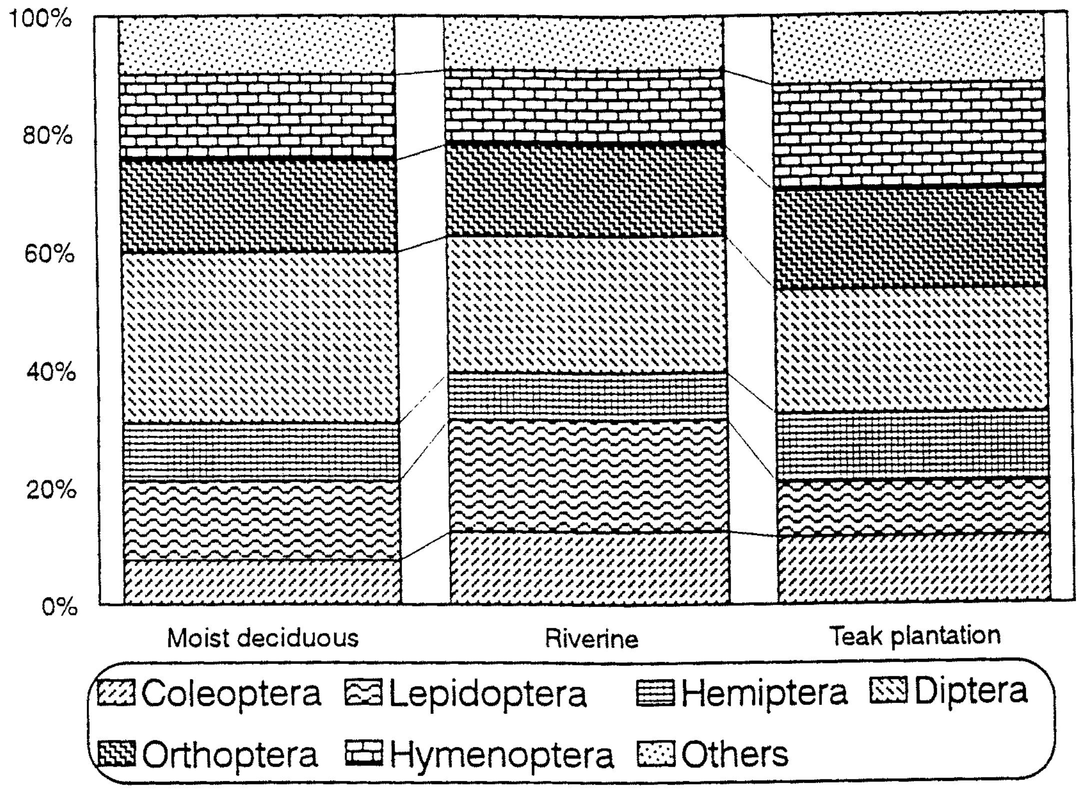

Figure 4.8 Percentage composition of insect community in three different habitats sampled by sweeping

Year	Season	Habitats			Total
		MD	RI	TP	
1994-95	N-E Monsoon	426	371	236	1033
	Winter	560	536	299	1394
	Summer	263	292	195	749
	S-W Monsoon	742	709	454	1904
	Total	1991	1908	1184	5080
1995-96	N-E Monsoon	483	451	336	1269
	Winter	471	501	276	1247
	Summer	241	317	210	767
	S-W Monsoon	707	602	405	1714
	Total	1902	1871	1227	4997
1994-96	N-E Monsoon	909 (23%)	822 (22%)	572 (24%)	2302 (23%)
	Winter	1031 (26%)	1037 (27%)	575 (24%)	2641 (26%)
	Summer	504 (13%)	609 (16%)	405 (17%)	1516 (15%)
	S-W Monsoon	1449 (37%)	1311 (35%)	859 (36%)	3618 (36%)
	Total	3893	3779	2411	10077
MD = Moist deciduous; RI = Riverine; TP = Teak plantation					

Table 4.3 Relative abundance of insects in different habitats, seasons and years.

The abundance of insects as well as the abundance of various insect groups varied among the three habitats. There was differences in the pattern of seasonal preference even in the same habitat during different years (Table 4.3). However, the total insect abundance from all the habitats together showed no significant variation between the years (F = 0.11, P = 0.92; Kruskal Wallis anova (χ^2) = 0.007, P = 0.93). The fluctuations in insect abundance in all the habitats were significantly correlated (P < 0.01) among themselves. The same was true in the abundance of other major insect orders in different habitats also.

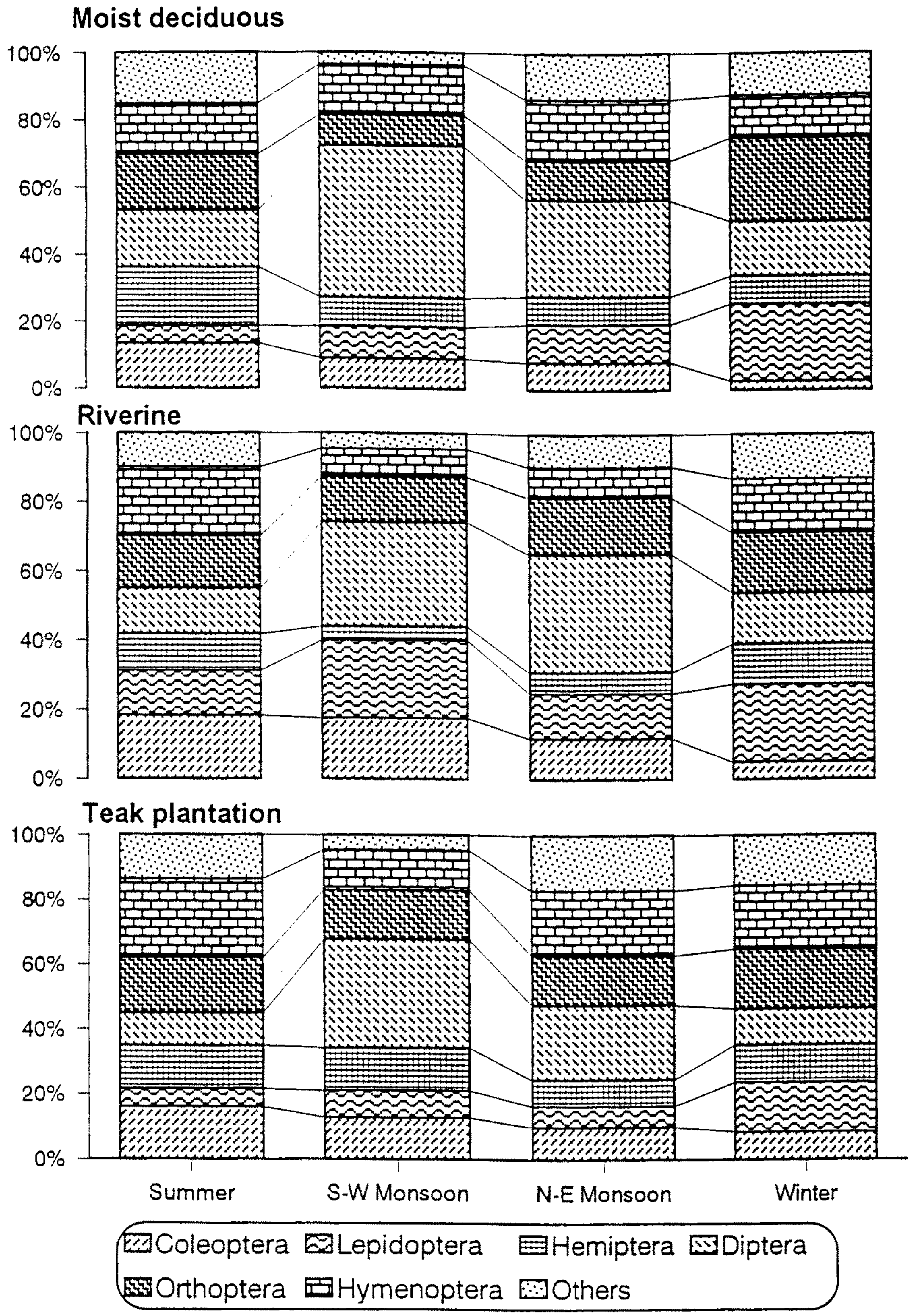

Figure 4.9 Seasonal variation in the percentage composition of insect community in three different habitats sampled by sweeping

4.4.4.1 Community composition

Although there was an apparent difference in insect abundance among the three habitats(Figure 4.7), with moist deciduous and riverine habitats together accounting for a major proportion (76 %) of the total insect abundance, the relative proportion of different insect orders in the over all insect abundance of different habitats did not show as much variation (Figure 4.8). However, Diptera was present in significantly higher proportions in the moist deciduous habitat, compared to other habitats. This higher abundance of Diptera was mainly due to the peak abundance of this order during the south-west monsoon of both the years. Hymenoptera and Lepidoptera were the other two major groups that showed inter-habitat difference in their proportion in total abundance. The proportion of Hymenoptera was comparatively high in the teak plantation, while that of Lepidoptera was high in the Riverine habitat (Figure 4.9).

The similarity between three habitats in terms of the proportion of different insect groups in the total abundance was calculated using the following formula after Whittakar (1960).

$$I = 1 - 0.5(\sum |ai-bi|)$$

Where,"*I*" is the proportionate similarity between the two samples, "**ai**" is the proportion of total individuals in sample "**a**" that belong to the order **i** and "**bi**" is proportion of total individuals in sample "**b**" that belong to the order **i**. A complete similarity gives *I* = 1 and a complete dissimilarity gives *I* = 0. This index was used in ecological studies earlier by Murdoch *et al.* (1972) and Whittakar (1960).

The similarity indices obtained demonstrate a high degree of similarity among the insect community of these three habitats, as far as the relative proportions of different insect orders are concerned. The moist deciduous and riverine habitats showed maximum similarity (I = 0.89), while teak plantation showed the highest similarity with the moist deciduous habitat (I = 0.88) followed by riverine (I = 0.87).

4.4.4.2 Seasonality of insects in various habitats

The relative abundance of insects showed much temporal fluctuations during the 24 months study period in all the habitats (Figure 4.10). The moist deciduous habitat showed maximum amount of monthly variation with a standard deviation of 45.5% from the mean monthly abundance, followed by teak plantation (38.3%) and riverine (34.34%) habitats. The comparatively small variation in the insect abundance in the riverine habitat may be attributed to the relatively less seasonal changes in the vegetation and micro-climatic conditions of this area, mainly due to the availability of water and moisture all through the year.

4.4.4.3 Species richness

The average number of morpho-species obtained per sampling effort is considered as a measure of species richness. Higher species richness was

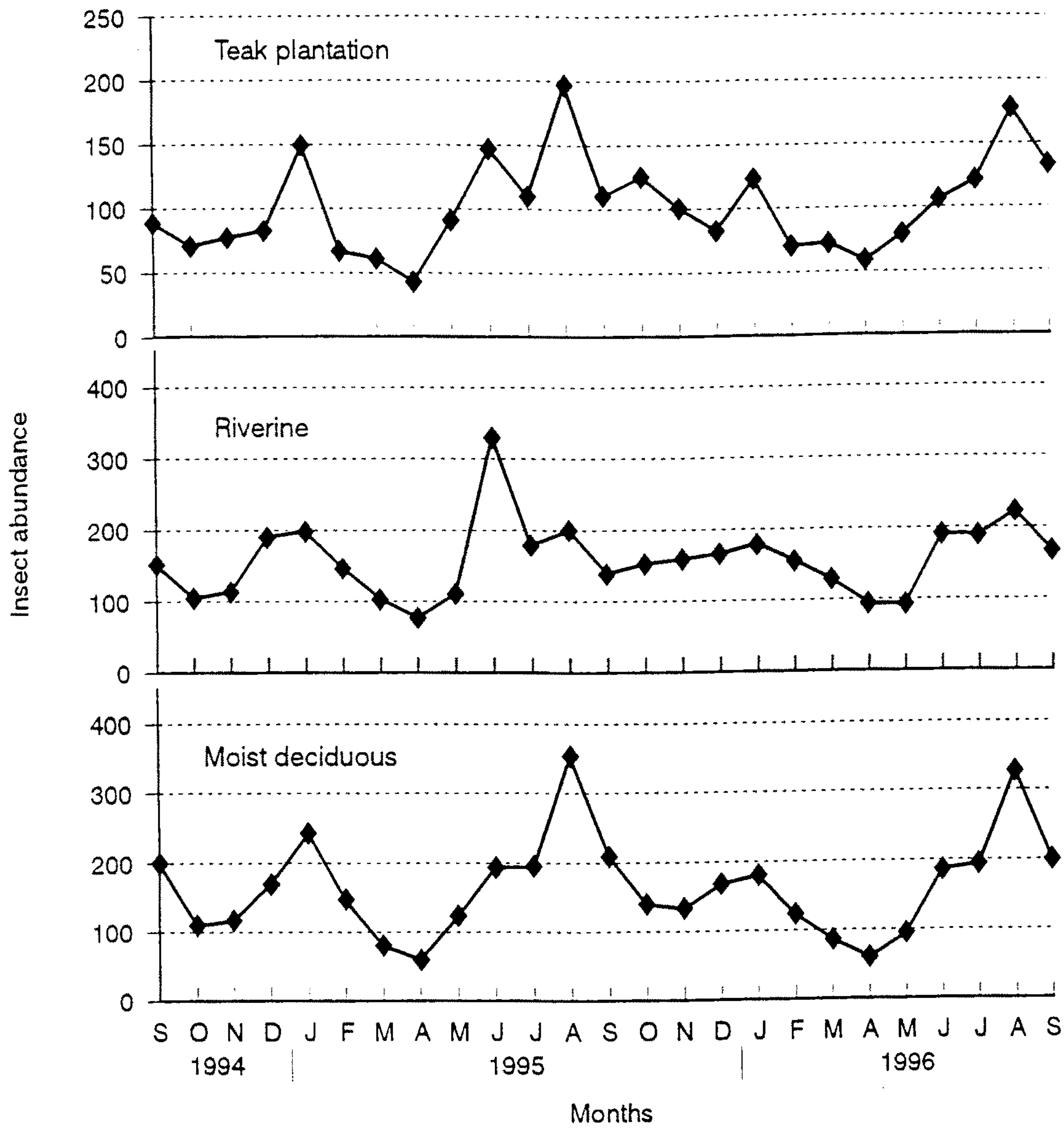

Figure 4.10 Monthly fluctuation of insect abundance in three habitats.

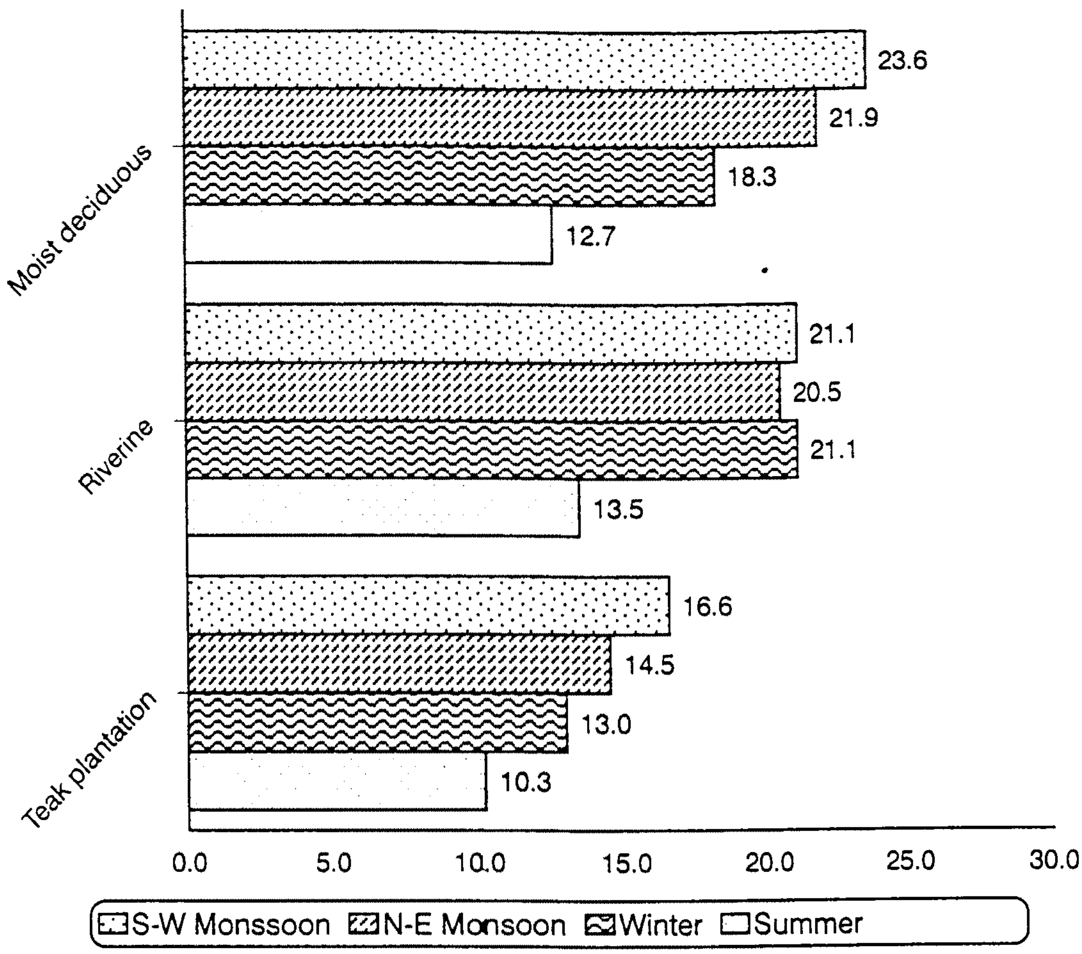

Figure 4.11 Species richness of insects obtained per sampling effort in different habitats during different seasons

recorded in the moist deciduous and riverine habitats than in teak plantation in all the seasons (Figure 4.11). As reported earlier by Murdoch *et al.* (1972) from the southeast Michigan, here also the difference in the diversity of insects between the habitats might be because of the difference in the ground level vegetation between the habitats.

The species richness was highest in south-west monsoon and lowest in the summer in all the habitats. However, in riverine habitat winter was also as species rich as the south-west monsoon, followed by north-east monsoon and summer. In the moist deciduous and teak plantation the species richness in different seasons was in the following order: south-west monsoon > north-east monsoon > winter > summer.

4.5 DISCUSSION

4.5.1 Insect seasonality in different habitats

The relative abundance of insects varied significantly among the habitats, while the seasonal abundance pattern and the community composition of insects did not show much variation among the habitats. The maximum abundance of insects was observed in the moist deciduous habitat, where the plant diversity was also the maximum. The seasonality of insects showed significantly similar pattern of fluctuation in all the habitats. The abundance of insects differed significantly between seasons in all the three habitats. Hence, the overall insect population of the area had well defined seasonal abundance pattern. From the above results, it appears that, in a given area the spatial variation in insect abundance is very much dependent on the habitat type while the temporal fluctuation pattern is independent of the habitat type and is controlled by the complex interactions with the various biotic and abiotic factors.

The under story vegetation in the teak plantation had low diversity, as it was dominated largely by the shrub *Glycosmis pentaphylla.* The low abundance of insects was probably due to the unpalatable nature of this plant to most of the insects of the area, as evidenced by the comparatively very less damaged leaves. The similarity in the seasonal abundance pattern of insects irrespective of the difference in sites has been observed in a study in Australia, where the abundance of *Carpophilus spp*. (Coleoptera, Nitidulidae) was found high during spring and early summer in all the four sites (James *et al.* 1995)

4.5.2 Role of ecological factors on seasonality

The seasonality of insect abundance was not significantly correlated with any of the environmental factors individually at the one percent significance level. However, the linear regression obtained with the multiple factors indicated the significant role of these environmental factors in determining the insect seasonality, irrespective of the habitat type. Although, the insect abundance in all the three habitats was found to be correlating neither with rainfall nor with the number of rainy days in any significant direct way, the pattern of rain fall with maximum number of rainy days helped to bring about a sudden increase in the insect abundance in the very beginning of the south-west monsoon season during 1995. But when the rainfall continued, the insect abundance diminished drastically during the middle of the same season ie. July, and then escalated again to reach the peak abundance in the latter part of the season ie. in August, where there were fewer number of rainy days. During the second year (1995-96), the monsoon was late but heavier and the number of rainy days was fewer than in the same period of the previous year. This type of rainfall pattern, however, produced comparatively less amount of change in the insect abundance between May and June during the year (80% more in June than in May) than in the previous year(108 % more in June than in May). The insect abundance increased gradually during the first two months of the season before reaching a peak in the third month.

