# FOOD AND FEEDING HABIT OF INSECTIVOROUS BATS (CHIROPTERA) OF PEECHI-VAZHANI WILDLIFE SANCTUARY, WESTERN GHATS, KERALA.

by

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## THESIS

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# DECLARATION

I hereby declare that this thesis entitled "**Food and feeding habits of insectivorous bats (Chiroptera) of Peechi-Vazhani Wildlife Sanctuary, Western Ghats, Kerala**" is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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# CERTIFICATE

Certified that this thesis, entitled "**Food and feeding habits of insectivorous bats (Chiroptera) of Peechi-Vazhani Wildlife Sanctuary, Western Ghats, Kerala**" is a record of research work done independently by **Mr. Sachin K Aravind (2012-17-104)** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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# INTRODUCTION

# INTRODUCTION

In their present form, bats have been on Earth for over 52 million years and during this period they have diversified into at least 1,116 extant species (Simmons, 2005). Bats are the second largest group of mammals in the world after rodents. They are found everywhere in the world except in the extreme desert and polar region. Bats have evolved an incredibly rich diversity of behavioral, feeding, and roosting habits. By day, many species occupy caves and cave-like structures, such as tombs, mines and buildings; others roost in tree cavities and foliage, sometimes modifying foliage into unique tent-like structures. By night, bats fill the skies to forage on a diversity of food items ranging from insects, nectar, and fruit, to seeds, frogs, fish, reptiles, small mammals, and even blood (Simmons and Conway, 2003).

Bats are the only true flying mammals. Their forelimbs form webbed wings, making them flying mammals. Bats do not flap their entire forelimbs as birds do, but instead flap their spread-out digits, which are very long and covered with a thin membrane called patagium. Some bats can see with their eyes while others use echolocation to understand the surroundings. Bat echolocation is a perceptual system where ultrasonic sounds are emitted by bats, specifically to produce echoes. By comparing the outgoing ultrasonic pulse with the returning echoes, the brain and auditory nervous system can produce detailed images of the bats surroundings. This allows bats to detect, locate and even classify their prey in complete darkness. At 130 decibels intensity, bat calls are some of the most intense, airborne animal sounds (Arita and Fenton, 1997).

The order Chiroptera contains 1116 species of bats which are sub-categorized as the Megachiroptera (Fruit bats) and Microchiroptera (Insectivorous bats). Recent molecular phylogenetic studies challenged this traditional subdivision and proposed that the bats can be subdivided into two new suborders, Yinpterochiroptera (Pteropodidae, Rhinolophidae, Megadematidae and Rhinopomatidae) and Yangochiroptera (all the remaining families) (Teeling*et al.*, 2005).

Among the estimated 1,116 bat species (Simmons, 2005), over two thirds are either obligate or facultative insectivores. They include species that glean insects from vegetation and water in dense forests to those that feed in open space above forests, grasslands, and agricultural landscapes (Whitaker*et al.*, 2009). Most of the remaining are frugivorous and nectarivorous. Some are carnivorous which feeds on frogs, lizards, rodents etc., piscivorous which feeds on small fishes and vampires which feeds parasitically on other animals for blood.

Foraging modes of bats are of different kinds. Aerial hawking bats captures prey on the fly, either directly capture with mouth or often scooping with patagium or tail membrane and transferring to their mouth. Gleaning bats, those that take prey from surfaces, generally forage in cluttered environments (e.g., dense forests) where background echoes can mask echoes from insects (Jones and Rydell, 2003). Some gleaners are able to actively discriminate targets using low-intensity broadband echolocation calls, whereas others passively listen for prey-generated sounds or use vision and/or olfaction (Neuweiler, 1989). Trawling bats glean insects off the water surface using their long feet and/or tail membrane. Fly-catching and perch-hunting bats hang from perches and wait for aerial and ground-dwelling prey, respectively. These foraging modes, however, are not mutually exclusive, and it is often difficult to categorize a species (Habersetzer and Vogler, 1983).

Bats provide value to ecosystems as primary, secondary, and tertiary consumers that support and sustain both natural and human dominated/anthropogenic ecosystems ranging from the simple to the complex. Insectivorous species, largely feeding on airborne insects and other arthropods, suppress both naturally occurring and anthropogenically-generated insect pest populations (such as agricultural pests and insects that annoy or transmit specific pathogens to humans and other mammals) and contribute to the maintenance of ecosystem stability (Fleming and Racey, 2010). Microchiroptera play an important role in maintaining balance among the insect pest population in forest as well as agricultural land. Insectivorous bats collectively consume large quantities of insects each night. Study on diets of insectivorous bats reveals that some of the bats are selective feeders, which actively select among the available prey population (Siemers and Schnitzler, 2000), others are generalist feeders which feed on a wide diversity of insects and opportunistically consuming appropriately sized prey according to its availability with in a foraging habitat (Barclay and Brigham, 1994).

Insectivorous bat activity and diversity are strongly correlated with arthropod abundance (Wickramasinghe*et al.*, 2003) suggesting that insectivorous bats seek out areas of concentrated prey sources. Although there is considerable variation in the relative proportions of insects consumed by different species, most insectivorous bats eat large quantities of lepidopterans (moths), coleopterans (beetles), dipterans (flies), homopterans (cicadas, leaf hoppers), and hemipterans (true bugs) (Wickramasinghe*et al.*, 2004). Some species also eat unusual prey items such as scorpions, spiders, etc., (Kurta and Whitaker, 1998). Considering this into perspective insectivorous bats can feed on large quantities of insect, which are notable agricultural pests. This in turn increases the importance of bats as bio control agents in insect pest management. Few studies have measured the actual impacts of insectivorous bats on natural or agro-ecosystems. Insectivorous bats can have direct and indirect impacts on pests and plants through both density mediated (consumption) and trait-mediated (behavioral) interactions. Even the presence of insectivorous bats reduces the pest population through behavioral interactions (Huang *et al.*, 2003).

Bats are considered excellent bio indicators because they respond to a wide range of human induced changes in habitat quality and climate, including urbanization, agricultural intensification, logging, habitat loss and fragmentation, global climate change and over hunting for bush meat (Clarke *et al.*, 2005).

Unfortunately, bats face many threats. Bats in western cultures have long been subjects of disdain and persecution and have often been showed in the popular media as rampant vectors of disease, blood-sucking demons, ingredients of witches brew, and, at times, associated with the dark side of religious practices. Common myths include that bats are associated with the devil, extracts from the skin of bats can cure baldness and meat can cure asthma. As with many myths and folklore, there may be some elements of truth, yet the vast majority of real or imagined pictures of bats often portrayed in art, poetry, books, movies, television etc., them as having little redeeming value except to frighten for the sake of corporate or personal profit (Allen, 1962). Bats in India face catastrophic loss of habitat, which decreases foraging areas, reduces prey populations and often forces bats to live in around human habitations. This proximity to human, especially such structures as temples, tunnels and archaeological ruins are used as roosts, often create the gravest threats to bat populations (Mistry, 2003).

Knowledge of the ecology of bats and their habitats and roosting requirements is needed in many areas in order that land management policies may allow for the protection of roosts and foraging areas (Nowak, 1994). Field work carried out on bats can contribute to the information that is required for their conservation throughout the world. Even in the most basic form, data on species present, altitudinal range and habitat use, for example, from any area that has been poorly studied is worth collecting.

The present study envisage to understand the feeding habits and food preference of insectivorous bats of Peechi-Vazhani Wildlife Sanctuary. The information brought in would be of immense use for the managers of the protected areas, so that at the time of planning and implementation of the management strategies of the protected areas, they can take into consideration these group of animals too. Such basic information on feeding habits and food preference of bats can enlighten the economic importance of bats and also ensure conservation of this group of mammals.

# REVIEW OF LITERATURE

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## 2.1 ORDER CHIROPTERA

Bats belong to the order chiroptera (cheiros - hand and pteron - wing) and it includes 1116 species (Simmons, 2005). But as per IUCN Red List of Threatened Species, there are 1150 species of bats in the world (IUCN, 2010). Bats are the second-most species rich group of mammals after rodents. They make up around 20 percent of all known living mammal species. In some tropical areas, there are more species of bats than of all other kinds of mammals combined (Hill and Smith, 1984).

Pre-bats were small, quadrupedal, arboreal creatures resembling insectivores which probably began by gliding from tree to tree. Subsequently they evolved powered flight which is used by both Mega and Micro chiropterans today. Kunz (1982) stated that the evolution of flight and echolocation in bats was undoubtedly a prime factor in the diversification of feeding, roosting habits, reproductive strategies and social behaviors.

According to the old classification, the order Chiroptera has two suborders, the *Megachiroptera* (megabats) and the *Microchiroptera* (microbats). All of the megachiropterans belong to the same family, *Pteropodidae* (flying foxes or the Old World fruit bats), while the microchiropterans have been distributed across a total of 17 families (Altringham, 1996).

The 1116 species of bats are distributed in 18 families (Simmons, 2005). Megachiroptera includes 186 species in one family, Pteropodidae. The remaining 17 families (930 species) belong to the suborder Microchiroptera.

Bats are widely distributed and have been recorded throughout the world excepting the Antarctic and a few Oceanic Islands (Mickleburgh*et al.*, 2002). Of the 18 families of bats, eight families (Pteropodidae, Rhinopomatidae, Nycteridae, Megadermatidae, Rhinolophidae, Hipposideridae, Myzopodidae and Mystacinidae) are restricted to the Old World; six families (Noctilionidae, Phyllostomidae, Desmodontidae, Natalidae, Furipteridae and Thyropteridae) are restricted to the New World; and three families (Emballonuridae, Molossidae and Vespertilionidae) are found both in the Old and New Worlds (Mickleburgh*et al.*, 2002; Simmons 2005).

### 2.1.1 Megachiroptera and Microchiroptera

The Old World fruit bats are confined to the Old World tropics and feed exclusively on, flowers, nectar, pollen and fruit. They are generally larger than Microchiropterans, with forearm lengths of 40–220 mm. They weigh from 20 g to 1.5 kg, with wingspan approaching 2 m. Most fruit bats have rather dog-like faces, hence the name flying foxes. They generally have large eyes, simple ears and muzzles. Skull and jaws are typically adapted to deal with tough-skinned fruit. Although most Megachiropterans are brown in colour, some are patterned or otherwise brightly coloured. With the exception of genus *Rousettus*, Megachiropterans do not use echolocation, but rely on vision and smell for orientation (Altringham, 1996; Nowak, 1999). Megachiropterans inhabit South-Asia, Sub-Saharan Africa and western parts of Oceania, including northern Australia.

The Microchiropterans, as the name states, are generally smaller than Megachiropteran bats. The Microchiroptera show considerable variation in form and structure. They range in size from very small with forearms of 22.5mm, to moderately large with forearms of 115.0mm. Many species have nose leaves or other dermal outgrowths above the nostrils or on the lips. A tragus (a lobe of skin inside the pinna of the ear) is usually present. The interfemoral membrane is usually well developed and the tail relatively long. The second digit lacks a claw and the eyes are generally small (Hutson *et al.*, 2001). Many Microchiropterans have become specialized to eat different kinds of foods. While all Microchiropteran families prey upon insects to some extent, a few feed on fruit, nectar and pollen and three species in one subfamily, Desmodontinae, feed on vertebrates and blood. Some bats are carnivorous (feeding on other bats, rodents, birds, reptiles, amphibians, and even fish). The ears are often large and complex, and many species have Nose-leaves. Both features are associated with echolocation, and all species of *Microchiroptera* have advanced echolocation capabilities. Although most species have small eyes, they often have a good vision. There are species which are able to locate their prey without echolocation, by listening for prey generated sounds or by using vision. Microbats probably have insectivorous ancestry and that is reflected by their teeth, despite their diversification into a wide range of diets. Microbats inhabit all continents except Antarctica and the arctic regions (Altringham, 1996).

Megachiropterans and Microchiropterans differ in many ways. Megachiropterans found only in the Old World tropics, while Microchiropterans are much more broadly distributed. Megachiropteran species control their body temperature within a tight range of temperatures and none hibernates; many Microchiropterans have labile body temperatures, and some hibernate (Hill and Smith, 1984; Nowak, 1991).

Phylogenetic analysis with diverse methods resulted in a well-resolved phylogeny, dividing the order Chiroptera into two suborders and four super-familial groups, rendering Microchiropterans paraphyletic. The two suborders in the new molecular based classification are Yinpterochiroptera (includes the families Pteropodidae, Rhinolophidae, Megadermatidae and Rhinopomatidae) and Yangochiroptera (includes all the remaining 14 families) (Teeling*et al.*, 2005).

## 2.2 ECHOLOCATION IN BATS

Bats are one of the most extraordinary mammal orders. Not only they are the only flying mammals, but they also possess the capability of advanced echolocation. Even in bats, echolocation is not a pervasive trait. Microbats and the *Rousettus* genus of Megachiropterans use high frequency echolocation and rely on hearing as their major locational sense. The frequencies used in echolocation by bats fall usually between 25 kHz and 100 kHz, although some species emit and analyze principal components as high as 150 kHz (Grinnell, 1995). The size and echo reflectance of the insect and, importantly, the frequency and intensity of the echolocation calls determine the prey detection range in the dark (Houston *et al.*, 2003; Surlykke and Kalko, 2008). Since the lower frequency calls are less affected by atmospheric attenuation, they reach further than high frequencies. The long, quasi constant frequency calls (between 10 and 20 kHz ) of large aerial hunting bats, might result in maximum detection distances of several meters for very large insects and for night-migrating passerine birds that some bats prey upon (Estok*et al* ., 2009). But in most bats, prey detection ranges are restricted to at most a few metres (Holderied and von Helversen, 2003; Surlykke and Kalko, 2008), owing to the high absorption of ultrasound in air and the low target strength, especially of small insects.

Bat echolocation has a dual role: it is used by bats for orientation and foraging, but can also communicate species identity (Voigt-Heucke *et al.*, 2010), individual identity (Kazial *et al.*, 2008; Yovel *et al.*, 2009), sex (Kazial and Masters, 2004) and group affiliation (Voigt-Heucke *et al.*, 2010). The authors, Voigt-Heucke *et al.* (2010) were not aware of any other taxon in which a ubiquitous behavior exhibited by an animal explicitly for a non-social purpose, such as orientation, additionally serves a function as a signal for its conspecifics.

### 2.2.1 Types of calls in bats

Bats are a special case in acoustic communication as they possess two different call types: social calls, exclusively used in social interactions, and echolocation calls, emitted for orientation and foraging. In contrast to ultrasonic echolocation calls, social calls are often lower than 20 kHz in frequency and thereby in principle sounds audible to humans, and usually of multiharmonic structure (Fenton, 2003). Social calls have been shown to be individually distinct (Carter *et al.*, 2008), or be used also in general for a group (Racey and Swift, 1985), to mediate group foraging (Wilkinson and Boughman, 1998), for courtship displays (Behr and von Helversen, 2004) and territorial interactions (Behr *et al.*, 2006). By contrast, echolocation has for a long time only been viewed as an acoustical tool that enables bats to orient in darkness, a prerequisite for the location of prey and navigation at night (Griffin, 1958; Schnitzler *et al.*, 2003).

## 2.3 FEEDING BEHAVIOUR

Knowledge of the dietary composition can provide better understanding of the ecology and behavior of a species, and dietary information is essential for effective management of any species (Kurta and Whitaker, 1998). Different species of animals feed on different food types whereas closely related species and individuals of same species of animals depend on almost same food resources. The type of food composition predicts an animal's basal metabolic rate, which, in turn, determines aspects of the animal's population ecology and home-range size (McNab, 1980). More than the dietary composition, studies on feeding habits of animals serve knowledge about the feeding location, feeding method, feeding time, quantity of food and food preferences of the animals. Understanding the diet of a threatened animal species is particularly important, because a population decline may be related to the diet; for example, lack of suitable prey may affect the population of a species (McKenzie and Oxford, 1995) or exposure to toxic chemicals fed through contaminated prey (Clawson and Clark, 1989). Feeding behavior reflects the energy demands during various stages of animal life. For example, increased food consumption in lactating bats accommodated reproductive energy demands and was facilitated by raising food availability. Bats produce new offspring when they can consume maximum food. During period of winter, as a result of low food availability and low temperature, bats limits their activities to reduce the energy needs and some of them may turn into hibernation. (Anthony and Kunz, 1977).

Most bat species of the world are almost exclusively feed on different insects. Insectivorous bats mostly capture insects from the air, but some may glean from foliage, ground or even water surface. Bats are voracious feeders and can consume a sizable portion of their body mass each night in insects, an estimated 30-50 percent of their body mass. Most food of insectivorous bats consists of around 30-40 main types. Bats do not eat different kinds of insects at one time. So that a faecal pellet often contains only one to four types of insects (Whitaker *et al.*, 2009). Bats usually feed on traditional foraging habitats. They spent majority of the feeding time on the traditional foraging grounds where insect availability is sufficient for the bat population. They selected alternative, more abundant and more profitable prey at certain times of the year, mostly by switching from their traditional feeding habitats to secondary (mostly temporary) foraging grounds. This provides them with the maximum feeding at low expense of energy and satisfies increased energy demand during the reproductive period. While exploiting temporary feeding grounds, the bats visit usually between two and five foraging patches on the same night. The closer the patches, the more frequently the bats switched between the patches. The flight speed is comparatively less during feeding and greatest when the bats were commuting from feeding grounds to their roost at dawn (straight flight at many meters above the ground); some bats travels at a speed of60 miles per hour (Arlettaz, 1996).

Among the estimated 1,116 bat species globally (Simmons, 2005), over two thirds are either obligate or facultative insectivores (Whitaker *et al.*, 2009). Based on the foraging behavior, 113 species of Indian bats can be classified into frugivorous (13 species), insectivorous (97 species) and carnivorous (2 species) (Bates and Harrison, 1997). Faecal analysis of insectivorous bats revealed that, diets of individual bats were diverse. All available insects (3 to 10mm in body length) were accepted as food items (Anthony and Kunz, 1977). Insectivorous bats feed on different orders of class insecta and spiders. Forest bats feed predominantly on Coleoptera, Homoptera, Lepidoptera, Hemiptera, Orthoptera, Odonata and Araneae while semi urban bats preferred Lepidoptera, Coleoptera, Diptera and Hemiptera (Jacobs, 1999). Some of the bats like *Megaderma lyra* shows cannibalism, piscivory and carnivory (Madhavan, 2003).

Insectivorous bats mostly consume flying insects during flight. Studies on the diet and feeding behavior of insectivorous bats have confirmed predictions based on wing morphology that a large proportion of species are able to catch prey from surfaces (Fenton and Bell, 1979). The insectivorous bats never searched by walking on the ground. The bat seized the prey in its mouth, briefly struck its mouth at the thorax or possibly at the inter-femoral membrane and took off immediately. Prey was never eaten on the ground, but uneaten parts were discarded on the wing during a slow, widely circling flight (Arlettaz, 1996). Microchiroptera have been reported to glean prey from all types of surfaces: water, ground, grass, cliff walls, tree bark, branches or leaves. Preys include flightless insects as well as newborns, larvae of insects (Fenton, 1982).

Insectivorous bats start feeding in the evening and may continue till dawn. Peak activity time of different insectivorous bat species varies considerably. Feeding time of each night can be considered as before midnight and after midnight foraging period. Food intake after midnight was generally less than during the first foraging bout. Over 60 percent of the total nightly intake occurs before midnight bout, when insect availability was highest. During day time insectivorous bats completes their process of food digestion and absorption. They start night feeding with its stomach completely free of foods. But there may be faecal matter content in the gut as remnants of the previous meal. So that the faecal matter collected during day time may be of previous days feeding (Anthony and Kunz, 1977).

Kunz *et al.* (1995) studied on the dietary energetics of Mexican Free-tailed Bat. According to them, stomach content analysis of pregnant and lactating female individuals of *Tadarida brasiliensis* revealed that the diet, expressed as percent volume, consists largely of lepidopterans, coleopterans, hymenopterans and dipterans, in decreasing order of percent volume. They found no significant difference in the diet of pregnant and lactating females when expressed as percent volume. However, when expressed as percent frequency, proportionately more pregnant females fed on lepidopterans, coleopterans and dipterans than did lactating bats and proportionately more lactating females fed on hymenopterans. Average energy density of bat stomach was 31.2 kJ/g dry mass. This relatively high energy density of stomach contents, as compared to whole insects, can be attributed to the consumption of insects high in lipid content (especially flying ants) and the abdomens only of moths and beetles (other body parts culled and discarded). Estimates of food intake in night increased markedly from mid to late pregnancy, stabilized or decreased during late pregnancy, and increased again during early to mid-lactation, may be due to high energy demands. Average nightly feeding rate doubled from pregnancy to lactation and increased threefold during the first half of lactation period.

Feldhamer *et al.* (1995) studied on the diet of the food of Evening Bat (*Nycticeius humeralis*) and Red Bat (*Lasiurus borealis*). They observed that Coleopterans represented the primary food item by volume for evening bats and red bats. The single most important food for evening bats was the spotted cucumber beetle in the study area; a significant agricultural pest and this individual species were consumed by 7.9 percent of the diet by red bats.

Whitaker (1995) studied on the diet of *Eptesicus fuscus* from maternity colonies in Indiana. He observed that the insect eaten by Big Brown Bats (*Eptesicus fuscus*) in Indiana were mostly agricultural pest species: scarab beetles (Scarabaeidae), the spotted cucumber beetle (Chrysomelidae), stinkbugs (Pentatomidae) and leafhoppers (Cicadellidae). Larvae of the genus *Diabrotica* were also present, they are called corn rootworms, probably one of the most important agricultural pests in Indiana. Feeding of bats commenced in spring and ceased by the second week of November. Spotted cucumber beetles were important foods in early April, then again in late summer and autumn. Scarabs were important component of diet throughout the bats active season. Green stinkbugs were most heavily eaten in late May and early June and again in September. Dipterans, Lepidopterans, Trichopterans and hymenopterans were minor foods in diet. They suggested that since big brown bats are so beneficial, these species must be protected legislatively, perhaps federally, by an act. Farmers should not evict or otherwise persecute bats, but should encourage these insectivorous bats to form maternity colonies near agricultural lands. Also, bridges could be designed in such a way as to encourage bats to use them as roosts.

