

**ABUNDANCE, ROOST CHARACTERISTICS, ACOUSTICS AND DIET
COMPOSITION OF SELECTED BAT SPECIES IN SOUTH WAYANAD
FOREST DIVISION**

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(15-02MS-003)**

DISSERTATION

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DECLARATION

I hereby declare that this dissertation titled “**Abundance, roost characteristics, acoustics and diet composition of selected bat species in South Wayanad Forest Division**” is a bonafide record of research work done by me during the course of my Master’s research program and that the dissertation has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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1. INTRODUCTION

Bats are mammals of the order Chiroptera, the only mammals with the ability for flight. Chiroptera is the second largest order of mammals after rodents, with over 1300 species broadly divided into two major suborders *viz.*, the less specialized and largely fruit-eating megabats and the highly specialized, echolocating and insectivorous microbats. Megachiroptera is represented with a single family (Pteropodidae) and Microchiroptera includes 17 different families (Johnsingh and Manjrekar, 2013). However recent advances in molecular phylogeny suggest a different grouping system for bats called Yinpterochiroptera-Yangochiroptera classification, with two new orders erected defacing the old classification. Yinpterochiroptera or Pteropodiformes, includes the taxa formerly known as megabats (Pteropodidae) and five of the microbat family's *viz.*, Rhinopomatidae, Rhinolophidae, Hipposideridae, Craseonycteridae, and Megadermatidae. Yangochiroptera, or Vespertilioniformes, includes most of the microbat families except for the five families included in Yinpterochiroptera (Teeling *et al.*, 2005; Hutcheon and Kirsch, 2006). However, the validity of this classification is questioned and the traditional classification system is still followed. A total of 128 bat species are present in South Asia (Srinivasulu *et al.*, 2010), of which 119 bat species belonging to eight families and 37 genera are recorded from the Indian Subcontinent (Bates and Harrison, 1997). A total of 50 bat species belonging to seven families and 22 genera are recorded from Western Ghats.

The ecological services performed by bats through pollination, seed dispersal and by controlling insect population are inevitable. The evolution of flight and echolocation in bats was a prime mover in the diversification of feeding and roosting habits, reproductive strategies, and social behaviors in the group. The dietary diversity (including insects, fruits, leaves, flowers, nectar and pollen, fish, other vertebrates and blood) exhibited by bats remains unparalleled among other living mammals (Bates and Harrison, 1997).

Conditions and events associated with roosting were also significant in designing the behavior and ecology of bats. Bats are found to roost on caves, tunnels, tree holes, tree foliage, buildings, under the bridges, unused wells *etc.* The roosting ecology of bats gives an insight into a complex interaction of physiological, behavioral and morphological adaptations and demographic response. Roost abundance and availability, risk of predation, distribution and abundance of food resources, social organization *etc.* influences the roosting ecology of bats (Kunz, 1982). Density and size of caves acts as the major predictor of species diversity and population size (Furey and Racey, 2005). Several factors including habitat types, climatic conditions, social behavior, spatial and temporal distribution and availability of water sources, *etc.* were found to influence the distribution of bat species across various habitats (Kunz, 1982; Estrada *et al.*, 1993, Estrada and Coates-Estrada, 2002; Kofoky *et al.*, 2006; Shafie *et al.*, 2011; Pina *et al.*, 2013; Almeida *et al.*, 2014). However chiropterans still remain as one of the least studied group of mammals and information on the ecology and behavior of many species is still unavailable.

Although there are several studies on bats from Western Ghats, few are from Kerala, most of which are diversity studies. 29 species of bats belonging to seven families and 17 genera are known from Kerala (Nameer, 2015). There are no published data available on the diversity and distribution of bat species in Wayanad landscape; however Divakar (2015) reported 10 species belonging to 7 families and 8 genera from Wayanad Wildlife Sanctuary. The present study focused on identifying the diversity, distribution, roosting and feeding ecology of bat species across various habitat types in South Wayanad Forest Division. The study also aimed at developing a baseline data on acoustic sampling for selected species of microchiropterans.

The major objectives of the study are:

1. To estimate bat species abundance, diversity and species composition in different habitats of South Wayanad

2. To study the roost characteristics and preferences of different bat species in the landscape
3. To find out the diet composition of selected bat species in the landscape
4. To develop a baseline data on acoustic sampling for selected species of microchiropterans

2. REVIEW OF LITERATURE

2.1. DIVERSITY

2.1.1. Studies on bats in South Asia

Status of South Asian Chiroptera Conservation Assessment and Management Plan Workshop (2002) reviewed 123 bat species of which 17 species were endemic to South Asia.

Hassan and Nameer (2006) reviewed and compared the diversity of chiropterans of Pakistan with that of the Palearctic region and Indo-Malayan region. They reviewed 8 families of the order Chiroptera of which 23 genera were present in Pakistan. They mentioned the role of bats in the agro-ecosystem. They also identified threats affecting survival of bat species.

Sedlock *et al.* (2008) re-sampled chiropterans in Mount Isarog Natural Park, Philippines. The survey was conducted in agro-pastoral areas after a gap of 17 years. They documented 26 bat species, which belonged to six families. This survey resulted in nine new records of bat species for Isarog Natural Park. They used mist nets, harp nets and tunnel traps for capturing of the bats.

Struebig *et al.* (2008) studied the diversity, distribution and representation of bats in the protected areas of Borneo. They recorded 96 species representing 7 families. They selected 23 protected areas for the study. They showed that deforestation and hunting affected population of bat species.

Fukuda *et al.* (2009) evaluated bat species diversity in primary forests, secondary forests, orchards and oil palm plantations of Borneo. They recorded 28 species representing 5 families. Diversity was relatively high in primary forests and low in oil palm plantations. They showed that many bat species rarely used agricultural land for feeding and these plant communities were not suitable for maintaining bat diversity.

Furey *et al.* (2010) studied bat diversity in Vietnamese limestone karst areas. They recorded 36 species of bats, which belonged to 5 families. Species

richness was greater for Vespertilionidae family. The study revealed that primary forests in Vietnamese karst were important for bat diversity. High numbers of bat species at low abundance were present in the disturbed and heavily degraded karst forests. They also stressed the importance of protection of bat species.

Srinivasulu *et al.* (2010) listed 128 species of bats from South Asia, including 115 microchiropterans and 13 megachiropterans. The study revealed that family wise percent endemism was greatest in Pteropodidae followed by Hipposideridae, Rhinolophidae and Vespertilionidae. They identified bats based on a series of external, cranial and dental measurements.

Johnsingh and Manjrekar (2013) published a book “Mammals of South Asia” in which they listed 149 species of bats, which belonged to 8 families and 44 genera from the Indian subcontinent and Myanmar. They explained about the species *Latidens salimalii* as well as the habitat, reproduction and conservation of various other bat species in general.

Aul *et al.* (2014) carried out the first extensive survey of bats in the Andaman and Nicobar Islands. The study was conducted in 40 islands. Their objective was to map the bat species, their habitats and distribution. They identified 25 bat species representing 13 genera. They rediscovered the endemic Nicobar Flying Fox (*Pteropus fannulus*) after a century. They sighted an albino *Hipposideros diadema nicobarensis* from Katchal Island. They reported the first records of *Rhinolophus yunanensis*, *Murina cyclotis* and *Hipposideros larvatus* from the Andaman islands and *Taphozous melanopogon*, *Murina cyclotis*, *Pipistrellus* sp., *Myotis horsfieldii dryas* and *Cynopterus brachyotis* from the Nicobar island. They discussed the anthropogenic pressure on the *Pteropus* species.

2.1.2. Studies in India

Anderson (1881) catalogued 252 species of primates, prosimians, chiroptera and insectivores. The author collected 1116 specimens of bats representing 113 species and 27 genera.

Sinha (1980) explained the taxonomy and zoogeography of bat species in Rajasthan. The author recorded 21 species of bats representing 7 families. The study showed that the genera of bats in the region were largely oriental and to a lesser extent palaeartic. *Cynopterus sphinx sphinx*, *Taphozous longimanus longimanus* and *Scotophilus kuhlii kuhlii* were recorded for the first time in Rajasthan.

Sinha (1981) studied taxonomy, distribution and ecology of bat species in Gujarat. The author recorded 22 species and subspecies of bats. The study revealed that the range of several species of bats had been considerably extended. Important measurements of different bat species were also reported.

Bates and Harrison (1997) published a book on bats named as “Bats of the Indian Subcontinent”. They gave detailed explanation about 119 species of bats, which belonged to 37 genera and 8 families. External, cranial and dental measurements of different bat species were included in this book. They also reviewed the distribution pattern, habits, feeding, reproduction and conservation status of bats of the region.

Alfred *et al.* (2002) published a checklist of mammals of India. They listed 397 species of mammals which included 46 endemic and 77 threatened species. The checklist revealed that 112 species of bats, which belonged to 7 families and 35 genera, were present in India. They mentioned the status and distribution of bat species.

Nameer (2008) published a checklist of Indian mammals. He listed 417 species of Indian mammals belonging to 48 families which included 114 species of bats belonging to 8 families and 8 subfamilies.

Talmale and Pradhan (2009) published a checklist of valid Indian bat species. They listed 117 species of bats, which belonged to 8 families and 39 genera.

Korad *et al.* (2010) carried out a study on diversity, distribution and habitat preference of bat species in Pune district, Maharashtra. They surveyed bat

colonies for 3 years. They recorded 25 bat species, which belonged to 6 families and 10 genera. They explained the ecology of bat species. The study showed that majority of bat species preferred to roost in cavities (cavities or artificial). They recommended the protection of natural caves.

Korad (2014) studied the diversity, distribution and conservation of the chiropterans in Maharashtra state. The author reviewed the existing literature for compiling the species checklist. 41 bat species were listed representing 8 families and 23 genera. The study recommended the conservation of bat species. The study revealed the distribution pattern of bat species in Maharashtra state.

2.1.3. Studies in Kerala

Das (1986) studied taxonomy and geographical distribution of the species of bats in Silent Valley. The author collected 6 species of bats representing 3 families and 5 genera. The study showed that the genus *Rousettus* was represented in the Indian Union by *Rousettus leschenaulti leschenaulti*. External and cranial measurements of bat species of the region were reported.

Madhavan (2000) conducted an extensive survey and collected specimens of 24 taxa of bats representing 6 families and 14 genera. The survey was conducted in Thrissur District and other places of Kerala including North, South and Central parts of Kerala. The author selected agricultural areas for the study.

Nameer (2015) published a checklist of 118 species of mammals of Kerala. He listed 29 species of bats belonging to 7 families and 17 genera. The IUCN status of the species was also recorded.

2.1.4. Studies in Wayanad

Reshma (2013) did an ecological study on two different roosts of *Pteropus giganteus*. The study showed that availability of food sources and rain fall were the major factors affecting the fluctuations in the population size. Predation, hunting and habitat loss were major threats of this bat species. The author recommended the conservation of roost sites.

Divakar (2015) carried out a study on diversity, habitat preference and feeding habits of chiropterans in Wayanad Wildlife Sanctuary. He recorded 10 bat species, which belonged to 6 families and 8 genera. He examined guano samples of *Pteropus giganteus*, *Rhinolophus rouxii* and *Megaderma spasma*. Mixed species roosting was also reported in his study.

2.2. ECOLOGY OF BATS

Kunz (1982) published a book on ecology of bats. The book gave a comprehensive account of roosting ecology, roost fidelity and social organization of bats. The author reviewed physiological aspects of roosting and hibernation. Literature was reviewed for examining the diversity of roosting adaptations of bats and to consider how they were influenced by opposing selective pressure. The author emphasized adaptations to day and night roosting behaviour and ecology during the non hibernating period so as to achieve an integrated view of the relationships between roosting habits, foraging strategies, energy economy and social organization.

Ducummon (2000) studied ecological and economic importance of bats. The author found that chiropterans had lost countless traditional roosts in caves, old tree hollows and many of them moved into abandoned mines. The study revealed that a colony of *Tadarida brasiliensis* fed upon two tons of insects per day, largely crop consuming moths.

Wikinson and South (2002) selected six life history and ecological factors to use in a comparative study of longevity among 64 bat species. They recorded that the life span of bats was 3.5 times greater than a non flying placental mammal of similar size. They found that life span significantly increased with hibernation, body mass and occasional cave use but decreased with reproductive rate and was not influenced by diet or colony size.

Zubaid *et al.* (2002) published a book on functional and evolutionary ecology of bats. They provided information about thermal biology of hibernation, energetic, daily heterothermy and the evolution of basal metabolic rate. They

covered topics like wing morphology and its implications in flight performance as well as the relationship between cranial morphology and feeding ecology. The authors said that use of high latitudes, social organization and population structure in *Plecotus auritus* were strongly influenced both by the climate and by species wing morphology. In nectar feeding bat species, morphological specialization is related to tongue extension (maximal capacity) but is not strongly associated with nectar extraction rates.