Comparison of the seasonal abundance of insects between 1994-95 and 1995-96 showed that the insect abundance was less in the seasons with fewer number of rainy days. During north-east monsoon which immediately follows the south-west monsoon, the insect abundance was high during 1995-96 when the number of rainy days was fewer and the rainfall was higher compared to 1994-95, where the number of rainy days were more and the rainfall was lesser. Winter had the least rains, with five rainy days during the winter of 1994- 95 and four during the winter of 1995-96. Although statistically insignificant, the overall insect abundance was slightly higher during 1994- 95 compared to that of 1995-96 in all the sampling methods except the knock down method in which the insect abundance was significantly higher during 1995-96 ($F = 9.65$, $P = 0.005$). This was due to the significantly higher abundance of Lepidoptera ($F = 4.26$, $P = 0.05$) and Orthoptera ($F = 9.64$, $P = 0.005$) during 1995-96. The higher abundance of these essentially folivorous insect groups - Lepidoptera (caterpillars) and Orthoptera- indicates the higher foliage abundance in the forest due to the unusual mid summer rains in 1995-96. However, as it has been established in the insect herbivores of the tropical savannas (Price *et al.* 1995) and leaf miners of Mexico (Nestel *et. al* 1994), here too the overall insect abundance of the area did not show a direct significant relation with the plant phenology.

A relatively higher abundance of insects was recorded during the summer of 1995-96, although the number of rainy days were fewer than that in the summer of 1994-95. This may be due to the difference in the timing of the rain; the rains were in April during 1994-95 and in May during 1995-96. The effect of the mid summer rains during the latter year on the insect abundance was reflected in the summer catches itself. The effect of the late summer rain (pre-monsoon showers) during May, just preceding the south-west monsoon of 1994-95 has also appears to have helped in enhancing the insect abundance, which resulted in the high peak observed in June 1994-95.

4.6 CONCLUSIONS

1. Insect abundance significantly differed among the seasons. The highest abundance was in south-west monsoon and the lowest in north-east monsoon.

2. Although the insect abundance differed among the habitats, it fluctuated seasonally in a similar fashion in all the three habitats, namely moist deciduous, teak plantation, and riverine. As a generalisation, it could be stated that, the abundance levels of insects are determined by the habitat conditions, while, it is the climatic conditions that determine the seasonal fluctuations in the abundance.

3. Fewer number of rainy days found to favour the insect abundance during the south-west and north-east monsoons,

4. Moist deciduous habitat recorded the highest insect abundance among the three habitats, which was followed by the riverine habitat. The teak plantation had the least representing less than one fourth of the total insect abundance of the three habitats.

5. The seasonal abundance pattern of insects was similar in all the habitats with the highest similarity between that the moist deciduous and riverine habitats

6. Riverine habitat had the highest abundance of Coleoptera and Lepidoptera, while Hemiptera, Diptera, Orthoptera and Hymenoptera were abundant in the moist deciduous habitat compared to other habitats.

7. Mostly, monsoon had the highest insect abundance in all the habitats studied. This seasonal preference was evident in the seasonality pattern of most other major insect orders too.

8. Among the insect orders, Diptera was the most abundant and strongly seasonal insect order which showed regular annual cycles of abundance fluctuations with consistently high abundance levels during August in both the years in all the habitats.

9. The bird abundance did have a negative impact on the insect abundance, but was not statistically significant.

CHAPTER V

SEASONALITY OF INSECT GROUPS

5.1 INTRODUCTION

Insect orders vary in their micro-habitat requirements and tolerance to various biotic and abiotic environmental factors. As a result, the seasonality pattern has also been found highly variable in different insect groups (Janzen 1973 &1976, Frith and Frith 1985, Argyropoulou *et al.* 1994, Giller and Doube 1994, Furuta *et al.* 1996). In the present study, monthly data on the abundance of six selected insect groups (Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera and Orthoptera), collected from the three different habitats (moist deciduous, riverine and teak plantation) were used for analysing the seasonality patterns. The results obtained showed distinct temporal patterns in the abundance of most insect orders studied.

5.2 METHODS

Three different sampling methods, namely light trapping, knock down sampling and sweep sampling were used for estimating the abundance of different insect orders in the moist deciduous habitat, while sweep sampling method alone was used in the riverine and teak plantation. Since the sweep sampling was the only method used in all the three habitats (moist deciduous, riverine and teak plantation), the inter-habitat comparison of insect abundance among these three habitats is made on the basis of sweep sampling data. Detailed methodology and a comparison of the efficiency of different methods used for the sampling is given in Chapter III.

5.3 DATA ANALYSIS

For each insect order, the total monthly data per three sampling efforts obtained from the three sampling methods, namely light trap, knock down and sweeping were used for in the analyses as an index of their abundance. Comparison of insect abundance in various habitats was made using the data from 300 sweeps in each habitat. Significance of the difference in insect abundance between seasons and habitats was determined using the significance of the F-ratio obtained by the analysis of variance. Kendall's coefficient of concordance was used to test the significance of the hierarchical patterns of abundance between the seasons and habitats. Cross correlations, Pearson correlation coefficients and Multiple (step wise) linear regression procedures were used to explain the interrelations between the insect abundance patterns in different habitats and seasons and different ecological factors. Monthly data on the following ten ecological factors were considered for the analysis: monthly rainfall, number of rainy days, relative humidity, maximum temperature, minimum temperature, and abundances of mature leaves, young leaves, flowers, flower buds, and birds. Among these, data for the bird abundance, rainfall and rainy days were available for the entire study period, while that on temperature and humidity for 18 months and the data on the phenology of plants were available for the last 11 months of the study. In the analytical procedures of statistics such as correlations and regressions, the data were excluded pair-wise in the case of missing values in any variable.

5.4 RESULTS AND DISCUSSION

5.4.1 Order: Coleoptera

Members of this insect order are hard bodied insects, with the fore wings modified into elytra which is not used for the flight but serves to protect the membraneous hind wings. Mouth parts are of biting and chewing type; development is holometabolous. Different kinds of larvae are present, which are generally regarded as grubs and the larval stages are generally completed in the decayed biological materials. The order Coleoptera comprises the largest number of species than any other order and an estimated 20% of the total insect population of the world (Samways 1993) comes under this single order. Erwin's entomological explorations into the tropical rain forest canopy (Erwin and Scott 1980, Erwin 1983) have illustrated the extreme richness, diversity and habitat specificity of this insect group. Of the 1069 species of coleopterans recorded by him, from the canopy layers of the four types of forests, namely Black-water

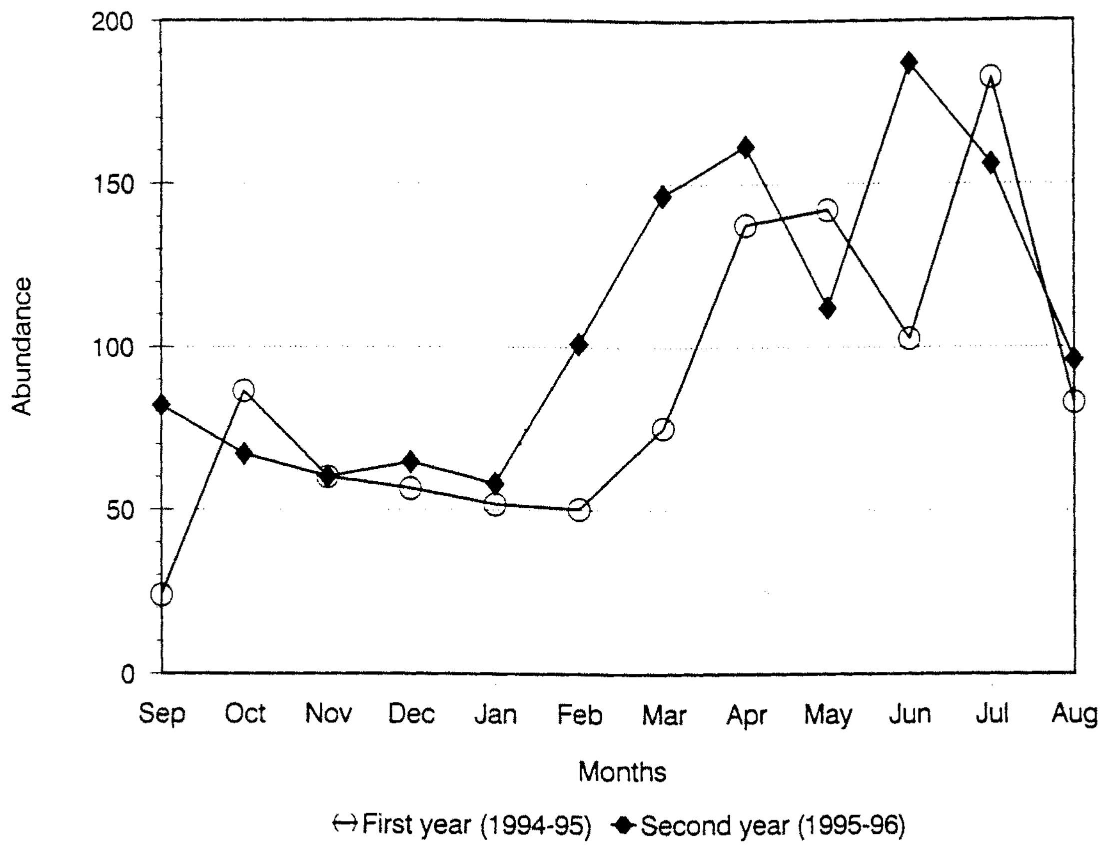

Figure 5.1 Comparison of the monthly fluctuations in the overall Coleopteran abundance between the years (Pooled data from three methods)

forest, White-water forest. Mixed water forest and Terra firme forest of Manaus in Brazil, only one percent was shared by all the four forest types.

There are studies reported from India and abroad on various economically important coleopteran species, such as Parthenium beetles (Jayanth and Bali 1993b), dung beetles (Giller and Doube 1994) and wire worms (Seal *et al.* 1992). Coleopterans are especially important in the agricultural (Nestel *et al.* 1994) and silvicultural systems (Powell 1982 & Lozano *et al.* 1993). Many native as well as exotic species of Coleoptera have wreck havoc in many parts of the world. The Sal Borer (*Hoplocerambyx spinicornis*) from India (Verma 1998) and the Asian Long-horned Beetle from New York (Haack *et al.* 1997) are well known examples from the recent past. Coleopterans are also known for their usefulness as ecological indicators (Pearson and Cassola 1991, Rodriguez *et al.* 1998) and biocontrol agents (Jayanth and Bali 1993) as well. The importance of seasonality in the temporal resource partitioning among various spatially co-existing dung beetle species has been highlighted by Giller and Doube (1994). However, studies on the forest coleopteran seasonality are only a few (Janzen 1976). Moreover, most of the studies are focused on the seasonality of certain families, such as Carabidae (Paarmann and Stork 1987, Vennila 1991).

In the present study, the Coleoptera was third in abundance (15% of the total insect abundance), the first and second being Hymenoptera and Lepidoptera respectively (Figure 4.1). It was the fifth largest insect order of the

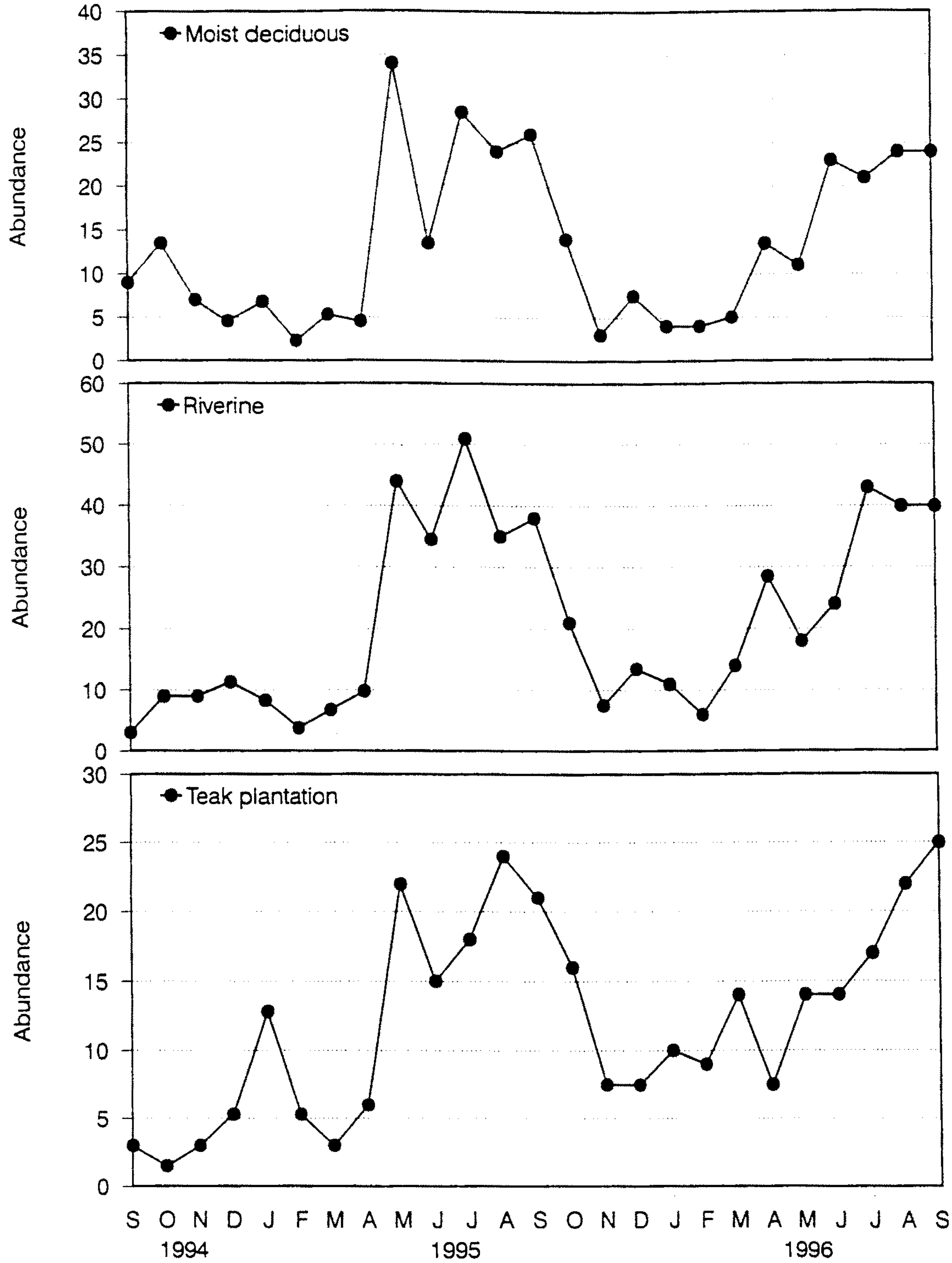

Figure 5.2 Monthly fluctuations in the abundance of Coleoptera in different habitats

shrub and herb layers according to the sweep sampling data in which the Coleoptera represented 11% of the total insects sampled. Coleopterans showed significant seasonal ($F = 25.96$, $P < 0.001$) and inter-habitat ($F = 11.12$, $P < 0.001$) variations (Figures 5.3 and 5.4). The inter-annual comparison of coleopteran abundance showed a higher abundance during 1995- 96. However, the pattern of monthly fluctuations during this year was more or less similar to that of 1994- 95, with the peaks and troughs in the abundance pattern showing a clear lag of one month (Figure 5.1). The cross correlation between the monthly data on the insect abundance of 1994- 95 with that of the 1995- 96 at one month's lag showed that this shift in the abundance pattern during the second year was statistically significant ($r = 0.8927$, $P < 0.01$). However, the peak abundance was in south-west monsoon followed by summer in both the years of study.

5.4.1.1 Seasonality in different habitats

Of the three habitats studied, the riverine habitat had the maximum coleopteran abundance during most of the months. Their abundance in the three habitats was in the order riverine > moist deciduous > teak plantation (Kendall's coefficient of concordance (W) = 0.42, $P < 0.001$). The pattern of temporal fluctuation shown by the coleopterans was similar among the habitats (Figure 5.2). However, the riverine and moist deciduous habitats showed the highest correlation between them ($r = 0.90$; $P < 0.01$). Generally, the coleopteran abundance was high in south-west monsoon and low during winter (Figure 5.3 and Table 5.1).

Habitat	Seasons								Total	Percentage of Grand total
	N-E Monsoon		Winter		Summer		S-W Monsoon			
Moist deciduous	36	(23.5%)	15	(9.4%)	37	(23.7%)	67	(43.4%)	154	28.7%
Riverine	44	(17.9%)	27	(11%)	61	(24.7%)	114	(46.4%)	245	45.5%
Teak plantation	26	(18.7%)	25	(17.9%)	33	(23.9%)	55	(39.5%)	139	25.8%
Total	106.1		66.3		130		236		539	
% of Grand total	19.7%		12.3%		24.2%		43.8%			100%

Note:- Figures in parenthesis are percentage from the total of each habitat.

Table 5.1 Relative seasonal abundance of Coleoptera (mean of two years) in three different habitats (Sweep sampling)

5.4.1.1.1 Moist deciduous forest

The overall abundance of Coleoptera in the moist deciduous habitat was second to riverine habitat. However, the month-wise data showed that the abundance of coleoptera was the lowest in this habitat in many of the months, compared to other habitats. Abundance of Coleoptera showed its peak in south-west monsoon followed by summer, north-east monsoon and winter respectively. Nevertheless, the highest abundance recorded was in the summer of 1995, in May.