Lacki*et al.* (1995) observed on the food habits of Gray Bats (*Myotis grisescens*). According to them eleven families from nine orders of insects were eaten by these insectivorous bats, with Coleoptera, Trichoptera, Diptera, and Lepidoptera occurring at the highest percent volumes. They also fed on Hemiptera, Homoptera, Hymenoptera, neuropteran, Orthoptera and Plecoptera. Three coleopteran families (Carabidae, Chrysomelidae and Scarabaeidae) were common in the diet of gray bats. Ephemeropterans were not observed in faecal samples, in contrast to their availability at foraging sites. Data indicate that gray bats foraged both opportunistically and selectively at that site.

Whitaker *et al.* (1996) studied about the dietary variation in *Tadarida brasiliensis*, they found that lactating female individuals fed largely on coleopterans and lygaeid bugs during evening feeding bouts and mostly on moths during morning feeding bouts. These results suggest that interpretations of food habits in this and other species may be biased unless samples from both nightly feeding bouts are included in the faecal matter analysis. Diets of different individuals during the same feeding bout were strikingly similar, suggesting that lactating females either fed in the same general habitats or they encountered or preferentially fed on similar prey items among those available during the feeding time in the study area. More food is eaten in the first feeding bout than second feeding bout. Faecal matter analysis indicates that at least five pellets are needed to establish the number of insect taxa consumed by a bat.

Whitaker *et al.* (1997) studied on the diet of Red Bat (*Lasiurus borealis*) in winter. It was generally assumed that during winter insectivorous bats in temperate climates hibernate and thus do not feed, whereas bats in warmer climates remain active and do feed. However they observed, bats often fly in winter, even in higher latitudes, and it has been assumed that they were feeding, based on small quantities of chitin in intestines and on the occurrence of feeding buzzes. During the study digestive tracts of Red Bats (*Lasiurus borealis*) collected in winter were analyzed and reported that these bats fed on insects of the orders Lepidoptera, Diptera, Coleoptera, Hymenoptera and Hemiptera during winter season.

Kurta and Whitaker (1998) studied on the diet of the endangered Indiana Bat (*Myotis sodalis*) on the Northern Edge of its range. According to them dietary preferences of Indiana bats were determined by analyzing 382 faecal pellets collected beneath roost trees in southern Michigan, over parts of 3 years. Although terrestrial insects (Lepidoptera and Coleoptera) usually dominated the food items of Indiana bats in more southern states, those in Michigan consumed mostly insects associated with aquatic environments. Indiana bats in Michigan fed primarily on Trichoptera (55.1% of volume) and Diptera (25.5%), followed by Lepidoptera (14.2%) Coleoptera (1.4%) Hymenoptera (1.1) and Neuroptera (0.9%). Consumption of Diptera was highest during lactation (48.2%), whereas consumption of Lepidoptera was least during this time (7.7%). Although most insectivorous bats were assumed to be not feeding on mosquitoes (Culicidae), but these insects were a consistent component of the diet of Indiana bats and were eaten most heavily during pregnancy (6.6%).

Vertis *et al.* (1999) studied temporal variation in prey consumed by Big Brown Bats (*Eptesicus fuscus*). They observed that there is temporal variation in prey consumed by bat and availability of insect. Also there is variation in diet when considering life stages of bat like juvenile adult and pregnant bat.

Fenton *et al.* (1999) studied diet of bats of Southeastern Brazil and relation to echolocation. They observed that echolocation frequency made selective feeding in insectivorous bats. Response of each insect types to the echolocation and bats ability to locate and capture it varies according to species of bat and type of insect. Bats which can easily detect insects by echolocation on flight fed on flying insects more. Also predictions on insects species fed by bats based on echolocation frequency and insect type found to be true in the actual situation which adds to the importance of echolocation in makeup of the feeding behavior of bats.

Whitaker and Yom-Tov (2001) studied on the diet of insectivorous bats of Northern Israel. They studied on three different species of insectivorous bats *Rhinopoma microphyllum, Rhinopoma hardwichei* and *Asellia tridens*. They found that diet of these bats include insects from the orders Coleoptera, Diptera, Hemiptera, Heteroptera, Homoptera, Hymenoptera, Isoptera, Lepidoptera, Orthoptera, Plecoptera and Trichoptrera and also spiders.

Whitaker and Weeks (2001) studied on the diet of Big Brown Bat (*Eptesicus fuscus*) at a location at Indiana where agricultural fields were not present. And they compared this result with the diet of *Eptesicus fuscus* from agricultural areas where these bats fed predominantly on agricultural pests. They observed that diet of *Eptesicus fuscus* is almost same in both cases. Scarabaeid beetles, spotted cucumber beetles *(Diabrotica undecimpunctata),* green stink bugs, carabid beetles, other beetles, cicadellid bugs and lepidopterans were the most important foods in both foraging areas, although the order varied somewhat. In this study they radio tagged one individual of big brown bat, they observed that these bats travel more than 5 km during the feeding bout. Also they concluded that this may be the reason behind the similarity in diet in both cases.

During the study of diet of bats in Indiana by Brack and Whitaker (2004), faecal pellets from 97 individuals of seven species of bats were collected using cloth bags. Faecal matter from each bat was treated as a single sample for analysis. Foods were identified and percent volume estimated visually for each faecal matter sample. They could identify insects of the order Lepidoptera, Coleoptera, Diptera, Trichoptera, Hymenoptera, Neuroptera, Hemiptera, Homoptera and Orthoptera.

Whitaker (2004) studied prey selection of insectivorous bats in a temperate zone to test the null hypothesis that insectivorous bats eat primarily whatever is available in the foraging area. During the study they collected faecal samples of eight species of bats from the same location. But this study proved that different bat species fed on different insects selectively. Bats selectively fed on insect orders Coleoptera, Lepidoptera, Homoptera, Hemiptera, Diptera, Trichoptera, Neuroptera, Orthoptera and Hymenoptera.

Whitaker and Barnard (2005) studied diet of big brown bat from a colony at Georgia.Based on analysis of faecal pellets, they found that June bugs (Scarabaeidae) were the most abundant food of big brown bats (*Eptesicus fuscus*) forming 36.9 percent of the food overall. They were eaten heavily early in spring and less so in late summer. Ground beetles (Carabidae) were the second most abundant food item (12.1%) of the diet overall. Beetles, collectively, made up 57.7 percent of the faecal sample, followed by hymenopterans (10.7%; composed primarily of Formicidae), dipterans (10.5%), Homoptera (8.8%) and Hemiptera (5.0%). Lepidopterans made up 2.8 percent of the diet. Most of the insects under Scarabaeidae are agricultural pests adds to the importance of insectivorous bats.

Walters *et al.* (2007) observed foraging behavior of Eastern Red bats (*Lasiurus borealis*). During the study 13 individual bats of different age radio tagged and released. Observation on the movement of radio tagged individual bats revealed that they were having smaller home ranges when compared to other species of same area and foraged in woodlands and over newly planted tree fields, open water, park and pasture lands more than predicted by randomly generated points and avoided highly urban areas such as commercial lands, gravel pits and transportation corridors.

Whitaker *et al.* (2007) studied about the food habits of Rafinesque's Big-eared bat. They found that these bats fed primarily on moths throughout much of the year, although they fed a few other insects, mainly flies and beetles. 99.4 percent of the total faecal pellets contained Lepidopterans and 82 percent of the faecal pellets contained 100 percent Lepidopterans. This indicates that these bats are very much specialized in foraging on Lepidopterans especially moths. Also they could observe that these bats fed on insects of the order Lepidoptera, Diptera, Hemiptera, Coleoptera and Trichoptera.

According to Whitaker *et al.* (2009), insect parts can be collected from either stomach content or faecal pellets. For analysis of stomach content, bats should be killed immediately upon capture to minimize digestion in stomach. This approach raises ethical and legal issues with respect to sampling large or even small numbers of bats, especially when threatened species are involved. Analysis of faecal content helps to conduct nondestructive sampling (Kunz and Whitaker, 1983). While it is true that most bats thoroughly chew their food, it is usually possible to identify most prey remains in faecal matter to a reasonable level, at least to order and often to family and also insect parts are more concentrated in faecal matter than the stomach content. And less volume of faecal matter is required for analysis than stomach content (Black, 1972).

Certain food items are very difficult to identify to family or beyond because of the tiny pieces left after parts have been culled and discarded, and where the remainder has been finely chewed by bats. Advantage of stomach content analysis is that insect parts are not so damaged as in the faecal matter and insect parts remain partially intact connected together by musculature and other tissues which facilitates easy identification and enumeration of insect parts (Kunz and Whitaker, 1983). For the food analyst examining stomach content or faecal matter, lack of culled parts can increase difficulty of identification because these items often include diagnostic characters. Moths are easy to identify to order level, because they are represented by a large mass of scales mixed with other parts. Problems associated with differential digestion of food are not so serious in case of insectivorous bats because most food passes through the alimentary canal of bats rapidly and most insects have hardened exoskeletons composed mostly of protein and chitin. Faces can be collected from individually captured bats that subsequently can be immediately released unharmed. Faeces also can be collected beneath roosts, assuming that identity of the bats is known and that there is no contamination from bats of other species from nearby roosts or any other species occupying the same roost (Whitaker *et al.*, 2009)

One of the potential biases encountered in faecal matter analysis is that bats may cull insect parts before ingestion. It becomes difficult to identify the insect if parts possessing identifiable characteristics are lost (Kunz and Whitaker, 1983). A criticism over faecal matter analysis method is that soft bodied insects may get digested and become unrecognizable, results in under estimating the kinds and quantity of the insects actually eaten by bats. Food habit analysis of mammals including insectivorous bats are generally expressed in terms of percentage frequency based on the number of individuals in which a food component occurred and percentage volume based on volumetric measurements (Kunz, 1974). When examining pellets from beneath the roost, each pellet is considered as a sample for statistical purposes (Whitaker *et al.*, 2009).

According to Kunz and Whitaker (1983), to evaluate the reliability of faecal analysis in determining food habits of insectivorous bats, individual insects of different orders were identified to major taxa by the first author, weighed, enumerated and fed to 14 female little brown bats (*Myotis lucifugus*). Faecal pellets were collected from these insectivorous bats and sent to the second author without informing him of the insects which had been fed to the bats. The second author identified the insect fragments from the faecal pellets and determined the percent volume and percent frequency for each insect order. The four most common insect taxa recovered in the faecal pellets were the same as those in the diet and occurred in the same order of importance when expressed as percent volume and percent frequency. Whitaker could identify insects of Lepidoptera, Trichoptera, Culicidae, Tipulidae, Neuroptera, Diptera, Chironomidae, and Coleoptera from faecal pellets through faecal matter analysis. This blind test was the first to demonstrate that faecal analysis can generate reasonable estimates of food items eaten by insectivorous bats.

Hard exoskeleton of insects contains polymer chitin which is generally found undigested in the faecal matter of insectivorous bats. Insectivorous bats chew their food into very tiny pieces, thus exposing more digestible soft parts to digestive processes. Chitin is resistant to the typical digestive system, resulting in parts of legs, antennae, and wings passing through the tract fully intact. But some species of bats have got an enzyme chitinase, which can digest chitin in their alimentary canal. According to Whitaker *et al.* (2004) chitinase was found in the intestines of nine species of six genera of insectivorous bats of Indiana. Species under study were the Northern Myotis (*Myotis* *septentrionalis*), the Little Brown Myotis (*Myotis lucifugus*), the Indiana Myotis, (*Myotis sodalis*), the Big Brown bat (*Eptesicus fuscus*), the Eastern Pipistrelle (*Pipistrellus subflavus*), the Evening Bat (*Nycticeius humeralis*), the Red Bat (*Lasiurus borealis*), the Hoary Bat (*Lasiurus cinereus*), and the Silver-haired Bat (*Lasionycteris noctivagans*). Chitinase was found in summer and in winter, but at significantly lower levels in winter season. Chitinase in summer may help to separate body parts of insects by breaking down softer connective tissue. In winter, it may break down remnants of chitin left over from summer foraging and could even serve as a supplemental source of energy and nutrients. Chitinase was produced in these bats by six previously known species ofchitinase-producing bacteria, two of *Serratia*, three of *Bacillus*, and one of *Enterobacter*, and by four species previously unknown to produce chitinase, *Hafnia alvei*, *Citrobacter amelonaticus*, *Enterobacter aerogenes* and *Enterobacter cloacae*. This suggested that chitinase has little visible effect on heavier chitinous body parts in summer since the food rapidly passes through the alimentary canal, and during winter the remnants of chitin were digested slowly producing small energy during hibernation.

## 2.4 ECOSYSTEM SERVICES

### 2.4.1 Bats as bio control agents in insect pest suppression

Insectivorous bats are integral components of terrestrial ecosystems. Insectivorous bats play a crucial role in reducing the insect pest population of agricultural and forest areas. They feed large quantity of insects each day and majority of these insects are pests (Anthony and Kunz, 1977). This reduces the cost on pest management in both agricultural as well as forest lands. Also helps in gaining more economic output. This presents both ecological and economic rationales for their protection (Pierson, 1988). Even though insectivorous bats mainly feed on insects but some bats eat small vertebrates also. The Indian

False Vampire Bat (*Megaderma lyra*) is considered as a good friend of farmers as this species consume rats and mice which destroy different agricultural crops (Sinha, 1986).

Based on the food composition in diet, number of total insects per faecal pellet, number of specific agricultural pest species in each pellet, and the number of active foraging days per year, Whitaker (1995) calculated that a colony of 150 big brown bats (*Eptesicus fuscus*) annually consumes approximately 600,000 cucumber beetles, 194,000 June beetles, 158,000 leafhoppers, and 335,000 stinkbugs. Subsequently, assuming that each female cucumber beetle lays 110 eggs, this average-sized bat colony could prevent the production of 33,000,000 cucumber beetle larvae (corn rootworms), which are severe crop pests. While these calculations include a large number of assumptions and ignore various sources of natural variation from the data, this study took the extra step in translating ecological data into a form more readily appreciated by the public. With the addition of data on corn rootworm damage to crops in the study area, an economic value for this colony could be estimated (Whitaker, 1995).

At peak lactation, a female Brazilian Free-tailed Bat (*Tadarida brasiliensis)* can consume up to 70 percent of her body mass in insects each night. Also these bats frequently culls her prey, consuming only the nutrient-rich abdomen of moths while discarding the wings, head, and appendages, which greatly increases feeding efficiency and hence the quantity of insects consumed (Kunz *et al*., 1995). To put this in perspective, an average populated maternity colony of one million Brazilian free-tailed bats weighing 12g each could consume up to 8.4 metric tons of insects in a single night. These studies hint at the immense capability of nightly insect consumption and at the potential role of bats in suppression of arthropod populations.

### 2.4.2 Redistribution of nutrients from guano

Guano from bats has long been mined from caves for use as fertilizer on agricultural crops due to the high concentrations of elements like nitrogen and phosphorous, the primary limiting nutrients of most plant life. Although the benefits of nitrogen and phosphorous to plants are well known, most of the evidence supporting bat guano as fertilizer is anecdotal. Because bats regularly or occasionally roost in caves, they are thought to provide the primary organic input to cave ecosystems, which are inherently devoid of primary productivity in the absence of sunlight. Cave-dwelling salamander and fish populations and invertebrate communities are highly dependent upon the nutrients from bat guano (Culver and Pipan, 2009). Bat redistribute nutrients by guano, like pepper-shaker effect because insectivorous bats consume energy rich insects, do rapid digestion during flight, and forage significant distances over heterogenous habitat types, it is expected that guano is sprinkled over the landscape throughout the flight. Thus, bats contribute to nutrient redistribution from nutrient-rich sources or areas (e.g., lakes and rivers) to nutrient-poor regions (e.g., arid or upland landscapes). Reichard estimated that a colony of one million Brazilian free-tailed bats, *Tadarida brasiliensis*, could contribute 3,600,000 kJ/day of energy and 22,000 g of nitrogen in the form of guano to roost area. He also demonstrated that moderate applications of guano in a controlled greenhouse experiment promoted growth in a grass species (Indian grass, *Sorghastrum nutans),* but reduced root/stem ratio and had a neutral effect on two other native species: little bluestem, *Schizachyrium scoparium*, and prairie coneflowers, *Ratibida columnifera*, respectively. He further speculated that guano deposition in roost and foraging area may have species specific effects on plant communities and thus emphasize the need for more in-depth experimental and field studies (Reichard, 2010).

### 2.4.3 Indicators of Habitat degradation

Bat assemblages may be useful indicators of habitat disturbance and quality (Fenton *et al.*, 1992). Bat population declines as a result of various disturbances to habitats like habitat loss, habitat fragmentation, hunting, anthropogenic activities, and various pollutions (Racey, 1998). Diversity and abundance of bats can be regarded as an indicator of disturbance to the habitat (Medellin *et al.*, 2000).

### 2.4.4 Bats in medicine and culture

Bat symbols appear in historic artifacts, such as wall paintings in Egyptian tombs from 2000 B.C., Chinese bowls carved in white jade, Japanese prints, and ancient temple paintings of the Mayan bat god. In fact, the Mayan "Zotzil," or the bat people, continue to live in southern Mexico and Guatemala even in cities with the same name: "Tzinacantlan," or the Bat City. Such cultural things are not only symbolically cherished for their historical significance but also generate direct revenue for the countries and museums that display them to curious tourists. Bats have also long been used for making food and medicine. Witches and sorcerers used bats in ancient magic to induce desire and drive away sleep. Shamans and ancient physicians used bats to treat ailments of patients ranging from baldness to paralysis. Some of these traditions continue today, even though bats are now consumed primarily as bushmeat (Allen, 1962). One exception for this is the anticoagulant compound that is found in the saliva of the common vampire bat, *Desmodus rotundus*. This compound, Desmodusrotundus Salivary Plasminogen Activator (DSPA), has attained considerable attention from the medical community as a potential treatment for strokes because, unlike the alternatives, it can be administered much later after a stroke has occurred and still be effective (Schleuning, 2000). Today, bats provide aesthetic value through cave visits, nocturnal tours and educational nature programs in national parks. These activities provide adventure and life memories for the public and revenue for the communities and corporate companies involved. Bats also commonly appear as symbols or logos in popular movies (e.g., *Batman*), products (e.g., Bacardi rum), and services (e.g., Halloween), all major revenue-generating endeavors (Norberg, 1999). Finally, the study of bat echolocation and locomotion has provided inspiration for advanced technologies in such fields as sonar systems, biomedical ultrasound and sensors for autonomous systems, wireless communication, and BATMAVs (bat-like motorized aerial vehicles) which are used mainly in important fields like defense, communication and medicine. Although extremely difficult to quantify the values, it is important to recognize value of bats to ancient and contemporary traditions and science.

## 2.5 THREATS

Bat populations are declining globally as a result of an increasing number of factors such as habitat loss and fragmentation, disturbances to roosts, exposure to toxins, human hunting pressures and introduced predators (Racey, 1998).

Insectivorous bats are very much susceptible to the accumulation of toxins (e.g. pesticides) because of their high trophic level and long lifespan. Toxic substances enter the body through intoxicated preys (Clark, 1988). Knowledge of the feeding behavior of bats is useful for identifying potential sources of toxins (Clawson and Clark, 1989). Currently, chemical pesticides are the primary agent of reducing agricultural pest population, which undoubtedly makes wildlife at danger of chemical exposure. Pesticide exposure may be an important factor of decline for some populations of insectivorous bats, especially species whose diet includes a substantial portion of agricultural insect pests (Smith, 1987; McLaughlin and Mineau, 1995). Pesticides have a number of effects on various bat species. These include direct mortality (Clark, 1981; Clark *et al.*, 1983), altered behaviour (Clark, 1986; Clark and Rattner, 1987) and transfer of toxins to their offsprings (Clark and Lamont, 1976). The adverse impacts of organochlorine pesticides (e.g. DDTs) on bats have been well-documented (Clark, 1981, 1988). In some countries organochlorines have been banned and organophosphate and carbamate pesticides are suggested as alternatives, although organochlorine residues are still present in soils and still accumulate in bat populations throughout the globe (Thies and McBee, 1996).

Bats roosting in buildings, caves and mines are more vulnerable to human disturbance and exclusion from the roost area. Human disturbance to roosts, including the activities of hunters or even researchers, can have negative effects on resident bat populations (Mohr, 1972). Tuttle (1975) reported that anthropogenic disturbances to maternity colonies of Gray Bat (*Myotis grisescens*) can result in very heavy mortality of the young ones, who may be left in roosts by fleeing females. Increased flight activity and echolocation by hibernating bats occurs as a result of human presence and disturbances, which may end in premature depletion of fat reserves as the reserves are used for energy requirement which cause increased winter mortality due to starvation. This potentially important source of mortality requires more study, particularly because population census by researchers and hunting by hunters occurred when bats are highly aggregated in hibernating period (Thomas, 1995).

Bats roosting in caves, mines, tree holes, abandoned buildings are also vulnerable to environmental disturbance and disasters (e.g. floods and structural collapse). With some foresight, structural collapse and floods may be avoided, although providing protection for all roosts is probably not feasible. Caves and mines supporting large populations or high species diversity should be assessed and given special protection (Arita, 1996). Attempts at exclusion from buildings are same as habitat destruction, the impacts of these practices on bats may be expected to include low survival and reproduction. Proximate causes of these effects may include occupation of buildings with less favorable microclimates and greater distances to water and foraging areas (Neilson and Fenton, 1994).

Some insectivorous bat species have very specific roost and habitat requirements. Loss or alteration of roosting and feeding habitat may powerfully affect bat species with these specific characteristics. It has been stated that land-use change is one of many factors leading to recent insectivorous bat population declines (Crampton, 1995).

## 2.6 CONSERVATION

Conservation aspect of insectivorous bats includes several components of bat conservation. Important components among them are protection of foraging habitat, protection of the prey base and protection of bat roosts (Fenton, 1997; Pierson, 1998). Protection of foraging habitat is the most important component. For many species of bat, bat–habitat relationships are poorly studied yet. Many factors complicate this relationship, including the high mobility of bats, which enable them to access a broad range of habitats away from roosts. Recent technological advances like use of bat detectors, radio tracking bats have enhanced understanding on bat-habitat relationship (Fenton, 1997). This results in implementing more effective conservation strategies.