Lumsden (2004) investigated the ecology and conservation of an assemblage of insectivorous bats in rural landscapes, with particular focus on their foraging and roosting requirements. The author recorded 13 species of insectivorous bats. The study found that *Nyctophilus geoffroyi* and *Chalinolobus gouldii* had different wing morphology, which might be influential in how they used the landscape, and anecdotal evidence suggested differences in their roosting ecology. The author recorded inter and intra specific differences in the roost selection. The study suggested that the number of roost trees that were required for an individual or colony was influenced by the frequency with which bats moved between roosts, the proportion of roosts that were re-used, the distance between consecutive roosts, and the size of roosting colonies.

Hofstede and Fenton (2004) compared bat fly and mite densities among wild caught bats with different roosting preferences. Grooming behaviour was analyzed for bat species with high and low ectoparasite density using camcorder. The authors showed that there was no difference in the frequency of grooming behaviour for individuals with and without bat flies. There was difference in grooming behaviour at the species level. The study suggested that ectoparasite densities and grooming behaviour were related to roosting preferences in bats.

Furey and Racey (2005) published a chapter on conservation ecology of cave bats. They said that the density and size of caves were the best predictors of species diversity and population sizes. The authors described cave microclimate in detail. They stated that growth in limestone quarrying and cave tourism industries worldwide severely threatened cave dwelling bat species.

Chaverri and Kunz (2006) described the plants used as roost resources by *Artibeus watsoni* in Costa Rica. They compared roosting ecology between two sites which varied in the degree of human influence. The study showed that fidelity of bats to tents was low and used several tents intermittently within a restricted area. They suggested that males were primarily responsible for tent construction.

Adams and Pedersen (2013) reviewed evidence for co-operative behaviour in bats and the possible mechanism that might prevent cheating. They stated that co-operative behaviour in bats was shaped by ecology, life history and social structure.

Stone (2013) published a book on bats and lighting. The author provided detailed information about bat roosting, emergence, commuting, foraging, breeding, hibernation and swarming.

2.3. HABITAT ASSESSMENT OF BATS

Estrada *et al.* (1993) conducted a study on bat species richness and abundance in tropical rain forest fragments and in agricultural habitats at Los Tuxtlas, Mexico. They found that both small and large forest fragments dispersed in the study area were rich in bat species and that isolating distance played an important role influencing the fragment species richness. Recaptured bat species indicated inter habitat movements in the fragmented landscape. The study indicated that majority of species occurred in low numbers.

Estrada and Estrada (2002) conducted a study in continuous forest, forest fragments and in an agricultural mosaic habitat island at Los Tuxtlas, Mexico. They captured 39 species of bats. The largest proportion of bats was captured at the mosaic habitat, followed by forest fragments and continuous forest habitats. Less variation in proportion of individuals captured was evident in the case of the nectarivore-insectivore guild at three habitats. The authors recorded evidence of continuous breeding activity for a high number of species at the three habitats.

A study by Menzel *et al.* (2005) compared bat activity levels in five habitat types (forested riparian areas, clear cuts, young pine plantations, mature pine plantations and pine savannas). They monitored bat activity in different canopy levels. Evening bat activity was greater above rather than within or below the forest canopy. The study showed the importance of riparian habitat.

Faria (2006) studied Phyllostomid bats of a fragmented landscape in Brazil. The author reported a total of 39 Phyllostomid bat species from 5 subfamilies. They found little evidence of fragment size effects on community structure. The study revealed that qualitative habitat changes induced by fragmentation, such as edge formation and forest regrowth, affected bat species community structure.

Law and Chidel (2006) compared bat species activity in remnant forests, old eucalyptus plantations, young eucalyptus plantations and paddocks. They found that all bat species used revegetation sites. Activity and species richness in revegetation was less than that of paddock matrix and remnants. They also found greater bat species activity in old, large plantings.

Kofoky *et al.* (2007) studied habitat use, seasonality and roost selection of bat species in Tsingy de Bemaraha National Park, Madagascar. The study revealed that bat species activity was significantly lower inside the forest than at the interface between agricultural land and forest. In caves, bat species abundance and species richness were low. Species richness was similar in both seasons.

A study by Shafie *et al.* (2011) compared two contrasting habitat types (secondary forest and oil palm plantation) in Malaysia. The oil palm plantation had great bat abundance and there was no significant difference in species richness between the two sites. The niche breadth value for each species was very low.

Pinna *et al.* (2013) conducted a study of habitat use by phyllostomid bats in natural forest fragments and eucalyptus plantations in the Brazilian Cerrado. Natural forest fragment assemblages were characterized by higher species

richness, diversity and evenness compared to those in eucalyptus plantations. The study showed impoverishment of bat assemblages in eucalyptus plantations suggesting that conservation measure should be preferentially directed towards preservation of native forest habitat.

Frey-Ehrenbold *et al.* (2013) investigated the impact of connectivity, habitat structure and activity of bat guilds in farm land dominated matrices. They found that bat species activity was significantly higher around landscape elements compared to open control areas. Their results showed that short and long range echolocating bats were more active in well connected landscapes and species richness increased significantly with connectivity. They also found that total bat activity was unaffected by the shape of landscape elements.

A study by Cormier (2014) examined the difference in insectivorous bat species diversity and activity in the habitat gradient between forest and pineapple farm in Costa Rica. The study showed that agricultural environments affected and lowered bat species presence. In this study, no significant difference existed in mean number of species between habitats, but a significant difference existed in mean number of passes (number of times a bat passed the recorder) per family in each habitat.

Almeida *et al.* (2014) conducted a study on habitat characteristics and insectivorous bat activity. Two types of comparisons were made during the study: First between forest, forest edge, and open habitat and second between open habitat with and without water body nearby. This study showed that insectivorous bat activity in the neotropics was also influenced by spatial complexity of vegetation and the presence of water bodies.

Ramadhan and Winarni (2015) compared habitat of bat species of genus *Cynopterus* in Indonesia. They captured 4 bat species (*Cynopterus brachyotis*, *Cynopterus horsfieldii*, *Cynopterus minutes* and *Cynopterus sphinx*). The study showed that *Cynopterus* species diversity was higher in agricultural gardens than in forests. They observed the overlapping of habitat use.

2.4. ACOUSTIC SAMPLING OF BATS

Moss and Zagaeski (1994) suggested that frequency modulated bat species could discriminate between targets that differed in shape and another that they could discriminate between targets that differed in rate of movement.

Parsons and Jones (2000) recorded echolocation calls from 14 sympatric species. They easily identified two species of *Rhinolophus* from call duration and spectral measurements. They used discriminant function analysis and multilayer back propagation perceptrons for the identification of other bat species. This was the first published study to use artificial neural networks to classify the echolocation calls of bats to species level.

Brigham *et al.* (2004) summarized the current status and value of a bat call library. They focused on evaluating the applications, capabilities and limitations of equipment designed to detect and analyze bat echolocation calls.

Jones and Teeling (2006) suggested that certain bats with sophisticated echolocation (horseshoe bat species) shared a common ancestry with non echolocation bats (old world fruit bats). They showed that the extensive adaptive radiation in echolocation call design was shaped largely by ecology. The authors said that the echolocation provided some remarkable examples of convergent evolution within bats which made reconstruction of ancestral call types problematic.

Raghuram *et al.* (2006) recorded the echolocation calls of 13 microchiropteran species from Kudremukh National Park in the Western Ghats of Karnataka, of which the calls of *Pipistrellus coromandra*, *Pipistrellus affinis*, *Pipistrellus ceylonicus* and *Harpiocephalus harpia* were recorded for the first time. They conducted the study by using standard techniques; including mist netting acoustical and roost surveys. Their study indicated that echolocation calls could be used successfully for non-invasive acoustic surveys and monitoring of bat species in the future.

Bohn *et al.* (2007) investigated both the production and perception of isolation calls in *Pylostomus hastatus*. They found no difference in performance when females had to discriminate between pups from the same and different social groups. The study indicated that females should be able to accurately identify their young using isolation calls.

Furey *et al.* (2009) recorded the echolocation calls of insectivorous bat species commuting and foraging in a variety of Karst habitats of in North Vietnam. They also monitored these animals in caves. The authors recorded 382 echolocation calls of 31 species belonging to Pteropodidae, Megadermatidae, Rhinolophidae, Hipposideridae and Vespertilionidae. Acoustic sampling resulted in a significant increase in the overall number of bat species recorded in a variety of foraging and commuting habitats and in a cave.

Frick (2013) provided a brief overview of current popular systems for long term echolocation monitoring. The author said that the acoustic recordings could be used to evaluate changes in use and activity.

Sophany *et al.* (2013) provided the first description of time expanded echolocation calls from a Cambodian bat assemblage comprising 17 species from Phnom Kulen National Park. They used D240x ultrasound detector with a sampling frequency of 307 kHz (Pettersson Elektronik AB, Sweden) and stored digitally on an Edirol R-09HR recorder (Roland, USA). Discriminant function analysis of 428 echolocation calls produced by the 13 bat species indicated that acoustic identification was feasible in most instances by correctly classifying 85% of calls.

Basil *et al.* (2014a) proposed a classification scheme based on perceptual, spectrum and cepstral features for the classification of bats. They compared it with perceptual and cepstral feature-based classification scheme. The authors found that perceptual, spectrum and cepstral feature based bat classification scheme outperformed the perceptual and cepstral feature-based classification scheme and showed more accuracy. They said that acoustic identification of bats could be made use of to ensure objective identification of species.

Basil *et al.* (2014b) carried out an extensive review on the various techniques used to identify and classify bats using their species specific echolocation calls. They also described techniques like speech recognition, voice recognition and artificial neural networks.

Wordley *et al.* (2014) recorded echolocation calls of 15 bat species (*Rhinolophus beddomei*, *Rhinolophus rouxii*, *Rhinolophus lepidus*, *Hipposideros pomona*, *Barbastella leucomelas darjelingensis*, *Hesperoptenus tickelli*, *Miniopterus fuliginosus*, *Miniopterus pusillus*, *Myotis horsfieldii*, *Myotis montivagus*, *Pipistrellus ceylonicus*, *Scotophilus heathii*, *Scotophilus kuhlii*, *Rousettus leschenaultia* and *Megaderma spasma*) from the Valparai plateau in the Anamalai Hills, southern Western Ghats of India. They reported the first record of *Barbastella leucomelas darjelingensis* in South India. The study revealed that call frequencies for some species (*Rhinolophus rouxii* and *Hipposideros pomona*) differed from those published from other parts of the species ranges.

Russo and Voigt (2016) remarked that bat call identification was a serious practical issue because biases in the assessment of bat distribution or habitat preferences might lead to wrong management decisions with serious conservation consequences.

2.5. DIETARY ANALYSIS

Brigham (1990) analyzed and compared the diets of Big Brown Bats (*Eptesicus fuscus*) and Common Nighthawks (*Chordeiles minor*). These species foraged at the same place and overlapped temporally in their foraging periods. The study revealed that Trichopterans were the most important prey item for both bats and birds and Hymenopterans and Coleopterans were eaten by *Chordeiles minor* in proportions greater than expected on the basis of availability. The bats showed no preference for Hymenopterans. The study found that prey selection by *Eptesicus fuscus* and *Chordeiles minor* at the park could not be termed opportunistic.

McAney *et al.* (1991) developed a key for the identification of Arthropoda from bat droppings. Their study gave instructions on how to collect and prepare droppings for examination. They found only one bat fly in the 1894 bat droppings. They described variety of prey remains and drawings which also helped for identification of the insects.

Ades (1994) studied the dietary seasonality of insectivorous bats in Hong Kong. The study revealed that bat diets were more diverse in summer than winter dry season and all species of insectivorous bats preferentially consumed termites in early summer. The study found that *Hipposideros pomona sinensis* and *Miniopterus magnater macrodens* were moth specialists, *Hipposideros armiger* specialized on beetles and *Rhinolophus rouxi sinicus* ate mainly moths and beetles.

Whitaker *et al.* (1994) examined the diet of 9 bat species from Israel. They found seasonal variation in the food habits of different bat species.

Dunning and Kruger (1996) conducted a study on predation upon moths by free foraging *Hipposideros caffer* in the Kruger National Park of South Africa. They found that these bats, whose echolocation calls were inaudible to moths, fed more upon tympanate Lepidoptera. The study showed that *Hipposideros caffer* took fewer moths of the family Geometridae. These bats ate significantly fewer Arctiid moths of those species capable of clicking than those of species that could not.