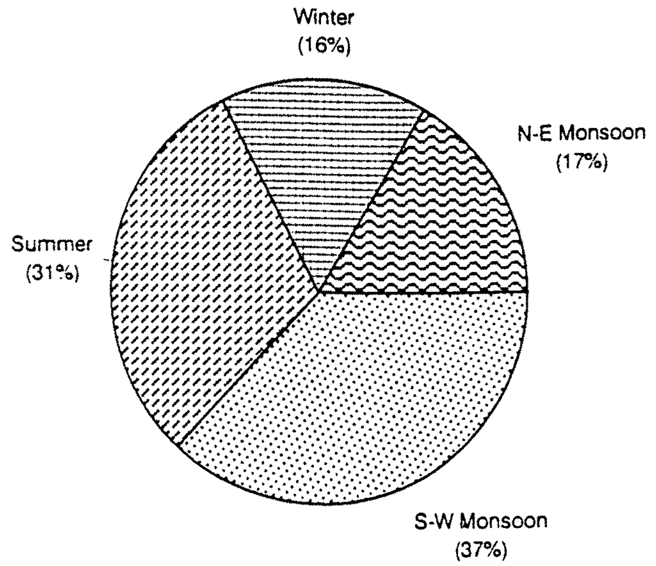

Figure 5.3 Seasonal abundance of Coleoptera

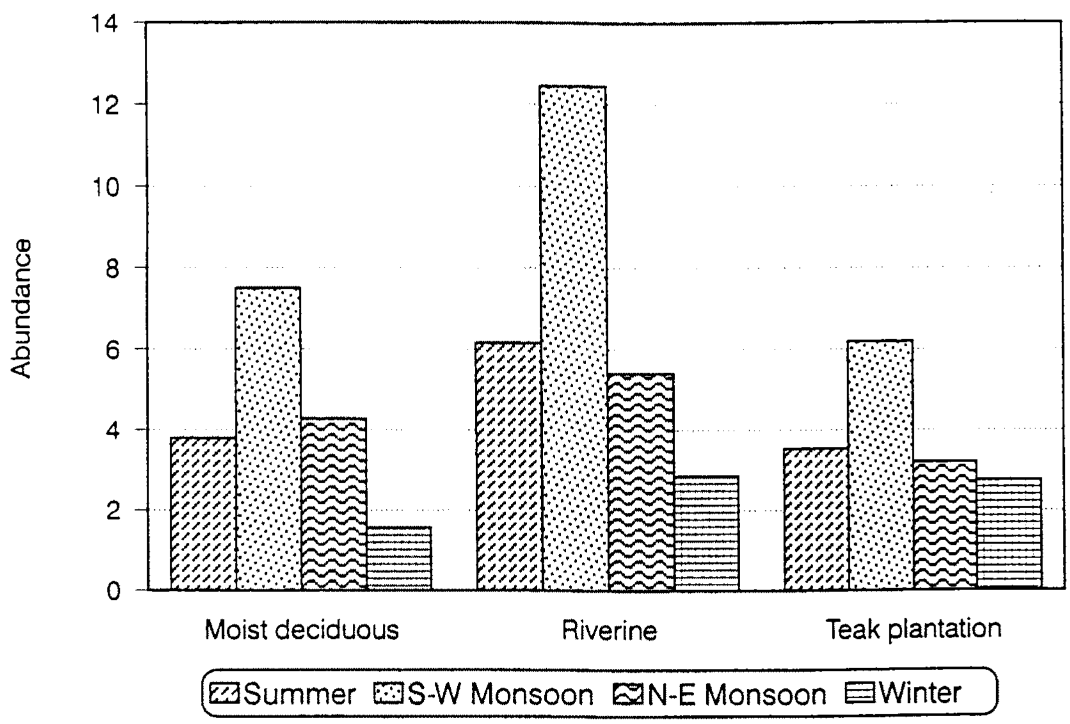

Figure 5.4 Seasonal abundance of Coleoptera in different habitats

5.4.1.1.2 Riverine habitat

Riverine habitat was the most preferred habitat of Coleoptera in the study area (Figure 5.2). During most of the study period, the abundance of Coleoptera was highest in this habitat compared to other habitats. Especially during the south-west monsoon and summer the abundance was higher in this habitat than in other habitats. In winter the abundance was the least in this habitat (Figure 5.4). The peak abundance of Coleoptera in this habitat was observed in south-west monsoon season. Next to it in abundance was the summer season, followed by north-east monsoon and winter respectively (Table 5.1).

5.4.1.1.3 Teak plantation

The overall abundance of Coleoptera in teak plantation was the least among the habitats. However, during winter the abundance of coleopterans in teak plantation was almost similar to that in riverine habitat, but much more than that of moist deciduous habitat (Table 5.1). Here too, the south-west monsoon season was the most preferred season followed by summer.

5.4.1.2 Role of Ecological factors

The monthly variations of coleopteran abundance had a significant positive correlation with the monthly rainfall ($r = 0.589$, $P = 0.002$) and number of rainy days (r = 0.517; P = 0.01). However, there was a significant negative correlation with flower (r = -0.8025; P = 0.003) and bird abundance (r = -0.601; P = 0.01). No significant correlation was found with the humidity, temperature and abundance of young leaves. Unlike in the moist deciduous and riverine habitats, the coleopteran abundance of the teak plantation showed no significant correlation with the rainfall and rainy days, but it had a significant direct correlation with the humidity and minimum temperature. The result of the multiple linear regression of coleopteran abundance with the various environmental factors suggests that, the amount of rainfall and abundance of flowers in the area were the two most important factors to which the coleopteran abundance was significantly related. The regression model obtained was of the following form,

$$\mathbf{A_C = (162.41 \pm 14.3) + RF \times (0.12 \pm 0.04) + A_F(-5.48 \pm 1.22)}$$

Where,

$\mathbf{A_C}$ = Abundance of Coleoptera

RF = Monthly rainfall in mm and

$\mathbf{A_F}$ = Abundance of flowers (mean abundance of flowers of eight species of plants in percentage)

5.4.1.3 Discussion

Spatial changes in the species composition has been well established in Carabid beetles which are known indicators of environmental quality and hence have conservation potential (Vennila 1991, Butterfield *et al.* 1995, Butterfield 1996). Seasonality studies on the coleopterans elsewhere have shown that number and composition of species vary between sites (James et al. 1995). The results of present study illustrates the significant temporal and spatial variations in the coleopteran abundance.

There is a striking difference between the fluctuation patterns in the abundance of diurnal (sampled by knock down and sweeping methods) and nocturnal (sampled by light trapping) coleopterans. The high abundance of nocturnal coleopterans observed in the summer samples could be either because of an actual increase in the population of nocturnal coleopteran species, or a temporary change in the activity pattern from day hours to night hours in the otherwise diurnal coleopteran species, in order to avoid the higher diurnal temperatures and probably, the predation pressure from the birds. Since summer was the major breeding season of birds in the area, there was a likelihood of higher bird predation during the day light hours. Another possible reason for the higher abundance of coleopterans in the light trap in summer is the relatively larger area of visibility of light during this season because of the sparse foliage density within the forest which helped to attract insects from more distances compared to other seasons.

The high coleopteran abundance during summer in riverine habitat may be due to the lesser diurnal temperature, and more green vegetation in this habitat than in the other two habitats. Availability of water in the perennial stream passing through this habitat also could be a possible factor that attracted insects towards this habitat during summer.

Among the ecological factors monitored, the rainfall and the flower abundance were the major factors affecting the coleopteran abundance in the study area. The major ecological factors found to be affecting the coleopteran abundance were the flower abundance and monthly rainfall. Temperature in the range of 25- 32°C with a monthly rainfall over 450 mm received in 13 to 25 days appeared to be optimal for the coleopteran abundance.

5.4.2 Order: Diptera

The members of order Diptera are generally known as "flies". They include large to medium sized insects with only a single pair of wings, unlike most other groups of insects which have four pairs. The hind-wings are modified into minute club shaped structures called halters. The mouth parts are mainly of sponging or suctorial type. Mesothorax is comparatively larger than other thoracic segments. Development is holometabolous with complete metamorphosis. Larvae are legless. Dipterans are generally regarded as the most highly evolved insect group. Diverse forms such as scavengers, plant feeders, parasites, and predators are present within this group. Some of the dipterans are notorious vectors of human diseases in the tropical countries. Malaria, sleeping sickness, and filariasis are transmitted by dipteran vectors and hence, their seasonal abundance patterns have direct implications on the health of human and livestock. However, only a few studies are reported on the seasonality of even economically important dipterans from India (Narladkar *et al.* 1993). Comparatively more records are available from abroad (Chadee *et al.* 1992, Chadee and Tikasingh 1992, Chadee 1994, Kasana and Ali-Niazee 1996).

The order Diptera occupies the fourth position in the total insect population of the area (Figure 4.1). The pattern of monthly fluctuations in the dipteran abundance was almost the same during both the years of study, with the highest abundance during August in both the years (Figure 5.5). In sweep samples Diptera had the highest proportion (25% of the total insect abundance). They showed a strong seasonal preference towards the south-west monsoon, followed by the north-east monsoon in all the habitats (Figures 5.7 & 5.8).

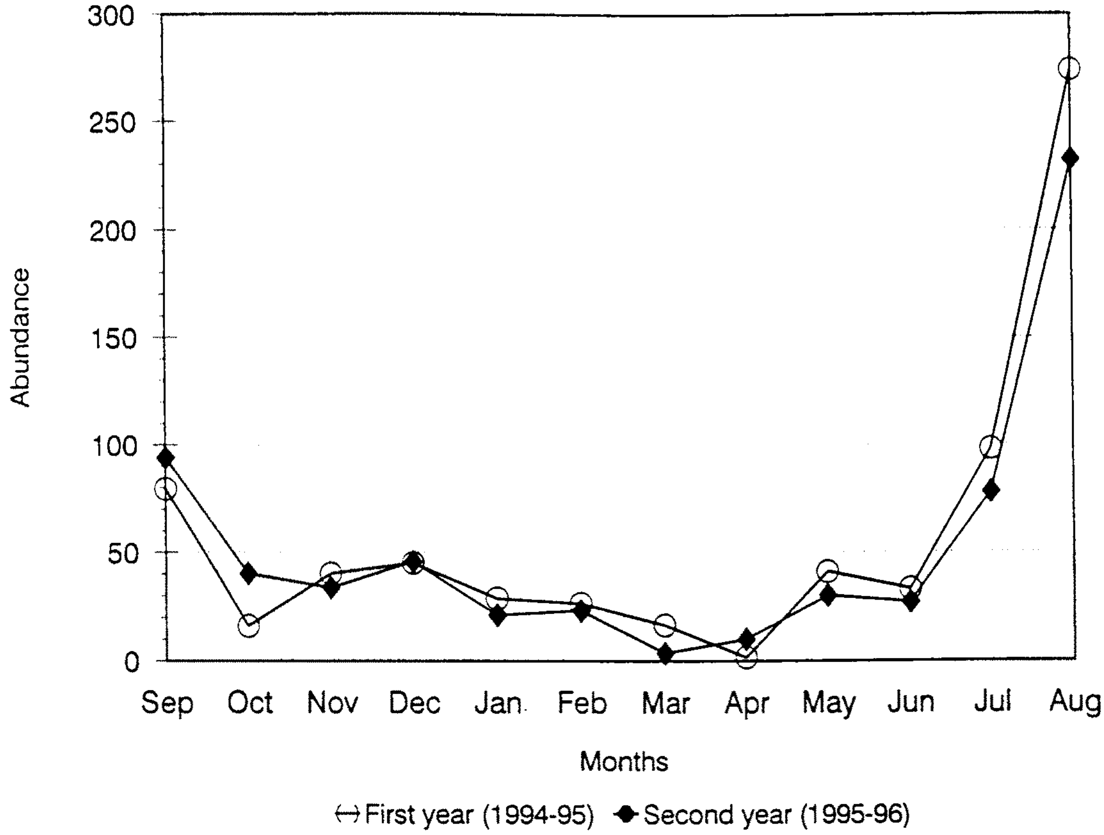

Figure 5.5 Comparison of the monthly fluctuations in the abundance of overall Dipteran abundance between the years (Pooled data from two methods)

5.4.2.1 Seasonality in different habitats

Seasonal variations in the dipteran abundance were predominant, but similar in all the three habitats (Figure 5.6). Of the total dipterans sampled during the study by sweep sampling, 50.5% was from south-west monsoon alone, while both the monsoons together contributed about 77% of the total dipterans (Table 5.2). Invariably the wet seasons in general and south-west monsoon in particular was preferred by Dipterans in all the habitats (Figure 5.8).

5.4.2.1.1 Moist deciduous forest

Dipteran abundance was the highest in moist deciduous habitat, as 44.8% of the total dipterans were collected from this habitat alone. The most preferred season was south-west monsoon which registered 50.5% of the total dipterans recorded, followed by north-east monsoon (26%), winter (14.7%) and summer (8.6%). The seasonal preference was in the same order during both the years.

5.4.2.1.2 Riverine habitat

Riverine habitat follows moist deciduous in the order of preference by dipterans. 35% of dipterans were recorded from this habitat. Like in the moist deciduous habitat, here too a strong preference was noticed towards the monsoon (Figure 5.8). Of the total dipterans sampled, 42% was collected during

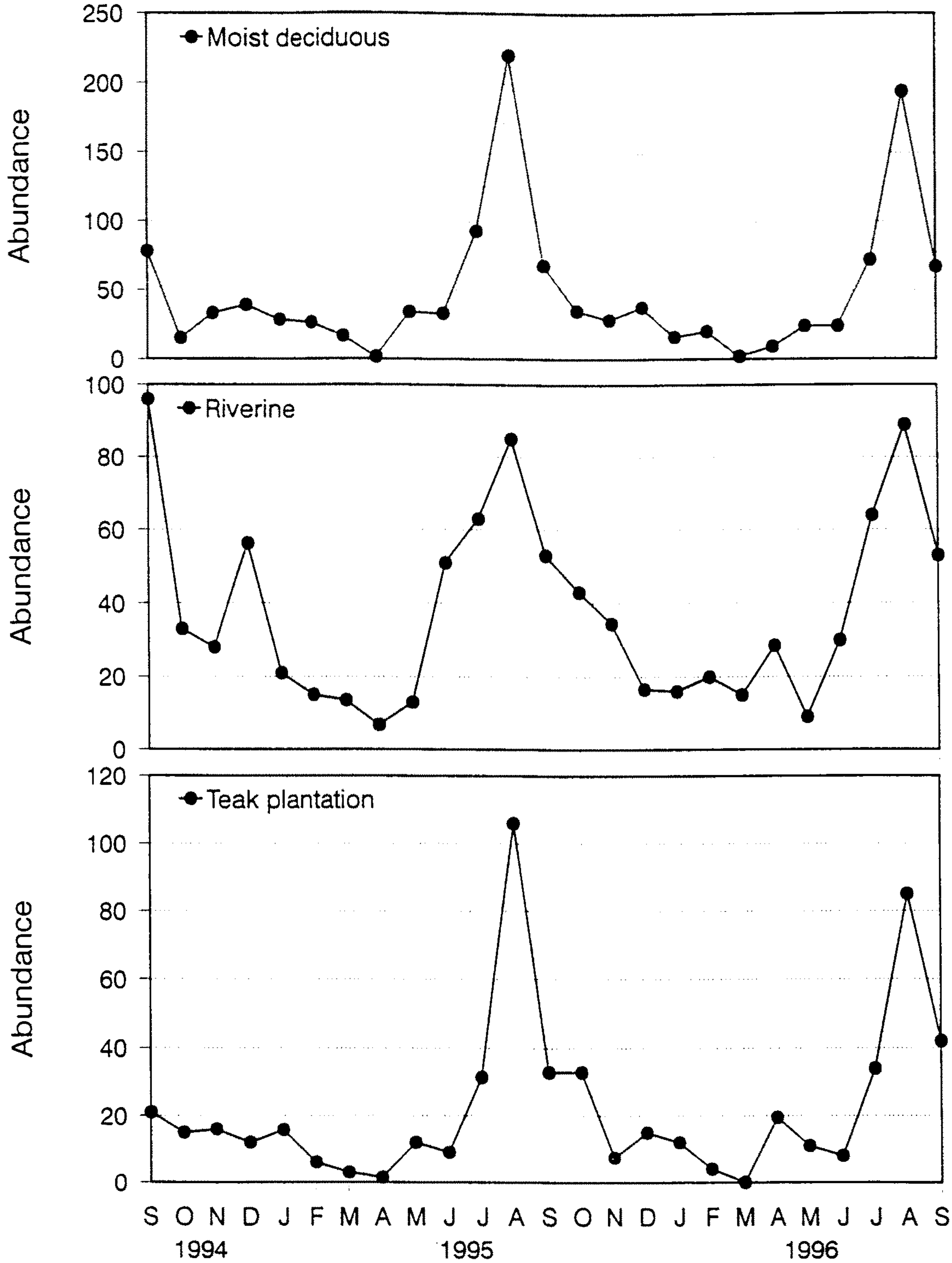

Figure 5.6 Monthly fluctuations in the abundance of Diptera in different habitats

the south-west monsoon season. The subsequent order of preference of seasons was north-east monsoon, winter and summer respectively, which was the same for both years.

5.4.2.1.3 Teak plantation

The least abundance of dipterans was recorded from this habitat. The order of preference of the seasons within this habitat too was the same (south-west monsoon > north-east monsoon > winter >summer) as in the moist deciduous and riverine habitats (Figure 5.8) during both the years.

Habitat	Seasons				Total	% of Grand total
	N-E Monsoon	Winter	Summer	S-W Monsoon		
Moist deciduous	129 (22.4%)	84 (14.6%)	44 (7.6%)	318 (55.4%)	574	44.8%
Riverine	144 (31.9%)	72 (16.1%)	43 (9.5%)	191 (42.4%)	450	35.2%
Teak plantation	63 (24.6%)	32 (12.7%)	24 (9.2%)	137 (53.5%)	256	20.0%
Total	335	188	110	646	1280	
% of grand total	26.2%	14.7%	8.6%	50.5%		100%

Note:- Figures in parenthesis are percentage from the total of each habitat.

Table 5.2 Relative seasonal abundance of Diptera (mean of two years) in three different habitats (Sweep sampling)

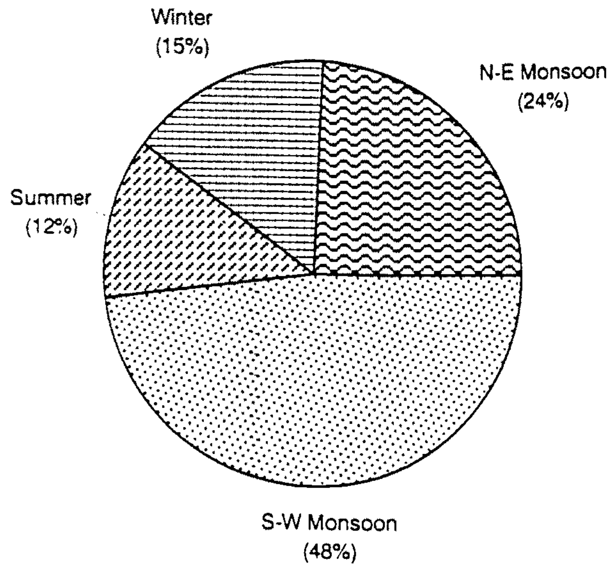

Figure 5.7 Seasonal abundance of Diptera

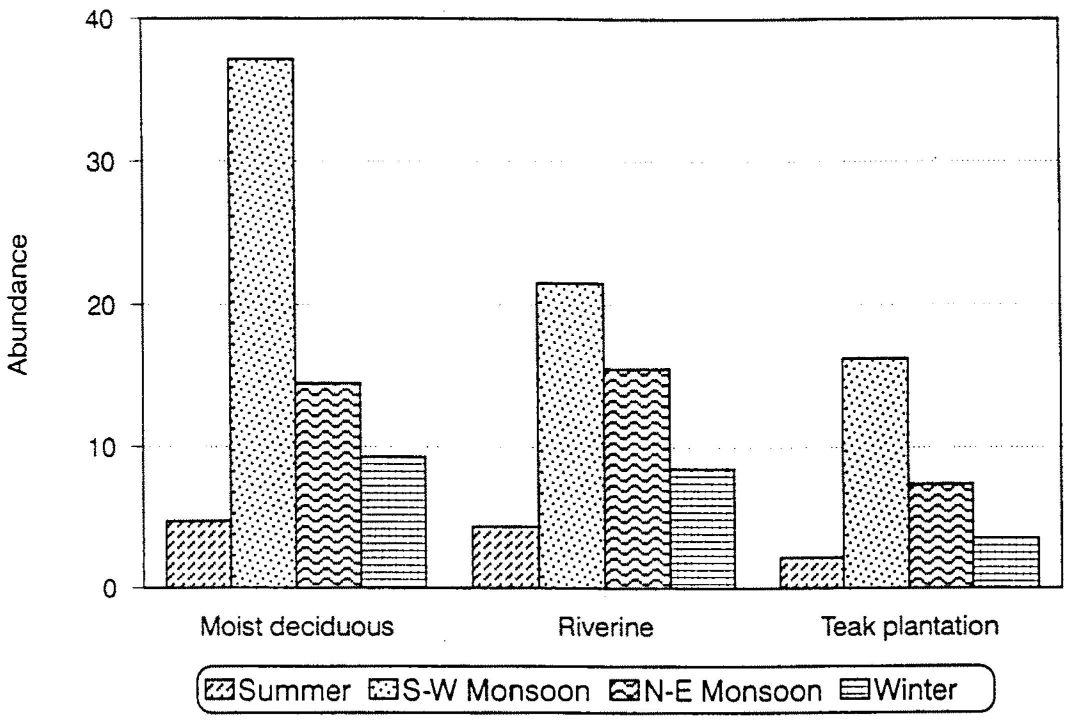

Figure 5.8 Seasonal abundance of Diptera in different habitats

5.4.2.2 Role of ecological factors

The pattern of fluctuation in the monthly abundance of Diptera showed significant positive correlation with the number of rainy days ($r = 0.44$; $P = 0.031$) and the relative humidity ($r = 0.54$; $P = 0.02$). Significant negative correlations were observed with the maximum diurnal temperature ($r = -0.597$; $P = 0.009$) and average diurnal temperature ($r = -0.61$; $P = 0.008$). The stepwise multiple linear regression for estimating the most significant ecological factors with which the monthly dipteran abundance showed a significant regression, yielded the following regression model equation.

$$\mathbf{A_D = (928.90 \pm 310.135) + T_M\,(-23.96 \pm 9.296)}$$

Where,

A_D = Dipteran abundance during the month

T_M = Maximum diurnal temperature during the month

The resulted equation showed that the mean maximum temperature was the most important factor that decide the seasonality of dipteran abundance in the area. The Dipteran abundance was negatively related to the maximum temperature with lower temperatures favouring the abundance of Diptera.