Dietary analysis and understanding of feeding behavior of insectivorous bats enables to identify insect pests threatening agriculture (Whitaker, 1995) and publicizing the importance of insectivorous bats in controlling agricultural pest population can be a very powerful conservation tool. Agricultural insect pest feeding by bats and intoxication with pesticides in agriculture are closely related and both should be considered when conservation activities are undertaken (Agosta, 2003).

As the conservation approaches are shifting from a single species concept to ecosystem level concept (Minta *et al.*, 1999), the accent of abundant species becoming understood. Insectivorous bats feed on a large number of insect species. In this context, abundant species definitely provide critical ecosystem services (Pierson, 1998). In practice conservation efforts are mainly focused on rare and threatened species, and as it may continue with the same practice, abundant species having wide range of distribution and large population must be considered very important for conservation practices. Continuing research to understand causes behind population declines and important life-history needs of abundant insectivorous bats, so emphasizing their conservation requirements, should be useful in directing research for other abundant bat species also. Moreover, conserving the large population of abundant bats is consistent with an ecosystem level conservation approaches (Agosta, 2003).

One of the main reasons behind the very less studied status of insectivorous bats is its unique body features like small body size, volancy, nocturnal activity, low reproductive rate, and acoustic orientation. Technological advances have improved research and conservation attempts (Kunz, 2003). But there continues to be a lack of methodologies and consistent, repeatable research approaches to provide the knowledge needed to address ecology of insectivorous bats (Thompson, 2006). Knowledge on the ecology and population status of insectivorous bat species of Indian subcontinent is still very limited.

From the view of developing guidelines for integrating forest bat habitat requirements at strategic and operational planning levels, information about the patterns of community structure and habitat use by organisms at multiple spatial and temporal scales is very important (Kunz, 1996).

# MATERIALS AND METHODS

# MATERIALS AND METHODS

## 3.1 STUDY AREA

### 3.1.1 Name, location and extent

Peechi-Vazhani Wildlife Sanctuary, lies within the geographical extremes of latitudes 10° 26'N and 10° 40'N and longitudes 76° 15'E and76° 28'E in Thrissur District, Kerala State (Fig. 1). The sanctuary was established in 1958. It consists of 125 $km^2$ and is contiguous with the forest areas of Nelliampathy and Palappilly reserves. On south, the sanctuary has a common boundary with Chimmony Wildlife Sanctuary (Fig. 1).

### 3.1.2 Terrain

The terrain of the sanctuary is undulating and is hilly and the altitude range varies between 45 m to 900 m above MSL.

### 3.1.3 Climate

The sanctuary is blessed with copious rains, typical of the state, good sunlight and hot and humid weather.

***Rainfall***

The sanctuary receives showers from both northeast and southwest monsoons. Pre-monsoon showers are often received in the month of April. Southwest monsoons bring in precipitation from June till September. Heavy showers associated with thunderstorms are common. Northeast monsoons bring reasonable rains during October -November. Average precipitation in the sanctuary is 3000 mm.

#### *Temperature*

The sanctuary enjoys salubrious weather with cooler months during November to January and hotter days between February to May. The hilltops are relatively cooler when compared to plains owing to altitudinal effects. Mean maximum temperature recorded is 39.4°C with a mean minimum temperature of 18.9°C.

#### *Relative Humidity*

Relative humidity is always greater than 55% and attains 100% during the rainy season.

#### *Winds*

North-East winds blowing through Palakkad gap of the Western Ghats have desiccating effect and cause heavy leaf fall, resulting in accumulation of combustible organic debris on the forest floor inducing forest fires.

### 3.1.4 Water Source

There are numerous streams small and big, flowing over the entire sanctuary, most of which join the three main rivers Kurumali, Manali and Wadakkanchery. Majority of these streams dry up during summer. There are two reservoirs, Peechi and Vazhani formed by construction of two dams across the rivers Manali and Wadakkanchery. The water-spread area of the two reservoirs is 14.793 sq km.

### 3.1.5 Habitat and vegetation

Zoo-geographically the area is classified as Indo-Malayan Region. The sanctuary provides a mosaic habitat for the bats by the presence of moist

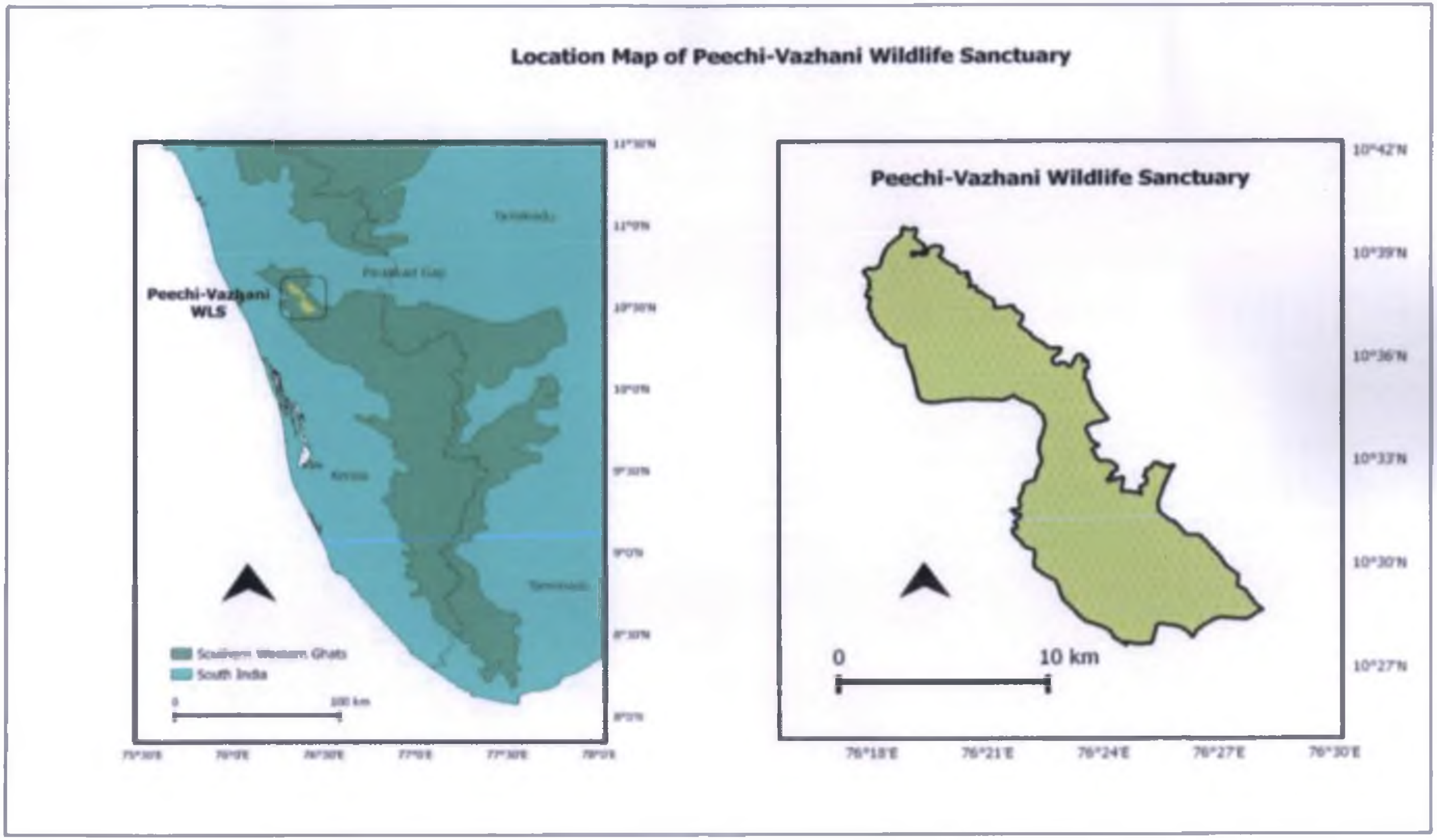


Fig. 1 Study area: Peechi-Vazhani Wildlife Sanctuary

deciduous forests, semi-evergreen forests, riparian forests as well as evergreen forests. Major portion of the sanctuary, nearly 80 per cent is moist deciduous forest, 15 per cent is evergreen and semi-evergreen forests and the balance five percent is under plantations of teak and softwood species.

Evergreen forests are found in higher slopes of the sanctuary and in patches at some places amidst moist deciduous forests. The dominant species found are *Palaquium ellipticum, Cullenia exarillata, Mesua ferrea, Canarium strictum* with canes and reeds.

Semi-evergreen type of forests is restricted to valleys and moist pockets. The dominant species are *Artocarpus hirsutus, Toona ciliata, Hopea parviflora, Mangifera indica* and *Vitex altissima.*

Moist deciduous type of forests is an intermediary stage between semi evergreen and dry deciduous type of forests. These forests are predominated by tree species like *Dalbergia latifolia, Xylia xylocarpa, Terminalia tomentosa* and *Lagerstroemia lanceolata.*

The mosaic pattern of the vegetation helps the bats to exploit the area efficiently (Verboom and Speoelstra, 1999). The rich abundance of the fruit trees like *Dillenia pentagyna, Ficus* sp., *Spondias mangifera, Ziziphus* sp. etc. makes the sanctuary an abode of fruit bats.

Other main peculiarity of the sanctuary is the presence of large number of *Tetrameles nudiflora* tree, whose trunk bears large hollows, which offers the bats a comfortable roosting house. The sanctuary also provides large dead and standing trees with holes and rocky patches with large caves which are all ideal for bats (Akbar *et al.*, 1999; Grindal, 1999).

## 3.2 BAT ROOSTS IN THE PRESENT STUDY

Two roosts were selected for the present study. Many of the tree hole roosts identified were discarded as the bats abandoned the roosts and migrated to some other roosts. First one was a rock cave roost located at Vellani area of Peechi-Vazhani Wildlife Sanctuary (Plate 1) and the species occupied were *Rhinolophus rouxii* and *Hipposideros speoris*. Second one was a roost inside a building at the Kerala Agricultural University campus, Vellanikkara adjacent to Peechi-Vazhani Wildlife Sanctuary (Plate 2), and occupied by *Hipposideros ater*.

## 3.3 SPECIES OF INSECTIVOROUS BATS IN THE PRESENT STUDY

The present study is envisaged to understand the diet and dietary preference of selected Microchiropteran bat species and to highlight their ecological importance. During this study faecal pellet of three species of insectivorous bats were analyzed, those bats are *Rhinolophus rouxii* (Rufous Horseshoe Bat), *Hipposideros speoris,* (Schneiders Leaf-nosed Bat) and *Hipposideros ater* (Dusky Leaf-nosed Bat). Brief description of the insectivorous bat species are the following.

### *Rhinolophus rouxii* Temminck, 1835 (Rufous Horseshoe bat)

Its nose leaf is broad and pelage is soft and silky. There is considerable variation in pelage colour, ranging from orange, russet brown, buffy brown to grey The lancet is of variable height, sometimes triangular in shape with straight sides, sometimes with a well-developed tip and concave margins below. The forearm length of this species varies from 44.5 to 52.3 mm with average of 49.3mm. The baculum has a long, parallel-sided shaft and the base is expanded. The mean length is 2.3mm and greatest width 0.7mm (Plate 3).

*Hipposideros speoris* Schneider, 1800 (Schneiders Leaf-nosed Bat)

Its nose leaf has three supplementary leaflets, of which the outer is distinctly smaller than the other two. The pelage colour is variable, some individuals are grey, palest on the ventral surface and between the shoulders on the upper back; they are darker on the flanks and posteriourly, others are yellowish-brown or bright orange- brown. The baculum is minute with a slightly expanded base, narrow shaft and a simple blunt tip. Forearm length varies between 45.6 to 54.0 mm with an average of 50.7 mm (Plate 4).

*Hipposideros ater* Templeton, 1848 (Dusky Leaf-nosed bat)

This is a small species of Hipposideros, with a significantly shorter forearm. Forearm length ranges from 34.9 to 38 mm with an average of 36.3 mm. The wings and inter femoral membrane are naked, above and below, and are a uniform dark brown/black. The pelage is variable in colour ranging from dull yellow, golden-orange or pale grey to dark brown on the dorsal aspect. The hair bases are paler than the tip. The ventral aspect is usually paler than the back. (Plate 5).

Plate 1. Roost of *Hipposideros speoris* and *Rhinolophus rouxii*

Plate 2. Roost of *Hipposideros ater*

Plate 3. *Rhinolophus rouxii*

Plate 4. *Hipposideros speoris*

Plate 5. *Hipposideros ater*

## 3.4 METHODS

### 3.4.1 Selection of roosts

Reconnaissance survey was done to identify the permanent bat roosts of the Peechi-Vazhani Wildlife Sanctuary and adjacent areas. Permanent bat roosts are only preferred to ensure the availability of bats faecal samples consistently throughout the study period. Faecal matter were collected from two roosts and three species regularly once in a month throughout the study period.

### 3.4.2 Capturing technique

Mist nets and butterfly nets were used to capture bats in this study. The most common devices for capturing bats are the mist nets which are structures of braided or monofilament nylon with a usual mesh size of 36 mm and overall size of 10 x 1.5 m. These nets were set across the mouth of roosts from 6pm onwards. Nets were watched continuously to remove bats immediately from nets when they were caught in nets. If the net is un-attended, the captured bats struggle and become entangled that they cannot be removed easily and perhaps with injury to bats and damage to nets. Butterfly nets were used for capturing bats inside a cave especially during day time when bats did not come out. Bats perches from building or cave roosts, and start flying when cause a small disturbance. Butterfly nets of larger diameter modified with mosquito net were used to capture bats on low speed flight or hovering inside the roost.

### 3.4.3 Field observations

Trapped bats were immediately identified by taking morphological measurements. Measurement such as forearm length (FA), hind foot length (HF), head to body length (HB), ear length (E) and tail length (T) were taken using digital calipers. Identified bats were placed separately in clean cotton cloth bags for faecal sample collection.

### 3.4.4 Faecal sample collection

In capturing live bats for food analysis, it is essential to collect faecal samples immediately upon collecting them, otherwise food in the tract will be digested and the insect remnants will not be in identifiable form. Bats kept alive in captivity for a period of time are of little or no use for food habitat analysis. Bats should be collected for food analysis during or soon after they return from a foraging bout, they are easily recognizable by their fully distended stomachs (Whitaker, 2009). This is particularly important because the food can pass through the gut quite rapidly.

Captured bats were kept in cotton cloth bags. After a while bat defecated and the faecal pellets were collected. Bats were released after half an hour. This provides for nondestructive faecal sample collection, without sacrificing the bats. Faecal pellets were transferred in to air tight containers and labelled them properly. In the case of *Hipposideros ater* the faecal pellets were collected from the roosting ground also. For the collection of the fresh and non-contaminated faeces, plastic polythene sheets were kept on the floor of the roost of *Hipposideros ater* and the faecal samples were collected after first feeding bout or in the next morning. This contains faecal matter and culled parts of insects that can be used as reference for identification of insects (Whitaker, 2009). Even though this method of faecal matter collection from roost floor is not the best method as completely digested faecal matter only drops on the floor yet this method offers minimum stress on the bats during sample collection and it also offers for the collection of culled parts of the same insects ingested. Culled parts are helpful in identification because identifiable parts like wings, head etc.

are present in culled parts. Collected insect parts were kept in freezers after drying in sunlight.

### 3.4.5 Laboratory studies

Laboratory analysis of faecal samples was done using the methodology given by Whitaker (2009). The faecal samples collected were taken into laboratory and analyzed for insect parts. The first step in faecal matter analysis is to soften the pellets so that they can be teased apart easily. Each of the pellet are transferred to a glass slide or petri dish, and water drops are added to it with a dropper. Pellet slowly absorbs water and become soft. This softened pellets can be teased apart with a needle. Pellet forms into a semi solid form. If particulate matter clouds the water, we can add more water a few times to clean up the matter. Over washing may cause in wash out of soft floating parts like scales so it should be done very carefully under a microscope or a hand lens. These slides can be stored horizontally in a refrigerator, after drying. Each slides are labelled based on the species and date of collection.

To identify the food items present in the faecal matter, the material was first observed under a stereo microscope and insect parts were spread out using a needle so as to examine each parts separately. Then larger parts which are observable under 10-50x magnification of stereo microscope were examined and photographs of larger insect parts were taken using the camera attached to microscope. For this purpose stereo microscope Labomed Digi2 was used. Then the prepared slide were taken to a compound microscope under which the samples are observed. Samples were first observed in the low power objective lens of 4x and gradually observed under 10x and 40x objective lens. This method was very successful because insect parts varies in size. Some of the parts which are not visible in stereo microscope were visible under a compound microscope and photographs were taken. It is very difficult to observe and take photograph under high power objective of compound microscope. Additional light should be supplied to objects in such situation, for this purpose a small projection lamp were used, sometimes a high lumen torch were also found to be useful. Also the examiner should be very careful when moving the slide platform otherwise it will be very difficult to take back the object into sight if it is lost form the sight. Each faecal pellet were examined separately for each species of bats. For each pellet, identified parts were noted down up to order level, the identification was done using keys provided by Whitaker *et al.*, (2009) and McAney *et al.*, (1991). Also the relative proportion of various insect orders were noted down as percent volume using visual estimation in each sample.

### 3.4.6 Data analysis

Percent Volume and Percent Frequency for each insect order can be calculated using the formulae given by Whitaker (2009).

Percent Volume = (Sum of individual volume / Total volume of sample)

Percent Frequency = (Number of occurrence / total number of samples)

### 3.4.7 Statistical analysis

Percentage volume data were arcsine transformed before subjecting to statistical analysis to correct non-normality. ANOVA based on type III sum of squares analysis was used to determine the variation in percent volume data of insect orders between species. Also Principle Component Analysis was done to describe the food preference for each bat species. Software used for statistical analysis were MS EXCEL and XLSTAT, a plugin software in MS EXCEL.

Olympus SZ61 Labomed Digi Zoom

Labomed Lx400 Labomed Digi 2

Plate 6. Different microscopes used in analysis
and imagingof bat droppings

# RESULTS

# RESULTS

## 4.1 FIELD OBSERVATIONS

### 4.1.1 Morphological measurements

The data regarding the morphological measurements like forearm length (FA), hind foot length (HF), head to body length (HB), ear length (E) and tail length (T) of the insectivorous bats captured for scat collection are given in Table 1. The measurements are compared with that of Bates and Harrison (1997).

Table 1. The mean morphological measurements of insectivorous bats captured from Peechi-Vazhani Wildlife Sanctuary

| Species | Present study | | | | | Bates and Harrison (1997) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FA | HF | HB | T | E | FA | HF | HB | T | E |
| *Rhinolophus rouxii* | 48.7 | 11.0 | 57.6 | 26.8 | 18.6 | 49.3 | 11.2 | 58.2 | 27.1 | 19.0 |
| *Hipposideros speoris* | 50.1 | 8.1 | 54.5 | 25.3 | 16.8 | 50.7 | 8.2 | 54.7 | 25.2 | 16.9 |
| *Hipposideros Ater* | 36.0 | 6.8 | 42.2 | 24.7 | 17.5 | 36.3 | 6.7 | 42.3 | 24.7 | 17.6 |

All measurements are in millimeter (mm)

## 4.2 LABORATORY OBSERVATIONS

### 4.2.1 Faecal matter analysis

Data regarding the percent volume and percent frequency of diet were taken for three selected species of bats of which faecal samples were available consistently throughout the study period. The selected bats species were *Rhinolophus rouxii, Hipposideros speoris* and *Hipposideros ater*.

The overall composition of food items taken by insectivorous bats differs from species to species of bats. From 150 samples analyzed representatives of eleven insect orders and Araneae (Spiders) were identified. The insect orders include Lepidoptera (Moths and butterflies), Coleoptera (Beetles), Diptera (Flies), Hymenoptera (Bees and Wasps), Hemiptera (Bugs), Isoptera (Termites), Orthoptera (Crickets and Grasshoppers), Odonata (Dragonflies and damselflies), Mantodea (Mantis), Neuroptera (Lacewings) and Ephemeroptera (Mayflies).

### 4.2.2 Brief descriptions about the characteristic features of these insect orders and Araneae (after Whitaker, 2009; McAney *et al.,* 1991).

Lepidoptera

Small, medium and large sized butterflies and moths with bright colors. Body and wings covered with flat scales, siphoning mouth parts, two pairs of membranous wings and five segmented are the main features. This insect order can be easily identified in the faecal samples by the presence of large number of scales with other parts (Plate 7).

Coleoptera

Small, medium and large sized insects, and is the largest order of the class insect and that includes beetles, weevils etc. Moveable head, biting and chewing mouth parts, segmented antennae, horny and feathery forewings (elytra), and membranous hind wings folded below elytra, legs variable with two claw and tarsi five segmented are the major identification characteristics of this insect order. This order can be easily identified in faecal samples by the presence of hard exoskeleton and legs (Plate 7).

### Diptera

Small and medium sized insects, with varying mouth parts, prominent mesothorax, one paired membranous forewings and five segmented tarsi. Second pair of wing modified into balancing organ (haltere) and antennae with many segments are the major identification feature of this insect order. Flies and mosquitoes comes under this insect order (Plate 8).

### Hymenoptera

Small and medium sized insects with biting and chewing type mouth parts, first abdominal segment fused with metathorax forming propodeum. Ants, bees and wasps come under this order. Simple wings with more than two to three very thin cross veins and numerous segmented antennae are the easy identification features of this insect order (Plate 9).

### Hemiptera

Represented by bugs. Insects with piercing and sucking mouth parts originating from the anterior part of the head. Usually with oval and flat shaped body and legs having 2 to 3 tarsi (Plate 8).

### Isoptera

Medium sized insect with movable head, biting type mouth parts and four segmented tarsi. Delicate wings with outer veins diagonal and tarsi with four segments with last one long and others short. Termites constitute this order (Plate 9).

### Orthoptera

Large sized insects including grasshoppers and crickets. Chewing type mouth parts, thick forewing, hind legs modified for leaping, femora greatly swollen and tibia with strong muscles are the major identification characters of this order (Plate 9).