Tan *et al.* (1998) reported that *Cynopterus brachyotis* fed on the fruits of 54 plant species and the leaves of 14 species. It was also found that the species fed on flower parts of four species. *Ficus* sp. was found to be the key component in the diet.

Whitaker Jr. and Yom-Tov (2001) analyzed the diet of some insectivorous bats from northern Israel. Coleoptera was the most common food item of *Rhinopoma microphyllum* during most of the year, followed by Lepidoptera and

Isoptera. They found that the diet of *Rhinopoma hardwickei* was composed mainly of beetles, moths and neuropterans.

Dumont and O'Neal (2004) investigated the potential role of feeding behavior in patterns of resource use within a sympatric assemblage of Pteropodids from Papua New Guinea. They found that feeding behavior varies between different species while feeding on soft and hard fruits.

Ramanujam and Verzhutskii (2004a) studied the diet and prey of the *Hipposideros ater*. A total of 2028 prey items were identified during the study. They found that Coleoptera was the largest group fed by this bat species. They suggested that this species fed on small insects at ground level.

Ramanujam and Verzhutskii (2004b) studied the prey of the *Pipistrellus coromandra* at Auroville, Southern India. They identified 267 prey items from their faeces. They showed that the basic food consisted of Lepidoptera and Colleoptera. The authors concluded that *Pipistrellus coromandra* could feed on larger insects than was previously supposed.

Bumrungsri *et al.* (2007) reported similar habitat usages and feeding preferences in two species of megachiropterans - *Cynopterus brachyotis* and *C. sphinx*. *C.brachyotis* fed more on small fruits and *C. sphinx* showed a significantly higher consumption of larger fruits.

Feldhamer *et al.* (2008) collected and analyzed data on the diet of eight species of insectivorous bats (*Eptesicus fuscus*, *Lasiurus borealis*, *Nycticeius humeralis*, *Myotis septentrionalis*, *Myotis lucifugus*, *Myotis sodalis*, *Myotis austroriparius* and *Perimyotis subflavus*). They showed that *Eptesicus fuscus* and *Nycticeius humeralis* had the greatest dietary similarity index value compared with the other chiropterans in the community and the highest hardness indices of prey consumed. Three species of *Myotis* consumed the greatest diversity of prey. They observed gleaning behaviour of *Myotis septentrionalis* and *Myotis lucifugus*. It was also seen that regional differences in diets were minimal within the same assemblage of bat species in the study area.

Mahmood-Ul-Hassan *et al.* (2010) analyzed the diet of *Pteropus giganteus* in urban habitats of Pakistan. They found that the bats fed on 20 species belonging to 11 plant families and plants in the family Moraceae comprised most of the bats diet. The study indicated that the four seasonal diets varied significantly. It was confirmed that the ecological services rendered by *Pteropus giganteus* such as pollination and seed dispersal, outweigh the losses caused by it such as damage to the ripe fruit.

Mohd-Azlan *et al.* (2010) found *Cynopterus brachyotis* mostly used areas close to human habitations. They found that *Cynopterus brachyotis* fed on 24 species (18 species of seeds and 6 species of fruits) and *Eugenia* sp. had the highest count from collected seeds.

Sophia (2010) examined the food items of *Hipposideros ater* from culled parts of the prey insects collected from their feeding roosts as well as from faecal pellet analysis. The author compared the insect pests from the foraging area with the diet of this bat species. The study revealed that the foraging time of *Hipposideros ater* and the activity period of insect pests coincided in the study area. This bat species helped in the control of major pests like *Tribolium* sp., *Hippotion celerio*, *Nausinoe geometralis*, *Othreis meterna*, *Othreis fullonica* and *Nelantitis leda ismene*. It was found that the nocturnal foraging behavior, echolocation capability, dentition and flight maneuverability of this bat species were adaptations that enhanced its ability to capture nocturnal prey insects in open space during their foraging flight.

Ahim and Moali (2013) analyzed the diet of four bat species (*Rhinolophus ferrumequinum*, *Rhinolophus hipposideros*, *Rhinolophus euryale* and *Rhinolophus blasii*) in the region of Kabylia Babors, in northern Algeria. They found that most consumed insect prey was Diptera. Their results showed that Chilopoda appeared in the diet of the four bat species.

Shetty (2013) studied the prey and nutritional analysis of *Megaderma lyra* from the west coast of Karnataka, India. The percent volume and percent frequency of food items present were also determined and were classified as basic

food, constant food, supplementary food and chance food. They identified 15 insect orders from study area. They showed that Coleopterans formed the major food item in all the three seasons (pre monsoon, monsoon and post monsoon) and Hemipterans formed the constant food in all the three seasons. Their results revealed that guano contained maximum carbohydrate during pre monsoon, lipid content during post monsoon and protein during pre monsoon and post monsoon period. It was also seen that guano was rich in phosphorus. Their study indicated that *Megaderma lyra* preyed substantially on several insects injurious to crops, gardens, lawns and rodents.

Pokhrel and Budha (2014) prepared a key for identification of insects from droppings. They mounted recovered insects and insect parts on slides, and photographed and identified the insects up to order and family level. They identified 10 insect orders and 25 families of insects. The authors compared studied characters with taxonomic characters from literature for the identification of insects. It was clearly found that insect abundance and diversity varied according to elevation range in the study conducted in Nepal.

Riccucci and Lanza (2014) studied the diet of European insectivorous bats species. They suggested that insectivorous bats fed on large quantities of Lepidoptera and other agricultural pests.

Ponmalar and Vanitharani (2014) analyzed the diet of *Rhinolophus rouxii*, *Rhinolophus pusillus*, *Rhinolophus lepidus* and *Rhinolophus beddomei* in Western Ghats. They identified nine insect orders from bat faecal sample. They proved that *Rhinolophus* bat species had control over the Lepidopteran, Coleopteran, Dipteran, Hymenopteran, Homopteran, Orthopteran, Hemipteran, Trichopteran and Neuropteran group of insect pests that infests the forest trees.

Weterrings *et al.* (2015) studied the dietary analysis of five insectivorous bat species (*Hipposideros armiger*, *Hypsugo cadornae*, *Rhinolophus thailandensis*, *Taphozous melanopogon* and *Taphozous longimanus*) from Kamphaeng Phet, Thailand. They analyzed a total of 151 faecal pellets and identified the fragments of 11 insect orders. Hemiptera and Coleoptera were the

most common food items found from total number of pellets. They observed large amounts of Diptera content in the diet of an urban population of *Taphozous longimanus*, which included a considerable amount of Culicidae. Their results showed that bats had a great role in the control of the vector mosquito population in Thailand.

3. MATERIALS AND METHODS

3.1. STUDY AREA

The present study was carried out in South Wayanad Forests of Nilgiri Biosphere Reserve from May 2017 to August 2017. Wayanad marks the southernmost boundary of the Deccan Plateau and is rich with its diverse habitat types and biodiversity. Wayanad lies between North latitude $11^{\circ} 26'$ to $12^{\circ} 00'$ and East longitude $75^{\circ} 75'$ to $76^{\circ} 56'$. The altitude varies from 600-2100 meters above Mean Sea Level. The mean average rain fall in this district is 2322 mm. Meppadi, Vythiri and Lakkidi regions of Wayanad are considered as the highest rainfall regions in Kerala. Annual rain fall ranges from 3000 to 4000 mm. High altitude regions experience severe cold. Wayanad experiences a high relative humidity which goes even up to 95 percent during the south west monsoon period.

Forests of Wayanad District is divided into three major administrative divisions, *viz.*, Wayanad Wildlife Sanctuary (344.44 km²), Wayanad North (214.29 km²) and Wayanad South Forest Divisions (325.339 km²). Wayanad Wildlife Sanctuary (WWS) includes two unconnected portions with revenue land and settlements in between. The northeastern portion includes only Tholpetty Range which is continuous with Nagarhole Tiger Reserve and Kakkanakote Reserved Forest of Karnataka and Brahmagiri Hills of North Wayanad Division. The southern region includes Sulthan Bathery, Muthanga and Kurichiad Ranges which is connected to Bandipur Tiger Reserve of Karnataka and Mudumalai Tiger Reserve of Tamil Nadu. Forests in the North and North eastern parts of the district are included in the North Wayanad Forest Division, which is bordered by Aralam Wildlife Sanctuary and Kottiyoor Forest of Kannur district to west, Brahmagiri Wildlife Sanctuary (Karnataka), Nagarhole TR and Wayanad Wildlife Sanctuary to east and South Wayanad Forest Division to south. North Wayanad Forest Division is divided into three ranges *viz.*, Mananthavady, Periya and Begur. Forests in the south and south east parts of the district are included in the South Wayanad Forest Division. Meppadi, Kalpetta and Chedelesh are the Forest Ranges

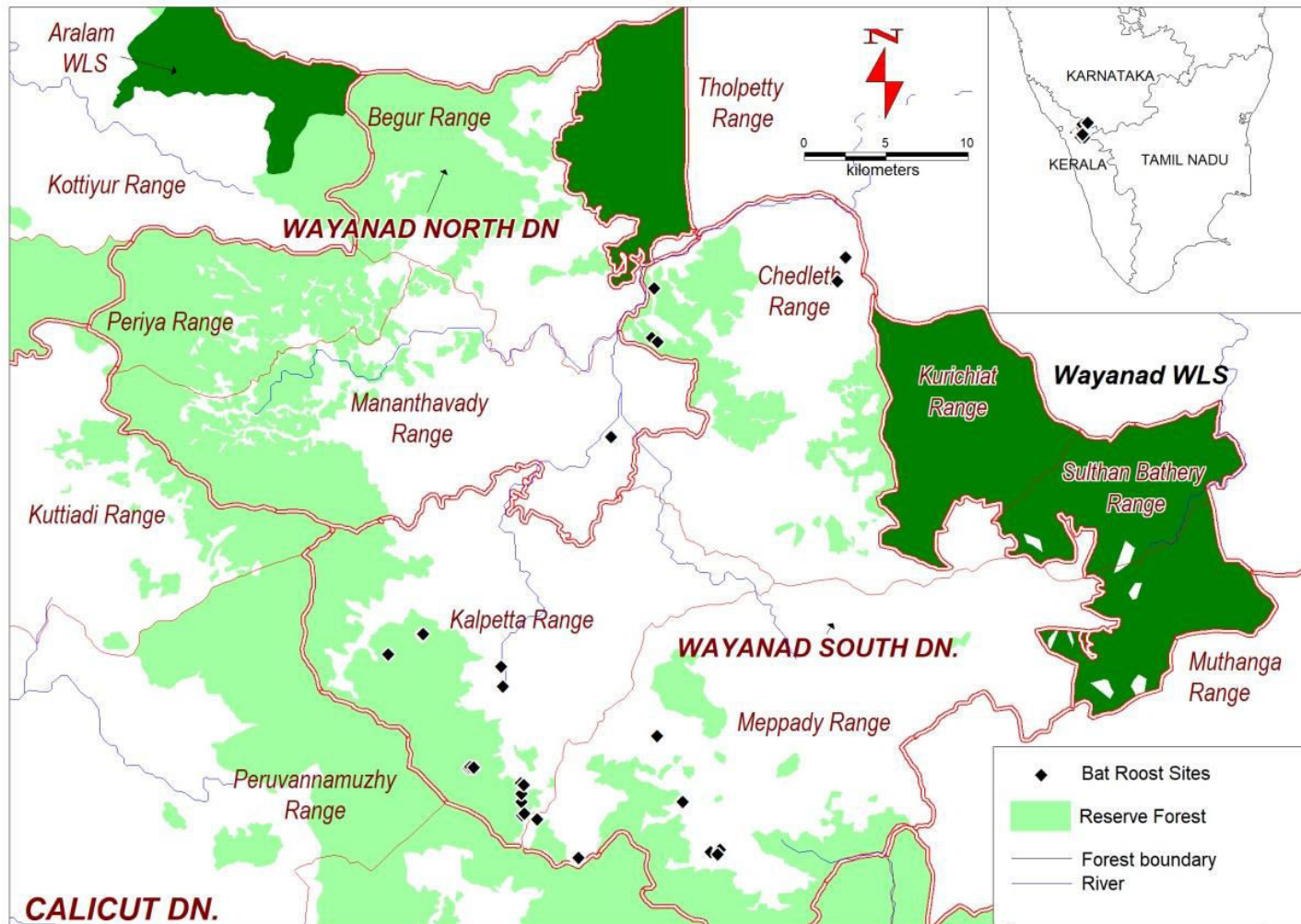


Fig. 1. Map showing the location of bat roost sites in South Wayanad Forest Division

coming under the division. It is bordered by Peruvannamuzhi and Thamarasseri Ranges of Kozhikode district and Vazhikkadavu Range of Malappuram District to the West and North Wayanad Forest Division to the North. Nagarhole TR, Bandipur TR and Wayanad WWS makes boundary to the north east and south east part of the Division in Chedelesh Range. A small part of Meppadi Range makes border with Gudallur Reserved Forest of Nilgiri district to the southeast.