5.4.2.3 Discussion

Diptera being delicate insects, with the larval stages mostly in the decaying vegetable matter, prefer relatively lesser temperature and higher moisture. However, the seasonality pattern observed during the present study suggested that, the abundance pattern of Diptera was less dependent on the rainfall pattern than it was on the temperature. This was evident from the absence of the backward shift in the dipteran abundance pattern during the second year, which was observed in the case of Coleoptera, where the backward shift in the abundance pattern reflected the early pre-monsoon rains during the second year. In the case of Diptera, although there was a good amount of early rain fall in April itself in 1995- 96 unlike the 1994- 95, the abundance peak of dipteran (in August) was the same as in the previous year (Figure 5.5).

Of the total dipterans sampled from all the habitats by sweeping method 45% was from moist deciduous habitat, followed by riverine and teak plantation which contributed 35% and 20% respectively (Table 5.2). Diptera contributed the largest proportion of the insect community in all the habitats. However, it highly varied among different habitats and seasons. Diptera contributed 31% of the total insects sampled in the moist deciduous habitat, 25% in the riverine habitat and 23% in the teak plantation. Among the four seasons, the south-west monsoon season contributed the maximum proportion (50.5%) of the Dipterans followed by the north-east monsoon (26.2%) winter (14.7%) and summer (8.6%) respectively (Table 5.2). The same order of seasonal preference was observed in all three habitats.

Interestingly, the dipteran pest Walnut husk flies of the Willamette valley of Oregaon, USA (Kasana and AliNiazee 1996) has shown the similar pattern of seasonal abundance as obtained at Siruvani. The seasonality studies on the dipteran vectors such as mosquitoes also had illustrated a strong seasonality with maximum abundance during the wet seasons (Chadee 1994 & Chadee *et al.* 1992). The optimal environmental conditions for the dipteran abundance were: temperature in the range of 24 to 31°C, humidity in the range of 76- 81%, and a monthly rainfall of 92 to 223mm received in 15 days.

5.4.3 Order: Hemiptera

Order Hemiptera includes small to large sized insects commonly called bugs. The forewings are heavier in texture than the hind ones. There are two major sub-orders under Hemiptera namely Heteroptera and Homoptera. The forewings have got a uniform texture in the suborder Homoptera, while in Heteroptera the tips are more membranous compared to the base. Mouth parts are of piercing and sucking type. Development is hemimetabolous with partial metamorphosis. Hemiptera includes some of the most important groups of plant pests such as leaf hoppers, aphids and scale insects. Besides the impact

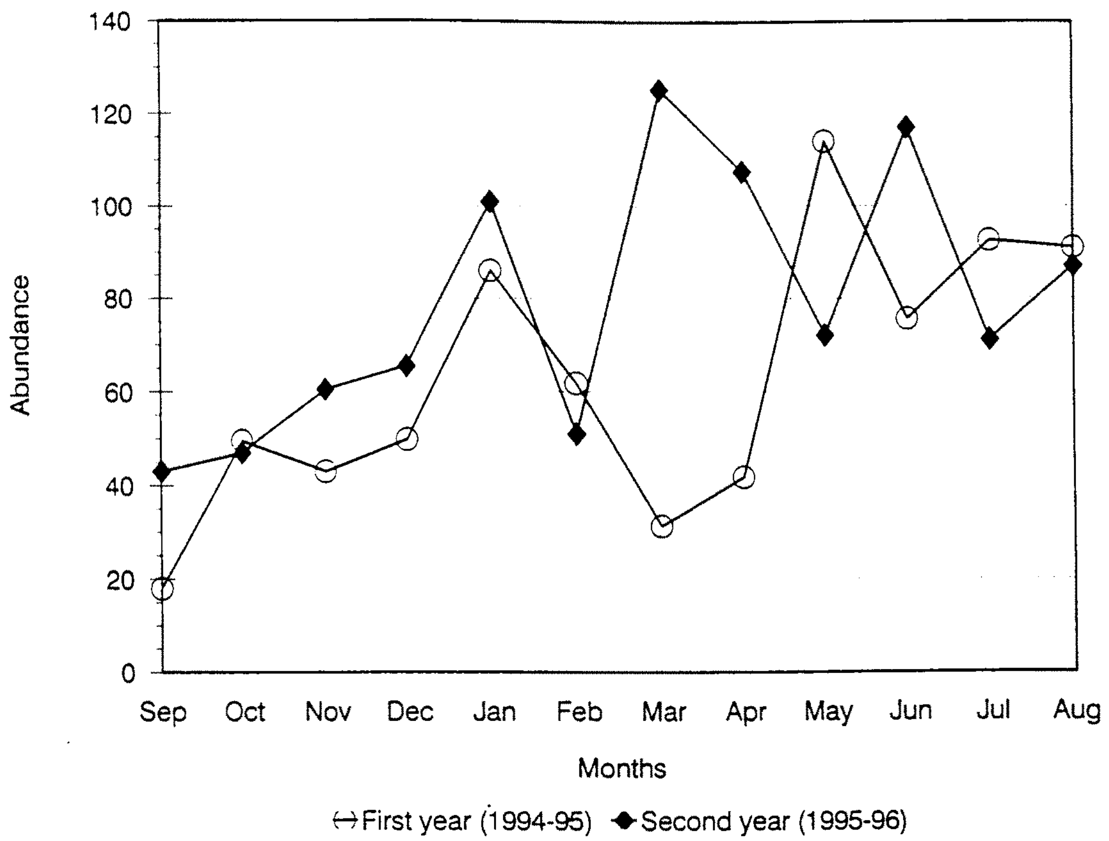

Figure 5.9 Comparison of the monthly fluctuations in the overall Hemiptera abundance between the years (Pooled data from three methods)

caused on the plants by the feeding activity of these insects, they also negatively affect plants in many other ways. Toxic effects of their saliva cause distortion and stunted growth. Almost all the plant feeding bugs secrete honey dew which facilitates fungal attacks. In addition, many species are vectors of viral diseases of plants. Some of the species are predators and are often used in biological control programmes. In spite of all these importance, seasonality studies on Hemiptera in the wild are rare. One such study is by Novotny and Basset (1998) on the Ficus feeding hemipterans of the rainforests of New Guinea. Steinbauer (1997) has described the seasonal development of two univoltine species of Hemiptera, *Amorbus obscuricornis* and *Gelonus tasmanicus* on the *Eucalyptus sp.* in Tasmania. The aphids (Family: Aphididae), being a major group of economically important pests have received relatively more attention in India (Agarwala and Ghosh 1984).

Hemiptera was the least abundant insect order in the study area representing only 11% of total insect abundance (Figure 4.1). In all the habitats, except moist deciduous, Hemiptera was the least abundant. South-west monsoon was the most preferred season of hemipterans followed by winter, summer and north-east monsoon (Table 5.3, Figures 5.11 and 5.12). Although the riverine and moist deciduous habitats had higher abundance of Hemiptera compared to teak plantation, the relative proportion of Hemiptera was highest in the insect samples of teak plantation with 13% of the insects sampled from this habitat belonging to this order. The observed proportion of hemiptera in the moist deciduous habitat was 11%, while that in the riverine was 9%. Although there was a significant difference in abundance between the habitats, the abundance variation observed among habitats was the least in Hemiptera compared to other insect orders.

The pattern of fluctuation in the abundance of Hemiptera was similar from September to February in both the years with a peak in January, but was dissimilar from March to August. During this period (March- August) there was only a single peak in 1994-95 which was in May where as, there were two peaks in 1995- 96, (in March and June). The complete pattern is different from March to August, as the peak of one year correspond to a fall in the other year and vice-versa (Figure 5.9).

5.4.3.1 Seasonality in different habitats

Seasonal variation in the abundance of Hemiptera was significant ($F = 5.24$; $P = 0.002$) and the pattern varied among habitats (Table 5.3). Unlike most other insect orders, hemipteran abundance did not have a well defined seasonal pattern. Generally the moist deciduous was the most preferred habitat by Hemiptera while, the the south-west monsoon was the most favourable season (Table 5.3).

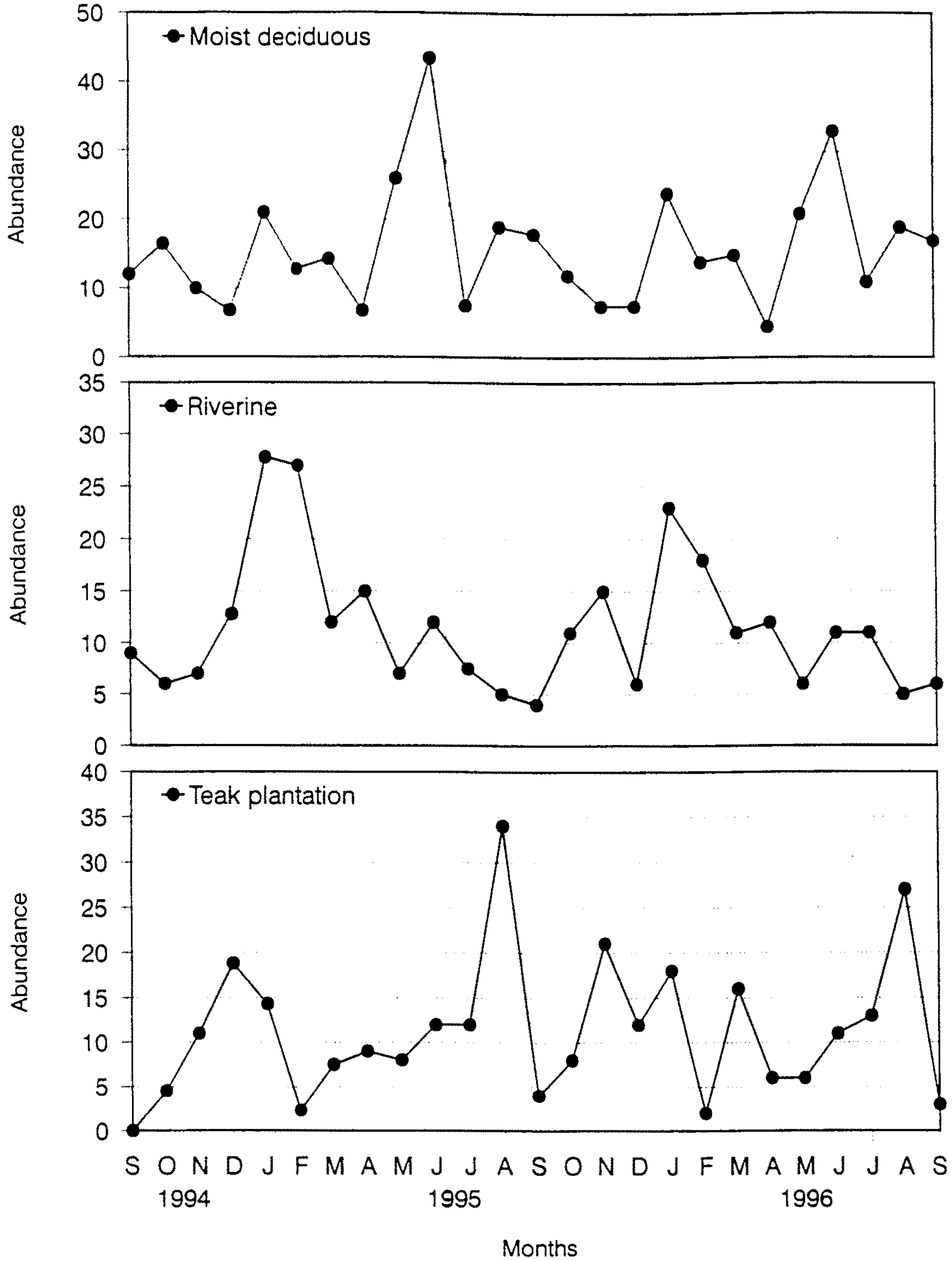

Figure 5.10 Monthly fluctuations in the abundance of Hemiptera in different habitats

5.4.3.1.1 Moist deciduous forest

The maximum abundance of hemipterans (40.6%) was in moist deciduous forest (Table 5.3). This habitat had the second largest proportion of hemipterans (10.6%) in the total insect community, after the teak plantation. South-west monsoon was the most preferred season for hemipterans in this habitat followed by summer, winter and north-east monsoon (Table 5.3). Inter annual difference in the seasonal preference was prominent. During 1995- 96, the pattern was slightly different from the general pattern, with the second and third preferences being winter and summer, while first and last preferences ie. south-west monsoon and north-east monsoon remained unchanged. Hemipteran abundance pattern in this habitat showed no direct correlation with that of other habitats.

Habitat	Seasons				Total	Percentage of Grand total
	N-E Monsoon	Winter	Summer	S-W Monsoon		
Moist deciduous	38 (19.9%)	43 (22.5%)	44 (22.9%)	67 (34.8%)	191	40.6%
Riverine	26 (18.5%)	57 (40.8%)	32 (22.4%)	26 (18.3%)	141	29.9%
Teak plantation	24 (17.5%)	34 (24.2%)	26 (19%)	55 (39.3%)	139	29.5%
Total	88	134	102	147	471	
% of Grand total	18.8%	28.5%	21.6%	31.2%		100%
Note:- Figures in parenthesis are percentage from the total of each habitat.						

Table 5.3 Relative seasonal abundance of Hemiptera (mean of two years) in three different habitats (Sweep sampling)

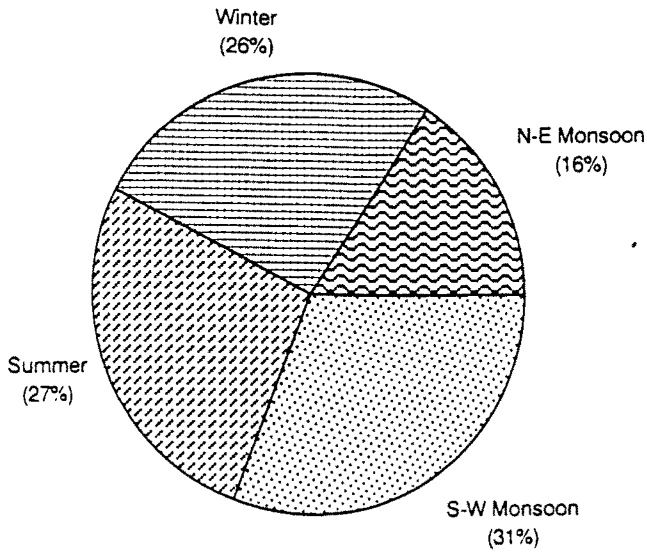

Figure 5.11 Seasonal abundance of Hemiptera

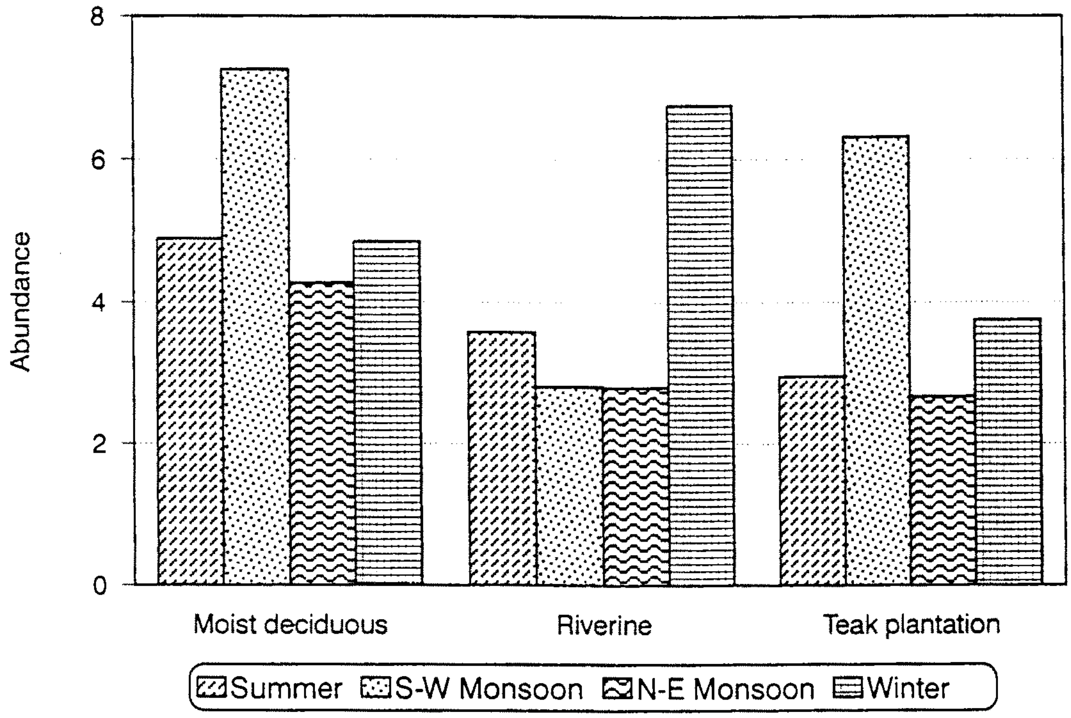

Figure 5.12 Seasonal abundance of Hemiptera in different habitats

5.4.3.1.2 Riverine habitat

The riverine habitat was preferred to by the hemipterans, following the moist deciduous. The seasonal variation in the abundance of hemipterans was significant only in this habitat ($F=5.439$, $P=0.007$). Winter was preferred to the most in this habitat which contributed 40.8% of the total hemipterans recorded from this habitat. Summer was next to it, with 22.4% of hemipterans. The preference to north-east monsoon and south-west monsoon were almost the same (Table 5.3). There was a slight difference in the order of preference between 1994- 95 and 1995- 96. During the former year, the abundance of Hemiptera was in the order winter > summer > south-west monsoon > north-east monsoon, while during the latter, the order of preference was winter > north-east monsoon > summer > south-west monsoon. Pearson correlation analysis showed a significant negative correlation between the hemipteran abundance in this habitat and the rainfall ($r= -0.406$, $P= 0.05$) as well as the number of rainy days ($r= -0.507$, $P=0.01$).

5.4.3.1.3 Teak plantation

Teak plantation and the riverine habitats had almost the same proportion, with 29.5% and 29.9% of the hemipteran abundance being recorded from these habitats respectively (Table 5.3). Although the Hemiptera was less abundant in the teak plantation compared to other habitats, its proportion in the insect community was the highest in this habitat. The most preferred season for hemipterans in teak plantation was the south-west monsoon which had 39% of the total hemipterans recorded from this habitat. This was followed by winter(24%), summer (19%) and north-east monsoon (18%). The seasonal abundance pattern showed a difference between the years. The order of preference was south-west monsoon > winter > summer > and north-east monsoon during 1994- 95, while it was south-west monsoon > north-east monsoon > winter > summer during 1995- 96. However, this difference was not statistically significant (F= 2.317, P= 0.107).

5.4.3.2 Role of ecological factors

Hemiptera did not show much fluctuation between the seasons, and there was no significant correlation with any of the ten ecological factors monitored during the study. No significant linear regression could be observed between the ecological factors and the hemipteran abundance.

5.4.3.3 Discussion

Among the six insect orders, the least variation in abundance between seasons was observed in Hemiptera. Since the hemipterans are mainly plant sap feeders which suck the plant juices from the delicate parts of the plant body, the foliage density of the vegetation is likely to have an effect on the seasonality of these insects. The highest abundance of hemipterans was in the south-west monsoon. In the riverine habitat the winter was preferred to the most . Invariably the north-east monsoon was the least preferred by Hemiptera in all the habitats.