### Odonata

Large sized and bright colored insects include dragonflies and damselflies. Chewing type mouth parts, membranous wings with many cross veins and dark pterostigma towards the coastal apex slender and elongated abdomen, legs modified for holding the preys are the major identification features of this order (Plate 9).

### Mantodea

Represented by the mantis. Characterized by two grasping spiked forelegs in which prey items are caught and held. Unusual long coxa which together with trochanter give the impression of femur and it is spiky. Discoidal spines are present at the base of the femur. The forelegs ends in a delicate tarsus made of 5 to 6 segments and ending in a two toed claw. Spiky coxa helps in easy identification of this order (Plate 8).

### Neuroptera

This order is represented by net-winged insects like lacewings, antlions etc. The adults of this order possess four membranous wings with the forewings and hindwings of the same size and with many veins. They have chewing mouth parts and undergo complete metamorphosis. They are soft bodied insects (Plate 9).

Ephemeroptera

Represented by Mayflies. The wings are membranous with extensive venation and are held upright like those of a butterfly. The hindwings are much smaller than the forewings and may be vestigial or absent. Adults have short flexible and bristle like antennae. They have long forelimbs (Plate 9).

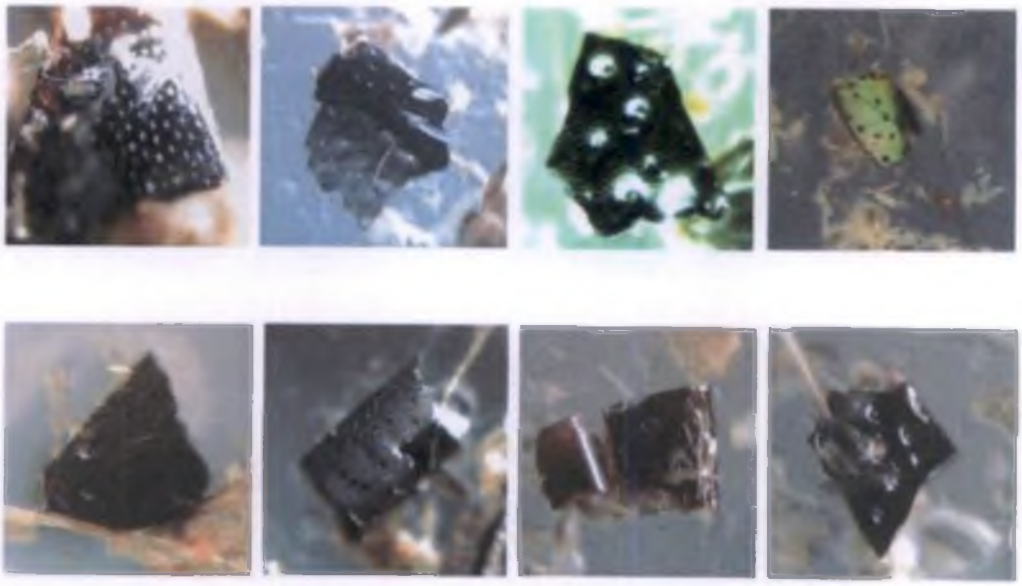
Araneae

Represented by spiders. They are air breathing arthropods that have eight legs and chelicerae with fangs that inject venom. Largest order if Arachnids. Segmented body and jointed limbs. They have hairy legs and body characterized by dense tuft of fine hairs between the paired claws at tip of legs. This order can be easily identified by its hairy legs often present in the faecal samples (Plate 9).

### 4.2.3 Mean percent volume and percent frequency of different food components in the diet of insectivorous bats from Peechi-vazhani WLS

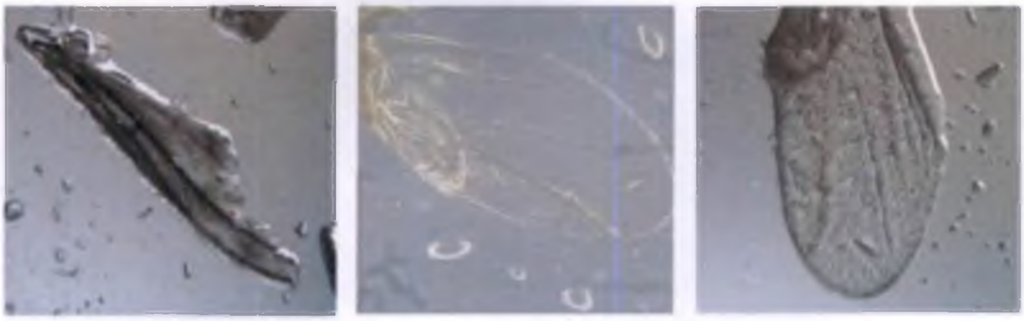
Mean of the percent volume and percent frequency of different insect orders and spiders in the diet of all the three species of insectivorous bats viz; *Rhinolophus rouxii, Hipposideros speoris* and *Hipposideros ater* collected from different locations are given separately in Table 2.

Lepidopteran fragments from fecal samples



Coleopteran fragments from fecal samples

Plate 7. Insect fragments of the orders Lepidoptera and Coleoptera from fecal samples



Dipteran fragments in fecal samples

Hemipteran fragments from fecal samples

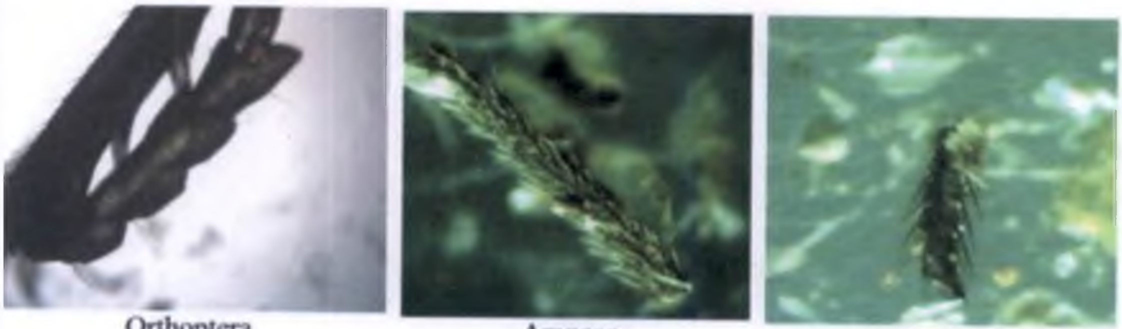
Mantodea fragments from fecal samples

Plate 8. Insect fragments of the orders Diptera, Hemiptera and Mantodea from fecal samples

Hymenoptera Hymenoptera Isoptera

Ephemeroptera Mantodea Mantodea

Odonata Odonata Neuroptera



Orthoptera Araneae Araneae

Plate 9. Insect Fragments of the orders Hymenoptera, Isoptera, Mantodea, Odonata, Ephemeroptera, Neuroptera, Orthoptera and Araneae from faecal samples

Table 2. Percent volume and Percent frequency of the different insect orders in the diet of insectivorous bats of Peechi-Vazhani WLS.

| Sl. No. | Insect order | *Rhinolophus rouxii*(n=50) | | *Hipposideros speoris*(n=50) | | *Hipposideros ater* (n=50) | |
|---|---|---|---|---|---|---|---|
| | | P.V. | P.F. | P.V. | P.F. | P.V. | P.F. |
| 1. | Lepidoptera | 37.6 | 100 | 37.2 | 100 | 36.2 | 100 |
| 2. | Coleoptera | 29.1 | 100 | 34.1 | 100 | 26.1 | 100 |
| 3. | Diptera | 13.3 | 86 | 9.4 | 82 | 21.6 | 100 |
| 4. | Hymenoptera | 3 | 22 | 2.6 | 24 | 1.8 | 18 |
| 5. | Hemiptera | 4.2 | 40 | 2.8 | 32 | 7.3 | 60 |
| 6. | Isoptera | 3.8 | 38 | 4.2 | 30 | 2.8 | 22 |
| 7. | Orthoptera | 2.4 | 22 | 2.5 | 30 | 2 | 20 |
| 8. | Odonata | 2.3 | 20 | 2.9 | 30 | 0.8 | 8 |
| 9. | Mantodea | 0.6 | 6 | 0 | 0 | 0 | 0 |
| 10. | Neuroptera | 0.8 | 12 | 1 | 18 | 0 | 0 |
| 11. | Ephemeroptera | 1 | 10 | 1 | 16 | 0 | 0 |
| 12. | Araneae | 1.9 | 34 | 2.3 | 46 | 1.4 | 28 |

P.V. - Percent Volume, P.F. - Percent Frequency

## 4.4 DIET OF *Rhinolophus rouxii* AT PEECHI-VAZHANI WLS

### 4.4.1 Comparison of percent volume of different insect orders in diet of *Rhinolophus rouxii*

In the diet of *Rhinolophus rouxii,* faecal matter analysis reveals that Lepidoptera was the most preferred insect order. Lepidoptera ranked first with a mean percentage volume of 37.6 percent (Range: 30 to 45). Coleoptera ranked second with a mean percentage volume of 29.1 percent (Range: 20 to 35). Diptera ranked third with a mean percent volume of 13.3 percent (Range: 0 to 25). The following insect orders in the descending order of percentage volume are Hemiptera (Mean = 4.2; Range: 0 to 20), Isoptera (Mean = 3.8; Range: 0 to 15), Hymenoptera (Mean = 3; Range: 0 to 20), Orthoptera (Mean = 2.4; Range: 0 to 20), Odonata (Mean = 2.3; Range: 0 to 15), Araneae (Mean = 1.9; Range: 0

to 10), Ephemeroptera (Mean = 1; Range: 0 to 15), Neuroptera (Mean = 0.8; Range: 0 to 10) and the least preferred was Mantodea with a mean percent volume of 0.6% percent (Range: 0 to 15)(Table 3 and Fig. 2).

Table 3. Comparison of percent volume of different insect orders in diet of *Rhinolophus rouxii*

| Sl. No. | Insect order | Percent volume | S.E. |
|---|---|---|---|
| 1 | Lepidoptera | 37.6 | 0.53 |
| 2 | Coleoptera | 29.1 | 0.56 |
| 3 | Diptera | 13.3 | 0.93 |
| 4 | Hymenoptera | 3 | 0.83 |
| 5 | Hemiptera | 4.2 | 0.82 |
| 6 | Isoptera | 3.8 | 0.81 |
| 7 | Orthoptera | 2.4 | 0.71 |
| 8 | Odonata | 2.3 | 0.69 |
| 9 | Mantodea | 0.6 | 0.36 |
| 10 | Neuroptera | 0.8 | 0.32 |
| 11 | Ephemeroptera | 1 | 0.44 |
| 12 | Araneae | 1.9 | 0.39 |

S.E.: Standard Error

### 4.4.2 Comparison of percent frequency of different insect orders in diet of *Rhinolophus rouxii*

In the diet of *Rhinolophus rouxii* Lepidoptera and Coleoptera ranked first in terms of percent frequency. Both of these orders are with Percent frequency of 100 percent i.e., they are present in all the faecal samples. Diptera ranked third with percent frequency 86 percent followed by Hemiptera (40%), Isoptera (38%), Araneae (34%), Hemiptera (22%), Orthoptera (22%), Odonata (20%), Neuroptera (12%), Ephemeroptera (10%) and Mantodea (6%) in the descending order (Table 4, Fig. 3).

Table 4. Comparison of percent frequency of different insect orders in diet of *Rhinolophus rouxii*

| Sl. No. | Insect order | Percent frequency |
|---|---|---|
| 1 | Lepidoptera | 100 |
| 2 | Coleoptera | 100 |
| 3 | Diptera | 86 |
| 4 | Hymenoptera | 22 |
| 5 | Hemiptera | 40 |
| 6 | Isoptera | 38 |
| 7 | Orthoptera | 22 |
| 8 | Odonata | 20 |
| 9 | Mantodea | 6 |
| 10 | Neuroptera | 12 |
| 11 | Ephemeroptera | 10 |
| 12 | Araneae | 34 |

### 4.4.3 Comparison of diet of *Rhinolophus rouxii* between different seasons

In the diet of *Rhinolophus rouxii*, Lepidoptera ranked first in terms of percent volume in all the three seasons, southwest monsoon (36.75%), northeast monsoon (39.5) and summer (37.5%). Coleoptera ranked second and Diptera ranked third in terms of percent volume in all the seasons. Lepidoptera was fed with highest percent volume (39.5%) in northeast monsoon whereas Coleoptera was in summer (30.5%). Isoptera ranked fourth in southwest monsoon (6.75%) whereas Hemiptera ranked fourth in northeast monsoon (6.5%) and summer (4.25%) in terms of percent volume. Isoptera showed a hike in percent volume in both southwest monsoon (6.75%) and northeast monsoon (4%) compared to low percent volume in summer (0.75%). Odonata also showed a hike in percent volume in summer (3.25%) compared to other seasons. All the insect orders and Araneae were present in both southwest monsoon and summer whereas Mantodea and Ephemeroptera were absent in northeast monsoon. Araneae showed highest percent volume in summer (2.5%) compared to other seasons (Table 5).

Table 5. Comparison of diet of *Rhinolophus rouxii* between different seasons

| Sl. No. | Insect order | Southwest Monsoon (PV) | Northeast Monsoon (PV) | Summer (PV) |
|---|---|---|---|---|
| 1 | Lepidoptera | 36.75 | 39.5 | 37.5 |
| 2 | Coleoptera | 27.75 | 29 | 30.5 |
| 3 | Diptera | 13.5 | 12 | 13.75 |
| 4 | Hymenoptera | 2.75 | 3.5 | 3 |
| 5 | Hemiptera | 3 | 6.5 | 4.25 |
| 6 | Isoptera | 6.75 | 4 | 0.75 |
| 7 | Orthoptera | 2.25 | 2 | 2.75 |
| 8 | Odonata | 1.75 | 1.5 | 3.25 |
| 9 | Mantodea | 1.25 | 0 | 0.25 |
| 10 | Neuroptera | 1.25 | 1 | 0.25 |
| 11 | Ephemeroptera | 1.25 | 0 | 1.25 |
| 12 | Araneae | 1.75 | 1 | 2.5 |

PV: Percent Volume

## 4.5 DIET OF *Hipposideros speoris* AT PEECHI-VAZHANI WLS

### **4.5.1 Comparison of percent volume of different insect orders in the diet of *Hipposideros speoris***

In the diet of *Hipposideros speoris* Lepidoptera ranked first in terms of percent volume. This insect order was present in diet with a mean percent volume of 37.2 percent (Range: 25 to 50). Coleoptera ranked second with a mean percent volume of 34.1 percent (Range: 20 to 55). Diptera ranked third with a mean percentage volume of 9.4 percent (Range: 0 to 15) followed by Isoptera (Mean = 4.2; Range 0 to 25), Odonata (Mean = 2.9; Range 0 to 15), Hemiptera (Mean = 2.8; Range 0 to 20), Hymenoptera (Mean = 2.6; Range 0 to 20), Orthoptera (Mean = 2.5; Range 0 to 15) and Araneae (Mean = 2.3; Range 0 to 5). The least consumed insect orders were Neuroptera (Mean = 1; Range 0 to 15) and Ephemeroptera (Mean = 1; Range 0 to 15) (Table 6 and Fig. 5).

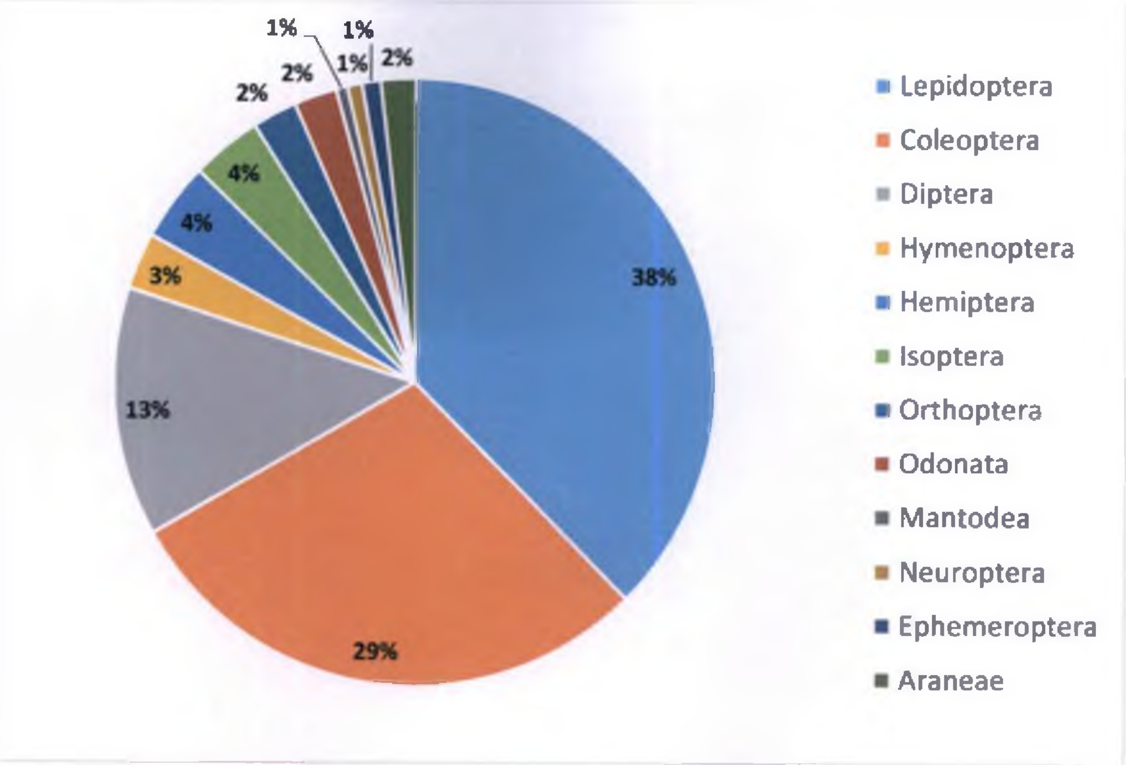


Fig. 2. Percent volume composition of diet of *Rhinolophus rouxii*

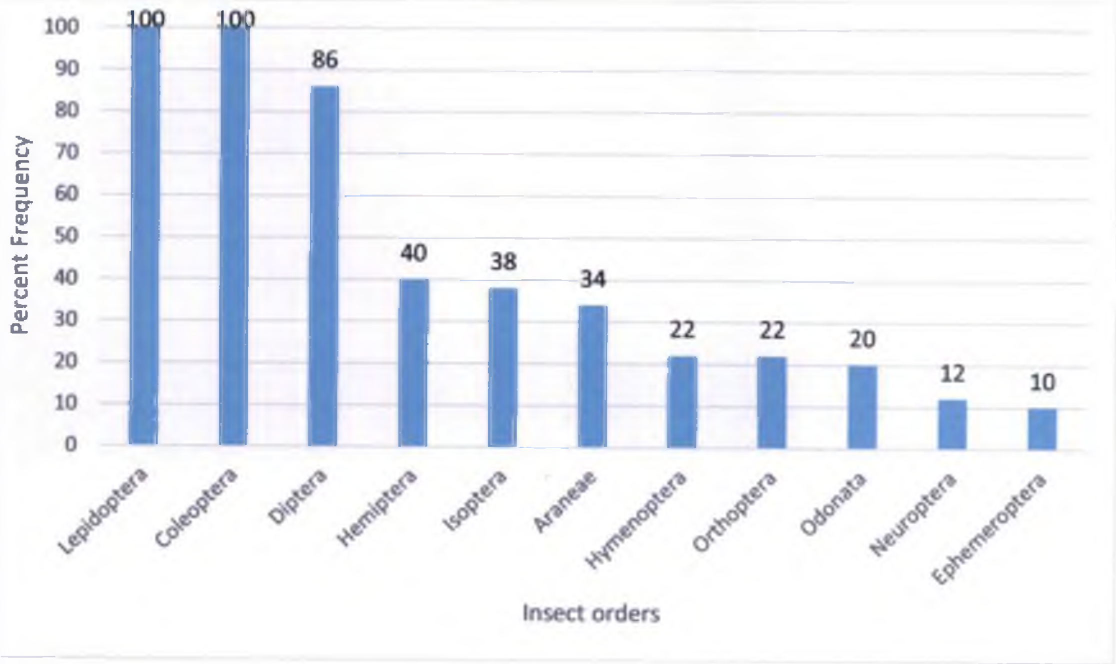


Fig. 3. Percent frequency composition of diet of *Rhinolophus rouxii*

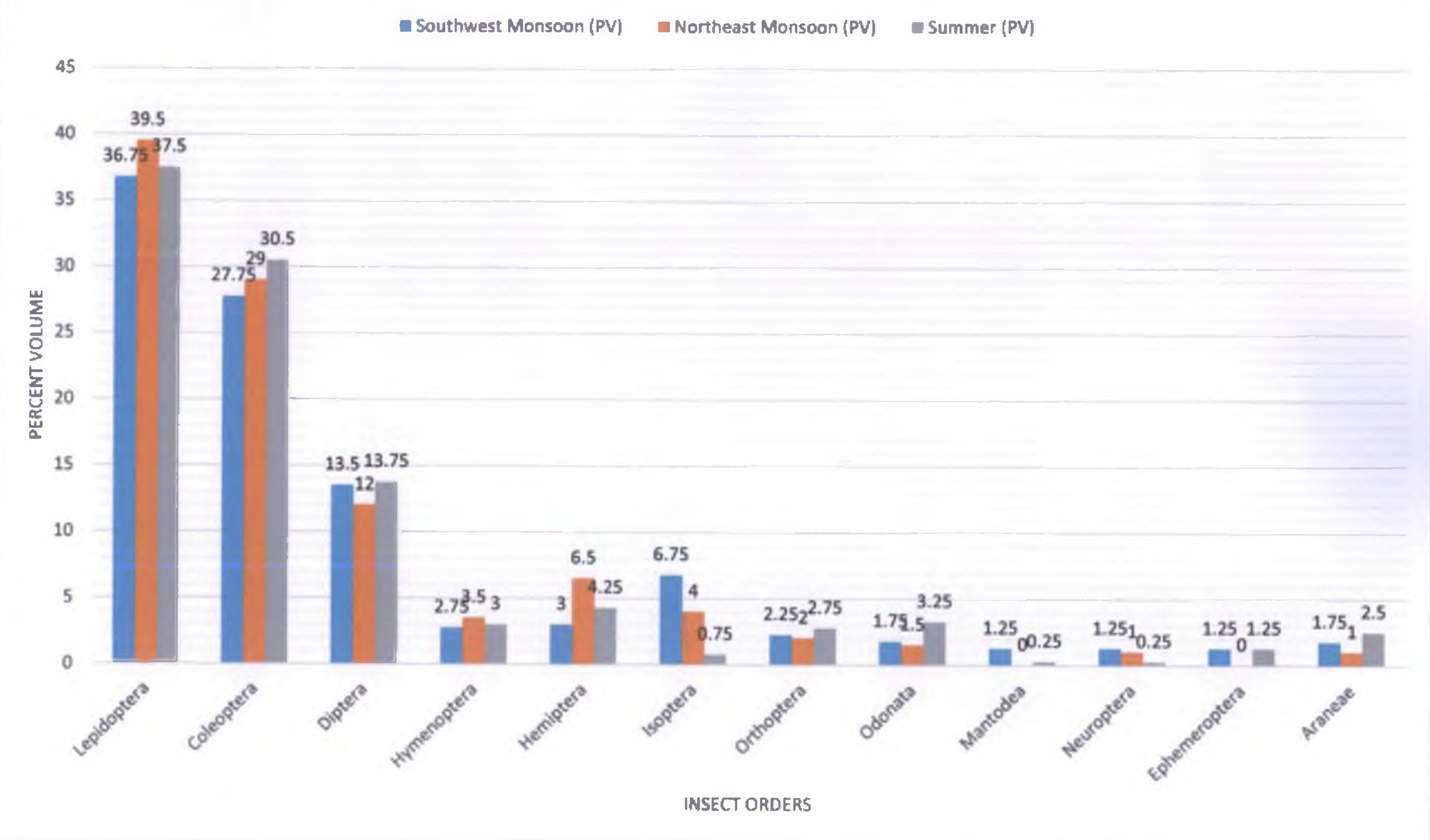


Fig. 4. Comparison of Percent volume different insect orders in diet of *Rhinolophus rouxii* between different seasons