Wayanad harbors a great diversity of fauna and flora. Vegetation types in Wayanad is dominated by Malabar floristic elements and includes 5 major forest types *viz.*, West-coast tropical evergreen forest (evergreen), West-coast tropical semi-evergreen forest (semi-evergreen), Southern moist-mixed deciduous forest (moist-deciduous), Southern dry-mixed deciduous forest (dry-deciduous), Southern wet-montane grasslands (grasslands) and wet-temperate forest (shola). South and North Wayanad Forest Divisions are dominated by evergreen and semievergreen vegetation. High elevation areas above 1200 m, like Brahmagiri, Banasura, Kurichyarmala, Settukunnu, Amba, Sugandhagiri, Chembra, Elambaleri, Manikkunnumala, Vellarimala etc are characterized by shola-grassland ecosystem. Moist deciduous forests occupies the major portion of Wayanad Wildlife Sanctuary, Chedelesh Range of South Wayanad and some portions of Begur Range in North Wayanad. Dry deciduous forests are mostly seen in the region where Wayanad wildlife division makes border with Bandipur and Mudumalai Tiger Reserves. Small pockets of Semi evergreen vegetation is seen in Chedelesh, Begur and Kurichiad Ranges. Riparian vegetation makes a separate ecosystem in the river delta of Kuruva Reserve Forest included in Chedelesh Forest Range. Riparian vegetation is highly disturbed in most of the regions in Kabini River stretch, which is the major river in Wayanad. Panamaram River in South Wayanad and Mananthavady River in North Wayanad still retains small pockets of riparian vegetation surrounded by settlements. Panamaram Heronry is a small island in Panamaram River, where annual nesting of several bird species is recorded. Teak, Acacia and Eucalyptus plantations are also found in the protected and non-protected forest regions of Wayanad. Marshy grasslands called “Vayals” are a characteristic feature of this landscape, which itself makes a

separate ecosystem. Vayal ecosystems outside the forest areas are mostly modified for paddy, banana or ginger cultivation. The mid-level plateau of the district is the most densely populated area, which covers a major part of the land and the natural vegetation of these areas are mostly replaced by Coffee, Tea, Eucalyptus, Banana and Rubber plantations.

3.2. BAT ROOST SITE SAMPLING

The study was carried out in Reserved Forests, plantations and urbanized areas of South Wayanad. Tree holes, caves, tunnels, bridges, buildings, wells, bamboo clumps and all potential roosting sites in selected areas were screened for the presence of bats. Direct and indirect signs of bat species were observed to confirm the presence. Bat species were identified by following published keys (Srinivasulu *et al.* 2010 and Bates and Harrison 1997). Photographs were taken from each roosting site for further references.

Roost counts were taken to estimate the population size of each colony. Direct count were employed to understand the population size of small ($n < 50$) and large ($n > 50$) colonies. Type of roost, height of the roost from ground, length and width of roosts, orientation of entrance (cave, tunnel and tree hole roosts), GBH, height and species diversity of tree roosts, canopy cover, temperature (inside and outside of roosts), humidity (inside and outside of roosts), distance from water source, distance from human settlements and distance from roads were recorded.

Canopy cover was estimated visually, temperature and humidity were measured using regular calibrated meters (Digital Thermo- Hygrometer). Altitude, latitude and elevation of each roosting sites were recorded using standard GPS reader (Garmin- GPS 72H).

3.2.1 Diversity index

The Shannon diversity index (H) of prey species in the insectivorous bat species were calculated that consider both abundance and evenness of species

present. Where P_i is the proportion of individual species i relative to the total number of species S .

$$H = - \sum_{j=1}^S P_i \ln P_i$$

3.3. TREE SPECIES IDENTIFICATION

Photographs of the trees (trunk, bark, leaves, flowers and fruits) were taken. Leaves of trees along the first transect were also collected for identification. Identification was done by referring standard keys published (Suresh *et al.*, 1999). Girth at breast height and total height of each individual tree were measured.

3.4. ACOUSTIC SAMPLING

Bats were located in the roost site, without disturbance clear photographs were taken using Cannon Eos digital 550D camera for species identification with reference scale. Bat species were identified based on measurements taken from photographs with scale. Bat echolocation calls were recorded using a Pettersson D200 ultrasound detector (www.batsound.com) with a sampling rate range from 10-120 KHz recorded into Lenovo A6010 mobile in WAV file format. A total of 46 minutes of echolocation calls were recorded for three bat species such as *Rhinolophus rouxii*, *R. beddomei* and *R. pusillus*.

From the sampled call data a total of 15 clear calls with the highest signal to noise ratio were selected from each individual recording for the selected three species and all the call parameters were measured using Bat Sound software (4.1.4). For each call parameter, the mean based on up to 15 calls for the selected three individual bats species was used for further analysis. For each call the parameters such as start frequency, end frequency, call duration, call interval time, frequency of maximum energy (FMAX) from power spectrum, bandwidth were obtained (Wordley *et al.*, 2014).

3.4.1 Discriminate function analysis

Linear Discriminate function analysis (IDFA) was used to classify bat calls from the South Wayanad Forest division to the species. Analysis was carried out for Rhinolophid bats producing Constant Frequency (CF) calls based on variables such as call duration, call interval time, start frequency, end frequency, peak frequency and band width using IBM SPSS Statistics 21. We used 15 individual echolocation call data for species such as *R. beddomei*, *R. pusillus* and *R. rouxii*. DFA was run with all the five variables (Wordley *et al.*, 2014). IDFA was performed with leave-one-out of cross validation to test a statistical model to reduce over fitting and give insight into how the model will work on an independent dataset. All calls were independent as they were all recorded from different bats. The tolerance values for all the independent variables are less than 0.1, so multicollinearity is not occurring in either model. All the call parameters of three species showed normal distribution in Kolmogorov Smirnov Test except *R. rouxii* of Frequency Maximum (FMAX).

3.5. DIETARY ANALYSIS

Diet composition of one fruit bat (*Cynopterus brachyotis*), two species of insectivorous bats (*Rhinolophus beddomei* and *R. rouxii*) were studied. A total of 120 bat droppings of each species were collected and preserved in 10% formalin from non-forest areas. Fruit bat droppings were collected from residential places of Vythiri region. Guano samples of *R. beddomei* and *R. rouxii* were collected from Elambilery and Suganthagiri non-forest areas of South Wayanad Forest Division. Droppings were dissolved in water and microscopically examined (Magnus MSZ-TR Trinocular microscope with 10x magnification) to identify the diet composition. Fruit bat diet composition was determined based on undigested seeds, fruit pulp of fruiting plants. Seeds collected from bat droppings were dried and identified using standard reference keys of fruit and seeds of Western Ghats (Sasidharan, 2006). Insect remains of insectivorous bat droppings were identified upto order level using reference keys (McAney, *et al.*, 1991; Pokhrel and Budha,

2014). The frequency of each prey species were recorded to find out the percentage composition of prey item. The fruit remnants from fruit bat were quantified based on volume, rather than number of fruits. Since, there is greater variation in the fruit size that ranges from 1.4mm to 33mm that could result in lower frequency of larger seeds with higher representation of smaller seeds.

3.5.1 Similarity index

Diet composition similarity between the *R. beddomei* and *R. rouxii* were determined using Pianka's index of similarity (Pianka, 1973).

$$O_{jk} = \sum P_{ij}P_{ik} / \left(\sum P_{ij}^2 \sum P_{ik}^2 \right)^{\frac{1}{2}}$$

Where P_i is the frequency of occurrence of prey item i in the diet of species j and k . Pianka's index (O) values varies between 0 (total separation) and 1 (total overlap) was used to find out diet similarity of insectivorous bats.

3.5.2. Statistical analysis

The abundance of bat species across different ranges and forest and non forest areas were tested using chi-square test. When the number of individuals was less than five, the species are grouped together as other species. Since the volume and frequency were in different scales, data was transformed into natural logarithm before analysis. Difference in the plant species composition in fruit bat droppings were tested using non-parametric Wilcoxon signed rank test for paired values.

4. RESULTS

4.1. ABUNDANCE OF BAT SPECIES

Abundance of bat species was estimated using roost count method. A total of 11 species were recorded in different locations of South Wayanad Forest Division. Bat species were belonging to five families such as Pteropodidae, Rhinolophidae, Megadermatidae, Emballonuridae and Vespertilionidae. Among different species *R. rouxii* and *P. giganteus* were two predominant species recorded in the study area. Other species such as *Megaderma spasma* and *Cynopterus brachyotis* were found in moderate abundance. Bat species such as *Kerivoula picta*, *Pipistrellus coromandra*, *R. lepidus*, *R. pusillus*, *Taphozus* sp. were recorded only once during the study period.

Table 1: Abundance of different bat species in South Wayanad Forest Division during the survey period from May 2017 to Aug 2017

S. No.	Family	Common Name	Species	Abundance of bat species
1	Lesser dog faced fruit bat	Pteropodidae	<i>Cynopterus brachyotis</i>	19
2	Painted woolly bat	Vespertilionidae	<i>Kerivoula picta</i>	1
3	Lesser false-vampire bat	Megadermatidae	<i>Megaderma spasma</i>	49
4	Little Indian bat	Vespertilionidae	<i>Pipistrellus coromandra</i>	1
5	Indian flying fox	Pteropodidae	<i>Pteropus giganteus</i>	1637
6	Beddome's horseshoe bat	Rhinolophidae	<i>Rhinolophus beddomei</i>	4
7	Blyth's horseshoe bat	Rhinolophidae	<i>Rhinolophus lepidus</i>	1
8	Least horseshoe bat	Rhinolophidae	<i>Rhinolophus pusillus</i>	1
9	Rufous horseshoe bat	Rhinolophidae	<i>Rhinolophus rouxii</i>	1897
10	Horseshoe bat	Rhinolophidae	<i>Rhinoplopus</i> sp.	3
11	Sheath-tailed bat	Emballonuridae	<i>Taphozus</i> sp.	1
			Total	3614



Pteropus giganteus



Cynopterus brachyotis

Plate 1: Fruit bat species found in South Wayanad Forest Division



Rhinolophus rouxii



Rhinolophus rouxii side view



Rhinolophus beddomei



Rhinolophus beddomei side view

Plate 2: Insectivorous bat species found in South Wayanad Forest Division



Rhinolophus lepidus



Rhinolophus lepidus side view



Rhinolophus pusillus



Rhinolophus pusillus side view

Plate 3: Insectivorous bat species found in South Wayanad Forest Division



Megaderma spasma



Pipistrellus coromandra



Kerivoula picta



Rhinolophus sp.

Plate 4: Insectivorous bat species found in South Wayanad Forest Division

4.2. BAT ABUNDANCE ACROSS DIFFERENT RANGES

The abundance of bat species was significantly more in Chedelet, followed by Kalpetta and Meppadi ($\chi^2=2999$; $df=2$; $p<0.00$). *R. rouxii* was recorded more in Chedelet and it was least in Meppadi range. The number of species recorded was low in Kalpetta range (4) than other two ranges. A total of 110 individuals of *Pteropus giganteus* were recorded in Meppadi forest range. Nine individuals of *Cynopterus brachyotis* and four individuals of *Rhinolophus beddomei* found from the abandoned buildings in non-forest areas.

In Chedelet range bat species *Megaderma spasma* were recorded from a tree hole of *Artocarpus hirsuta* from forest. *Taphozus* sp. and *Rhinolophus lepidus* were recorded in abandoned buildings of non-forest area. *Kerivoula picta* were recorded in plantain species *Musa acuminata* from private land.

Table 2: Abundance of bat species in different ranges of South Wayanad Forest Division during the survey period from May 2017 to Aug 2017

Species	Ranges			Total
	Chedelet	Kalpetta	Meppadi	
<i>Rhinolophus rouxii</i>	1304	593		1899
<i>Pteropus giganteus</i>	1500	27	110	1637
<i>Megaderma spasma</i>	48		1	49
<i>Cynopterus brachyotis</i>		10	9	19
<i>Rhinolophus beddomei</i>			4	4
<i>Kerivoula picta</i>	1			1
<i>Pipistrellus coromandra</i>	1			1
<i>Rhinolophus lepidus</i>	1			1
<i>Rhinolophus pusillus</i>		1		1
<i>Rhinopopus</i> sp.			3	1
<i>Taphozus</i> sp.	1			1
Total	2856	631	127	3614

A total of 631 individuals of bats recorded from Kalpetta range. Evergreen and semi evergreen were the dominant vegetation. A total of 593 individuals of *Rhinolophus rouxii* found from abandoned buildings and tunnels including forest and non-forest area. A roosting of *Pteropus giganteus* was found in non-forest

area. 10 individuals of *Cynopterus brachyotis* found from non forest area. A rare species called *Rhinolophus pusillus* found inside from tunnel.