Among the three habitats, abundance of hemipterans in moist deciduous habitat was the maximum. However, the pattern of abundance was neither consistently high in the riverine habitat nor showed a regular hierarchical pattern among the habitats (the Kendall's coefficient of concordance was insignificant at 95% confidence interval). Fluctuation in the seasonal abundance pattern was significantly different between the habitats ($F= 3.4$, $P= 0.035$). Hemipteran abundance of riverine habitat was correlated with the nocturnal abundance of hemipterans ($r = 0.41$, $P < 0.05$) recorded in the light trap, which probably indicate that nocturnal forms of these insects prefer the Riverine habitat during day time. The seasonal abundance fluctuations of hemipterans was significantly correlated with that of other three orders namely, Coleoptera ($r = 0.051$, $P = 0.01$), Lepidoptera ($r = 0.511$, $P = 0.01$) and Orthoptera ($r = 438$, $P = 0.03$). None of the ecological factors monitored during the study showed significant correlation with the Hemipteran abundance. One of the reasons for the same may be the relatively small sample sizes. It may be noted that hemipterans were comparatively fewer than the other orders in the samples.

5.4.4 Order: Hymenoptera

Hymenoptera, comprising ants, bees and wasps are minute to moderate sized insects with two pairs of membraneous wings. Hind wings are generally smaller than the forewings. The forewing and hind wing are fastened together by a series of hooks. The mouth parts are primarily of biting pattern. A marked constriction between the thorax and abdomen is almost always present. Ovipositor is modified for piercing or stinging in most species; development is holometabolous. These insects are known for their social organisation and beneficial activities such as pollination, seed dispersal, honey production and biological control of insect pests. Ant species richness and diversity in some areas of Western Ghats were described by Gadagkar et al (1993).

Hymenoptera was the most abundant insect group in the study area, as it constituted 32% of the total samples of both the years. South-west monsoon was the most preferred followed by winter, north-east monsoon and summer (Table 5.4).

Among the habitats, moist deciduous was the most preferred, followed by riverine and teak plantation, contributing 39%, 31% and 40% percent of the total hymenopteran abundance respectively (Table 5.4).

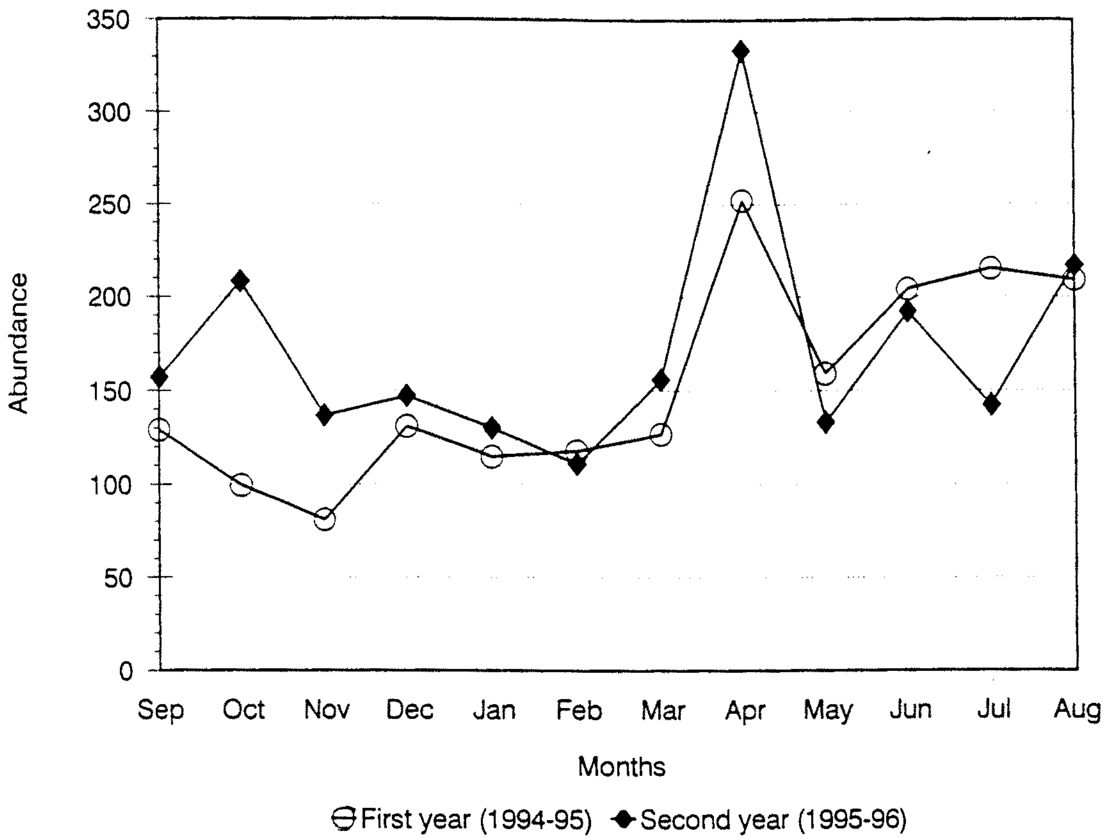

Figure 5.13 Comparison of the monthly fluctuations in the overall Hymenopteran abundance between the years (Pooled data from three methods)

5.4.4.1 Seasonality in different habitats

Seasonal abundance patterns of Hymenoptera were quite different in all the three habitats. Distinct inter-habitat changes were recorded. The maximum abundance of the Hymenoptera was in the moist deciduous habitat followed by riverine and teak plantation (Table 5.4). Percentage contribution of Hymenoptera in the total insect community was maximum in teak plantation (18%) followed by moist deciduous (15%) and riverine (12%). It was the second largest insect order in the moist deciduous and teak plantation habitats, and only fifth in the riverine habitat. There was no significant inter-habitat correlation between the fluctuations in the abundance pattern of Hymenoptera.

5.4.4.1.1 Moist deciduous forest

Among the habitats, moist deciduous had the second largest proportion of Hymenoptera (10.6%). The most preferred season of Hymenoptera in moist deciduous habitat was the south-west monsoon, followed by the north-east monsoon winter and summer respectively (Table 5.4). This order of preference was the same during both the years of study.

Hymenoptera in moist deciduous habitat showed a significant positive correlation with the number of rainy days (P= 0.05) and a significant negative correlation with the humidity and average temperature of the day (P = 0.05). The

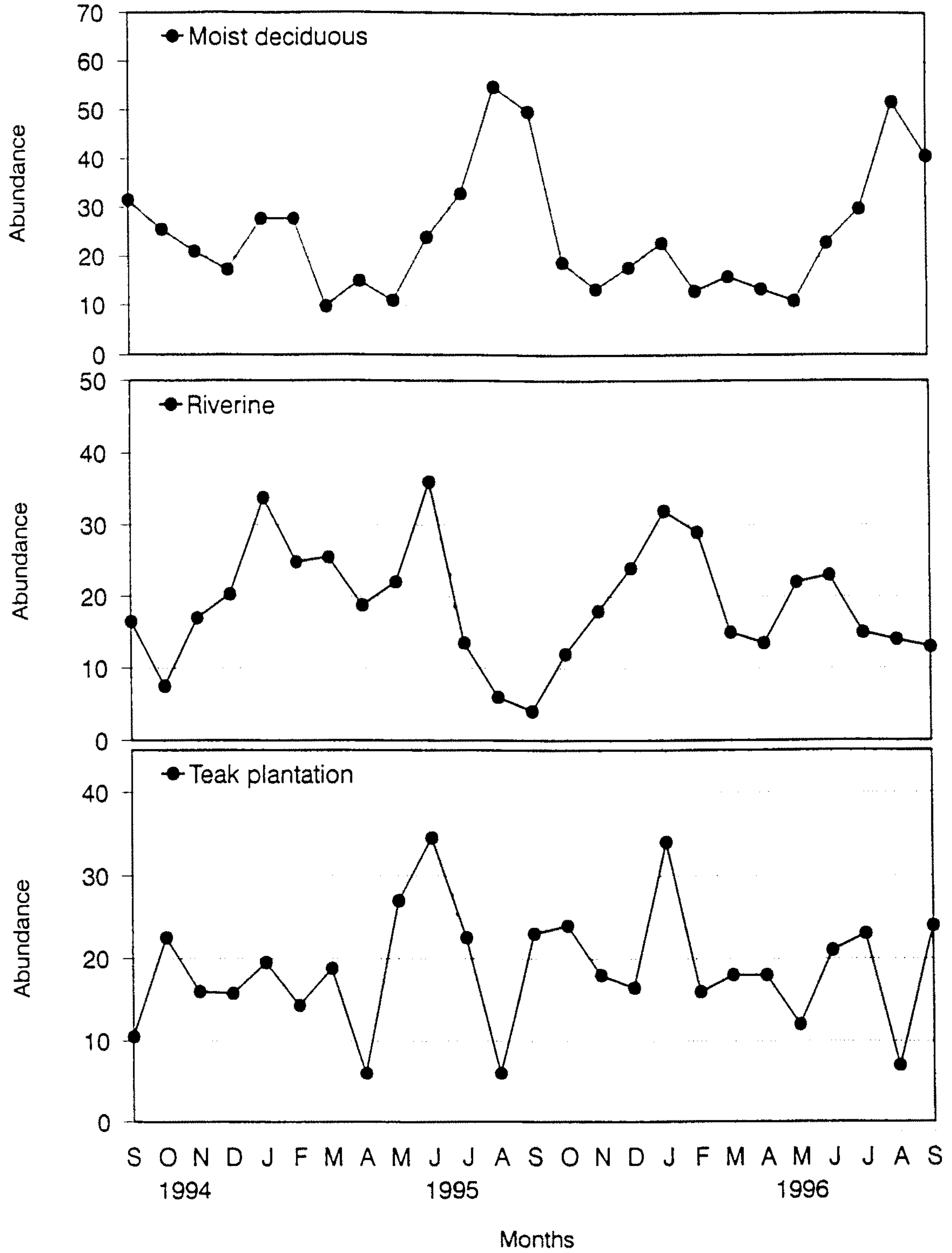

Figure 5.14 Monthly fluctuations in the abundance of Hymenoptera in different habitats

hymenopteran population of the habitat showed no significant correlation with that of the teak plantation while it showed significant negative correlation with the Hymenoptera of riverine habitat (P= 0.05).

Habitat	Seasons								Total	Percentage of Grand total
	N-E Monsoon		Winter		Summer		S-W Monsoon			
Moist deciduous	80	(27.7%)	63	(21.8%)	38	(13.1%)	109	(37.4%)	290	39.0%
Riverine	38	(16.2%)	82	(35.4%)	58	(25.2%)	54	(23.2%)	232	31.1%
Teak plantation	57	(25.7%)	58	(26.1%)	50	(22.5%)	57	(25.7%)	222	29.8%
Total		175		203		146		219	744	
% of Grand total		23.5%		27.3%		19.7%		29.5%		100%

Note:- Figures in parenthesis are percentage from the total of each habitat.

Table 5.4 Relative seasonal abundance of Hymenoptera (mean of two years) in three different habitats (Sweep sampling)

5.4.4.1.2 Riverine habitat

The insect community of riverine habitat had the least proportion of hymenopterans. The maximum abundance of Hymenoptera was recorded during winter which accounted for 35%of the hymenopterans, followed by summer, south-west monsoon, and north-east monsoon (Table 5.4 and Figure 5.16). There was a slight difference in the seasonality of Hymenoptera between the years. Although the major peak was in the same month during both the years, the minor peaks varied (Figure 5.13).

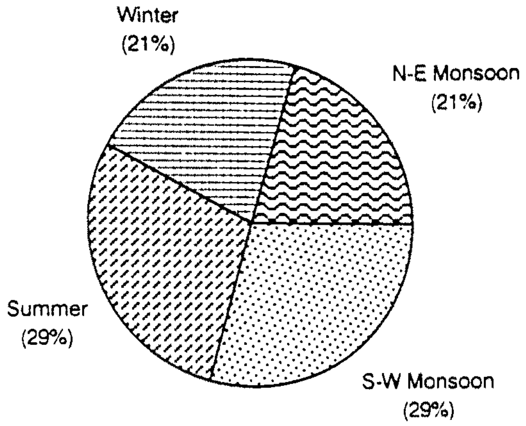

Figure 5.15 Seasonal abundance of Hymenoptera

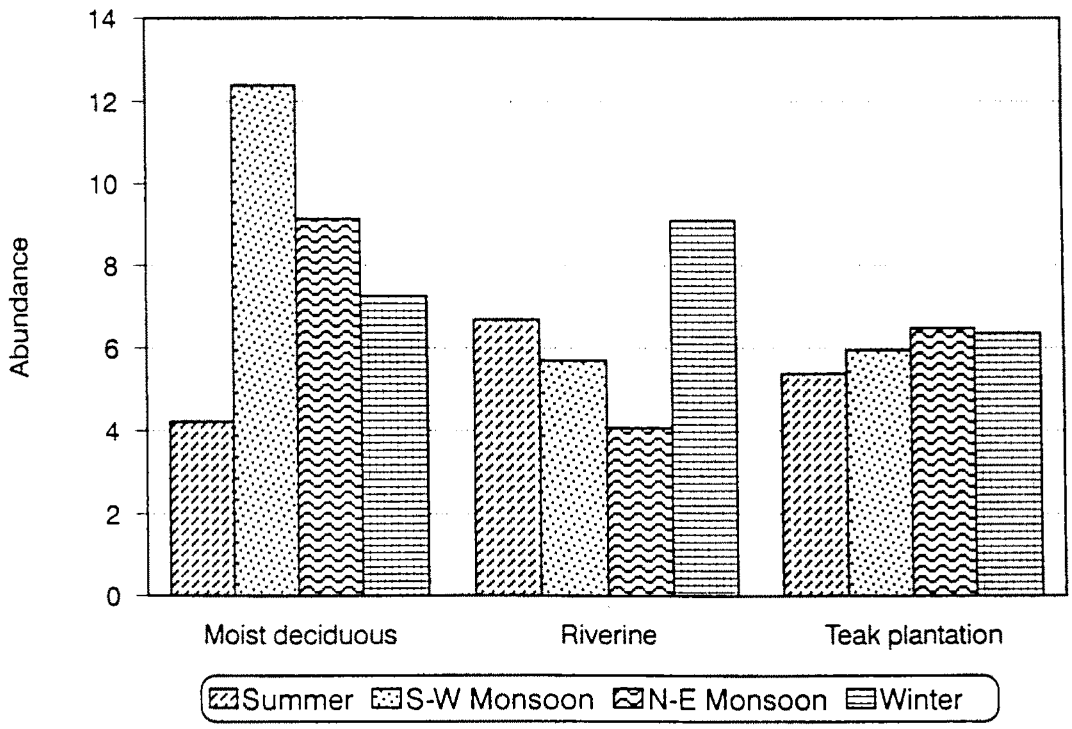

Figure 5.16 Seasonal abundance of Hymenoptera in different habitats

The hymenopteran abundance pattern in riverine habitat had a significant negative correlation with the number of rainy days of the month(r= -0.48, P= 0.02) and monthly rainfall (r= -0.43, P= 0.04).

5.4.4.1.3 Teak plantation

Although the abundance of Hymenoptera was the least in teak plantation, its relative proportion to the total insect community of the habitat was the highest (18%) compared to other habitats. The maximum abundance of Hymenoptera in this habitat was during the winter (26.1% of the total), followed by the south-west monsoon and north-east monsoon (25.7% each) and summer (22.5%). The seasonality varied between the years. During the first year the hierarchical order of hymenopteran abundance was south-west monsoon > winter > summer > north-east monsoon, while during the second year winter recorded the highest abundance followed by north-east monsoon, south-west monsoon and summer respectively.

The hymenopteran abundance of the other two habitats and the environmental parameters, such as humidity, temperature and rainfall found to have no direct correlation with the hymenopteran population of the teak plantation.

5.4.4.2 Role of ecological factors

Hymenoptera was the most abundant during the maximum rainy period of the year, ie. south-west monsoon. The number of rainy days in a month showed a positive correlation with the Hymenopteran abundance, but was statistically insignificant. No significant direct correlation was observed between the hymenopteran abundance and the environmental factors. However, the hymenopteran abundance did show a significant correlation with the abundance of Coleoptera ($r = 0.588$, $P = 0.003$), which was found significantly correlated ($r= 0.589$; $P= 0.002$) with the rainfall.

5.4.4.3 Discussion

Hymenoptera was the most abundant insect order of the study area according to the pooled data of three methods. The order includes diverse types of insects with varying seasonal preferences. The overall abundance of Hymenoptera varied significantly between seasons ($F= 3.3$; $P= 0.04$). The seasonal difference in abundance was significant in moist deciduous ($F= 5.76$; $P= 0.005$) and riverine ($F= 4.76$; $P= 0.01$) habitats, while in teak plantation, it was not significant ($F= 0.151$; $P= 0.93$). The abundance of Hymenoptera did not vary significantly between years, and the pattern of monthly fluctuation in the abundance was more or less similar in both years, with the abundance reaching its highest peak in April in both the years (Figure 5.13).

The seasonal abundance pattern of hymenopterans differed among the habitats. In the moist deciduous forest and teak plantation, abundance was the highest during south-west monsoon, while in the riverine habitat, winter was preferred to the most (Figure 5.16). However, variation among seasons in teak plantation was very little compared to other habitats and was statistically insignificant . Moist deciduous habitat was the most preferred habitat by the hymenopterans in the area. Their abundance did not show much difference between the riverine habitat and teak plantation.

Seasonal abundance pattern of the Hymenoptera was not significantly associated with any of the environmental factors monitored during the study. Hymenoptera was relatively more abundant during south-west monsoon and summer, when the temperature and rainfall were almost at its extremes. It is interesting to note that none of the abiotic factors examined found to have any significant role on the seasonal abundance pattern of Hymenoptera. As in the case of Hemiptera, in Hymenoptera too no significant regression could be observed with the environmental factors. Although the abundance of Hymenoptera showed a negative correlation with the abundance of birds, it was not statistically significant.

5.4.5 Order: Lepidoptera

Lepidoptera includes butterflies and moths, which are among the most popular insects. Small to large sized insects with two pairs of large membraneous wings, covered by minute flattened scales. Often, body and legs are also clothed in scales and hairs. Mouthparts consist of an elongated tubular proboscis which is a modification of the maxillae. Adult lepidopterans are mostly nectar feeding, while some species do not feed at all during adulthood. Paired antennae are of various shapes among the moths (Heterocera) and are almost always club shaped in the butterflies (Rhopalocera). Development is holometabolous. The larvae of Lepidopterans known as caterpillars are almost entirely plant feeding and have well developed mouthparts of biting type suited for their feeding habits. Caterpillars are serious pests of many plant species, and are a major component of the folivorous insects in forests. Average life span of the adults of this order is usually one to two months.

Order Lepidoptera was fourth in abundance (after Diptera, Orthoptera, and Hymenoptera), recorded in the sweep sampling. The overall abundance of Lepidoptera did not differ significantly between seasons.