Table 6. Comparison of percent volume of different insect orders in diet of *Hipposideros speoris*

| Sl. No. | Insect order | Percent volume | S.E |
|---|---|---|---|
| 1 | Lepidoptera | 37.2 | 0.83 |
| 2 | Coleoptera | 34.1 | 0.95 |
| 3 | Diptera | 9.4 | 0.76 |
| 4 | Hymenoptera | 2.6 | 0.74 |
| 5 | Hemiptera | 2.8 | 0.67 |
| 6 | Isoptera | 4.2 | 0.97 |
| 7 | Orthoptera | 2.5 | 0.59 |
| 8 | Odonata | 2.9 | 0.67 |
| 9 | Neuroptera | 1 | 0.40 |
| 10 | Ephemeroptera | 1 | 0.45 |
| 11 | Araneae | 2.3 | 0.35 |

S.E.: Standard Error

### 4.5.2 Comparison of percent frequency of different insect orders in diet of *Hipposideros speoris*

In the diet of *Hipposideros speoris* Lepidoptera and Coleoptera ranked first in terms of percent frequency. Both of these order possess percent frequency of 100 percent that is these orders are present in all the faecal samples. Diptera ranked second with a percent frequency of 82 percent followed by Araneae (46%), Hemiptera (32%), Isoptera (30%), Orthoptera (30%), Odonata (30%), Hymenoptera (24%), Neuroptera (18%) and Ephemeroptera (16%) (Table 7 and Fig. 6)

Table 7. Comparison of percent frequency of different insect orders in diet of *Hipposideros speoris*

| Sl No | Insect order | Percent frequency |
|---|---|---|
| 1 | Lepidoptera | 100 |
| 2 | Coleoptera | 100 |
| 3 | Diptera | 82 |

| Sl. No. | Insect order | Percent frequency |
|---|---|---|
| 4 | Hymenoptera | 24 |
| 5 | Hemiptera | 32 |
| 6 | Isoptera | 30 |
| 7 | Orthoptera | 30 |
| 8 | Odonata | 30 |
| 9 | Neuroptera | 18 |
| 10 | Ephemeroptera | 16 |
| 11 | Araneae | 46 |

### 4.5.3 Comparison of diet of *Hipposideros speoris* between different seasons

In the diet of *Hipposideros speoris* Lepidoptera ranked first in terms of Percent volume in all the three seasons, southwest monsoon (35.25%), northeast monsoon (37%) and summer (39.25%). Coleoptera ranked second and Diptera ranked third in terms of Percent volume in all the three seasons. Isoptera ranked fourth in terms of percent volume in southwest monsoon and northeast monsoon and hymenoptera ranked fourth in summer. Isoptera showed a higher Percent volume in southwest monsoon (7.5%) and northeast monsoon (5%) whereas showed lesser percent volume in summer (0.5). All the ten insect orders in the diet were present in southwest monsoon and summer whereas Ephemeroptera was absent in northeast monsoon (Table 8).

Table 8. Comparison of diet of *Hipposideros speoris* between different seasons

| Sl .No. | Insect order | Southwest Monsoon (PV) | Northeast Monsoon (PV) | Summer (PV) |
|---|---|---|---|---|
| 1 | Lepidoptera | 35.25 | 37 | 39.25 |
| 2 | Coleoptera | 31.5 | 35.5 | 36 |
| 3 | Diptera | 8.5 | 10 | 10 |
| 4 | Hymenoptera | 3 | 1 | 3 |
| 5 | Hemiptera | 2.75 | 3 | 2.75 |
| 6 | Isoptera | 7.5 | 5 | 0.5 |
| 7 | Orthoptera | 3.5 | 1.5 | 2 |

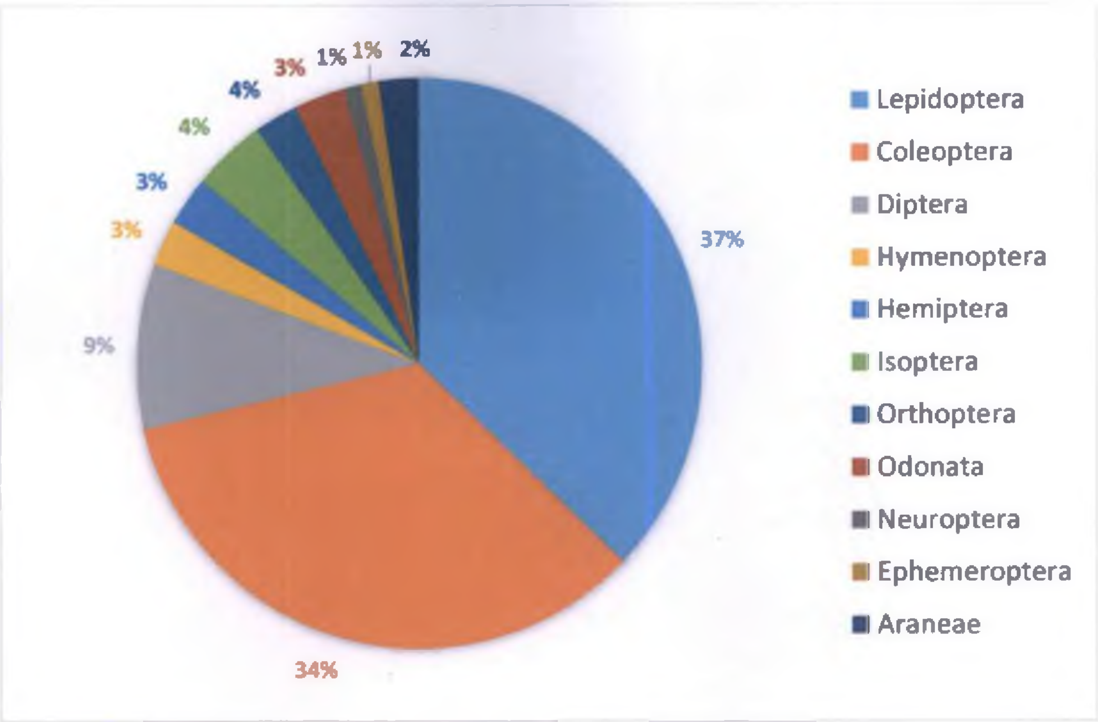


Fig. 5. Percent volume composition of diet of *Hipposideros speoris*

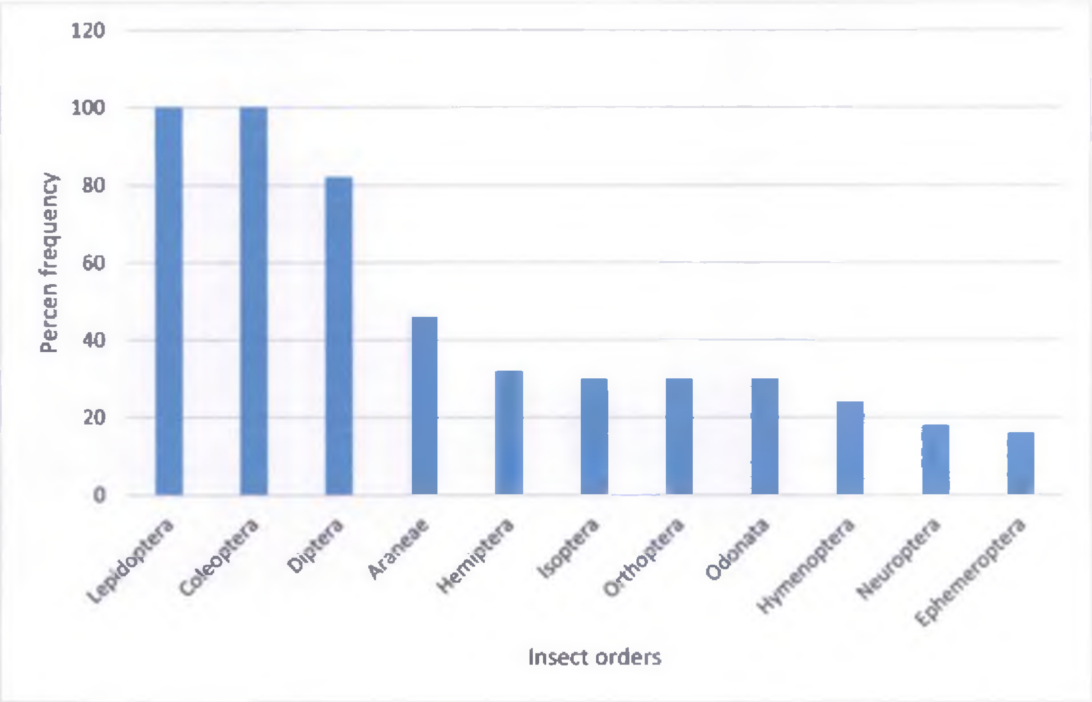


Fig. 6. Percent frequency composition of diet of *Hipposideros speoris*

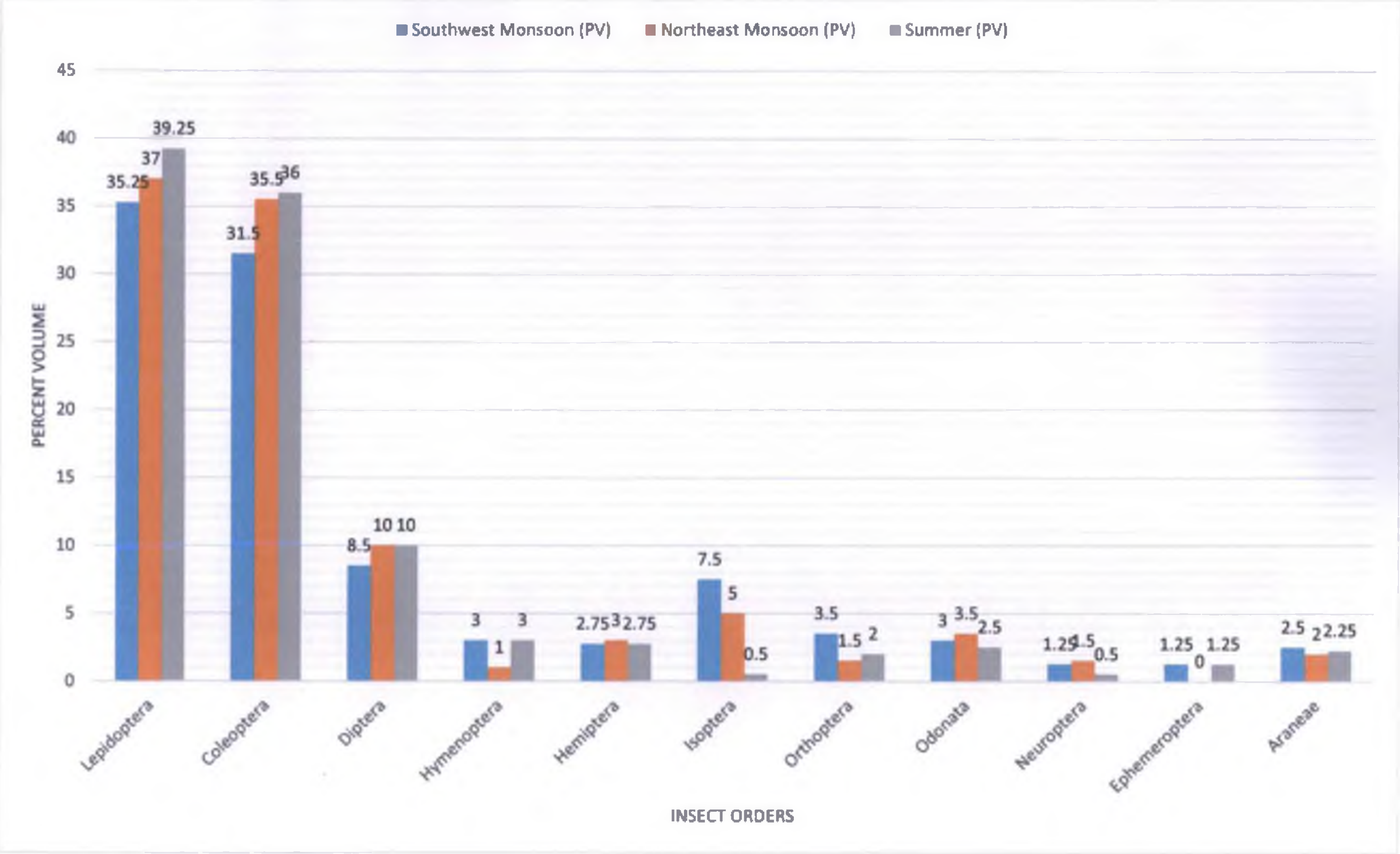


Fig. 7. Comparison of Percent volume of different insect orders in diet of *Hipposideros speoris* between different seasons

| Sl .No. | Insect order | Southwest Monsoon (PV) | Northeast Monsoon (PV) | Summer (PV) |
|---|---|---|---|---|
| 8 | Odonata | 3 | 3.5 | 2.5 |
| 9 | Neuroptera | 1.25 | 1.5 | 0.5 |
| 10 | Ephemeroptera | 1.25 | 0 | 1.25 |
| 11 | Araneae | 2.5 | 2 | 2.25 |

PV: Percent Volume

## 4.6 DIET OF *Hipposideros ater* AT PEECHI-VAZHANI WLS

### 4.6.1 Comparison of percent volume of different insect orders in diet of *Hipposideros ater*

In the diet of *Hipposideros ater* Lepidoptera ranked first in terms of mean percentage volume with a mean of 36.2 percent (Range: 30 to 45). Coleoptera ranked second with mean percentage volume of 26.1 percent (Range 20 to 55). Diptera ranked third with a mean percent volume of 21.6 percent (Range: 15 to 30) followed by Hemiptera (Mean = 7.3; Range: 0 to 20), Isoptera (Mean = 2.8; Range: 0 to 15), Orthoptera (Mean = 2; Range: 0 to 15), Hymenoptera (Mean = 1.8; Range: 0 to 15), Araneae (Mean = 1.4; Range: 0 to 5) and Odonata (Mean = 0.8; Range: 0 to 10) (Table 9 and Fig. 8).

Table 9. Comparison of percent volume of different insect orders in diet of *Hipposideros ater*

| Sl. No. | Insect order | Percent volume | S.E |
|---|---|---|---|
| 1 | Lepidoptera | 36.2 | 0.55 |
| 2 | Coleoptera | 26.1 | 0.63 |
| 3 | Diptera | 21.6 | 0.49 |
| 4 | Hymenoptera | 1.8 | 0.56 |
| 5 | Hemiptera | 7.3 | 0.94 |
| 6 | Isoptera | 2.8 | 0.76 |
| 7 | Orthoptera | 2 | 0.60 |
| 8 | Odonata | 0.8 | 0.38 |
| 9 | Araneae | 1.4 | 0.31 |

S.E.: Standard Error

### 4.6.2 Comparison of percent frequency of different insect orders in diet of *Hipposideros ater*

In the diet of *Hipposideros ater* insect orders Lepidoptera, Coleoptera and Diptera ranked first in terms of percentage frequency of 100%, they are present in all the sample analyzed. Hemiptera ranked second with 60% followed by Araneae (28%), Isoptera (22%), Orthoptera (20%), Hymenoptera (18%) and Odonata (8%) (Table 10 and Fig. 9)

Table 10. Comparison of percent frequency of different insect orders in diet of *Hipposideros ater*

| Sl. No. | Insect order | Percent frequency |
|---|---|---|
| 1 | Lepidoptera | 100 |
| 2 | Coleoptera | 100 |
| 3 | Diptera | 100 |
| 4 | Hymenoptera | 18 |
| 5 | Hemiptera | 60 |
| 6 | Isoptera | 22 |
| 7 | Orthoptera | 20 |
| 8 | Odonata | 8 |
| 9 | Araneae | 28 |

### 4.6.3 Comparison of diet of *Hipposideros ater* between different seasons

Lepidoptera ranked first in terms of percent volume in all the three seasons. Coleoptera ranked second in all the three seasons. Diptera ranked third in all the three seasons with comparatively higher percent volume in southwest monsoon (22.25%) northeast monsoon (20.5%) and summer (21.5%). All the insect orders and Araneae in the diet was present in both southwest monsoon and summer whereas Hymenoptera was absent in northeast monsoon.

Table 11. Comparison of diet of *Hipposideros ater* between different seasons

| Sl. No. | Insect order | Southwest Monsoon (PV) | Northeast Monsoon (PV) | Summer (PV) |
|---|---|---|---|---|
| 1 | Lepidoptera | 36.5 | 36 | 36 |
| 2 | Coleoptera | 25 | 26 | 27.25 |
| 3 | Diptera | 22.25 | 20.5 | 21.5 |
| 4 | Hymenoptera | 1.5 | 0 | 3 |
| 5 | Hemiptera | 7.5 | 9 | 6.25 |
| 6 | Isoptera | 2.5 | 5 | 2 |
| 7 | Orthoptera | 2.5 | 1 | 2 |
| 8 | Odonata | 1 | 1 | 0.5 |
| 9 | Araneae | 1.25 | 1.5 | 1.5 |

P.V.: Percent Volume

## 4.7 COMPARISON OF DIET BETWEEN EACH SPECIES OF INSECTIVOROUS BATS AT PEECHI-VAZHANI WLS

### 4.7.1 Comparison of diet between each species of insectivorous bats

There was no significant difference – species wise, season wise or both - in the insect groups Lepidoptera, Hymenoptera, Orthoptera, Mantodea, Ephemeroptera and Araneae. However there was a significant bat species wise difference in the consumption of Coleoptera, Diptera, Hemiptera and Neuroptera, while there was a season difference in the consumption of Coleoptera and Isoptera (Table 12). It is interesting to note that for Coleoptera there was a significant difference in both season and species wise consumption but the interaction of species and season was not significant. The difference in the mean consumption season and species wise is shown in Fig. 11.