Table 3: Abundance of bat species in forest and non-forest areas of South Wayanad Forest Division during the survey period from May 2017 to Aug 2017

S. No.	Species	Forest area	Non-forest	Total
1	<i>Rhinolophus rouxii</i>	533	1364	1899
2	<i>Pteropus giganteus</i>	110	1527	1637
3	<i>Megaderma spasma</i>	48	1	49
4	<i>Cynopterus brachyotis</i>		19	19
5	<i>Rhinolophus beddomei</i>		4	4
6	<i>Kerivoula picta</i>		1	1
7	<i>Pipistrellus coromandra</i>	1		1
8	<i>Rhinolophus lepidus</i>		1	1
9	<i>Rhinolophus pusillus</i>		1	1
10	<i>Rhinoplophus sp.</i>		3	1
11	<i>Taphozus sp.</i>		1	1
	Total	692	2922	3614

The abundance of bat species was significantly higher in the non-forest areas ($\chi^2=1548$; $df=1$; $p<0.00$). The number of bat species recorded is also higher in non-forest area. Though bat species such as *R. rouxii* and *P.giganteus* roost in the non-forest areas, they travel and forage in forest areas. The movement of bats towards forest area, were observed at dawn and dusk.

4.3. BAT ROOST CHARACTERISTICS

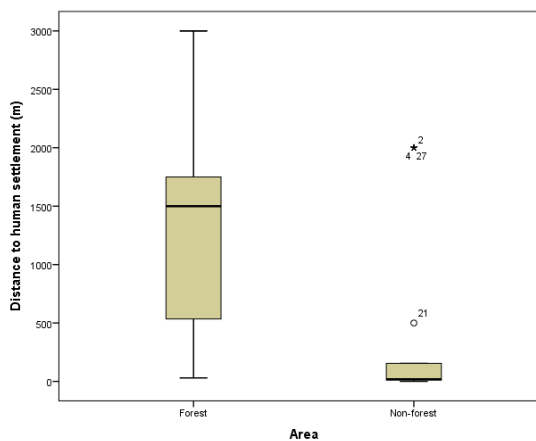
Roost site variables compared between forest and non-forest among the seven variables tested, variables such as distance to human settlement and distance to road were significantly different between the roost sites in forest and non-forest areas (Table-3). Distance to human settlement was more than 1500m in forest area than in non-forest (<100m; Fig. 2a.). Distance to nearest road was significantly higher in forest area (400m) than non-forest (10m; Fig. 2b.). Mean

canopy cover and temperature was higher in forest than non-forest but it was not statistically significant. Humidity and distance to water bodies were same between forest and non-forest areas.

Table 4: Bat roost site characteristics between forest and non-forest areas in South Wayanad Forest Division

Roost variables	Forest	Non forest	F	df	P
	Mean \pm SE	Mean \pm SE			
Altitude (m)	6.70 \pm 0.04	6.79 \pm 0.04	1.46	27	0.24
Distance to human settlement m (log)	6.40 \pm 0.68	4.05 \pm 0.48	6.72	27	0.02
Distance to road m (log)	5.52 \pm 0.69	3.63 \pm 0.34	7.19	27	0.02
Canopy cover (%)	51.43 \pm 12.23	32.86 \pm 6.19	2.1	27	0.16
Temperature ($^{\circ}$ C)	26.19 \pm 0.68	24.98 \pm 0.31	3.31	27	0.09
Humidity (%)	82.14 \pm 2.22	82.67 \pm 0.86	0.07	27	0.79
Distance to water bodies (m)	580.00 \pm 201.06	563.62 \pm 116.25	0.005	27	0.94

a. Distance to human settlement (m)



b. Distance to road (m)

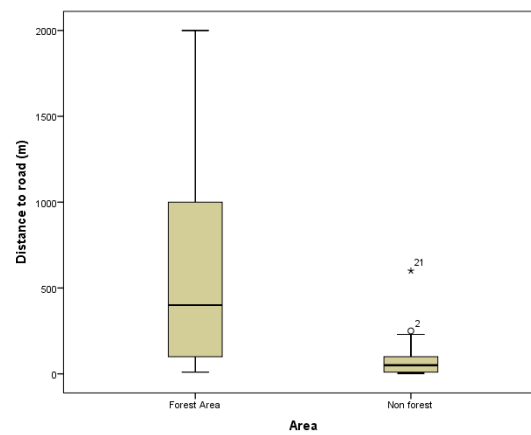


Fig. 2. Difference between forest and non-forest in the distance measured from the roost site to human settlement and distance to nearest road

4.4. ROOST CHARACTERISTICS OF DIFFERENT SPECIES OF BATS

Bat roost type varied according to species and certain bat species used diverse roost types. Roost types are man-made structure such as abandoned building, building, bridges and unused wells, natural roost are trees, tree holes, natural tunnel, caves and plantain. Bat species *Kerivoula picta* were sighted in plantain plantations. Majority of the bat species used abandoned buildings such as *Megaderma spasma*, *R. beddomei* and *R. lepidus*. *P.giganteus* was observed to roost mostly on trees in large colonies. Among different species *R. rouxii* was observed to roost on different types of roost such as abandoned buildings, rock caves, tunnel and unused wells.

P. giganteus were found to roost in 19 tree species such as in *Albizia saman*, *Haldina cordifolia*, *Artocarpus hirsuta*, *Bambusa arundinacea*, *Caryota urens*, *Gravia* sp., *Ficus racemosa*, *Ficus drupacea* var. *mysorensis*, *Spathodea campanulata*, *Crateva magna*, *Pongamia pinnata*, *Gmelina arborea*, *Holigarna nigra*, *Acacia auriculiformis*, *Acacia mangium*, *Holigarna arnottiana*, *Persea macrantha*, *Macaranga peltata*, and *Ficus* sp. There were substantial variations in the roost tree preference by *P. giganteus* in different locations of South Wayanad Forest Division.

Among the roost site characteristics of different species of bats only altitude at which bat spotted, temperature was significantly different for different species of bats (Table-5). Bat species such as *M. spasma*, *Kerivoula picta*, *P. coromandra*, *R. lepidus*, *Taphozus* sp. were observed to roost in lower elevation (~700m). *R. beddomei* and *R. rouxii* were recorded around 800m of elevation. *Cynopterus brachyotis* and *Rhinolophus* sp. were recorded in higher elevation >1000m. Thus there is significant variation in the species roost site selection according to elevation gradient of landscape ($\chi^2=16.74$; $df=10$; $p<0.00$). Temperature within the roost site varies from 23.5°C to 26.9°C for *C. brachyotis* and *R. beddomei* respectively. Roost site temperatures of different species of bats are shown in fig. 3. Roost temperature varied significantly among different

species of bats. Higher variation in temperature was observed in *P. giganteus* species.

R. pusillus and *P. giganteus* were observed to roost near water bodies within distance of less than 50m. Similarly bat species such as *K. picta*, *R. lepidus*, *R. pusillus* and *Taphozus* sp. were roost near human settlements. Though there was variation in the distance to water bodies, it was not statistically significant (Table-5).



Tunnel



Cave



Tree



Abandoned building



Tree hole

Plate 5: Habitats of bat species

Table 5: Roost characteristics of different species of bats (Kruskal-Wallis ANOVA) in South Wayanad Forest Division

Bat species	N	Altitude (m)	Temperature (C)	Humidity (%)	Distance to water body (m)	Distance to human settlement (m)	Distance to road (m)	Canopy cover (%)
<i>Cynopterus brachyotis</i>	5	1068.7 ± 96.66	23.5 ± 0.34	83.4 ± 1.29	700.2 ± 199.83	1202 ± 488.68	160.6 ± 47.35	23 ± 8.6
<i>Kerivoula picta</i>	1	769.0	24.9	80.0	800.0	10.0	70.0	90.0
<i>Megaderma spasma</i>	3	764.3 ± 12.97	26.8 ± 0.2	83 ± 3.61	310 ± 196.04	1170 ± 597.69	201.7 ± 151.67	46.7 ± 14.24
<i>Pipistrellus coromandra</i>	1	775.5	26.9	84.0	500.0	1000.0	400.0	25.0
<i>Pteropus giganteus</i>	2	911 ± 121.05	26.6 ± 0.75	78.5 ± 1.5	50 ± 10	97.5 ± 57.5	25 ± 10	25 ± 25
<i>Rhinolophus beddomei</i>	3	874.6 ± 78.78	26.9 ± 0.32	85 ± 4.36	63.3 ± 3.33	61.7 ± 46.76	9.7 ± 2.73	11.7 ± 6.01
<i>Rhinolophus lepidus</i>	1	770.0	24.9	80.0	900.0	8.0	60.0	10.0
<i>Rhinolophus pusillus</i>	1	919.0	24.4	80.0	15.0	10.0	4.0	40.0
<i>Rhinolophus rouxii</i>	8	798.4 ± 65.9	25 ± 1.81	82.1 ± 4.32	695 ± 653	644.7 ± 1081	545 ± 779.3	55.6 ± 35.4
<i>Rhinolopus sp.</i>	2	1089.6 ± 194.2	24.9 ± 1.6	86.0 ± 7.07	1250 ± 353	1015 ± 1393	120 ± 155.6	45 ± 21
<i>Taphozus sp.</i>	1	770.0	24.9	80.0	900.0	8.0	60.0	10.0
Total	28	880.4 ± 31.13	25.3 ± 0.3	82.5 ± 0.83	567.7 ± 98.77	647.3 ± 174.72	238.6 ± 86.79	37.5 ± 5.65
Median		794.9	25.0	81.0	550.0	37.5	60.0	30.0
Chi-square		17.68	17.89	6.68	10.32	9.10	9.53	11.76
df		10	10	10	10	10	10	10
P (Monte Carlo simulation 1000 times)		0.01	0.00	0.88	0.43	0.60	0.54	0.26

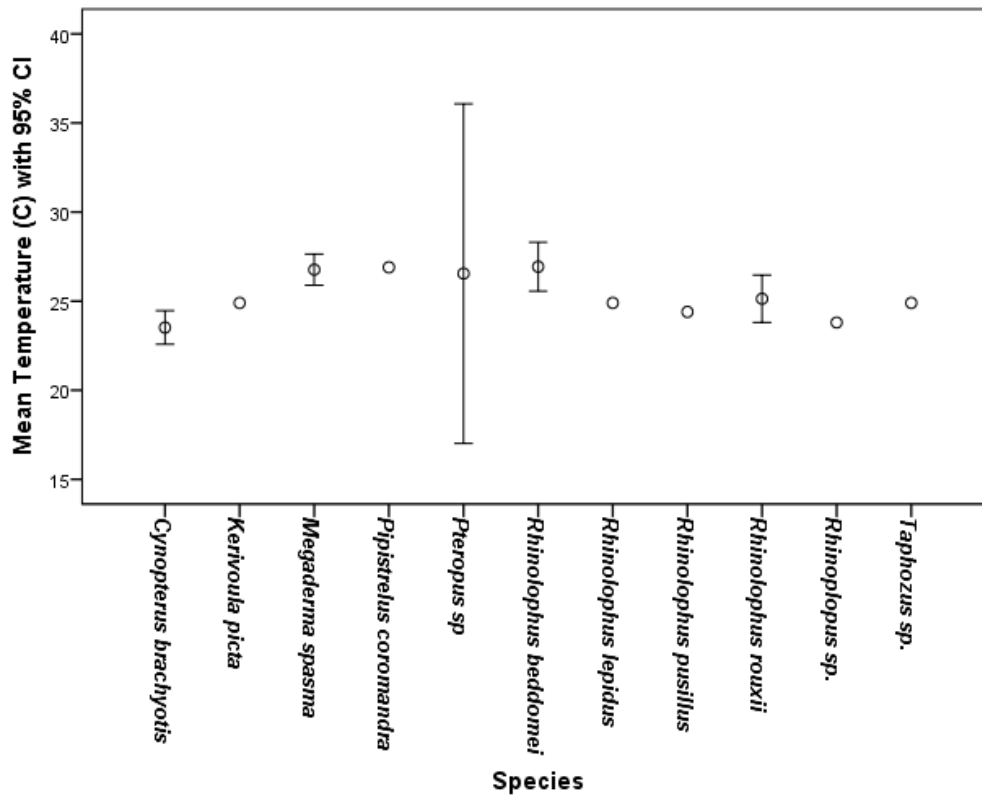
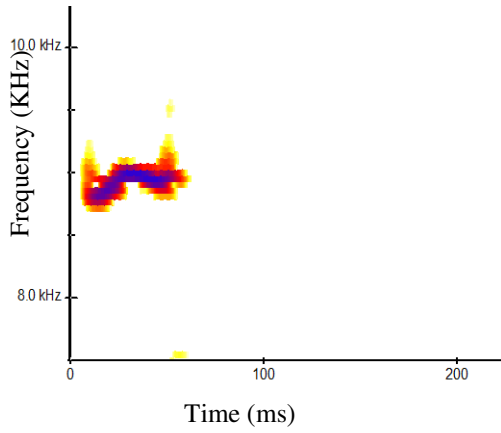


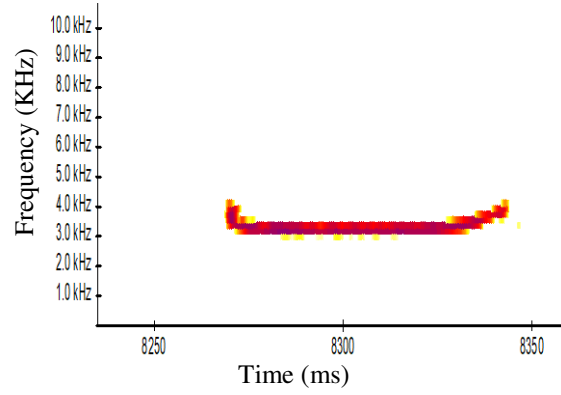
Fig. 3. Temperature variation in the different species of bat species in roost sites in South Wayanad Forest Division.