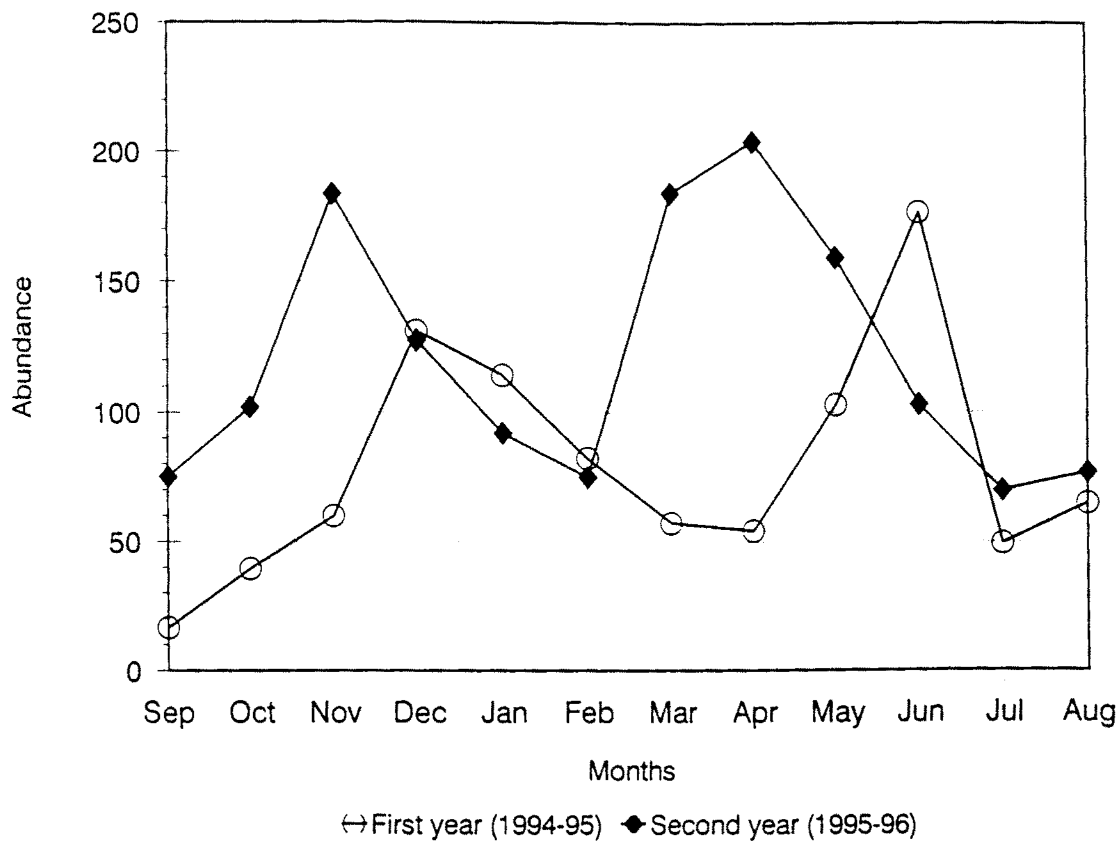

Figure 5.17 Comparison of the monthly fluctuations in the overall Lepidopteran abundance between the years (Pooled data from three methods)

5.4.5.1 Seasonality in different habitats.

Of the total insects recorded from three different habitats 14.5% belonged to Lepidoptera. Generally, winter was the most preferred season of this group, as 38% of the total lepidopterans were recorded during this season alone. The next preferred seasons were, south-west monsoon (36%), north-east monsoon (17%) and summer (8%) respectively. However, the fluctuation in the overall abundance of lepidoptera between seasons was not significant (F= 0.62; P= 0.6)

Generally, the the highest abundance of lepidopteran larva (ie. caterpillars) was recorded during the summer (knock down sampling), which was the least preferred season of butterflies (according to the transect counting data). The high abundance of the caterpillars was followed by the high abundance of the butterflies. The summer rains are likely to be a major factor affecting the caterpillar abundance. During the summer of 1995- 96, there was a sharp rise in the caterpillar abundance, corresponding to a high amount of rainfall during the mid- summer, in April (189mm), as opposed to the summer of 1994- 95, which recorded low abundance of caterpillars when the showers were in late summer. The rainfall benefits the caterpillar abundance indirectly, by causing the generation of new leaves, which form the major food source of caterpillars.

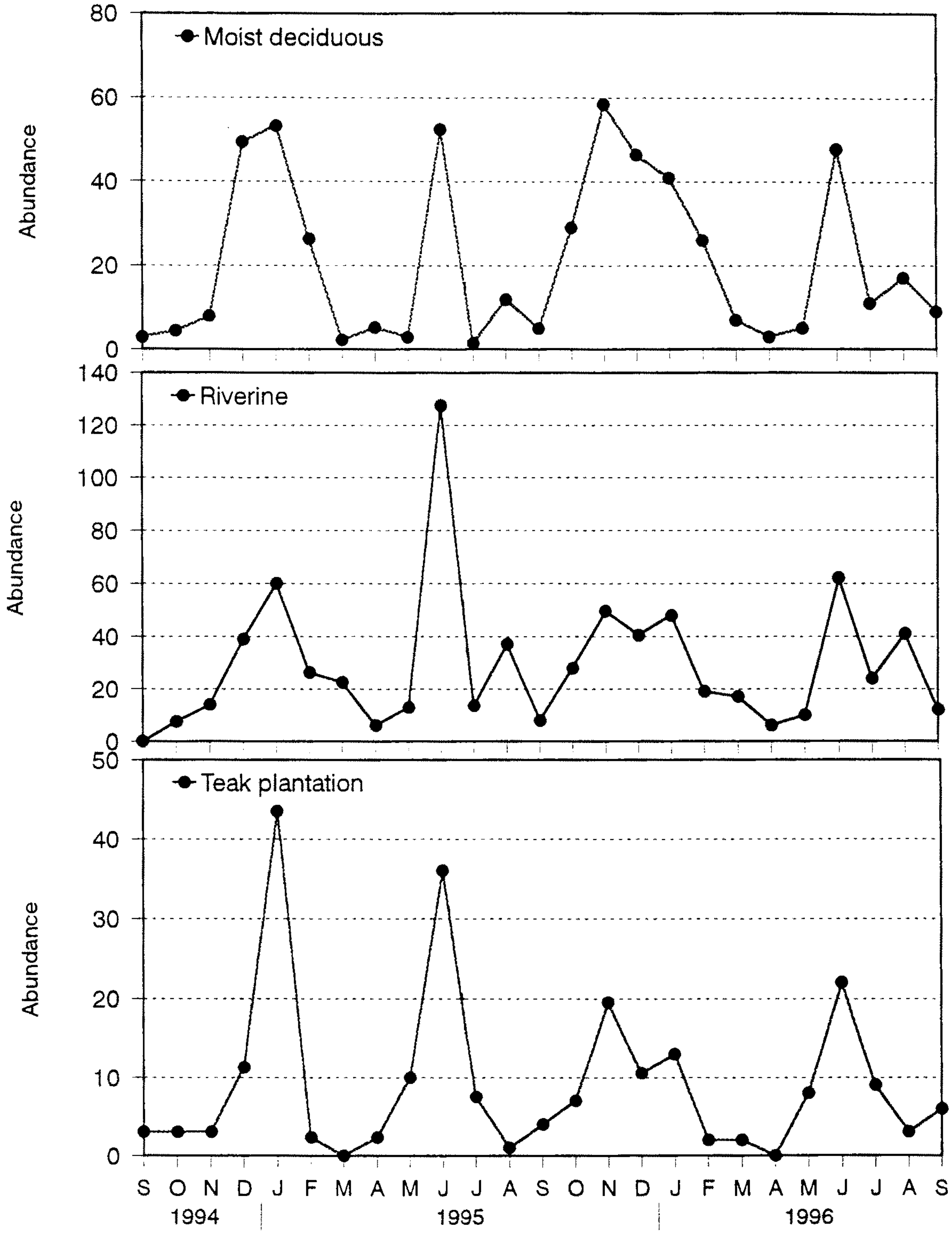

Figure 5.18 Monthly fluctuations in the abundance of Lepidoptera in different habitats

The seasonal abundance pattern of lepidoptera showed a comparable pattern in all the three habitats (Figure 5.18). The inter-habitat variation in the lepidopteran abundance was highly significant ($F = 16.11$; $P < 0.001$). Of the three habitats, the riverine had the maximum abundance of Lepidoptera followed by the moist deciduous forest and teak plantation (Table 5.5). It was the least abundant insect order in teak plantation, where it represented only 9% of the total insects, while it was the second most abundant order after Diptera, in the riverine habitat.

Lepidopteran abundance in the three habitats showed a high degree of positive correlation among them ($P < 0.01$). Environmental factors did not show any direct correlation with the lepidopteran abundance.

5.4.5.1.1 Moist deciduous forest

The abundance of lepidoptera in the moist deciduous habitat was second to Riverine. Of the total insects recorded from this habitat 13% were lepidopterans. Among the seasons, winter recorded the highest abundance of Lepidoptera accounting for almost 47% of the total recorded from this habitat, followed by south-west (27%) and north-east monsoons (21%) respectively (Table 5.5). However, during the second year the seasonal abundance pattern deviated slightly with the peaks advancing a month or two from from the first

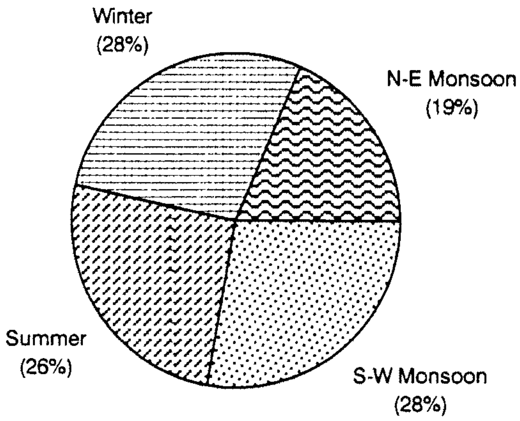

Figure 5.19 Seasonal abundance of Lepidoptera

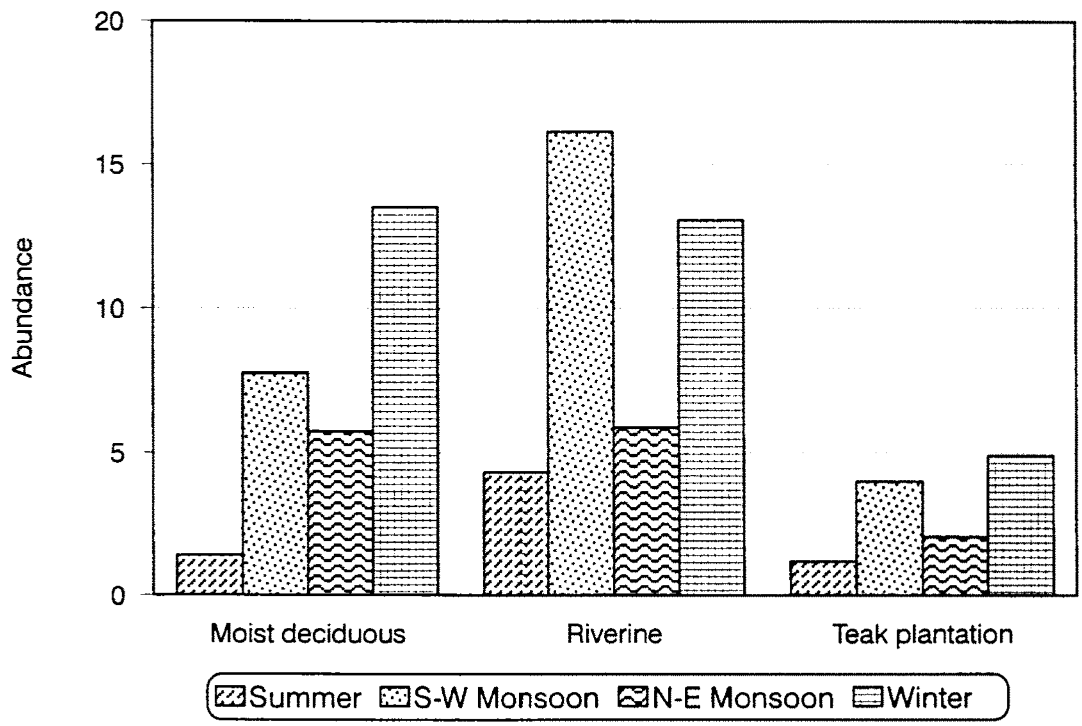

Figure 5.20 Seasonal abundance of Lepidoptera in different habitats

years pattern. The second and third preferred seasons during 1995-96 were north-east and south-west monsoons respectively.

The lepidopteran abundance in the moist deciduous habitat showed significant correlation with that in riverine (r=0.78; P< 0.001) and teak plantation (r= 0.74; P < 0.001). The environmental parameters such as rainfall, temperature and humidity showed no significant direct relation with the lepidopteran abundance.

Habitat	Seasons				Total	% of Grand total
	N-E Monsoon	Winter	Summer	S-W Monsoon		
Moist deciduous	54 (20.8%)	121 (46.8%)	13 (4.9%)	71 (27.4%)	259	35.5%
Riverine	54 (14.9%)	116 (32.4%)	37 (10.4%)	153 (42.4%)	360	49.2%
Teak plantation	20 (17.8%)	41 (37%)	11 (10%)	39 (35.2%)	111	15.3%
Total	127	279	61	263	730	
% of Grand total	17.4%	38.2%	8.4%	36%		100%

Note:- Figures in parenthesis are percentage from the total of each habitat.

Table 5.5 Relative seasonal abundance of Lepidoptera (mean of two years) in three different habitats (Sweep sampling)

5.4.5.1.2 Riverine habitat

Lepidoptera was the most abundant group in the riverine habitat representing 49% of the total lepidopterans recorded from the three different habitats. Within the habitat, Lepidoptera had the largest number among insect orders (19%). Maximum abundance of Lepidoptera in riverine habitat was recorded during the south-west monsoon which represented 42% of the total Lepidoptera recorded from this habitat, followed by winter (32%), north-east monsoon (15%) and summer (10%). However, during 1994- 95 there was a slight difference in this order seasonal preference (figure 5.17). The lepidopteran abundance in this habitat had been significantly correlated with the lepidopteran abundance of the other two habitats.

5.4.5.1.3 Teak plantation

Teak plantation was the least preferred habitat of lepidopterans. Among the insect orders in teak plantation, Lepidoptera was represented the least (9%). Generally, the most preferred season was winter, which accounted for 37% of the total lepidopteran abundance of this habitat. This was followed by the south-west monsoon, north-east monsoon and summer respectively (Table 5.5). The seasonality differed among the years. The order of preference of seasons was winter > south-west monsoon > summer > north-east monsoon during the 1994-95, while it was south-west monsoon > north-east monsoon > winter > summer, during the 1995- 96. The lepidopteran abundance of this habitat also showed no direct significant correlation with the environmental parameters such as rainfall, number of rainy days, humidity and temperature.

5.4.5.2 Role of ecological factors

The abundance fluctuation of the total Lepidoptera as estimated by the pooled data from all the methods showed significant correlation with the abundance of Orthoptera. This similarity in the abundance pattern is significant, since these two insect groups together form the most important source of food for insectivorous birds. No significant regression was observed between the lepidopteran abundance and the environmental factors studied.

5.4.5.3 Discussion

The lepidopterans are delicate winged insects in the adult form. Larval form of these insects popularly known as the caterpillars are one of the major sources of food for birds. Lepidopteran abundance was the highest during summer of 1995- 96 when there was higher rainfall than in the previous year and hence the young leaves were more. The major peaks in the abundance of lepidopteran larvae were in December and June during 1994- 95 and November and March during the 1995- 96. The backward shift in the pattern of abundance during the second year was probably due to the early rains during that year.

The peaks in the abundance of Lepidoptera were found in a wide range of environmental conditions. Generally, optimal conditions for lepidopteran abundance were; a temperature in the range of 25 to 32 °C, relative humidity between 40 and 85% and a monthly rainfall less than 279 mm received in fewer than 20 days. Seasonality of butterflies (Rhopalocera) and moths (Heterocera) was different; butterflies being more abundant during south-west monsoon and moths during summer.

5.4.6 Order: Orthoptera

Orthoptera includes medium to large sized insects (popularly known as grass hoppers) with well developed exoskeleton. Forewings are rather heavier in texture than the hind wings. Hind legs are well developed and adapted for hopping. Mouth parts are of biting type. Development is hemimetabolous. The ecology, abundance, spatial distribution, and host plant preferences of grasshoppers were studied earlier (Julka et al. 1982, Erhardt and Thomas 1991, Baker and Chazon 1993 & Coxwell and Bock 1995).

According to the data obtained by sweep sampling from the three habitats, orthopterans were second most abundant insect order representing about 16% of the total insect abundance. However, there was apparent differences in the relative abundance of this order among the seasons and habitats. Generally, winter was the most preferred season during which the orthopterans were most abundant in the study area.

5.4.6.1 Seasonality in different habitats

Among the three different habitats studied, the moist deciduous and riverine habitats had the maximum abundance of orthopterans followed by teak plantation. Invariably teak plantation had the least orthopteran abundance during all the seasons (Table 5.6).

Habitat	Seasons				Total	% of Grand total
	N-E Monsoon	Winter	Summer	S-W Monsoon		
Moist deciduous	50.5 (17.6%)	127.3 (44.4%)	40.1 (14%)	68.8 (24%)	286.7	36.6
Riverine	66 (22.3%)	96.1 (32.4%)	45.4 (15.3%)	89 (30%)	296.5	37.9
Teak plantation	44.5 (22.3%)	53.8 (26.9%)	33.4 (16.7%)	68.3 (34.2%)	200	25.5
Total	161	277.2	118.9	226.1	783.2	
% of Grand total	20.6	35.4	15.2	28.9		100

Note:- Figures in parenthesis are percentage from the total of each habitat

Table 5.6 Relative seasonal abundance of Orthoptera (mean of two years) in three different habitats (Sweep sampling).

Generally, the orthopteran population preferred winter most and summer the least, in all the habitats. The population trend in the riverine and teak plantation was significantly correlated ($r = 0.730$; $P < 0.01$). The riverine and moist deciduous habitats showed a negative correlation with the rainfall and rainy days while the teak plantation showed a positive correlation. However these correlations were statistically insignificant. The teak plantation and moist deciduous habitats showed negative correlation with the average temperature, while riverine habitat showed a positive correlation. All these correlations were

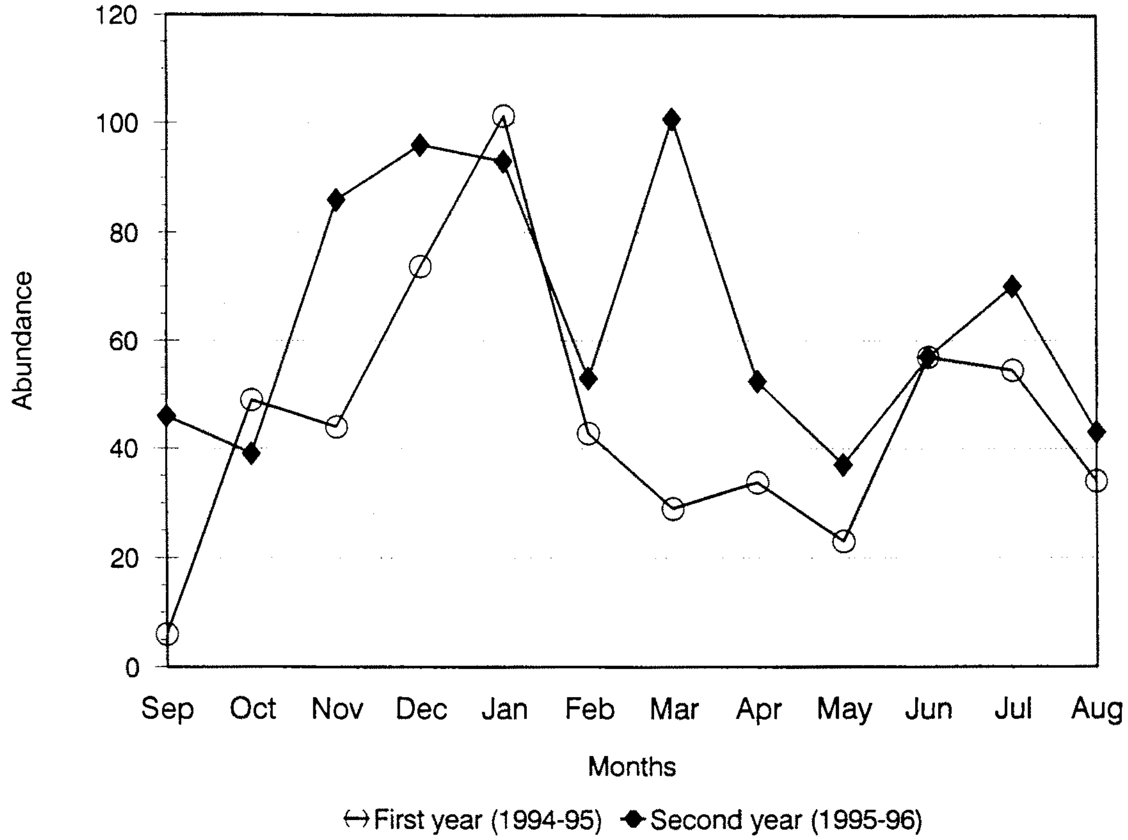

Figure 5.21 Comparison of the monthly fluctuations in the overall Orthopteran abundance between the years (Pooled data from three methods)