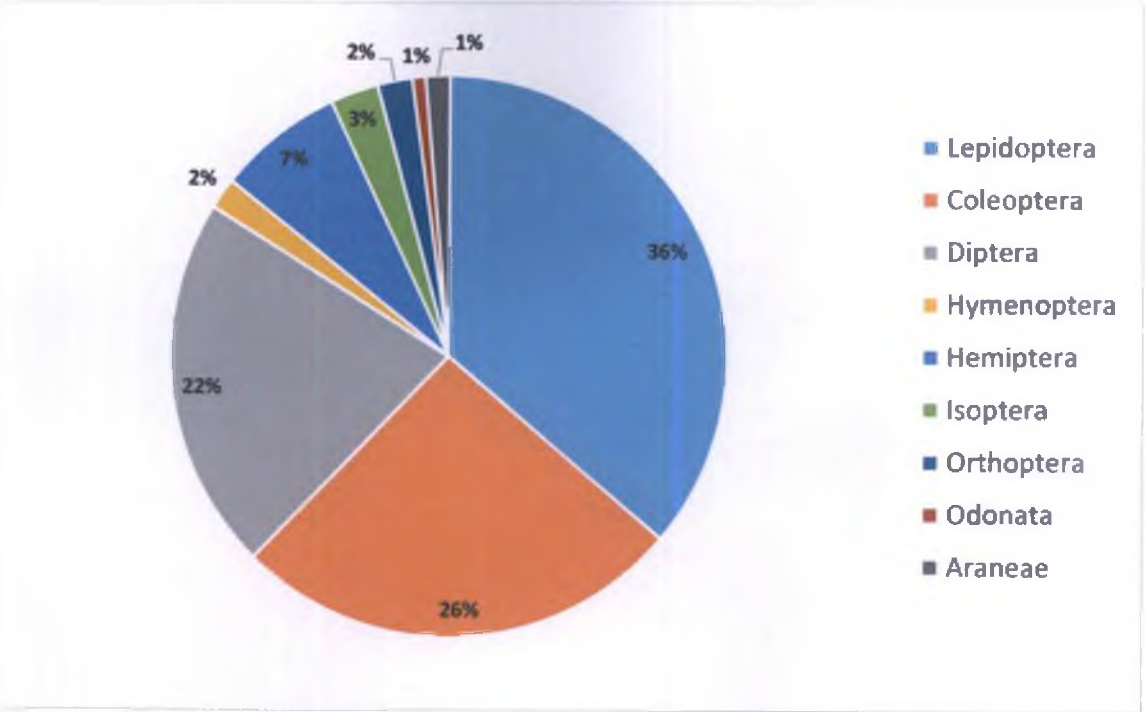


Fig. 8. Percent volume composition of diet of *Hipposideros ater*

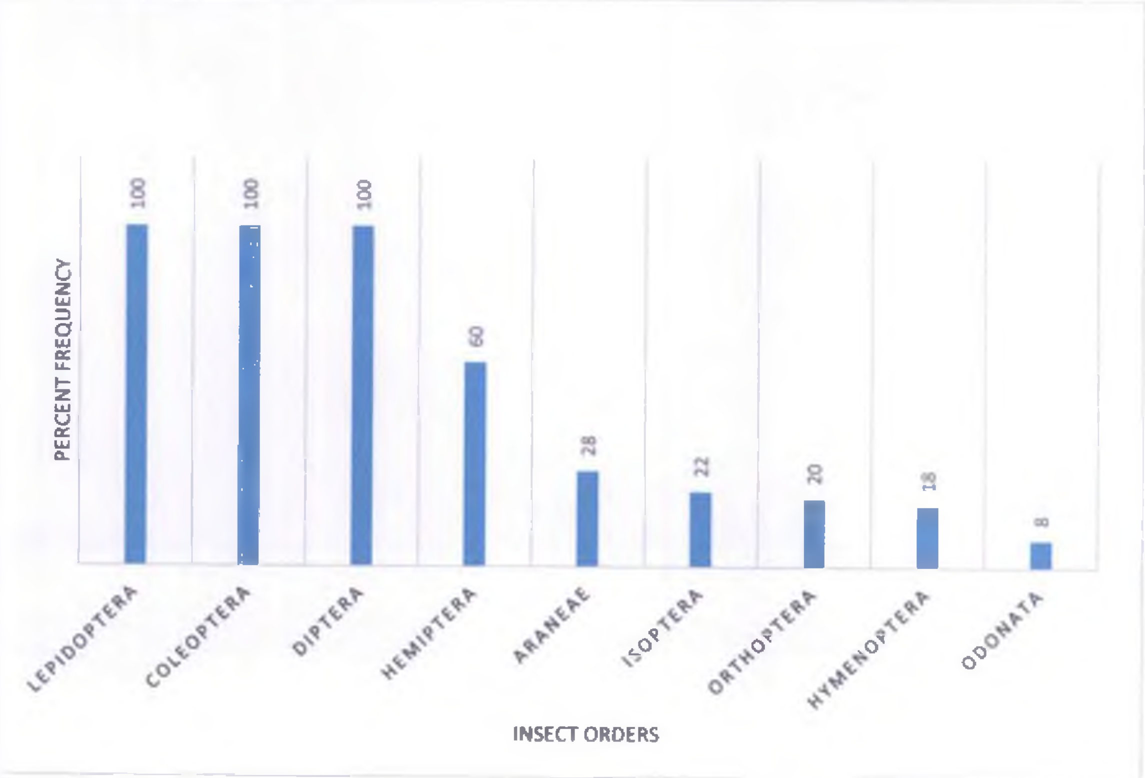


Fig. 9. Percent frequency composition of diet of Percent *Hipposideros ater*

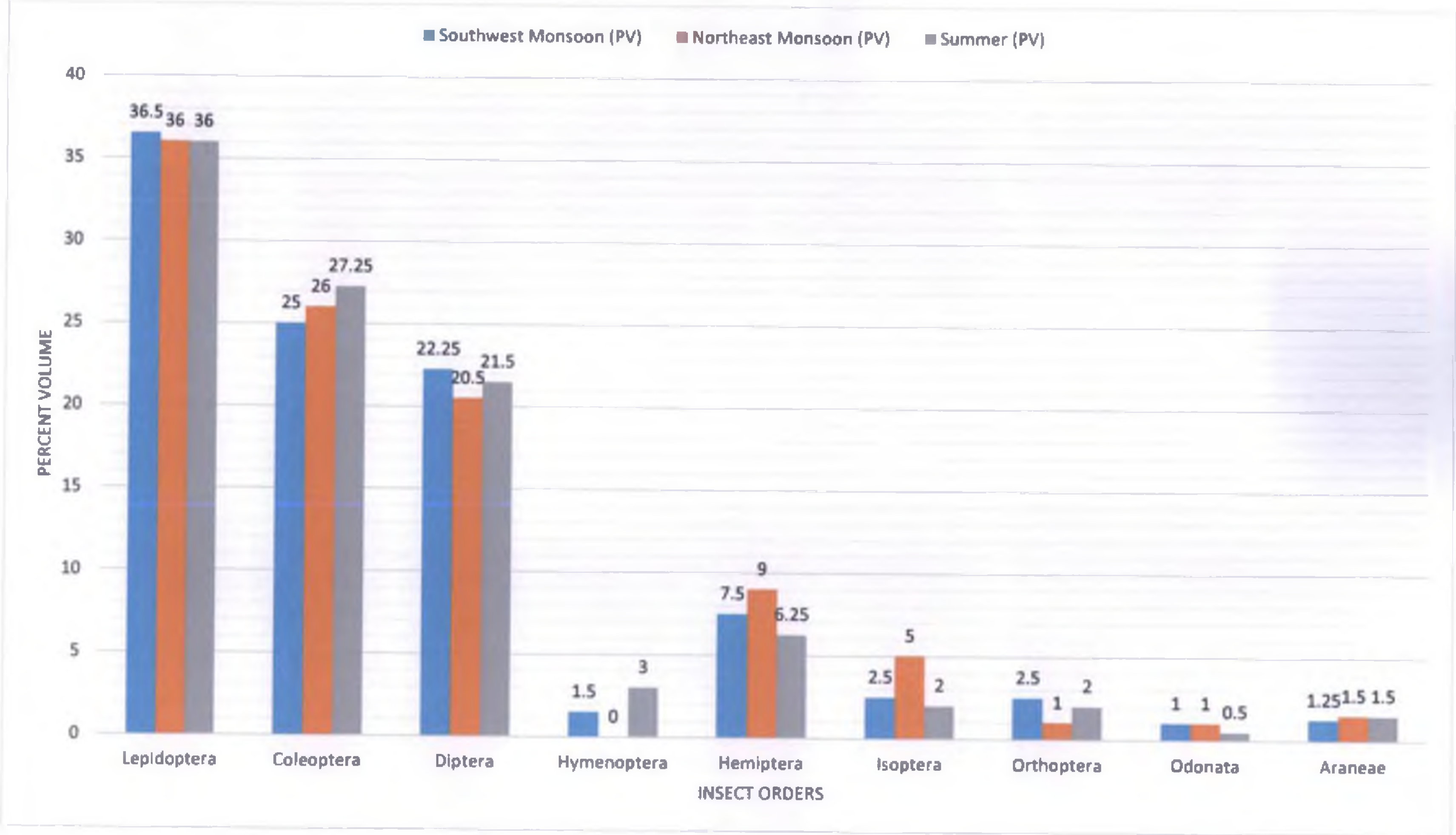
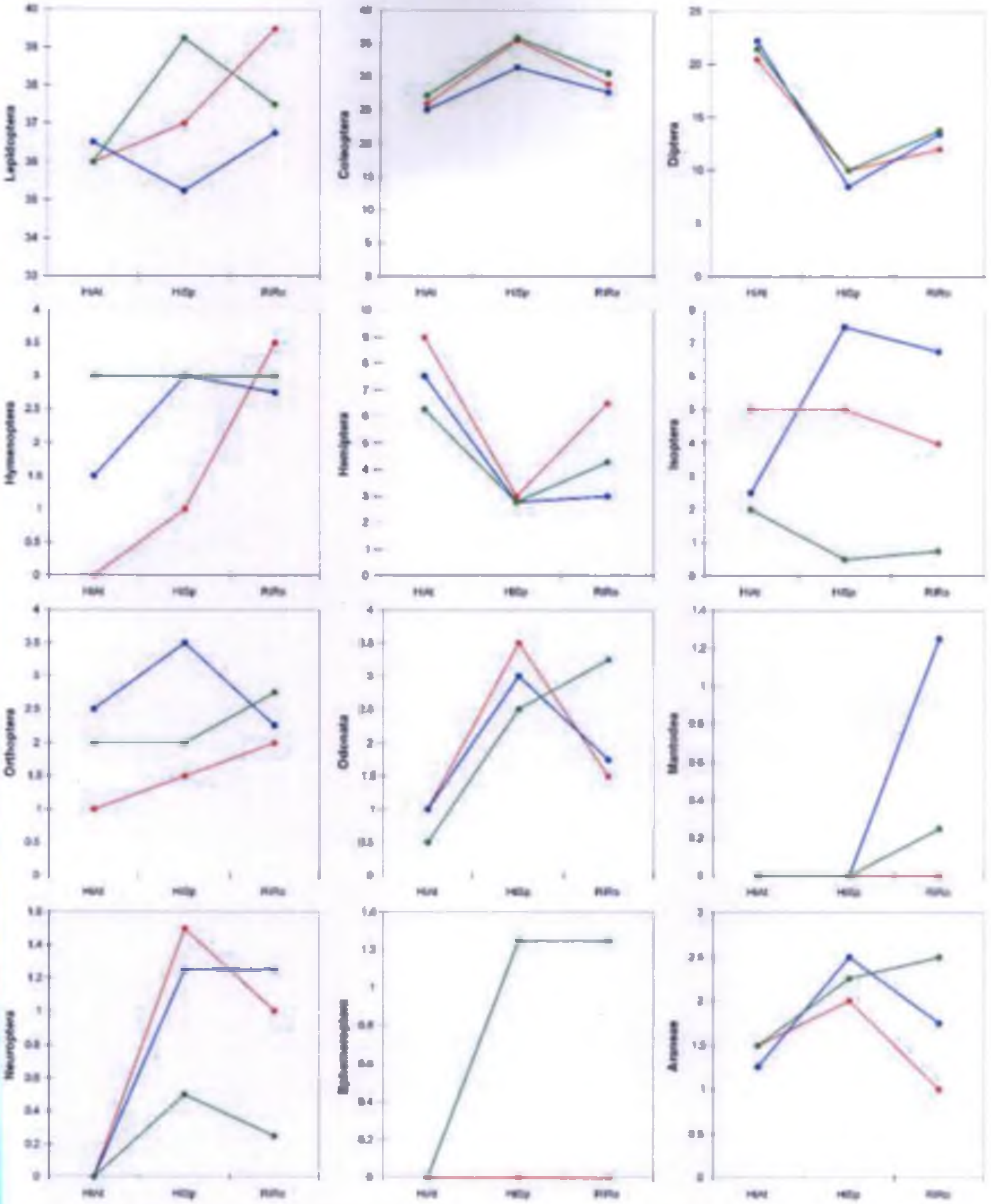


Fig. 10. Comparison of percent volume of different insect orders in the diet of *Hipposideros ater* between different seasons

Table 12. Comparison of diet between three different species of insectivorous bats, across the three seasons and their interaction at Peechi-Vazhani WLS

| Insect group | Interaction | F | P |
|---|---|---|---|
| Lepidoptera | Species | 1.639 | 0.198 |
| | Season | 1.644 | 0.197 |
| | Species x Season | 1.709 | 0.151 |
| Coleoptera | Species | 30.065 | **0.0001** |
| | Season | 5.878 | **0.004** |
| | Species x Season | 0.447 | 0.774 |
| Diptera | Species | 56.948 | **0.0001** |
| | Season | 0.285 | 0.752 |
| | Species x Season | 0.446 | 0.775 |
| Hymenoptera | Species | 1.047 | 0.354 |
| | Season | 0.839 | 0.434 |
| | Species x Season | 0.496 | 0.739 |
| Hemiptera | Species | 7.469 | **0.001** |
| | Season | 1.057 | 0.350 |
| | Species x Season | 0.435 | 0.783 |
| Isoptera | Species | 0.480 | 0.620 |
| | Season | 10.113 | **0.0001** |
| | Species x Season | 2.110 | 0.083 |
| Orthoptera | Species | 0.178 | 0.837 |
| | Season | 0.748 | 0.475 |
| | Species x Season | 0.273 | 0.895 |
| Odonata | Species | 2.868 | 0.060 |
| | Season | 0.022 | 0.978 |
| | Species x Season | 0.529 | 0.714 |
| Mantodea | Species | 1.665 | 0.193 |
| | Season | 1.073 | 0.345 |
| | Species x Season | 1.073 | 0.372 |
| Neuroptera | Species | 3.147 | **0.046** |
| | Season | 1.331 | 0.267 |
| | Species x Season | 0.380 | 0.822 |
| Ephemeroptera | Species | 1.506 | 0.225 |
| | Season | 1.205 | 0.303 |
| | Species x Season | 0.301 | 0.877 |
| Araneae | Species | 1.189 | 0.308 |
| | Season | 0.519 | 0.596 |
| | Species x Season | 0.426 | 0.790 |

P values in bold are significant at $\alpha = 0.05$



HiAt: *Hipposideros ater*, HiSp: *Hipposideros speoris*, RiRo: *Rinolophus rouxii*

🟦 Southwest Monsson 🟥 Northeast Monsoon 🟩 Summer

Figure 11: Plots of means for season and species wise differences of the insects in diet of the bats

### 4.7.2 Principal Component Analysis for insect preferences by insectivorous bats

The feeding preferences on the various insect orders by the three species of insectivorous bats is demonstrated using the principle component analysis (Fig. 12). According to which the *Rhinolophus rouxii* can be regarded as a generalist predator, as its niche overlaps with both *Hipposideros speoris* and *Hipposideros ater*. There is some niche overlap between *Hipposideros ater* and *Hipposideros speoris* but less than that of with *Rhinolophus rouxii*. *Hipposideros ater* and *Hipposideros speoris* have different insect preference. *Hipposideros ater* preferred primarily the members of the insect orders Hemiptera and Diptera, while the *Hipposideros speoris* preferred the insect orders Odonata, Coleoptera, Hymenoptera and Lepidoptera (Fig. 12).

### 4.7.3 Season wise feeding preferences of three species insectivorous bats at Peechi-Vazhani WLS

#### *4.7.3.1 Feeding preferences of three species insectivorous bats at Peechi-Vazhani WLS during South-west Monsoon*

Feeding preferences of three species insectivorous bats at Peechi-Vazhani WLS during South-west Monsoon is given in Fig. 13. The first two axes of PCA explained almost 40 % of the cumulative variance in season. There is niche overlap between *Hipposideros speoris* and *Rhinolophus rouxii* and both of them show a generalist predation. But the *Hipposideros ater* has a smaller niche overlap upon the feeding guilds on the other two species of insectivorous bats. During the south-west monsoon, the *Hipposideros ater* showed preference on the two insect orders such as Hemiptera and Diptera. *Hipposideros speoris* and *Rhinolophus rouxii* however, had a preference on the insect orders such as Lepidoptera, Coleoptera, Ephemeroptera and Neuroptera (Fig. 13).

### *4.7.3.2 Feeding preferences of three species insectivorous bats at Peechi-Vazhani WLS during North-East Monsoon*

Feeding preferences of three species insectivorous bats at Peechi-Vazhani WLS during North-East Monsoon is given in Fig. 14. The first two axes of PCA explained almost 50 % of the cumulative variance in season. *Rhinolophus rouxii* shows a generalist predation. There is distinct niche separation between *Hipposideros speoris* and *Hipposideros ater* as evidenced by the preference for insect orders that they fed on. *Hipposideros ater* during the north-east monsoon also had shown a preference towards the insect orders Diptera and Hemiptera (Fig. 14).

### *4.7.3.3Feeding preferences of three species insectivorous bats at Peechi-Vazhani WLS during summer*

The feeding preferences of three species insectivorous bats at Peechi-Vazhani WLS during summer season is given in Fig. 15. The first two axes of PCA explained almost 50 % of the cumulative variance in season. *Rhinolophus rouxii* during this season also shows generalist predation. In summer season *Hipposideros ater* had shown preference towards the insect order Diptera. However, *Rhinolophus rouxii* had a preference on the insect orders Mantodea, Ephemeroptera, Neuroptera and Hymenoptera. While the *Hipposideros speoris* preferred the insect orders Araneae and Coleoptera during the summer season (Fig. 15).

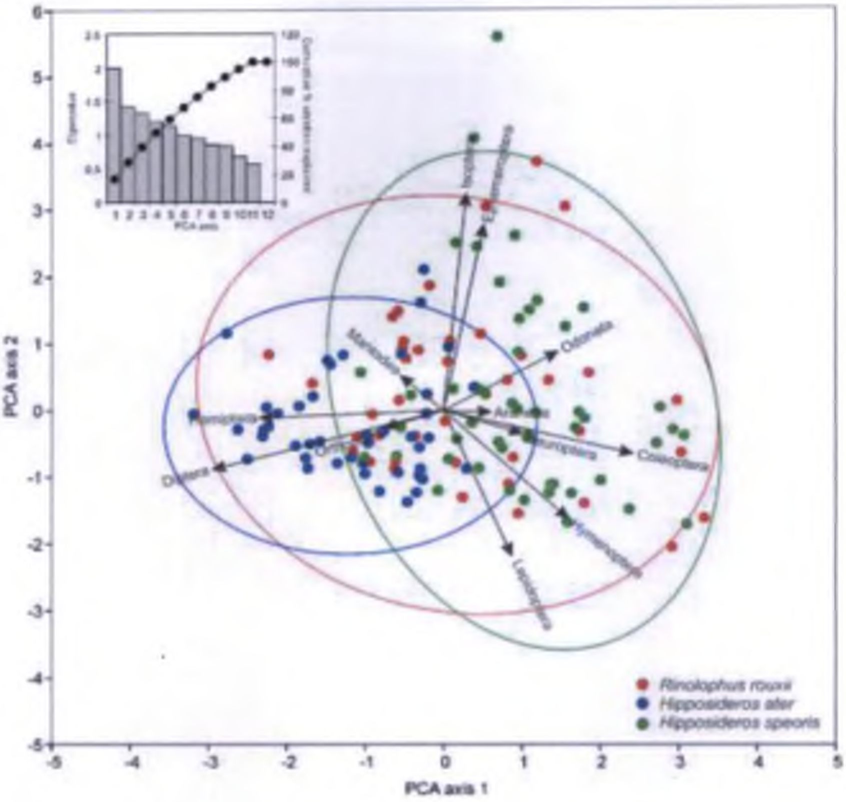


Fig. 12. Principle component analysis showing feeding preferences of the three bat species.

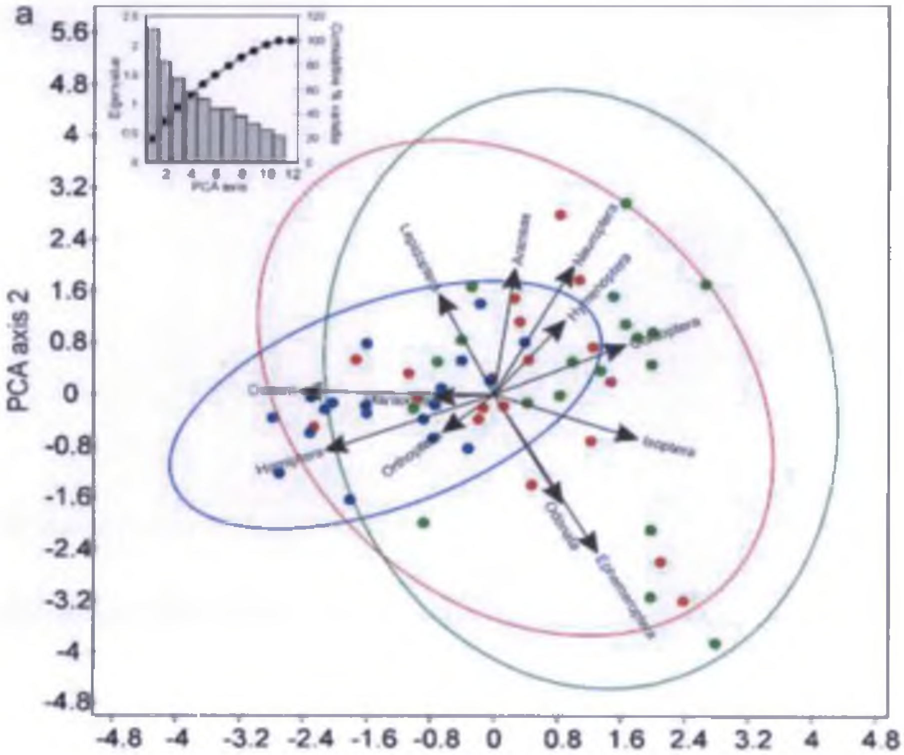


Fig. 13. Principle component analysis showing feeding preferences of the three bat species in southwest monsoon.