4.5. SOUND CHARACTERISTICS AND ANALYSIS

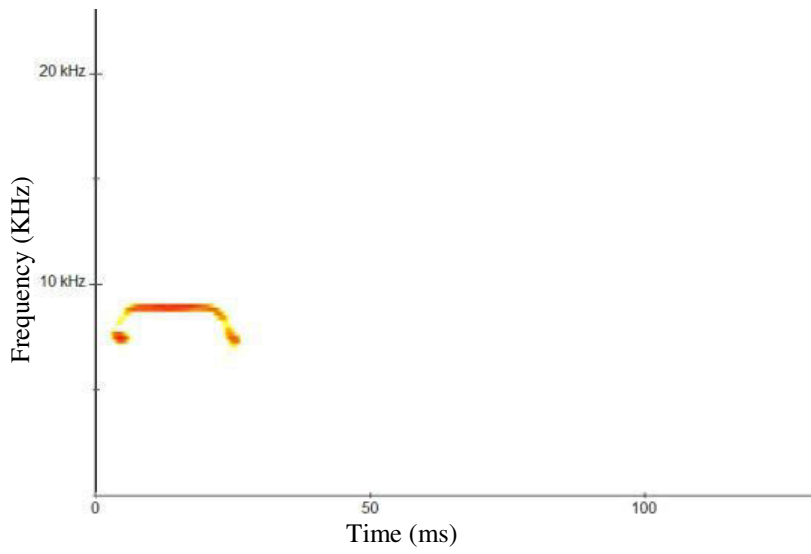
Call duration is the time in milliseconds measured between start and end frequencies, call duration was highest for *R. beddomei* (73.98 ± 5.67). Call duration varied significantly among the three species ($F=54.77$; $df=2$; $p<0.001$; Table-6). Interval time between call was significantly higher for *R. beddomei* (117.3 ± 19.3 ms), followed *R. pusillus* (77.13ms) and *R. rouxii* (73.8ms). Call parameters such as Start and end frequency, frequency maximum (FMAX) for bat species *R. pusillus* was significantly higher than other species. In contrast bandwidth was significantly higher for *R. beddomei*. *R. pusillus* and *R. rouxii* had similar bandwidth (Table-6).



Rhinolophus rouxii



R. beddomei



R. pusillus

Fig. 4. Echolocation calls of Rhinolophid bat species

Table 6: Call parameters of selected species of Rhinolophid bat species from South Wayanad Forest Division during the study period (May 2017-August 2017)

Species	Mean	SD	Min	Max	ANOVA
Duration (ms)					
<i>Rhinolophus beddomei</i>	73.98	5.666	63	85	F=54.77; df=2; p<0.001
<i>R.pusillus</i>	47.33	5.900	32	58	
<i>R.rouxii</i>	51.27	10.152	29	64	
Interval Time (ms)					
<i>R.beddomei</i>	117.27	19.385	96	144	F=31.59; df=2; p<0.001
<i>R.pusillus</i>	77.13	12.817	37	91	
<i>R.rouxii</i>	73.80	17.131	60	125	
Start Frequency (kHz)					
<i>R.beddomei</i>	45.35	2.073	42	48	F=1666.53; df=2; p<0.001
<i>R.pusillus</i>	111.03	3.347	100.6	116	
<i>R.rouxii</i>	82.85	3.716	78	90	
End Frequency (kHz)					
<i>R.beddomei</i>	31.70	3.123	26	38	F=1807.49; df=2; p<0.001
<i>R.pusillus</i>	103.44	3.960	100	111	
<i>R.rouxii</i>	73.53	2.625	70	78	
FMAX Frequency (kHz)					
<i>R.beddomei</i>	33.87	0.509	32.8	34.9	F=5636.23; df=2; p<0.001
<i>R.pusillus</i>	107.23	2.633	100.74	112.4	
<i>R.rouxii</i>	78.17	1.925	74.8	79.7	
Bandwidth (kHz)					
<i>R.beddomei</i>	13.65	0.87	8	22	F=6.37; df=2; p<0.001
<i>R.pusillus</i>	8.94	0.95	0.8	16	
<i>R.rouxii</i>	9.3	1.24	0.0	19.9	

4.5.1. Discriminate function analysis

Linear discriminate function analysis based on call parameters classified all the three bat species calls into three distinct clusters with 100% success. The variables in the function-1 are FMAX, end frequency and start frequency with eigen value 398.95 with 99.8% variance. Among this three variables FMAX- had lower Wilk's $\lambda = 0.004$; F=5636.23; df=42; p<0.001 when the data was

bootstrapped for 1000 times. The factors in function-2 consists of band width, call interval and call duration with eigen value of 11.58 and total variance was 2.9%. Cumulatively all the variables separated three bat species calls into three different clusters with 100% accuracy. Thus DFA for species that emitted CF calls distinguished 100% of calls correctly.

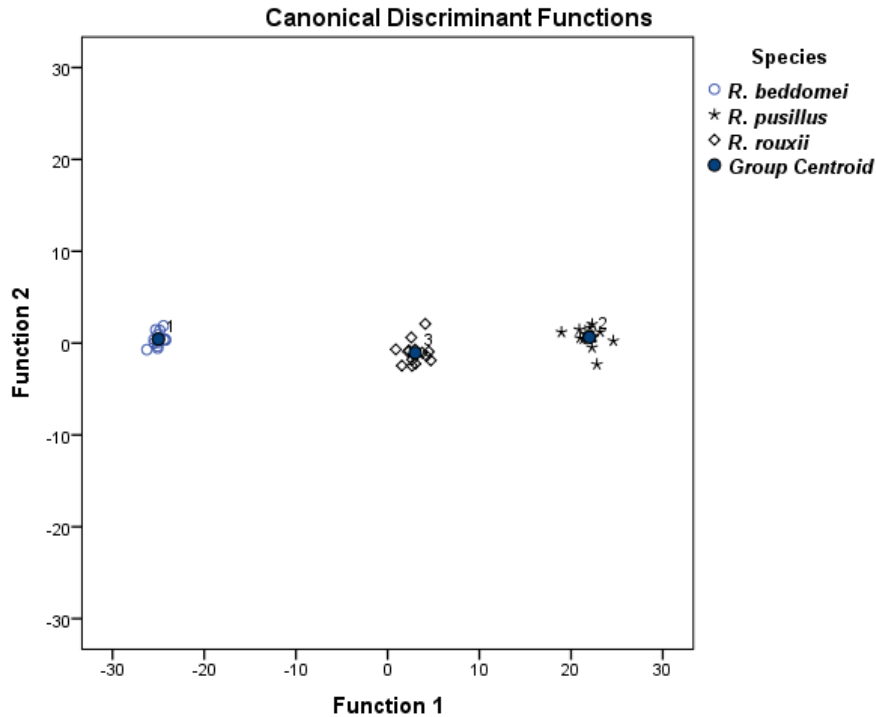


Fig. 5. Discriminate function analysis for Rhinolophid bat species

4.6. DIET COMPOSITION

4.6.1. Dietary analysis of fruit bat

The diet composition of fruit bat (*Cynopterus brachyotis*) was determined by both frequency and volume. Plant species belongs to 10 genera and eight families were identified as food plants that belong to Myrtaceae, Salicaceae, Phyllanthaceae, Moraceae, Anacardiaceae, Elaeocarpaceae and Lauraceae, Gnetaceae. Based on frequency of seeds obtained from guano, fruit species such as *Ficus* sp. were constituted higher frequency (46.5%), followed by *Psidium guajava* (26.7%) and *F. callosa* (18.9%) all the plant species seeds were less than

3.4 mm. Based on volume of seeds, fruit species such as *Gnetum* sp. (50.9%), *Cinnamomum* sp. (12.2%) and *Eleocarpus serratus* (6.6%) with higher size classes of 40.1mm, 9.2mm, and 11.4mm respectively had higher volume. There was significant difference between the volume of fruit and frequency ($Z=1.88$; $df=11$; $p<0.05$; Monte Carlo Simulation for 1000 times). It is essential to interpret the results cautiously, when using either frequency or volume from guano analysis.

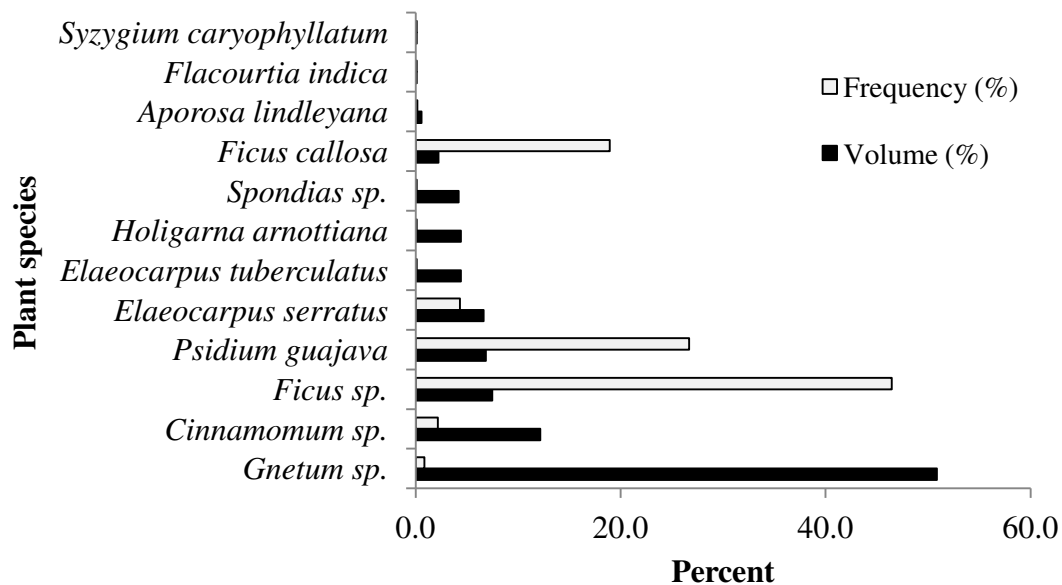


Fig. 6. Diet composition of *Cynopterus brachyotis*

4.6.2. Dietary analysis of insectivorous bat

A total of 12 and 9 prey items of insects were recorded in insectivorous bat species *R. beddomei* and *R. rouxii*. Among different insect prey species Coleoptera, Lepidoptera and Diptera were constituted 80% and 88% in the diets of *R. beddomei* and *R. rouxii* respectively. Insect order Coleoptera that constitute beetles were the predominant prey item for both species that constituted 55% and 73% for bat species *R. beddomei* and *R. rouxii* respectively. The major insect prey items were similar for both species. Further, *R. beddomei* were observed to prey more on Hymenoptera (especially ants; 5%) and Odonates (1.8%). Though the major prey items were similar, statistically there was significance difference in

percent composition of different insect prey items of both species (Wilcoxon Signed Rank Test $Z=-2.201$; $p<0.05$). Thus the variation in the prey items could be due to differences in the minor prey species, since the major prey about 80% were similar.