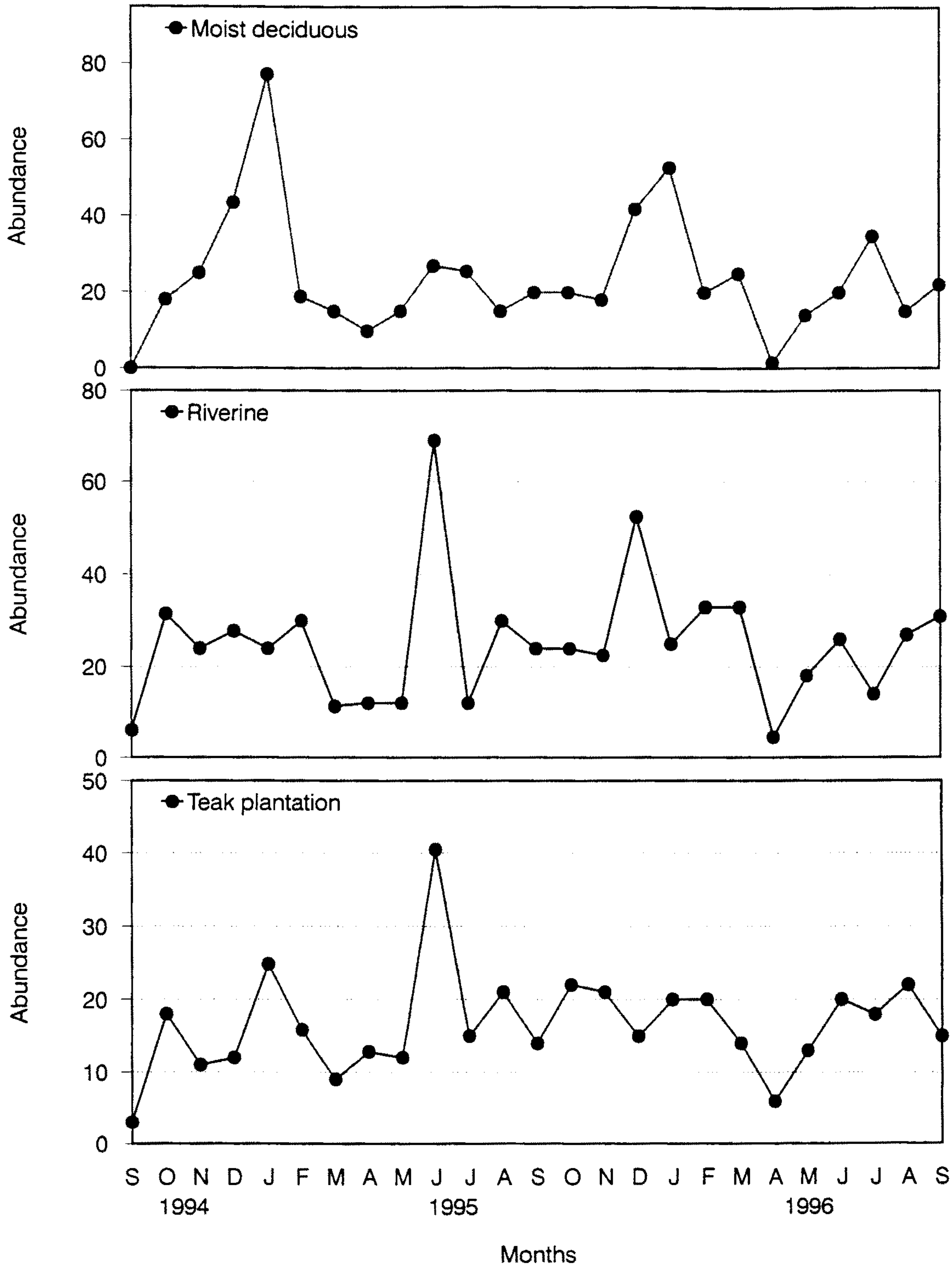

Figure 5.22 Monthly fluctuations in the abundance of Orthoptera in different habitats

statistically insignificant. The humidity and orthopteran abundance was also positively related but was statistically not significant.

5.4.6.1.1 Moist deciduous forest

The abundance of orthoptera was more or less the same in the riverine as well as moist deciduous forest. Among the seasons, the orthopteran population showed a remarkably high abundance during the winter accounting for 44% of the total orthopterans recorded, followed by south-west monsoon (24%), north-east monsoon (17.6%) and summer (14%) respectively. In this habitat, the orthopteran population showed maximum abundance during January of both the years of study (Figure 5.22).

5.4.6.1.2 Riverine habitat

This was the most preferred habitat of orthopterans. 38% of the total orthopterans sampled by sweep sampling were from this habitat. Here too the seasonal abundance patterns were similar to that of the moist deciduous habitat with winter being the most preferred season followed by south-west monsoon, north-east monsoon and summer (Table 5.6).

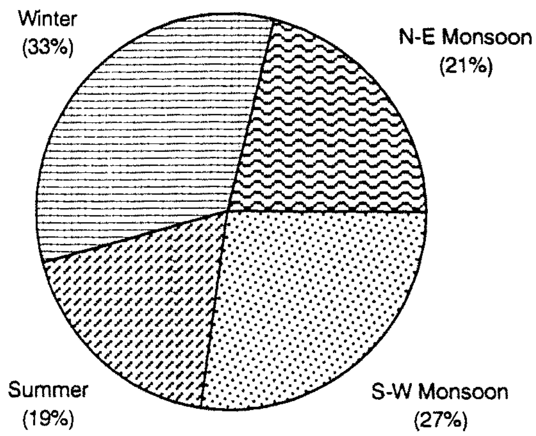

Figure 5.23 Seasonal abundance of Orthoptera

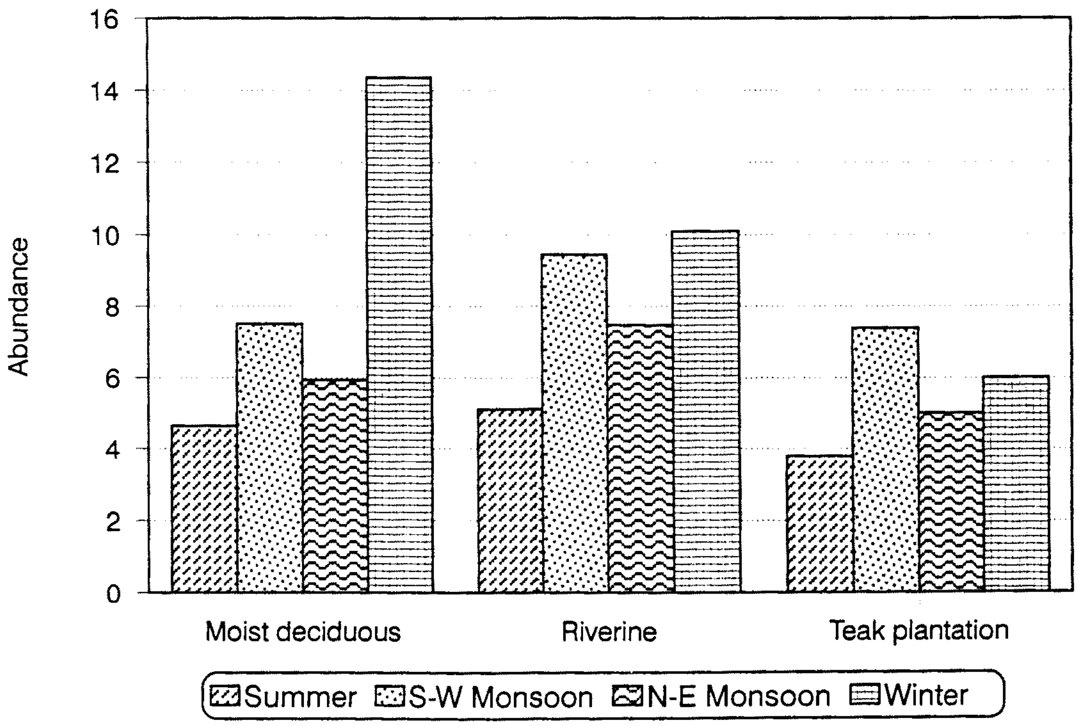

Figure 5.24 Seasonal abundance of Orthoptera in different habitats

5.4.6.1.3 Teak plantation

Teak plantation was the least preferred habitat of orthopterans. Unlike the other two habitats, the south-west monsoon was the most preferred season in this habitat with 34% of the total orthopterans being recorded during this season. The next preferred seasons were winter, north-east monsoon and summer. This pattern, however varied between the years as well (Figure 5.21). During the 1994- 95 the order of preference of seasons was south-west monsoon > winter > summer > north-east monsoon, while in the second year, it was south-west monsoon> winter = north-east monsoon > summer.

5.4.6.2 Role of ecological factors

Orthopterans did not show any significant direct correlation with any of the five abiotic factors. Among the biotic factors the total bird abundance in the area was found significantly correlated with the orthopteran abundance ($r = 0.44$; $P = 0.03$). The fitted regression equation obtained by stepwise regression is given below

$$\mathbf{A_O = 67.20 \pm 16.89) + A_B\ (0.339 \pm 0.12)}$$

Where,

A_O = total orthopteran abundance of a particular month (number obtained from all the three sampling methods),

A_B = total bird abundance (number of birds counted per two kilometre transect).

5.4.6.3 Discussion

Seasonal fluctuations were prominent in Orthoptera with high preference towards winter except in teak plantation where the peak was in south-west monsoon. Orthopterans are one of the most important food sources of many of the insectivorous birds and hence, the significant correlation obtained between the abundance of orthopterans and birds indicate the harmonic seasonal timing of bird population abundance with that of the Orthoptera.

Optimal conditions for the abundance of Orthoptera were: temperature in the range of 25- 32 oC with a relative humidity ranging between 78 and 85% and a monthly rainfall up to 279 mm received within 19 days.

5.5 SUMMARY AND CONCLUSIONS

The seasonality of six selected insect orders in a natural forest was studied using regular sampling of insects using three major methods namely, sweep sampling, light trapping and knock down sampling. The pooled data from all the three methods was used as an index of the insect abundance.

The seasonality patterns of different insect orders were analysed in relation with various environmental factors, such as rainfall, number of rainy days, humidity, temperature, plant phenology and bird abundance to decide the role of these factors in the seasonal patterns of insect orders. Seasonal patterns were compared between the three habitats, namely; moist deciduous, riverine and teak plantation.

Seasonality patterns varied among insect orders. Environmental factors affecting the seasonality also varied among different insect orders. Rainfall was the important factor in the Coleopteran seasonality, while in Diptera it was temperature, and in Orthoptera the bird abundance. However, certain other orders such as Hemiptera and Hymenoptera did not show any direct relationship with any of the environmental factors.

The following major conclusions were derived from the results.

1. Seasonal abundance of insects fluctuated more significantly in smaller sections of the population identified based on habitat or taxa, while the overall abundance of insects tend to fluctuate in a much lesser dimension, because of the probable buffering of an unfavourable season of one group of insects with another group that prefer that season.

2. The seasonal fluctuation in the abundance of different insect groups varied highly between years. Diptera was the only insect group that showed remarkably similar seasonal abundance pattern during both the years.

3. The seasonal fluctuations in abundance were remarkably similar between habitats in most of the insect orders.

4. The temporal abundance pattern of the Lepidoptera and Orthoptera showed similar pattern of fluctuations in their abundance in time. It is interesting to note that there was a corresponding fluctuation in the bird population also, which was statistically significant in the case of Orthoptera. As these two insect orders are the major components in the diet of insectivorous birds, it appears that, the abundance levels of orthopteran and lepidopteran insects in the region is a regulating factor of the local abundance of birds in the region.

5. The abundance patterns were significantly different among the insect orders. Significant difference in the abundance was observed in all the insect groups between seasons (with significant F ratios in ANOVA ($P < 0.005$). Maximum seasonal variation was recorded in the abundance of Diptera followed by Coleoptera and Lepidoptera. Hemiptera, Hymenoptera and Orthoptera showed relatively less seasonal fluctuations.

6. Among the orders, Lepidoptera and Orthoptera showed a similar seasonality pattern that was different from others. Both these orders showed higher preferences to the riverine habitat and winter season, while others generally preferred to moist deciduous forest and south-west monsoon.

7. Among the environmental factors, the temperature was a major factor which appear to be affecting the abundance of Diptera, while rainfall was important in the seasonal fluctuations of Coleoptera.

CHAPTER VII

STRATEGIES OF INSECT SEASONALITY

7.1 INTRODUCTION

Seasonal variation in the abundance of a species is an adaptive phenomenon evolved through evolution to take maximum advantage from the ambient environmental conditions. Presence of a distinct larval and imago stages which differ from each other in many ways, including the feeding mechanisms and even the ecological niche is a characteristic feature of holometabolous insects such as those belonging to the orders Lepidoptera, Coleoptera and Diptera. Equipped with the diverse modes of life styles and ecological requirements during different life stages, the insects have got an edge over most other organisms in resource utilization potential. Usually the larval and adult stages are separated with a dormant pupal stage which enable them to survive during adverse conditions. One of the major factors on which their success and survival depends on is how efficiently they time their life cycle so as to utilize the maximum resources and environmental conditions.

7.2 SEASONAL STRATEGIES

The mechanism involved in the regulation of insect development and seasonal cycles is a complex one. In addition to the primary genetic programming, environmental conditions which involve both density dependent as well as density independent factors also play an important part in insect seasonality. Density dependent factors are responsible for regulating the population about its average level of abundance, while the density independent factors such as climate and weather can cause catastrophic changes in the abundance either by enhancing the mortality rate, or by triggering a change in the neurosecretory cells (known as "endocrine switch") of the brain, which in turn switch on or off the various adaptive physiological mechanisms involved in the survival strategy, such as diapause and pupation.

In the present study, the pattern of fluctuations in the overall insect abundance was found less predominant compared to that in its component groups, such as different orders, families and species. This was because of the difference in the pattern of abundance of different component groups in the total abundance. For instance, the Diptera was highly abundant in August, while Lepidoptera and Orthoptera showed low abundance during this month, while an opposite trend was observed in December. The relative fluctuations in the insect abundance showed more definite patterns in the case of smaller and less diverse groups, compared to larger and more diverse groups. Hence, the fluctuation in abundance at the family level tends to be more prominent than that at the order level. However, for a thorough understanding of the mechanisms and factors involved in the seasonality, species specific studies on long-term basis has to be conducted.

In the present study, the seasonality patterns of different insect groups were related with different environmental factors. Temperature was the important factor in the seasonal fluctuations of Diptera, while abundance of Orthoptera was significantly related with bird abundance. In the case of butterflies, the flower abundance was a key factor that affected the abundance, especially in the families Satyridae, Papilionidae and Hesperidae. However, a direct linear relationship between the abundance and any single environmental factors was absent in most of the insect orders, but a combination of factor appears to have a direct impact on abundance as it was observed in the case of coleopterans and hesperidans.

7.3 EFFECT OF PREDATION

The role of predators in regulating the abundance of the prey has been well established in many of the predator prey systems (Galushin 1974, Andersson and Erlinge 1977, Erlinge *et al.* 1984, Kid and Lewis 1987, Erlinge *et al.* 1988, Korpimaki

1994, Gunnarsson 1996). Although, it has also been studied in insect- bird interactions (Wagner, 1981, Chai and Srygley 1990, Torgersen *et al.* 1990), such studies, especially in natural forests are very limited. The two basic mechanisms that are involved in the survival of the prey under predation pressure are i) avoidance of predation and ii) predator satiation.

The seasonal strategies against the predation vary among insect groups. In the present study, Orthoptera, which forms a major diet of the insectivorous birds, appear to have a seasonal strategy that is not much adapted for avoiding predation by birds, as there was a positive correlation between the abundance of birds and these insects. Therefore, it appears that the seasonal strategy in Orthoptera is predator satiation, rather than predator avoidance. Other groups of insects did not have simultaneous fluctuation with the abundance of birds, suggesting probably, that they were more successful in avoiding birds. Among them Coleoptera showed a significant negative relation with the bird abundance, clearly indicating a strategy of avoiding the bird abundance, which would probably be one of the reasons contributing to the high abundance of Coleoptera in the nature.

As it would be impossible for the resident local population of birds to track the orthopteran abundance closely without a significant time lag, it is likely that the synchrony in the abundance fluctuations in the insect prey and the birds is effected by the local migration and aggregation of the birds towards the higher prey densities. Since the abundance fluctuations of these insect groups were mostly unpredictable with different peak abundant months in different years, those birds that are able to locate the increased abundance of insects earliest and adjust their life cycle strategies (such as breeding) accordingly, will have an edge over other birds in the long-term survival. The results of the study indicates the presence of an evolutionary race between the birds and insects which enable the best adapted ones to survive.

Hence, as far as bird predation is concerned, except Orthoptera most other insect groups had a seasonal strategy trying to avoid the birds. While, in the case of birds, the local immigration and emigration in response to the prey densities might be an important factor deciding their abundance. The ability to search over greater areas for the prey and to assess the direction of the prey abundance are important traits that may be strongly favoured by evolution. Similar results are also been reported for birds by Korpimaki (1994), where the predator- prey relationship between birds and voles was examined.

7.4 CONCLUSION

From the data it is evident that in most cases the abundance of insect orders is not in full agreement with the biotic and abiotic factors, although a combination of several factors at time explained the peaks of abundance of insects. This is mainly because of the differential ecological requirements of different species of the order. The abundance of the species varies according to its own ecological requirements. This is evident in the case of Hesperidae, Satyridae and Papilionidae where, there was a definite positive relation with the overall flower abundance of the selected species of plants. However, if we take the abundance of Lepidoptera as a whole, such a correlation does not exist. It is also an established fact that sympatric species will have varying ecological requirements in order to avoid competition. This has been reported in plants (Ganesh 1996), birds (Cody 1973, Vijayan 1975, Vijayan 1984) and also in butterflies (Swengel 1997).

Therefore, to work out the insect seasonality, seasonality of individual species comprising the group has to be looked into. The present study gives an overall picture about the abundance and seasonality of insects in the moist deciduous forest of Siruvani.