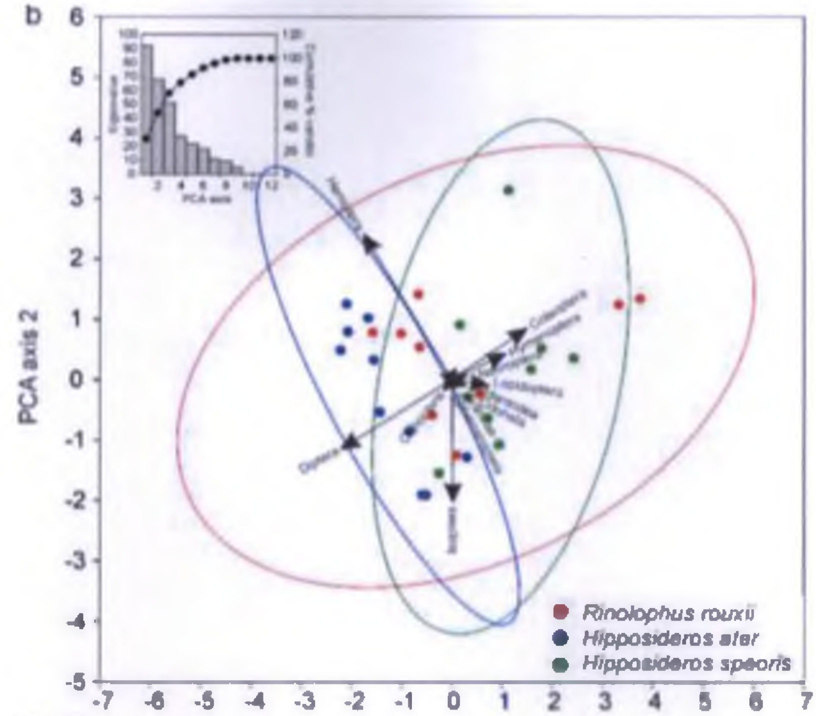


Fig. 14. Principle component analysis showing feeding preferences of the three bat species in northeast monsoon

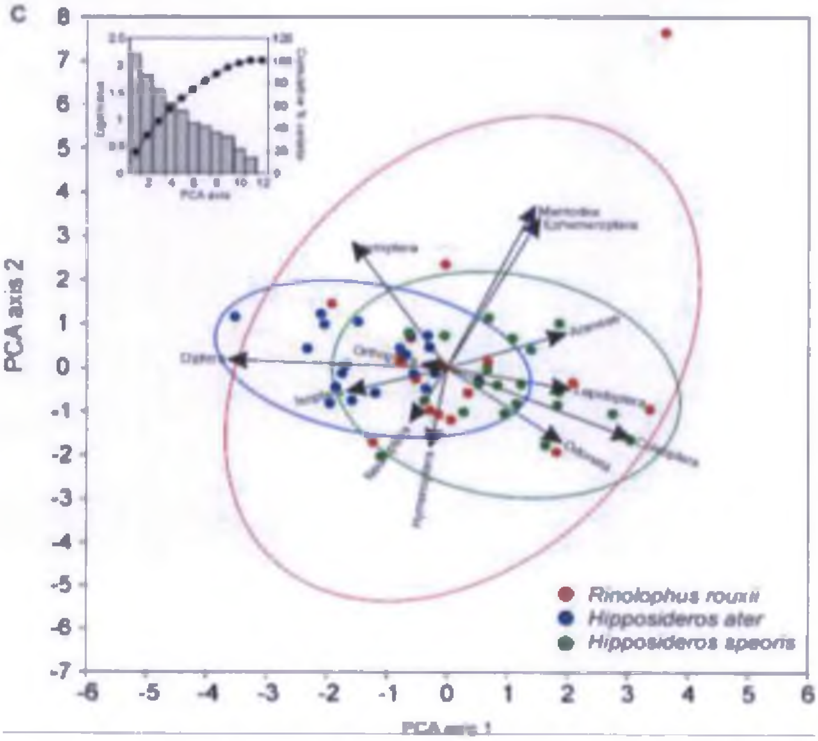


Fig. 15. Principle component analysis feeding preferences of the three bat species in summer

# DISCUSSION

# DISCUSSION

## 5.1 FOOD AND FEEDING HABITS OF INSECTIVOROUS BATS IN PEECHI-VAZHANI WILDLIFE SANCTUARY

Knowledge of the dietary composition can provide better understanding of the ecology and behavior of an animal, and dietary information is essential for effective management of any species (Kurta and Whitaker, 1998). Insectivorous bats are nocturnal flying mammals which uses echolocation for prey capture, and the best way to study its diet is through stomach content analysis and faecal matter analysis (Whitaker *et al.*, 2009). Stomach content analysis and identification of food remnants are so easy than the faecal matter analysis, but it involves killing of the bats through opening of the guts for stomach content analysis. It raises many ethical and conservation issues. So in the present study, nondestructive method of faecal matter analysis was adopted.

### 5.1.1 Food components in the diet of the insectivorous bats

Insectivorous bats fed on different orders of class Insecta and class Arachnida. They also occasionally fed on unusual prey items like scorpion and other invertebrates (Kurta and Whitaker, 1998; Jacobs, 1999). In the present study insects of different orders and spiders were present in the diet of all the three species of insectivorous bats under study viz. *Rhinolophus rouxii, Hipposideros speoris* and *Hipposideros ater.*

#### 5.1.1.1 *Insects in the diet of the insectivorous bats at Peechi-Vazhani WLS*

In the diet of *Rhinolophus rouxii* the percent volume for overall insect class was 98.1 percent. There were eleven insect orders in the diet, they were Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera, Odonata, Mantodea, Neuroptera and Ephemeroptera.

In the diet of *Hipposideros speoris* the percent volume for overall insect class was 97.7 percent. There were ten insect orders in the diet, they were Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Orthoptera, Odonata, Isoptera, Ephemeroptera and Neuroptera.

In the diet of *Hipposideros ater* the percent volume for overall insect class was 98.6 percent. There were eight insect orders in the diet, they were Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Orthoptera, Odonata and Isoptera.

All the insectivorous bats in the present study fed primarily on the insects, with more than 97 percent volume of diet consisting of insects. This points into the immense capability of insectivorous bats in insect predation and insect population regulation. A bat can consume insects up to 50 to 70 percent of body weight each night (Whitaker *et al.*, 2009, Kunz *et al.*, 1995). I have quantified the amount of insects that is being consumed by the bats under present study. Taking the minimum consumption by a bat (50% of body mass) into consideration, an individual of *Rhinolophus rouxii* with a body mass of 13g can consume approximately 6.5g of insects a day, *Hipposideros speoris* with a body mass of 12 g can consume 6g of insects a day and *Hipposideros ater* with a body mass of 7g can consume 3.5g of insects a day. Considering this consumption rate for a roost of 1000 individuals of insectivorous bats over a year, a roost of *Rhinolophus rouxii* can consume 2372.5 kg of insect a year, similarly *Hipposideros speoris* can consume 2190 kg of insects and *Hipposideros ater* can consume 1277.5kg of insects a year. This huge weight of insects include several millions of insects.

Similar results were obtained by Srinivasulu and Srinivasulu (2005) on the study of *Taphozous melanopogan* in the Borra caves in Andhra Pradesh. They could observe 11 insect orders in the diet of these bats from forest habitats and the overall percent volume of insects was 97.1 percent. In the present study, insectivorous bats were fed on eight to eleven insect orders. This indicates that a wide range of insects are fed by insectivorous bats and so that these bats can control population of a large number of insect species.

In the diet of all the insectivorous bats of present study, Lepidoptera and Coleoptera showed a percent frequency of 100 percent. In the case of *Hipposideros ater* Hemiptera also showed percent frequency of 100 percent. This indicates that all the individual bats from which faecal matter collected were fed on these insect orders.

#### 5.1.1.2 *Araneae in the diet of the insectivorous bats at Peechi-Vazhani WLS*

Order Araneae was present in the diet of all insectivorous bats of present study, in varying percent frequency and percent volume. Though the percent volume of spider in the diet of the insectivorous bats was comparatively lower, the percent frequency was higher. This indicates that spiders were fed by insectivorous more frequently but less in volume.

### 5.1.2 Seasonal variation in the diet of insectivorous bats at Peechi-Vazhani WLS

Seasonal variation in diet of the insectivorous bats during the present study was not significant. This points to the similarity of bat activity in different seasons. However, in the temperate regions there exists seasonal variation in the diet of the insectivorous bats (Whitaker et al., 1997). The insect order Isoptera showed a remarkable increase in percent volume in the monsoon season for the insectivorous bat diet. This could be because of outbreak of winged form of termites, which belonged to the order of Isoptera, during monsoon times.

### 5.1.3 Food preferences among the of insectivorous bats of Peechi-Vazhani WLS

The feeding preferences for insect orders was more or less same for all the three insectivorous bat species. Insect orders Coleoptera, Lepidoptera and Diptera were more preferred by all the three bats. But there is some difference as Diptera and Hemiptera were more preferred by *Hipposideros ater* than other two bat species. *Hipposideros speoris* preferred Coleoptera and Lepidoptera more when compared to other two species and *Rhinolophus rouxii* showed a generalist predation. These small difference in preference can be attributable to insect availability, echolocation ability by bats, the ability of the insect groups to detect the echolocation calls and thus avoiding the predator, morphology and jaw structure of the bats, habitat characteristics of foraging ground and foraging modes etc. Foraging modes adds to the species wise difference in preference as bats often use different foraging modes at the same time. Different foraging modes result in capture of insects from different locations such as air, water surface, tree barks, leaves, spider web etc., which in turn result in difference in insect consumption (Habersetzer and Vogler, 1983). The major reason behind the difference in preference might be echolocation and difference in morphology of bats especially difference in structure of jaws and wings (Altringham, 1996).

### 5.1.4 Different foraging modes of insectivorous bats of Peechi-Vazhani WLS

As insectivorous bats use different foraging modes, it consume different type of insects. In the present study, there were aerial insect like Coleoptera, Lepidoptera, Diptera, Hymenoptera, aquatic insects like Ephemeroptera, surface lying insects like Orthoptera (crickets) and other arthropods (spiders) in the diet. This indicates that these insectivorous bats captured prey on flight (aerial hawking), gleaned prey from surface (surface gleaning) and captured prey from water surface (trawling). But these foraging modes are not mutually exclusive and it is difficult to categorize a species (Habersetzer and Vogler, 1983).

### 5.1.5 Different foraging grounds of insectivorous bats of Peechi-Vazhani WLS

As the surrounding area of bat roosts consists of different habitat like forests, tree plantations, agricultural lands, paddy fields, ponds, streams, human habitations, the bats might be feeding on different habitats and different foraging grounds. Presence of aquatic insects like Ephemeropterans and Odonates, aerial insects like Coleopterans, Lepidopterans which consists many pests in agricultural land and plantations etc. indicates that bat might be feeding on different foraging grounds.

## 5.2 ECOSYSTEM SERVICES PROVIDED BY INSECTIVOROUS BATS OF PEECHI-VAZHANI WILDLIFE SANCTUARY

### 5.2.1 The role of arthropod pest suppression by the insectivorous bats

Insectivorous bats are extremely important in regulating the number of insects in forests and reducing herbivory (Kalka et al., 2008; Wilson and

Barclay, 2006). Although nearly 1500 injurious insects are associated with forest trees in the Indian region (Beeson, 1941; UNESCO, 1978) and most have been recorded from the natural forest, very few are known for their pest status in forests. These insect pests cause wide range of problems including mortality to forest trees. According to Nair et al., (1986) there were insect pest damage on the forest trees in moist deciduous forest of Peechi-Vazhani Wildlife Sanctuary. The majority of the insect pests were of insect orders Coleoptera (37.36%) and Lepidoptera (42.85%) and some from Hemiptera (12.08%), Diptera (2.19%) and Orthoptera (3.29%) of which many insects were vector of diseases of trees. The authors selected twenty economically important tree species for study. So the result emphasize the economic loss these insect species caused. During the present study the diet of all the three insectivorous bats, consisted of members of the insect orders Lepidoptera, Coleoptera, Diptera, Hemiptera and Orthoptera which also acted as major pestiferous species of insects to forests. The similarity in the diet and insect pest survey indicates the immense capability of insectivorous bats in controlling these pest insects and the economic advantage they provide to ecosystem.

These insectivorous bats fed on agricultural land and semi urban area also. There are a large number of insect pests of agricultural crops reported from Kerala and these insect pests of important agricultural crops belong to different insect orders. Insect orders Lepidoptera (41.05%), Coleoptera (20.52%), Diptera (3.68%), Hemiptera (21.05%), Orthoptera (4.21%), Hymenoptera (1.57%) and Isoptera (0.4%) mainly constitute the agricultural pests (Nair, 1978). Insect orders identified from the faecal samples constitute these insect orders of potential insect pest of agricultural crops. As these bats foraged on agricultural land, they might be feeding on many of these insect pest also. This indicate that bat plays a crucial role in controlling insect pest population in agricultural land.

There are a number of insect pests in human habitation like mosquitoes, houseflies, fruit flies belonging to the insect order Diptera, which spreads many contagious diseases harmful to mankind such as malaria, dengue fever, chikungunya etc. The present results indicate that the insectivorous bats in the study area, fed on Dipterans to a considerable extent, thus controlling their population.

Mosquitoes were found in bat diet at percent frequency of 17 percent (Whitaker and Lawhead, 1992) to as high as 77.4 percent (Anthony and Kunz, 1977). Dipterans contributed substantially in the diet of all the three bats of the present study and they accounted for 82 to 100 percentage frequency. Thus these bats play a very crucial role in the control of such harmful insect pests to mankind. In one of the study by (Reiskind and Wund, 2009), it was found that the Northern Long-eared Bats *(Myotis septentrionalis)* controlled the mosquitoes by 32 percent.

### 5.2.2 The role of the insectivorous bats as bio-control agents

Herbivorous arthropods destroy approximately 25-50% of crops globally (Pimentel et al., 1991). The response to these arthropod pest attack by modern agriculture has been predominantly through the application of synthetic pesticides. This practice that has led to many unintended problems including human health risks, degradation of ecosystem function and evolved toxicity resistance by pests (Benbrook, 1996). The World Resources Institute estimates that over 400 pest species have evolved resistance to one or more pesticides, and that despite an increase in pesticide use, the proportion of crops destroyed by insect pests has increased (WRI, 2009). By eliminating beneficial vertebrate and invertebrate predators through over usage of pesticides, insect species that are normally not known as pests are also elevated to pest status. To address this issue, importance of natural and bio-control measures for insect pest suppression should be given more emphasis. As observed, bats in the present study fed on a wide range of insects, and these bats plays an important role in insect pest suppression also. This indicates that these insectivorous bats can be used as a bio-control measure for insect pest suppression and ecofriendly substitute for chemical pesticides. This in turn reduces the cost on pesticides and reduce environment problems by chemical pesticides.

### 5.2.3 Redistribution of nutrients from bat guano

There were bat guano depositions in roosts of all the three insectivorous bats of present study. Guano from bats has long been mined from caves for use as fertilizer on agricultural crops due to the high concentrations of elements like nitrogen and phosphorous, the primary limiting nutrients of most plant life. Although the benefits of nitrogen and phosphorous to plants are well known, most of the evidence supporting bat guano as fertilizer is anecdotal (Culver and Pipan, 2009). This indicates that these bats redistribute the nutrients as they deposit guano in the roost and the nearby land of roosts. Also there might be redistribution to heterogeneous habitats in foraging area and in between foraging area and roost as they defecates during feeding bouts.

# SUMMARY

# SUMMARY

Insectivorous bats (Microchiroptera) are one of the least studied animals in Western Ghats especially in Kerala. Very little information is available on their ecology, behaviour, food and feeding habits, conservation etc. from Western Ghats, and there is no published information on their ecology and feeding behaviour from forests of Kerala. The objectives of the present study were to understand food and feeding habit and feeding preferences of insectivorous bats of Peechi-Vazhani Wildlife Sanctuary. The study was carried out in Peechi-Vazhani Wildlife Sanctuary and adjacent areas for ten months from May 2013 to February 2014. Three species of insectivorous bat species were selected for which permanent roost were available throughout the study period. The bat species were *Rhinolophus rouxii, Hipposideros speoris* and *Hipposideros ater*. The methods employed to study feeding habits were faecal matter analysis. Faecal pellets were collected for each species of bats once in a month and faecal matter analysis were done in a laboratory for identification and quantification of food components. The salient findings are summarized herein.

- From the faecal matter analysis of samples, representatives of eleven insect orders and Araneae (spiders) were identified. The insect orders include Lepidoptera (moths and butterflies), Coleoptera (beetles and weevils), Diptera (Flies), Hymenoptera (Ants, Bees and Wasps), Hemiptera (Bugs), Isoptera (Termites), Orthoptera (Crickets and Grasshoppers), Odonata (Dragonflies and damselflies), Mantodea (Mantis), Neuroptera (Lacewings) and Ephemeroptera (Mayflies).

- Faecal matter analysis of *Rhinolophus rouxii,* reveals that these bats fed on eleven insect orders and spiders. Insect orders identified were Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera, Odonata, Mantodea, Neuroptera and Ephemeroptera.

- In the diet of *Rhinolophus rouxii* Lepidoptera were the most preferred insect order. Lepidoptera ranked first with a mean percentage volume of 37.6 percent and the remaining insect orders were Coleoptera, Diptera, Hemiptera, Isoptera, Hymenoptera, Orthoptera, Odonata, Araneae, Ephemeroptera, Neuroptera, and Mantodea in the descending order of percent volume.

- In the diet of *Rhinolophus rouxii* Lepidoptera and Coleoptera ranked first in terms of percent frequency with 100 percent. The remaining insect orders in the descending order were Diptera, Hemiptera, Isoptera, Araneae, Hemiptera, Orthoptera, Odonata, Neuroptera, Ephemeroptera and Mantodea.

- Faecal matter analysis of *Hipposideros speoris* reveals that these bats fed on ten insect orders and spiders. Insect orders identified were Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera, Odonata, Neuroptera and Ephemeroptera.

- In the diet of *Hipposideros speoris* Lepidoptera ranked first in terms of percent volume with 37.2 percent. The remaining insect orders in the descending order of percent volume were Coleoptera, Diptera, Isoptera, Odonata, Hemiptera, Hymenoptera, Orthoptera, Araneae, Neuroptera, and Ephemeroptera

- In the diet of *Hipposideros speoris* Lepidoptera and Coleoptera ranked first in terms of percent frequency of 100 percent. The remaining insect orders in descending order were Diptera, Araneae, Hemiptera, Isoptera, Orthoptera, Odonata, Hymenoptera, Neuroptera and Ephemeroptera.

- Faecal matter analysis of *Hipposideros ater* reveals that these bats fed on eight insect orders and spiders. Insect orders identified were Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera and Odonata.

- In the diet of *Hipposideros ater* Lepidoptera ranked first in terms of mean percentage volume with 36.2 percent. The remaining insect orders in the descending order of percent volume were Coleoptera, Diptera, Hemiptera, Isoptera, Orthoptera, Hymenoptera, Araneae and Odonata.

- In the diet of *Hipposideros ater* insect orders Lepidoptera, Coleoptera and Diptera ranked first in terms of percentage frequency of 100%. The remaining insect orders in the descending order were Hemiptera, Araneae, Isoptera, Orthoptera, Hymenoptera and Odonata.

- There was no significant difference for percent volume in species wise, season wise or both in the insect orders Lepidoptera, Hymenoptera, Orthoptera, Mantodea, Ephemeroptera and Araneae. However there was a significant bat species wise difference in the consumption of Coleoptera, Diptera, Hemiptera and Neuroptera, while there was a seasonal difference in the consumption of Coleoptera and Isoptera. It is interesting to note that for Coleoptera there was a significant difference in both season and species wise consumption but the interaction of species and season was not significant.

- Principle component analysis was done to understand bat species wise feeding preferences for various insect orders. In this, *Rhinolophus rouxii* was a generalist predator and its niche overlaps with both *Hipposideros speoris* and *Hipposideros ater*. There is some niche overlap between *Hipposideros ater* and *Hipposideros speoris* but less than that of with *Rhinolophus rouxii. Hipposideros ater* and *Hipposideros speoris* have different insect preference. Members of the insect order Hemiptera and Diptera were more preferred by *Hipposideros ater* and the members of the insect order Odonata, Coleoptera, Hymenoptera and Lepidoptera were more preferred by *Hipposideros speoris.*

- The insectivorous bats of the present study fed on different insect orders, constituting the major insect pests in tree plantations, agricultural land, and urban areas which spread many diseases and cause economic loss to agriculture as well as forest plantation. This indicates that insectivorous bats plays a crucial role in suppression of insect pest population.

# REFERENCES

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Agosta, S.J., Morton, D., and Kuhn, K.M. 2003. Feeding ecology of the bat *Eptesicus fuscus:* 'preferred' prey abundance as one factor influencing prey selection and diet breadth. *J. Zool.* 260:2, 169-177.

Akbar, Z., Hong, L.W., and Sastroutomo, S.S. 1999. Insectivorous bats as natural predators of insect pests. Biological control in the tropics: towards efficient biodiversity and bioresource management for effective biological control. *Proceedings of the Symposium on biological control in the tropics*, March 18-19, Serdang, Malaysia. CABI Publishing, Wallingford, U.K. pp. 34-37.

Allen, G.M. 1962. *Bats: Biology, Behavior and Folklore.* Harvard University Press, Cambridge, MA, pp. 137-154.

Altringham, J.D. 1996. *Bats: Biology and Behaviour.* Oxford University Press, London, United Kingdom, 262p.

Anthony, E.L.P. and Kunz, T.H. 1977. Feeding strategies of the little brown bat, *Myotis lucifuges*, in southern New Hampshire. *Ecology,* 58:775-786.

Arita, H.T. 1996. The conservation of cave-roosting bats in Yucatan, Mexico. *Biol. Conserv.*76: 177–185.

Arita, H.T. and Fenton, M.B. 1997. Flight and echolocation in the ecology and evolution of bats. *Trends Ecol. Evol.* 12: 53–58.

Arlettaz, R. 1996. Feeding behavior and foraging strategy of free-living mouse-eared bats, *Myotis myotis* and *Myotis blythii*. *Anim. Behav.* 51: 1-11.

Barclay, R.M.R. and Brigham, R.M. 1994. Constraints on optimal foraging: a field test of prey discrimination by echolocating insectivorous bats. *Anim. Behav.* 48: 1013 –1021.

Bates, P.J.J. and Harrison, D.L. 1997. *Bats of the Indian sub-continent*. Harrison Zoological museum publications, London. p.258.

Beeson, C. F.C. 1941. *The Ecology and Control of the Forest Insects of India and the Neighbouring Countries* (Indian Reprint, 1961). Govt. of India, 767p.

Behr, O. and von Helversen, O. 2004. Bat serenades: complex courtship songs of the sac-winged bat (*Saccopteryx bilineata*). *Behav. Ecolo. Sociobiol.* 56: 106-115.

Behr, O., von Helversen, O., Heckel, G., Nagy, M., Voigt, C.C., and Mayer, F. 2006. Territorial songs indicate male quality in the sac-winged bat *Saccopteryx bilineata* (Chiroptera, Emballonuridae). *Behav. Ecol.* 17: 810-817.

Bellwood J J. and Fenton, M.B. 1979. Variation in the diet of Myotislucifugus (Chiroptera; Vespertillionidae). Can. J. Zool. 54: 1674- 1678.

Benbrook, C. M. 1996. *Pest Management at the Crossroads*. Consumer Union, New York, 306p.

Black, H.L. 1972. Differential exploitation of the moths by the bats Eptesicusfuscus and Lasiuruscinereus. *J. Mammal.* 53:598-601.