The prey species diversity (Shannon's index of diversity) was higher for *R. beddomei* (1.51) than *R. rouxii* (1.05), indicating wide array of food selection by *R. beddomei*.

The niche overlap estimated using Pianka index of similarity showed 98% overlap in the food niche overlap between *R. beddomei* and *R. rouxii*.

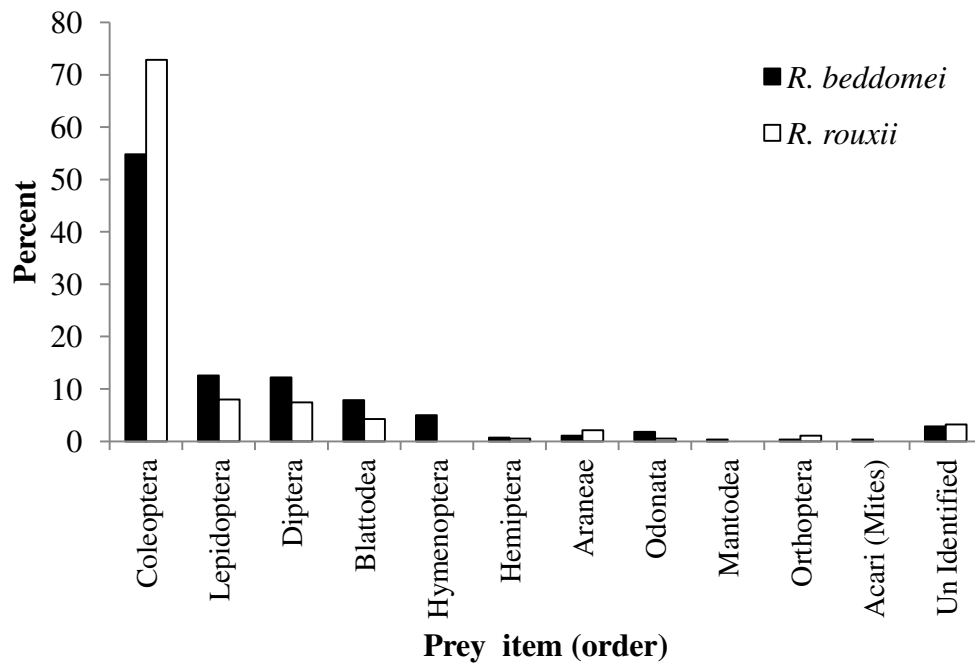
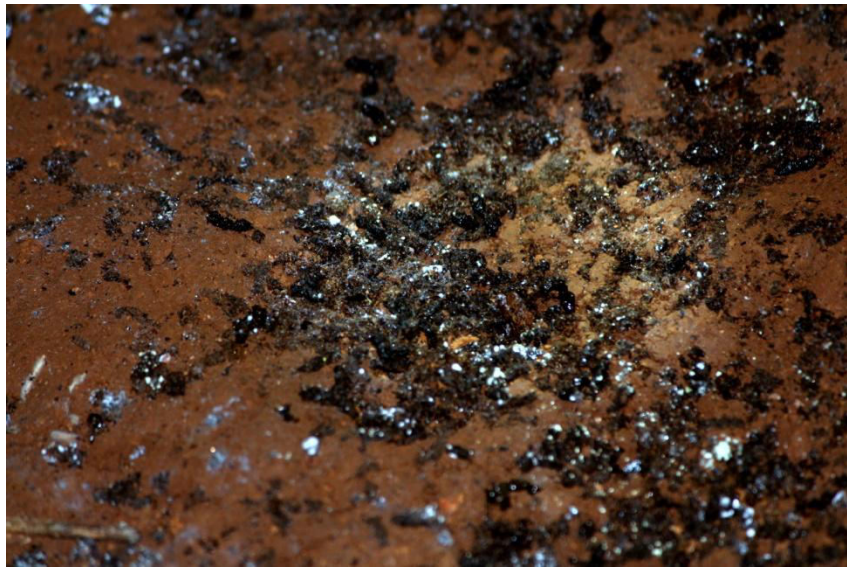


Fig. 7. Diet composition of insectivorous bats (*Rhinolophus beddomei* and *Rhinolophus rouxii*)

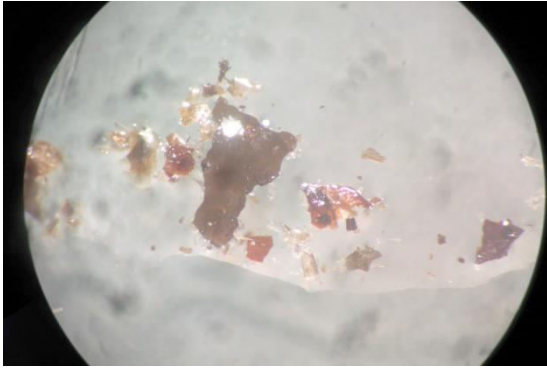


Guano and fruit remnants of frugivorous bat



Guano of insectivorous bat

Plate 6: Guano and Fruit remnants of frugivorous and insectivorous bats



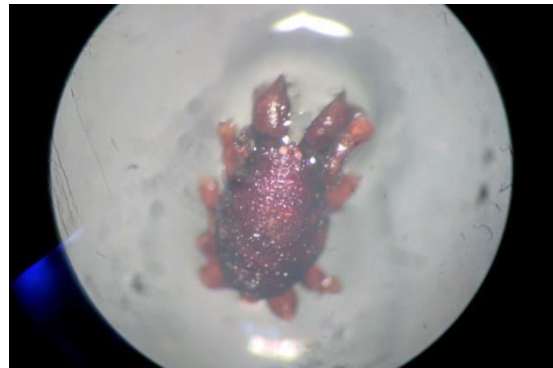
Coleoptera



Hymenoptera



Araneae



Acari (Mites)

Plate 7: Microscopic examination of two insectivorous bat species guano sample

5. DISCUSSION

In the present study bat species abundance, bat roost characteristics, bat call characteristics and dietary composition of fruit bat and insectivorous bat species were studied in the South Wayanad Forest Division from May 2017 to August 2017.

5.1. ABUNDANCE OF BAT SPECIES

Animal abundance and distribution are the core of ecology and essential for wildlife managers (Krebs, 1978). A total of 11 bat species recorded in the forest and non-forest areas of South Wayanad forest division (SWFD) during the study period (May 2017 to Aug 2017). Bat species comprised of five families and seven genera of which two species were frugivorous and nine were insectivorous. Among different families Rhinolophidae and Pteropodidae had maximum number of species and abundance respectively. *Rhinolophus rouxii* was the most recorded bat species from the study area followed by *Pteropus giganteus* and *Megaderma spasma*. Similarly a total of ten bat species belongs to six families and eight genera were recorded in the adjacent protected area of Wayanad Wildlife Sanctuary (Divakar, 2015).

Species abundance of *Pteropus giganteus* and *R. rouxii* was higher with 1637 and 1897 individuals in SWFD than Wayanad Wildlife Sanctuary (Divakar, 2015). A review paper on bat species in Kerala revealed that 29 species of bats belonging to seven families and 17 genera (Nameer, 2015). Though Nameer (2015) study was not complete assessment for Kerala based on available information, present study indicated that SWFD support 37.9% of bat species of Kerala. But results were constrained by short duration of study and it is expected that study area could support more number of species in SWFD.

A total of five species of bats belongs to Rhinolophidae were recorded in the study area. There were two species of bat in Vespertilionidae family were found. But Vespertilionidae was the most abundant bat family with a total of 52 species of bats reported from Western Ghats (Korad *et al.*, 2007).

Vespertilionidae bat are insectivorous bat species that are small and were captured using mist net method. In the present study bat species abundance was estimated by sampling in roost areas such as caves, tunnels, tree hole, unused wells, bridges and abandoned buildings. Thus difference in the method of sampling of bat species could have resulted in the differences in the higher abundance of bat species of Rhinolophidae family.

A rare species *Pipistrellus coromandra* was recorded from abandoned building Pathiri Reserve forest and it is first time reported from Kerala (Nameer, 2015). There were reports of their presence in Kudremukh National Park, Karnataka (Raghuram *et al.*, 2014) and in Western Ghats (Korad *et al.*, 2007).

5.1.1. Abundance of *Pteropus giganteus*

A total of 1500 individuals of *Pteropus giganteus* recorded from the riparian habitat of Panamaram river. Earlier studies in Wayanad reported a total of 538 individuals of *P. giganteus* in tree species *Acacia auriculiformis* from Sulthan Bathery (Divakar, 2015). Similarly 565 individuals of *P. giganteus* in tree species *A. mangium* were reported from Panamaram (Reshma, 2013). The abundance of *P. giganteus* varied in different years, seasonal variation depending on the fruit availability has been reported (Eby, 1991). *P. giganteus* is highly social species forming colonies that ranges from hundreds to several thousands (Eby, 1991; Reshma, 2013). They also prefer to roost near water bodies and human settlements (Bates and Harrison, 1997) due to factors such as obligate drinking behaviour and protection from natural predators. Thus present study reported the highest number of *P. giganteus* in Panamaram river of SWFD.

5.2. BAT ABUNDANCE ACROSS DIFFERENT RANGES

The abundance of bat species was significantly more in Chedeledh, followed by Kalpetta and Meppadi. One possible reason for bats in Chedeledh Range could be due to several roost sites of *R. rouxii* such as caves, unused well and abandoned buildings and species roosting trees of *P. giganteus*. *R. rouxii* was recorded more in Chedeledh and it was least in Meppadi Range. The number of

bat species recorded was low in Kalpetta Range than other two ranges. There is substantial variation in the vegetation composition, Chedelesh Range composed of tropical deciduous forest, Kalpetta and Meppadi area consisted of evergreen and semi-evergreen forest (Joy, 2016). The regional variation in the bat abundance could be due to differences in the vegetation composition and number of roosting sites.

A total of 110 individuals of *Pteropus giganteus* were recorded in Meppadi Forest Range in tree species such as *Holigarna arnottiana*, *Persea macrantha*, *Macaranga peltata*, *Artocarpus hirsute* and *Ficus* sp. Nine individuals of *Cynopterus brachyotis* and four individuals of *Rhinolophus beddomei* found from the abandoned buildings in non-forest areas. *Megaderma spasma* were recorded from the abandoned building at day time. *Megaderma spasma* reported from underneath of roof, which they used as night and day roost (Raghuram *et al.*, 2014).

In Chedelesh Range bat species *Kerivoula picta* were recorded in plantain species *Musa acuminata* from private land. *Kerivoula picta* had been reported in shrub species of *Chromolaena odorata* in Wayanad Wildlife Sanctuary (Divakar, 2015) and tender leaves of plantain (Madhavan, 2000). *K. picta* tend to roost in ground vegetation rather than high canopy.

5.2.1. Comparison between forest and non forest areas

From this study a total of 2922 individuals bat species found from non forest area and 692 bat species recorded from forest area. Comparison of non forest and forest area revealed that, from non forest area *Pteropus giganteus* were the most abundant bat species followed by *Rhinolophus rouxii*. Similar species composition was recorded in the Wayanad Wildlife Sanctuary (Divakar, 2015). Earlier studies reported that *Cynopterus* species was higher in non forest area than forest (Ramadhan, 2015). It was found that Agricultural habitats had the high bat species abundance and richness (Estrada *et al.*, 1993). Many roost sites and presence of perennial water bodies, abandoned buildings in the non-forest areas might have resulted in higher abundance of bats in non forest area.

5.3. BAT ROOST CHARACTERISTICS

Among different variables measured in roost site compared between forest and non forest, distance to human settlement and distance to road was significantly higher in forest area. In forest area apart from *R. rouxii* and *P. giganteus*, bat species *M. spasma* were recorded more that roost in tree holes and abandoned buildings. Their roost sites were located inside the forest that is away from human settlement and road (Divakar, 2015). Mean canopy cover and temperature was higher in forest area than non forest area. Roost-trees or the site characteristics help in population persistence as they provide a microclimate suitable for offspring development (Kerth *et al.*, 2003; Garroway and Broders, 2008).

Among different species of bats *Megaderma spasma*, *R. beddomei*, *R. lepidus* used to roost in abandoned buildings. *Pteropus giganteus* was found only in trees and they were observed to roost around 19 tree species. There were substantial variations in the roost tree preference by *P. giganteus* in different locations of South Wayanad Forest Division. Similar difference in the roost tree preferences were reported earlier (Reshma, 2013; Divakar, 2015).