Appendix I The list of plants recorded from the study area

Trees	
No.	Species
1	*Ailanthus sp*
2	*Albizzia lebbeck*
3	*Albizzia sp*
4	*Alstonia scholaris*
5	*Azadirachta indica*
6	*Bambusa arundinacea.*
7	*Bauhinia malabarica*
8	*Bauhinia racemosa*
9	*Bischofia javanica*
10	*Bridelia retusa*
11	*Butea monosperma*
12	*Cassia fistula*
13	*Chionanthus mala-elangi*
14	*Cordia mixa*
15	*Dalbergia latifolia*
16	*Dalbergia paniculata*
17	*Delonix regia*
18	*Erythrina suberosa*
19	*Streblus asper*
20	*Ficus glomerata*
21	*Gmelina arborea*
22	*Grewia tilifolia*
23	*Lagerstroemia parviflora*
24	*Litsea floribunda*
25	*Macaranga peltata*
26	*Mallotus tetracoccus*
27	*Mitragyna parvifolia*
28	*Morinda citrifolia*
29	*Olea dioica*
30	*Persea macaranga*
31	*Phyllanthus officianale*
32	*Polyalthia longifolia*
33	*Pterocarpus marsupium*
34	*Randia dumetorum*
35	*Sapindus emarginatus*
36	*Sapindus sp*
37	*Solanum verbacefolium*
38	*Stereospermum colais*

No.	Species
39	*Syzygium cumini*
40	*Tectona grandis*
41	*Terminalia bellirica*
42	*Terminalia paniculata*
43	*Terminalia tomentosa*
44	*Trewia latifolia*
45	*Trewia polycarpa*
46	*Wrightia tinctoria*
47	*Acrocarpus fraxinifolius*

Shrubs

No.	Species
1	*Acacia sp*
2	*Acasia leucophloea (s)*
3	*Albizzia sp(s)*
4	*Bambusa sp*
5	*Blumea sp*
6	*Cassia tora*
7	*Cippadessa bacciferra*
8	*Clausena dentata*
9	*Clerodendron infortunatum*
10	*Costus speciosus*
11	*Cryptolapis buchananii*
12	*Delonix regia (s)*
13	*Eupatorium odoratum*
14	*Ferns*
15	*Glycosmis pentaphylla*
16	*Gomphostemma sp*
17	*Helectris isora*
18	*Justicia betonica*
19	*Justicia wyanadensis*
20	*Lantana camara*
21	*Litsea floribunda*
22	*Maesa indica*
23	*Randia dumetorum (s)*
24	*Schummanianthus virgatus*
25	*Solanum torvum*
26	*Tragia involucrata*
27	*Zizyphus oenoplia*

* *(S)* = The saplings of trees

Appendix II List of birds recorded from the area

Sl. #	Common name	Scientific name
1	Barred Jungle Owlet	*Glaucidium radiatum*
2	Black Bulbul	*Hypsipetes medagascariensis*
3	Black Eagle	*Ictinaetus malayensis*
4	Blackheaded Babbler	*Rhopocichla articeps*
5	Blackheaded Oriole	*Oriolus xanthornus*
6	Blackwinged Kite	*Elanus caeruleus*
7	Blossomheaded Parakeet	*Psittacula cyanocephala*
8	Blue Chat	*Erithacus brunneus*
9	Blue Rock Thrush	*Monticola solitarius*
10	Bluewinged Parakeet	*Psittacula columboides*
11	Blyth's Reed Warbler	*Acrocephalus dumetorum*
12	Brahminy Kite	*Haliastur indicus*
13	Bronze Drongo	*Dicrurus aeneus*
14	Brown Flycatcher	*Muscicapa latirostris*
15	Cattle Egret	*Bubulcus ibis*
16	Chestnutbellied Nuthatch	*Sitta castanena*
17	Chestnutheaded Bee-Eater	*Merops leschenaulti*
18	Common Myna	*Acridotheres tristis*
19	Crested Serpent Eagle	*Spilornis cheela*
20	Crested Tree Swift	*Hemiprocne longipennis*
21	Crimsonbreasted Barbet (Coppersmith)	*Megalaima haemacephala*
22	Crimsonthroated Barbet	*Megalaima rubricapilla*
23	Crow pheasent	*Centropus sinensis*
24	Dull Green Leaf Warbler	*Phylloscopus trochiloides*
25	Dusky Crag Martin	*Hirundo concolor*
26	Fairy Bluebird	*Irnea puella*
27	Forest Eagle Owl	*Bubo nipalensis*
28	Forest Wagtail	*Motacilla indica*
29	Golden Oriole	*Oriolus oriolus*
30	Goldenbacked Woodpecker	*Dinopium benghalense*
31	Goldfronted Chloropsis	*Chloropsis aurifrons*
32	Goldmantled Chloropsis	*Chloropsis cochinchinensis*
33	Green Bee-Eater	*Merops orientalis*
34	Grey Drongo	*Dicrurus leucophaeus*
35	Grey Jungle Fowl	*Gallus sonneratii*
36	Grey Tit	*Parus major*
37	Grey Wagtail	*Motacilla cinerea*
38	Greyfronted Green Piegon	*Treron pompadora*
39	Greyheaded Bulbul	*Pyconotus priocephalus*
40	Greyheaded Flycatcher	*Culicicapa ceylonensis*
41	Heartspotted Woodpecker	*Hemicircus canente*
42	Hill Myna	*Gracula religiosa*
43	Honey Buzzard	*Pernis ptilorhyncus*

Sl. #	Common name	Scientific name
44	Hoopoe	*Upupa epops*
45	House Swift	*Apus affinis*
46	Imperial Pigeon	*Ducula badia*
47	Indian Black Drongo	*Dicrurus adsimilis*
48	Indian Blue Rock Piegon	*Columba livia*
49	Indian Crested Hawk Eagle	*Spizaetus orrhatus*
50	Indian Edible-nest Swiftlet	*Collocalia unicolor*
51	Indian Emerald Dove	*Chalcophaps indica*
52	Indian Goldenbacked 3 toed Woodpecker	*Dinopium javanense*
53	Indian House Crow	*Corvus splendens*
54	Indian Lorikeet	*Loriculus vernalis*
55	Indian Magpie Robin	*Copsychus saularis*
56	Indian Pitta	*Pitta brachyura*
57	Indian Roller	*Coracias benghalensis*
58	Iora	*Aegithina tiphia*
59	Jungle Babbler	*Turdoides striatus*
60	Jungle Crow	*Corvus macrorhynchos*
61	Jungle Myna	*Acridotheres fuscus*
62	Jungle Nightjar	*Caprimulgus indicus*
63	Koel	*Eudynamys scolopacea*
64	Large Cuckoo Shrike	*Coracina novaehollandiae*
65	Large Pied Wagtail	*Motacilla maderaspatensis*
66	Lesser Pied Kingfisher	*Ceryle rudis*
67	Loten's Sunbird	*Nectarinia lotenia*
68	Mahratta woodpecker	*Picoides mahrattensis*
69	Malabar Grey Hornbill	*Tockus griseus*
70	Malabar Trogon	*Harpactes fasciatus*
71	Malabar Whistling Thrush	*Myiophonus horsfieldii*
72	Malabar Wood Shrike	*Tephrodornis virgatus*
73	Nilgiri Thrush	*Zoothera dauma nelgherriensis*
74	Nilgiri Wood Pigeon	*Columba elphinstonii*
75	Palm Swift	*Cypsiurus parvus*
76	Paradise Flycatcher	*Terpsiphone paradisi*
77	Pigmey Woodpecker	*Picoides canicapillus*
78	Plaincoloured Flowerpecker	*Dicaeum concolor*
79	Purple Sunbird	*Nectarinia asiatica*
80	Purplerumped Sunbird	*Nectarinia zeylonica*
81	Racket tailed Drongo	*Dicrurus paradiseus*
82	Red Spurfowl	*Galloperdix spadicea*
83	Redrumped Swallow	*Hirundo daurica*
84	Redvented Bulbul	*Pycnonotus cafer*
85	Redwhiskered Bulbul	*Pycnonotus jocosus*
86	Roseringed Parakeet	*Psittacula krameri*
87	Rubythroated Yellow Bulbul	*Pyconotus melanicterus*
88	Rufous Babbler	*Turdoides subrufus*

Sl. #	Common name	Scientific name
89	Scarlet Minivet	*Pericrocotus flammeus*
90	Scops Owl	*Otus scops*
91	Shikra	*Accipiter badius*
92	Small Blue Kingfisher	*Alcedo atthis*
93	Small Green Barbet	*Megalaima viridis*
94	Small Greenbilled Malkoha	*Rhopodytes viridirostris*
95	Small Minivet	*Pericrocotus cinnamomeus*
96	Small Sunbird	*Nectarinia minima*
97	Small Yellownaped Woodpecker	*Picus chlororolophus*
98	Southern Speckled Piculet	*Picumnus innominatus*
99	Southern Spotted Owlet	*Athene brama*
100	Spotted Babbler	*Pellorneum ruficeps*
101	Spotted Dove	*Streptopelia chinensis*
102	Swallow	*Hirundo rustica*
103	Tailor Bird	*Orthotomus sutorius*
104	Thickbilled Flowerpecker	*Dicaeum agile*
105	Tickell's Blue Flycatcher	*Muscicapa tickelliae*
106	Tickell's Flowerpecker	*Dicaeum erythrorhynchos*
107	Tree Pie	*Dendrocitta vagabunda*
108	Verditer Flycatcher	*Muscicapa latirostris*
109	Velvetfronted Nuthatch	*Sitta frontalis*
110	White eye	*Zosterops palpebrosa*
111	White Rumped Spinetail	*Chaetura sylvatica*
112	Whitebellied Blue Flycatcher	*Muscicapa pallipes*
113	Whitebellied Tree Pie	*Dendrocitta leucogastra*
114	Whitebreasted Kingfisher	*Halcyon smyrnensis*
115	Whitebrowed bulbul	*Pyconotus luteolus*
116	Whitethroated Ground thrush	*Zoothera citrina*
117	Wiretailed Swallow	*Hirundo smithii*
118	Wynad Laughing Thrush	*Garrulax delesserti*
119	Yellowbrowed Bulbul	*Hypsipetes indicus*

* Refer Vijayan et al. (in press) for the complete bird list of the area

Appendix III Pearson Correlation coefficients between the abundance of insect orders in different sampling methods

	Insect group	S. Method	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Coleoptera	Knock down	1															
2	Coleoptera	Light trapping	0.223	1														
3	Coleoptera	Sweeping	0.387	0.172	1													
4	Diptera	Light trapping	-0.054	-0.315	.493(*)	1												
5	Dipmd	Sweeping	0.079	-0.32	.537(**)	.899(**)	1											
6	Hemkd	Knock down	.474(*)	0.334	0.364	0.212	0.239	1										
7	Hemlt	Light trapping	0.037	0.327	-0.072	-0.355	-0.318	0.109	1									
8	Hemiptera	Sweeping	0.203	-0.12	0.308	0.075	0.045	0.06	-0.066	1								
9	Hymenoptera	Knock down	-0.139	0.389	0.128	0.219	0.138	.424(*)	-0.371	0.052	1							
10	Hymenoptera	Light trapping	0.293	.691(**)	0.2	-0.225	-0.032	0.229	0.336	-0.207	0.214	1						
11	Hymenoptera	Sweeping	0.065	-0.392	.502(*)	.792(**)	.841(**)	0.103	-0.24	0.141	-0.076	-0.016	1					
12	Lepidoptera	Knock down	0.01	0.245	-0.353	-0.258	-0.386	0.353	-0.103	-0.197	.543(**)	0.039	-0.403	1				
13	Lepidoptera	Light trapping	0.208	0.375	.580(**)	0.161	0.201	.435(*)	0.046	.460(*)	0.327	0.015	-0.011	-0.135	1			
14	Lepidoptera	Sweeping	-0.197	-0.32	-0.343	-0.151	-0.161	-0.123	0.2	0.286	-0.074	-0.24	-0.127	0.063	-0.185	1		
15	Orthoptera	Knock down	0.363	0.078	-0.3	-0.182	-0.214	.501(*)	0.05	-0.154	0.145	0.051	-0.168	.685(**)	-0.281	0.281	1	
16	Orthoptera	Light trapping	-.477(*)	0.109	-.426(*)	-0.169	-0.218	-0.136	0.141	-.56(**)	0.144	0.176	-0.25	0.295	-.57(**)	0.169	0.173	1
17	Orthoptera	Sweeping	-0.099	-0.391	-0.222	-0.136	-0.139	-0.069	0.379	0.141	-.451(*)	-0.344	0.006	-0.19	-0.083	.600(**)	0.075	-0.084

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

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

Appendix IV Seasonality of butterflies in the study area

#. Species	First year (1994-95)												Second year (1995- 96)											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Danaidae																								
1 Common Crow	*	-	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2 King Crow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-	-	-
3 Blue Tiger	-	-	-	*	-	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4 Glassy Tiger	*	-	*	*	*	*	*	*	*	*	*	*	*	-	*	-	*	*	-	*	*	-	*	*
5 Plain Tiger	-	-	-	-	*	*	*	-	*	-	*	*	*	*	-	*	-	-	-	-	*	*	*	-
6 Striped Tiger	*	*	-	*	*	-	*	-	*	*	-	*	*	*	-	-	-	*	-	*	*	*	-	*
7 Malabar Treenymph	-	-	-	-	-	*	-	*	*	-	-	-	-	*	-	-	-	-	*	*	-	-	-	-
Nymphalidae																								
8 Angled Castor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	*	-	-	-
9 Common Castor	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	-	*	-	-	*	-	*
10 Tawny Coster	-	-	-	-	-	-	-	-	-	*	-	-	-	*	-	*	-	-	-	-	-	-	-	*
11 Danaid Eggfly	-	*	-	*	*	*	*	-	*	*	*	-	*	*	*	*	*	*	*	*	*	*	-	*
12 Great Eggfly	*	*	*	*	*	-	*	-	*	-	*	*	-	*	*	*	-	*	-	-	-	-	-	*
13 Greycount	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-
14 Common Leopard	-	-	-	*	-	-	*	-	-	*	-	-	-	*	*	*	*	*	-	*	-	-	-	*
15 Common Nawab	-	-	-	-	-	-	-	-	-	-	*	*	-	-	-	*	-	*	-	-	-	-	-	*
16 Blue Pansy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-
17 Chocolate Pansy	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	-	*	*	*	*	*
18 Grey Pansy	-	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19 Lemon Pansy	-	-	-	*	*	*	-	*	*	-	*	*	-	*	*	*	-	*	-	*	-	-	-	*
20 Yellow Pansy	-	-	-	-	*	*	*	*	-	-	-	-	-	*	-	*	*	-	*	-	-	-	-	-

* = Present; - = Absent

#. Species	First year (1994-95)												Second year (1995- 96)											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
21 Rustic	*	*	*	-	-	*	*	-	*	*	*	*	*	-	*	*	-	*	-	-	-	*	-	-
22 Chestnut streaked Sailer	-	-	-	*	*	-	-	-	*	-	-	*	-	*	*	-	*	*	-	-	*	-	-	-
23 Common Sailor	*	*	*	*	*	*	*	-	*	*	*	*	*	*	*	*	*	*	*	-	*	*	-	*
24 Sergeant	-	-	-	*	*	*	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-
25 Yeoman, tamil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-	-	-
Papilionidae																								
26 Southern Birdwing	*	*	-	*	*	*	-	-	*	*	*	*	*	*	*	*	*	*	-	*	*	*	*	*
27 Common Bluebottle	*	*	*	-	-	-	*	*	*	*	*	*	*	*	*	*	-	*	*	-	*	*	-	*
28 Tailed Jay	*	-	-	*	-	-	-	-	*	-	-	*	*	-	*	*	-	*	*	*	*	*	-	*
29 Limebutterfly	-	-	-	*	-	*	*	*	*	*	*	-	*	*	-	*	-	*	-	*	*	*	-	*
30 Common Mime	*	*	-	-	-	-	-	*	-	*	-	-	-	-	-	-	-	*	-	-	*	-	-	-
31 Blue Mormon	*	*	*	*	*	*	-	-	*	-	-	*	*	*	*	*	-	*	*	*	*	-	-	*
32 Common Mormon	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33 Common Peacock	-	*	-	*	-	-	-	-	-	*	-	-	-	-	*	-	-	-	-	-	-	-	-	-
34 Malabar Raven	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	*	-	-	-	-	-	-	-
35 Red Helen	-	*	*	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-
36 Common Rose	-	-	-	*	*	*	*	-	*	-	*	*	*	*	*	*	*	-	-	-	-	-	*	*
37 Crimson Rose	*	-	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38 Spot Swordtail	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-
Pieridae																								
39 Common Emigrant	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
40 Common Grass yellow	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
41 Jezebel	-	-	-	*	*	*	-	-	*	*	*	-	*	*	-	*	*	*	-	-	*	*	*	-
42 White Orangetip	-	-	-	-	-	-	-	-	-	-	-	*	-	-	*	-	-	*	-	-	-	-	-	-

* = Present; - = Absent

#. Species	First year (1994-95)												Second year (1995- 96)											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
43 Great Orangetip	*	*	-	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
44 Yellow Orangetip	*	-	-	-	-	-	-	-	-	*	-	*	*	*	-	-	*	-	-	-	*	-	-	*
45 Pioneer	*	-	-	*	-	*	*	*	*	*	-	-	*	*	-	*	*	*	*	*	*	*	-	-
46 Psyche	-	-	*	*	*	*	-	-	*	-	-	-	-	*	*	*	-	*	-	-	-	-	-	-
47 Common Wanderer	*	-	-	*	*	-	-	-	-	-	-	-	*	*	*	*	*	*	*	-	*	*	*	-
Satyridae																								
48 Gladeye Bush brown	*	-	*	*	*	-	-	-	*	-	*	*	-	*	*	*	*	*	*	*	*	-	*	*
49 Common Evening brown	-	-	-	-	-	-	-	-	-	-	*	-	-	*	*	*	-	*	-	*	*	-	*	*
50 Common Fivering	-	*	*	*	*	*	*	-	*	*	*	-	-	*	*	*	-	*	-	*	*	*	*	*
51 Common Bush brown	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-
52 White Fourring	*	-	*	*	*	*	-	-	-	-	*	*	*	-	*	*	-	*	-	-	-	-	-	*
53 Nigger	-	-	-	-	*	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-	-	-
Lycaenidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hesperidae	-	*	*	*	*	*	*	-	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

* = Present; - = Absent

Appendix V Seasonal abundance of butterflies (mean abundance per 9 counts)

#	Species	SEASON				Sum
		NE Monsoon	winter	Summer	S-W monsoon	
1	Common Crow	57	54	65	112	288
2	King crow	4	1	0	0	5
3	Blue tiger	37	87	46	27	197
4	Glassy tiger	17	36	14	17	84
5	Plain tiger	5	7	10	6	28
6	Striped tiger	7	3	10	9	29
7	Malabar treenymph	1	3	13	0	17
8	Angled castor	0	2	1	0	3
9	Common castor	27	23	10	7	67
10	Tawny coster	1	1	0	3	5
11	Danaid eggfly	24	27	20	14	85
12	Great eggfly	16	7	3	5	31
13	Grey count	3	0	0	0	3
14	Common leopard	4	9	9	2	24
15	Common Nawab	0	3	0	4	7
16	Blue pansy	0	1	0	0	1
17	Chocolate pansy	80	126	35	75	316
18	Grey pansy	1	0	0	0	1
19	Lemon pansy	6	20	7	10	43
20	Yellow pansy	1	12	8	0	21
21	Common rustic	12	3	2	9	26
22	Chestnut streaked sailer	3	6	2	2	13
23	Common sailer	41	80	10	22	153
24	Sergeant	0	8	0	0	8
25	Tamil yeoman	2	2	0	0	4
26	Southern birdwing	18	13	3	9	43
27	Common blue bottle	17	6	6	14	43
28	Tailed jay	11	7	4	5	27
29	Lime butterfly	9	10	14	19	52
30	Common mime	11	2	4	1	18
31	Blue mormon	21	11	7	4	43
32	Common mormon	82	78	30	58	248
33	Paris peacock ssp.	4	1	0	1	6
34	Malabar raven	20	3	0	0	23
35	Red helen	3	0	0	0	3
36	Common rose	8	35	3	13	59
37	Crimson rose	30	41	23	18	112
38	Spot swordtail	0	0	3	0	3
39	Common emigrant	138	45	177	505	865
40	Common grass yellow	93	104	47	91	335
41	Common jezebel	5	17	3	4	29
42	White orangetip	1	1	0	1	3

#	Species	SEASON				Sum
		NE Monsoon	winter	Summer	S-W monsoon	
43	Great orangetip	29	27	23	25	104
44	Yellow orangetip	4	2	1	4	11
45	Pioneer	4	13	15	18	50
46	Psyche	12	13	2	0	27
47	Common wanderer	18	10	3	4	35
48	Glad-eye bushbrown	37	43	8	11	99
49	Common evening brown	6	12	3	7	28
50	Common fivering	23	45	11	10	89
51	Common bushbrown	1	0	0	0	1
52	Wite fourring	25	24	0	9	58
53	Nigger	1	2	0	0	3

Appendix VI List of butterflies which had significant relation with major environmental factors (step-wise regression).

Species	Environmental factors			
	Flower abundance	Young leaf abundance	Bird abundance (Insectivorous)	Humidity
Common Crow			+	
King crow	+			
Blue tiger			+	
Glassy tiger			+	
Angled castor				+
Common castor	+			
Danaid eggfly	+			
Great eggfly	+			
Blue pansy	+			
Chocolate pansy	+			
Yellow pansy			+	
Chestnut streaked sailer			+	
Common sailer	+			
Sergeant	+			
Tamil yeoman	+			
Malabar raven	+			
Red helen	+			
Crimson rose	+		+	
Common jezebel			+	
Great orangetip	+			
Psyche	+			
Common fivering	+			
Wite fourring	+			
Nigger	+			
+ indicate the major factor(s) found affecting the seasonality for each species				