Brack, V. Jr. and Whitaker, J.O., Jr. 2004. Bats of the Naval Surface Warfare Center at Crane, Indiana. *Proceedings of the Indiana Academy of Science.* 113:66-75.

Carter, G.G., Skowronski, M.D., Faureand, P.A., and Fenton, M.B. 2008. Antiphonal calling allows individual discrimination in white-winged vampire bats. *Anim. Behav.* 76: 1343-1355.

Clark, D.R. Jr and Lamont, T.G. 1976. Organochlorine residues in females and nursing young of the big brownbat (*Eptesicusfuscus*). *Bull. Environ. Contam. Toxicol.* 15: 1–8.

Clark, D.R. Jr. 1981. Bats and environmental contaminants: a review. *United States Department of the Interior, Fish and Wildlife Service, Special Scientific Report-Wildlife*, 235, 1–27.

Clark, D.R. Jr, Clawson, R.L. and Stafford, C.J. 1983. Gray bats killed by dieldrin at two additional Missouricaves: aquatic macroinvertebrates found dead. *Bull. Environ. Contam. Toxicol.* 30: 214–218.

Clark, D.R. Jr. 1986. Toxicity of methyl parathion to bats: mortality and coordination loss. *Environ. Toxicol. Chem.* 5: 191–195.

Clark, D.R. Jr and Rattner, B.A. 1987. Orthene® toxicity to little brown bats (*Myotislucifugus*): acetylcholinesteraseinhibition, coordination loss, and mortality. *Environ. Toxicol. Chem.* 6: 705–708.

Clark, D.R. Jr. 1988. How sensitive are bats to insecticides? *Wildlife Society Bulletin*, 16: 399–403.

Clarke, F.M., Pio, D.V., and Racey, P.A. 2005. A comparison of logging systems and bat diversity in the Neotropics. *Conserv. Biol.* 19: 1194 – 1204.

Clawson, R.L. and Clark, D.R. Jr. 1989. Pesticide contamination of endangered gray bats and their food basein Boone County, Missouri, 1982. *Bull. Environ. Contam. Toxicol.* 42: 431–437.

Crampton, L. 1995. Habitat selection by bats and the potential impacts of forest fragmentation on bat populations in aspen mixedwood forests in northern Alberta. M.Sc thesis. University of Calgary, Calgary, AB. Pp. 114

Culver, D.C. and Pipan, T. 2009. *The Biology of Caves and Other Subterranean Habitats* (2nd Ed.) Oxford University Press, USA, 256p.

Estok, P., Zsebok, S., and Siemers, B.M. 2009. Great tits search for, capture, kill and eat hibernating bats. *Biol. Lett.* 6: 59–62.

Feldhamer, G.A., Whitaker, J.O. Jr., Krejca, J.K., and Taylor, S.J. 1995. Food of the evening bat (*Nycticeiushumeralis*) and red bat (*Lasiurus borealis*) from southern Ilinois. Proceedings of the Illinois Academy of Science, 88: 139-143.

Fenton, M. B., and G. P. Bell 1979. Echolocation and feeding behavior in four species of Myotis (Chiroptera). Can. J. Zool. 57:1271-1277.

Fenton, M.B. 1982. Echolocation, insect hearing, and feeding ecology of insectivorous bats. In: T. H. Kunz (Ed.), *Ecology of Bats*. Plenum Press, New York, pp. 261–285.

Fenton, M.B., Acharya, L., Audet, D., Hickey, M.B.C., Merriman, C., Obrist, M.K., Syme, D.M. and Adkins, B. 1992. Phyllostomid bats (Chiroptera: Phyllostomidae) as indicators of habitat disruption in theNeotropics. *Biotropica*, 24: 440–446.

Fenton, M.B. 1997. Science and the conservation of bats. *J. Mamm.* 78: 1–14.

Fenton, B., Whitaker, J.O. Jr., Vonhof, M. J., Waterman, J. M., Pedro, W. A., Aguiar, L. M. S., Baumgarten, J.E., Bouchard, S., Faria, D.M., Portfors, C.V., Rautenbach, N.I. L., Scully, W., and Zortea, M. 1999. The diet of bats from Southeast Brazil: the relation to echolocation and foraging behaviour. *Reuta bras. Zool.* 16: 1081-1085.

Fenton, M.B. 2003. Eavesdropping on the echolocation and social calls of bats. *Mamm. Rev.* 33: 193-204.

Fleming, T.H. and Racey, P.A. 2010. *Island Bats: Evolution, Ecology, and Conservation*. University of Chicago Press, Chicago, 549p.

George, V.J. 2002. Management plan of Peechi- Vazhani wildlife sanctuary, Kerala forest department, 112p.

Griffin, D.R. 1958. Listening in the Dark, Yale University Press, 174p.

Grindal, S. D. 1999. Habitat use by bats, *Myotis* sp. in Western Newfoundland. *Can. Field. Natur.* 113: 258-263.

Grinnell, A. D. 1995. Hearing in bats: An overview. In Popper, A. N. and Fay, R. R. eds,'Hearing by bats', Springer-Verlag. p. 230.

Habersetzer, J. and Vogler, B. 1983. Discrimination of surface-structured targets by the echolocating bat *Myotis myotis* during flight. *J. Comp. Physiol.* 152: 275–282.

Hill, J. E. and Smith, J. D. 1984. *Bats: A natural history.* Austin: University of Texas Press. 243p.

Holderied , M. W and von Helversen, O. 2003. Echolocation range and wing beat period match in aerial-hawking bats. *Proc. R. Soc. Lond. B Biol. Sci.* 270: 2293–2299.

Houston, R. D, Boonman, A., and Jones, G. 2003. Do echolocation signal parameters restrict bats choice of prey? In: Thomas, J. A, Moss, C. F, and Vater, M.(eds.), *Echolocation in Bats and Dolphins.* Chicago, University of Chicago Press. pp. 339–345.

Huang, F. N., Subramanyam, B., and Taylor, R. 2003. Ultrasound affects spermatophore transfer, larval numbers, and larval weight of *Plodia interpunctella* (Hubner) (Lepidoptera: Pyralidae). *J. Stored Prod. Res.* 39: 413–422.

Hutson, A. M., Mickleburgh, S. P., and Racey, P. A. 2001. *Microchiropteran bats: global status survey andconservation action plan*. IUCN/SSC Chiroptera Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK, 258 p.

IUCN. 2010. *IUCN Red List of Threatened Species,* version 2010.3. www.iucnredlist.org/initiatives/mammals.

Jacobs, D. S. 1999. The diet of the insectivorous Hawaiian hoary bat in an open and a cluttered habit. *Can. J. Zool.* 77(10): 1603-1608.

Jones, G. and Rydell, J. 2003. Attack and defense: interactions between echolocating bats and their insect prey. In: Kunz, T. H. and Fenton, M. B. (eds.), *Bat Ecology*. University of Chicago Press, Chicago, pp. 301–345.

Kazial, K. A. and Masters, W. M. 2004. Female big brown bats, *Eptesicus fuscus*, recognize sex from a caller's echolocation signals. *Anim. Behav.* 67: 855-863.

Kazial, K. A., Kenny, T. L., and Burnett, S. C. 2008. Little brown bats (*Myotis lucifugus*) recognize individual identity of conspecifics using sonar calls. *Ethology*, 114: 469-478.

Kunz,T. H. 1974. Feeding Ecology of a Temperate Insectivorous Bat (*Myotis Velifer*). *Ecology*, 55: 693–711.

Kunz, T. H. 1982. Roosting ecology. In: Kunz T. H. (ed.), *Ecology of Bats*. Plenum Press, New York, pp. 1–55.

Kunz, T. H. and Whitaker, J. O. Jr. 1983. An evaluation of fecal analysis for determining food habits of insectivorous bats. *Can. J. Zool.* 61: 1318- 1321.

Kunz, T. H., Whitaker, J. O. Jr., and Wadanoli, M. D. 1995. Dietary energetics of the insectivorous Mexican free-tailed bat (*Tadaridabrasiliensis*) during pregnancy and lacation. *Oecologia,* 101: 407–415.

Kunz, T. H. 1996. Measuring and monitoring biological diversity. In: Thomas, D.W (eds.) Standard methods for mammals. Washington, DC: Smithsonian Institution Press. 409 p.

Kunz, T. H., and Fenton, M. B. 2003. *Bat Ecology*. The University of Chicago Press, Chicago, IL, USA, 779 pp.

Kurta, A. and Whitaker, J.O. 1998. Diet of the endangered Indiana bat (*Myotis sodalis*) on the northern edge of its range. *Am. Midl. Nat.* 140: 280–286.

Lacki, M.J., Burford, S. and J.O. 1995. Whitaker, Jr. Food habits of gray bats in Kentucky. *J. Mamma*. 76: 1256-1259.

Mackenzie, G. A., OXFORD, G.S. 1995. Prey of the noctule bat (*Nyctalusnoctula*) in East Yorkshire*J. Zool., Lond.,* 236: 322–327.

Madhavan, A. 2003. Feeding habit of the Great Vampire Bat, *Megaderma lyra lyra.* Observation on the food and feeding habits of *Megaderma lyra* in laboratory condition. *Trends in Life Sci. India.* 8: 27-31.

McAney, C., Sheil, C., Sullivan, C., and Fairley, F. 1991. *The Analysis of Bat Droppings*. Occasional publications, Mammal society, 48p.

McLaughlin, A. and Mineau, P. 1995. The impact of agricultural practices on biodiversity. *Agric. Ecosyst. Environ.* 55: 201–212.

MCNAB, B.K. 1980. Food habits, energetics, and the population biology of mammals. *Am. Nat.,* 116:106–124.

Medellin, R.A., Equihua, M., and Amin, M.A. 2000. Bat diversity and abundance as indicators of disturbancein Neotropical rainforests. *Conserv. Biol.* 14: 1666–1675.

Mickleburgh, S.P., Hutson, A.M., and Racey P.A. 2002. A review of the global conservation status of bats. *Oryx,* 36(1):18-34.

Minta, S.C., Kareiva, P.M. and Curlee, A.P. 1999. Carnivore research and conservation: learning from history and theory. In: *Carnivores in Ecosystems: The Yellowstone Experience* (Ed. by T. W. Clark, A. P. Curlee, S.C. Minta and P. M. Kareiva), pp. 323–404. Yale University Press, New Haven, CT.

Mistry, S. 2003. Protecting the bats of India- Signs of progress and daunting challenge. *Bats*: 21: 8-11.

Mohr, C.E. 1972. The status of threatened species of cave-dwelling bats. *Bull. National Speleological Society* 34: 33–47.

Nair, K.S.S., Mathew, G., Mohanadas, K., and Menon, A. R. R. 1986. A Study Of Insect Pest Incidence In Natural Forests. KFRI Research Report, 28p.

Nair, M. R. G. K. 1978. A monograph on crop pests of Kerala and their control measures. Kerala Agricultural University, 189p.

Neilson, A.L. and Fenton, M.B. 1994 Responses of Little Brown Myotis to exclusion and to bat houses. *Wildlife Society Bulletin*, 22: 8–14.

Neuweiler, G. 1989. Foraging ecology and audition in echolocating bats. *Trends Ecol. Evol.* 4: 160–166.

Norberg, J. 1999. Linking nature's services to ecosystems: some general ecological concepts. *Ecol. Econ.* 29:183– 202.

Nowak, R. 1991. Order Chiroptera. In: Walker. (ed). *Mammals of the World* (5th Ed.). Baltimore, Johns Hopkins University Press. pp.190-194.

Nowak, R.A. 1994. *Wolker's bats of the World.* The Johns Hopkins University Press, Baltimore, 105p.

Pierson, E.D. 1998. Tall trees, deep holes, and scarred landscapes: conservation biology of North American bats. In: *Bat Biology and Conservation* (Ed. by T. H. Kunz and P. A. Racey), pp. 309–325. Smithsonian Institution Press, Washington, DC.

Pimentel, D., McLaughlin, V., and Zepp, A. 1991. Environmental and economic effects of reducing pesticide use. *BioScience* 41: 402–409.

Racey, P.A. and Swift, S.M. 1985. Feeding ecology of *Pipistrellus pipistrellus* (Chiroptera: Vespertilionidae) during pregnancy and lactation. *J. Anim. Ecol.* 54: 205-215.

Racey, P.A. 1998. Ecology of European bats in relation to their conservation. In: *Bat Biology and Conservation* (Ed. by T. H. Kunz and P. A. Racey), pp. 249–260. Smithsonian Institution Press, Washington, DC.

Reichard, J.D. 2010. *Seasonal Activity and Energetics of Brazilian Free-tailed Bats* (Tadarida brasiliensis) *in South Central Texas.* Unpublished doctoral dissertation, Boston University, Boston, MA.

Reiskind, M. H. and Wund, M. A. 2009. Experimental assessment of the impacts of northern long-eared bats on ovipositing *Culex* (Diptera: Culicidae) mosquitoes. *J. Med. Entomol.* 46: 1037–1044.

Schleuning, W.D. 2000. Vampire bat plasminogen activator DSPA-alpha-1 (desmoteplase): a thrombolytic drug optimized by natural selection. *Pathophysiol. Haemostasis Thromb.* 31: 118–122.

Schnitzler, H.U., Moss, C.F., and Denzinger, A. 2003. From spatial orientation to food acquisition in echolocating bats. *Trends Ecol. Evol.* 18: 386-394.

Siemers, B.M. and Schnitzler, H.U. 2000. Natterer's Bat (*Myotis nattereri* Kuhl, 1818) hawks for prey close to vegetation using echolocation signals of very broad bandwidth. *Behav. Ecol. Sociobiol.* 47: 400–412.

Simmons, N.B. 2005. Order Chiroptera. In: Wilson, D. E. and Reeder, D. M. (eds.), *Mammal Species of the World: A Taxonomic and Geographic Reference* (3rd Ed.). The Johns Hopkins University Press, Baltimore, pp. 312-365.

Simmons, N.B. and Conway, T. 2003. Evolution of ecological diversity in bats. In: Kunz, T. and Fenton, M. B (eds.), *Bat Ecology*. University of Chicago Press, pp. 493- 535.

Sinha, Y.P. 1986. The bats of Bihar; taxonomy and field ecology. *Rec. Zool. Surv. India. Occ. Pap.* 77: 67.

Smith, G.J. 1987. *Pesticide Use and Toxicology in Relation to Wildlife: Organophosphorous and Carbamate Compounds*. Publication 170. US Fish and Wildlife Service Resources.

Surlykke, A., and Kalko, E.K.V. 2008. Echolocating bats cry out loud to detect their prey. *PLOS ONE*, 3: 20-36.

Teeling, E.C., Springer, M.S., Madsen, O., Bates, P., O'Brien, S.J., and Murphy, W. J. 2005. A Molecular Phylogeny for Bats Illuminates Biogeography and the Fossil Record. *Science*, 307: 580-584.

Thies, M.L., Thies, K. and McBee, K. 1996. Organochlorine pesticide accumulation and genotoxicity in Mexican free-tailed bats from Oklahoma and New Mexico. *Archives of Environ. Contam. Toxicol.* 30: 178–187.

Thomas, D.W. 1995. Hibernating bats are sensitive to non-tactile human disturbance. *J. Mamm.* 76: 940–946.

Thompson, F.R., III, ed. 2006. Conservation assessments for five forest bat species in the Eastern United States. Gen. Tech. Rep. NC-260. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 82 p.

Tuttle, M.D. 1975. Population ecology of the gray bat (*Myotis grisescens*): factors influencing early growth and development. *Occasional Papers of the Museum of Natural History, University of Kansas*, 36: 1–24.

UNSECO. 1978. Pests and diseases in forests and plantations. In: *Tropical Forest Ecosystems:* 286-3 14.

Verboom, B. and Spoelstra, K. 1999. Effects of flood abundance and wind on the use of three lines by an insectivorous bat *Pipistrellus pipistrellus*. *Can. J. Zool.* 77: 1393-1401

Verts, B.J., Carraway, L.N., and Whitaker, J.O. Jr. 1999. Temporal variation in prey consumed by big brown bats (*Eptesicus fuscus*) in a maternity colony. Northwest Science 73: 114-120.

Voigt-Heucke, S.L., Taborsky, M., and Dechmann, D.K.N. 2010. A dual function of echolocation: bats use echolocation calls to identify familiar and unfamiliar individuals. *Anim. Behav.* 80: 59-67.

Walters, B.L., Ritzi, C.M., Sparks, D.W., and Whitaker, J. O. Jr. 2007. Foraging behavior of eastern red bats (*Lasiurus borealis*) at an urban-rural interface. *Amer. Nat.* 157: 365-373.

Whitaker, J.O., Jr., and Lawhead, B. 1992. Foods of *Myotis lucifugus* in a maternity colony in central Alaska. *J. Mamm.* 73: 646–648.

Whitaker, J.O., Jr. 1995. Food of the big brown bat *Eptesicus fuscus* from maternity colonies in Indiana and Illinois. *Am. Midl. Nat.* 134:346–360.

Whitaker, J.O., Jr., Neefus, C., and Kunz, T.H. 1996. Dietary variation in the Mexican free-tailed bat (*Tadarida brasiliensis mexicanus*). *J. Mamma.* 77: 716-724.

Whitaker, J.O., Jr., Rose, R.K., and Padgett, T.M. 1997. Food of the red bat, *Lasiurus borealis,* in winter in the Great Dismal Swamp, North Carolina and Virginia. *Amer. Natur.* 137: 408-411.

Whitaker, J.O., Jr., and Weeks, H.P. Jr. 2001. Food of *Eptesicus fuscus*, the big brown bat, in Indiana in the absence of cultivated fields and agricultural pests. Proceedings of the Indiana Academy of Science. 110: 123-125.

Whitaker, J.O. and Yom-Tov, Y. 2002. The diet of some insectivorous bats from northern Israel. *Mamm. Biol.* 67: 378-380.

Whitaker, J.O., Jr. 2004. Prey selection in a temperate zone insectivorous bat community. *J. Mamma.* 85:460-469.

Whitaker, J.O., Jr., Dannelly, H. K. and Prentice, D. A. 2004. Chitinase in insectivorous bats. *J. Mamm.* 85: 15-18.

Whitaker, J.O., Jr. and Susan M. Barnard. 2005. Food of big brown bats (*Eptesicus fuscus*) from a colony at Morrow, Georgia. Southeastern Naturalist 4:111-118.

Whitaker, J.O., Jr., Brooks, M., Scott, L., Finn, L.S., and Smith, C.L. 2007. Food habits of Rafinesque's Big-eared Bat from Florida. *Florida Sci.*70: 202-206.

Whitaker, J.O., Jr., McCracken, G.F. and Siemers, B. 2009. Food habits analysis of insectivorous bats. Chapter 27 In: T. H. Kunz and S. Parsons, Eds. Ecological and Behavioral Methods for the Study of Bats. Second Ed. Johns Hopkins University Press, Baltimore.

Wickramasinghe, L.P., Harris, S., Jones, G., and Vaughan, N. 2003. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. *J. Appl. Ecol.* 40: 984–993.

Wickramasinghe, L.P., Harris, S., Jones, G., and Jennings, N.V. 2004. Abundance and species richness of nocturnal insects on organic and conventional farms: effects of agricultural intensification on bat foraging. *Conserv. Biol.* 18: 1283–1292.

Wilkinson, G.S. and Boughman, J.W. 1998. Social calls coordinate foraging in greater spear-nosed bats. *Anim. Behav.* 55: 337-350.

World Resources Institute. 2009. *A Guide to the Global Environment.* Oxford University Press. Oxford, UK.

Wilson, J. M. and Barclay, R. M. R.. 2006. Consumption of caterpillars during an outbreak of western spruce budworm. *Am. Nat.* 155: 244–249.

# FOOD AND FEEDING HABIT OF INSECTIVOROUS BATS (CHIROPTERA) OF PEECHI-VAZHANI WILDLIFE SANCTUARY, WESTERN GHATS, KERALA.

by

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## ABSTARCT

**Submitted in partial fulfillment of the requirement for the degree of**

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**Faculty of Forestry**

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**DEPARTMENT OF WILDLIFE SCIENCES**
**COLLEGE OF FORESTRY**
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**KERALA, INDIA**

**2014**

# ABSTARCT

A field study was conducted to understand the food, feeding habit and food preferences of insectivorous bats (Microchiroptera) of Peechi-Vazhani Wildlife Sanctuary, Western Ghats, Kerala. The study was conducted from May 2013 to February 2014 in the selected roosts. Insectivorous bat species studied were *Rhinolophus rouxii, Hipposideros speoris* and *Hipposideros ater*.

The method adopted were faecal matter analysis. Faecal matter were collected for each species of insectivorous bats once in a month throughout the study period. These pellets were analyzed in laboratory to identify food components and percent volume. From the faecal matter analysis *Rhinolophus rouxii* were found to be feeding on eleven insect orders (Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera, Odonata, Mantodea, Neuroptera and Ephemeroptera) and spiders (Araneae), *Hipposideros speoris* were found to be feeding on ten insect orders (Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera, Odonata, Neuroptera and Ephemeroptera) and spiders (Araneae). And the *Hipposideros ater* was found to be feeding on eight insect orders (Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera and Odonata) and spiders (Araneae).

Lepidoptera was the most fed insect orders by all the three insectivorous bats under study. Coleoptera was the second most fed insect order and Diptera

was the third most fed insect order by these bats. They also fed on the insects belonging to the orders Hemiptera, Orthoptera and Isoptera. This points into the immense capability of these insectivorous bats in insect pest suppression as these insect orders include majority of the insect pests in forest, agricultural land and urban areas. There was a significant bat species wise difference in the consumption of Coleoptera, Diptera, Hemiptera and Neuroptera, while there was a seasonal difference in the consumption of Coleoptera and Isoptera. The study also revealed that the *Rhinolophus rouxii* was a generalist predator and its niche overlaps with both *Hipposideros speoris* and *Hipposideros ater*. There is some niche overlap between *Hipposideros ater* and *Hipposideros speoris* but less than that of with *Rhinolophus rouxii.* Insects of Hemiptera and Diptera were more preferred by *Hipposideros ater* and Insects of Odonata, Coleoptera, Hymenoptera and Lepidoptera were more preferred by *Hipposideros speoris.*