Among roost site characteristics of different bat species, temperature and altitude varies across species and roosting colonies. Roost site selection based on temperature difference in bat roost boxes had been reported (Kerth *et al.*, 2003). *Cynopterus brachyotis* and *Rhinolophus* sp. were recorded from higher elevation (>1000m). Roost temperature varied significantly among different species of bats. *P. giganteus* had higher variation in temperature. Bat species such as *K. picta*, *R. lepidus*, *R. pusillus* and *Taphozus* sp. were found near human settlements. *R. pusillus* and *P. giganteus* were observed to roost near water bodies (<50m).

Bat roost type varied according to species and certain bat species used diverse roost types for example *R. rouxii*. Majority of the bat species used Man-made structures. Among different species *Megaderma spasma*, *R. beddomei* and

R. lepidus were used abandoned buildings. The exploitation of man-made structure as substitutes for natural forest (Kunz *et al.*, 1980) enable bat to colonize in and increase abundance in non forest areas. *P.giganteus* was observed to roost mostly on trees in large colonies. Different species of bats selected roost sites in different elevation gradient might be result of foraging behaviour and to avoid competition among species. Forest restoration, building restoration, increased recreational use of caves are potential threat to bat abundance.

5.4. CALL PARAMETERS

Three species of Rhinolophidae call parameters such as duration, interval, start and end frequency, FMAX and bandwidth were analysed and found that all parameters varied significantly. Call parameters of *R. pusillus* is reported for first time. Call duration of *R. beddomei* was longer than other two species. In general, Rhinolophid bat species call duration is relatively longer than other bat species (Raghuram *et al.*, 2014). Slightly lower duration were reported 48 to 58.0ms in Kudremukh National Park (Raghuram *et al.*, 2014) and call duration range of 25 to 71 in Valparai (Wordley *et al.*, 2014). Thus call duration varied among different localities. Further call parameters have been reported to vary according to biogeographic range for a species (Hughes *et al.*, 2010). Thus it is essential to study call parameters from Wayanad region.

FMAX, start and end frequency was similar for both bat species *R. beddomei* and *R. rouxii* in different localities (Present study; Raghuram *et al.*, 2014; Wordley *et al.*, 2014). Hence these parameters can be used to distinguish bat species, but the method of call recording that is hand releasing, free foraging and zip line, animal stress level, wind speed, flowing water, insect calls could also influence call signature (Kunz and Parsons, 2000). In the present study calls were measured at the roost site when the bats were flying without any constraints mostly in abandoned buildings and tunnels.

Based on call parameters all three bat species classified in to three distinct clusters with 100% success by linear discriminate function analysis. Factor one composed of FMAX, end frequency and start frequency and factor two composed

of bandwidth, call interval and call duration. Thus bat species can be easily distinguished based on call parameters with 100% certainty. Similar bat species identification based on call parameters has been reported from Valapari area of four bat species of constant frequency with correct classification of 100% (Wordley *et al.*, 2014). The call parameters of three Rhinolophid species that differ from those published from other parts of the species range. Thus there is need for more local call libraries from tropical regions to be collected and published in order to record and identify bat species in non-invasive manner.

5.5. DIET COMPOSITION

5.5.1. Diet composition of *Cynopterus brachyotis*

Old world fruit bats have important role in seed dispersal and pollination (Dumont *et al.*, 2004). A total of 120 droppings of frugivorous bat *C. brachyotis* were collected and analyzed. Twelve different species of fruits were identified. Plant species belongs to 10 genera and eight families were identified as food plants. Higher diversity have been reported based on long term studies from Borneo, 24 species of seeds and fruits representing 16 genera and 15 families (Mohd-Azlan *et al.*, 2010). Among different tree species *Ficus* sp. had the highest frequency (46.5%) followed by *Psidium guajava* (26.7%), *Ficus callosa* (18.9%) and other species. But *Gnetum* sp. had the highest volume (50.9%) followed by *Cinnamomum* sp. (12.2%), *Ficus* sp. (7.5%), *Psidium guajava* (6.9%), *Elaeocarpus serratus* (6.6%), *Elaeocarpus tuberculatus* (4.4%), *Holigarna arnottiana* (4.4%), *Spondias* sp. (4.2%), *Ficus callosa* (2.2%) and other species. Tree species such as *Elaeocarpus tuberculatus*, *Cinnamomum malabathrum*, *Mangifera indica*, *Carallia brachiata*, *Syzigium cumini* and *Aporosa lindelyana* were the dominant tree species recorded from evergreen forest of South Wayanad Forest (Joy, 2016). Thus plant species that are abundant in the study area were observed in the diet as well. Similar fruit species composition has been reported in other bat species *P. giganteus* in the study area (Reshma, 2013). *C. brachyotis* feed more on smaller fruits than larger fruits in Thailand (Bumrungsri *et al.*, 2007). *Cynopterus brachyotis* also fed on Flowers of legume species and leaves of

14 plant species (Tan *et al.*, 1998). There was significant difference between the volume of fruit and frequency. Thus comparison of results with other studies should be done carefully, since the method of diet analysis either frequency or volume could vary the results.

5.5.2. Diet composition of Insectivorous bats

Diet composition of two Rhinolophids bats (*R. beddomei* and *R. rouxii*) were compared. Morphologically *R. beddomei* is larger than *R. rouxii* and sella ornamentation is distinct in former species. Between horseshoe and nose leaf is a median projection called Sella and it is characteristic features of Rhinolophids. Sella directs echolocation pulses to ears that are emitted through nostrils. Horseshoe bats takes insects while in flight in forest understory (Bates and Harrison, 1997). The major insect prey was similar for both species with Coleoptera, Lepidoptera and Diptera were constituted 80% and 88% in *R. beddomei* and *R. rouxii* respectively. There were difference in minor prey items *R. beddomei* were observed to prey more on Hymenoptera (especially ants) and Odonates. Similar prey composition had reported from tropical forest of Southern India (Ponmalar and Vanitharani, 2014; Divakar, 2015).

Prey species diversity was higher for *R. beddomei* than *R. rouxii*. Thus *R. beddomei* foraged on diverse prey where as *R. rouxii* foraged selective in their diet. Diet niche overlap based on prey species was 98% similar. Though both species feed on same niche, same insect prey item, morphological differences of bat species, foraging methods and insect prey abundance could enable both species to co-exist in the similar environment. Economically bat species are important, since insectivours bat helps to control harmful insect pest in the agricultural areas and mosquitos (Diptera) (Ades and John, 1994; Sophia, 2010).

6. SUMMARY

Bat species abundance, roost characteristics and selected Rhinolophid bat species call parameters (*R. rouxii*, *R. beddomei* and *R. pusillus*) and diet composition were studied (one fruit bat *Cynopterus brachyotis*, two species of insectivorous bats *Rhinolophus beddomei* and *R. rouxii*) from May 2017 to August 2017 in the South Wayanad Forest Division (SWFD).

Bat species abundance was estimated using roost count method, roost sites in forest and non forest area were surveyed for the presence of bat and potential roost sites proximity to roost site were surveyed. Bat species abundance across different ranges and between forest and non forest were compared. The roost site parameters such as temperature, altitude, canopy cover, humidity and proximity to water body, human settlement and nearest road were noted. Roost site characteristics among different bat species were tested using Kruskal-Wallis ANOVA. Bat call parameters were recorded in the roost site using ultrasound bat detector (Pettersson-D200) and analysed using Batsound Software. Call signature differences of selected bat species were tested using ANOVA and discriminate function analysis was used to find out call classification pattern. Diet composition of a fruit bat and insectivorous bat species were analysed and micrograph of different prey items were used to identify the diet composition. Prey species diversity and similarity in diet composition was calculated.

A total of 11 bat species, belonging to five families such as Pteropodidae, Rhinolophidae, Megadermatidae, Emballonuridae and Vespertilionidae were recorded. Among different families Rhinolophidae and Pteropodidae had maximum number of species and abundance. *Rhinolophus rouxii* was the highest in abundance (1899) followed by *Pteropus giganteus* (1637), *Megaderma spasma* (49), *Cynopterus brachyotis* (19) and *Rhinolophus beddomei*. Bat species such as *Kerivoula picta*, *Pipistrellus coromandra*, *Rhinolophus lepidus*, *Rhinolophus pusillus*, and *Taphozus* sp. were sighted. The abundance of bat species was significantly more in Chedelesh, followed by Kalpetta and Meppadi ($\chi^2=2999$;

df=2; $p < 0.00$). The number of bat species recorded and abundance was higher in non forest area than forest area might be due to factors such as, many roost sites and presence of perennial water bodies and abandoned buildings. Present study reported the highest number of *P. giganteus* in Panamaram river of SWFD.

Among different variables measured in roost site compared between forest and non forest, distance to human settlement and distance to road was significantly higher in forest area. Bat species such as *Megaderma spasma*, *R. beddomei*, *R. lepidus*, *R. rouxii* recorded from abandoned buildings, rock caves, tunnel and unused wells. *P. giganteus* roosted only on trees and there were substantial variation in roost tree selection. Among roost site characteristics, roost temperature and altitude varied across species. Further, bat species such as *K. picta*, *R. lepidus*, *R. pusillus* and *Taphozus* sp. were roost near human settlements. *R. pusillus* and *P. giganteus* were observed to roost near water bodies near water bodies (<50m). Different species of bats selected roost sites in different elevation gradient might be result of foraging behaviour and to avoid competition among species. Forest restoration, building restoration, increased recreational use of caves are potential threat to bat abundance.

Three species of Rhinolophidae call parameters such as duration, interval, start and end frequency, FMAX and bandwidth were analysed and found that all parameters varied significantly. Call parameters of *R. pusillus* is reported for first time. Call parameters have reported to vary in different localities, method of call recording and thus it is essential to study call parameters from Wayanad region. In the present study calls were measured at the roost site when the bats were flying without any constraints. The call parameters of three Rhinolophid species were classified with 100% certainty using discriminate function analysis. Call signatures differed from those published from other parts of the species range. Thus there is need for more local call libraries from tropical regions to be collected in order to identify bat species in non-invasive manner.

A total of 120 droppings of frugivorous bat *C. brachyotis* were analyzed (both frequency and volume were estimated) and 12 different species of fruits were identified. Plant species belongs to 10 genera and eight families were identified as food plants. *Ficus* sp. had the highest frequency (46.5%) followed by *Psidium guajava* (26.7%), *Ficus callosa* (18.9%) and other species. Diet composition based on volume was different with *Gnetum* sp. had the highest volume (50.9%) followed by *Cinnamomum* sp. (12.2%), *Ficus* sp. (7.5%) and other species. There was significant difference between the volume of fruit and frequency. Thus, comparison of results with other studies should be done carefully, since the method of diet analysis could vary results.

Diet composition of two Rhinolophid bat species (*R. beddomei* and *R. rouxii*) were compared. The major insect prey was similar for both species with Coleoptera, Lepidoptera and Diptera were constituted 80% and 88% in *R. beddomei* and *R. rouxii* respectively. There were difference in minor prey items, *R. beddomei* were observed to prey more on Hymenoptera (especially ants) and Odonates. Prey species diversity was higher for *R. beddomei* than *R. rouxii*. Thus, *R. beddomei* foraged on diverse prey whereas *R. rouxii* foraged on specific insect prey. Diet niche overlap based on prey species was 98% similar. Though both species feed on same niche, same insect prey item, morphological differences of bat species, foraging methods and insect prey abundance could enable both species to co-exist in the similar environment.

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**ABUNDANCE, ROOST CHARACTERISTICS, ACOUSTICS AND DIET
COMPOSITION OF SELECTED BAT SPECIES IN SOUTH WAYANAD
FOREST DIVISION**

**BIBIN PAUL M
(15-02MS-003)**

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**Faculty of Veterinary and Animal Sciences
Kerala Veterinary and Animal Sciences University
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8. ABSTRACT

Bat species abundance, roost characteristics and selected Rhinolophid bat species call parameters (*R. rouxii*, *R. beddomei* and *R. pusillus*) and diet composition were studied (one fruit bat *Cynopterus brachyotis*, two species of insectivorous bats *Rhinolophus beddomei* and *R. rouxii*) from May 2017 to August 2017 in the South Wayanad Forest Division (SWFD). Bat species abundance was estimated using roost count method. The roost site parameters such as temperature, altitude, canopy cover, humidity and proximity to water body, human settlement and nearest road were noted. Bat call parameters were recorded in the roost site using ultrasound bat detector and analysed using Batsound Software. Bat call was classified using discriminate function analysis. Diet composition of a fruit bat and insectivorous bat species were analysed and micrograph were used to identify prey species. Prey species diversity and similarity in diet composition was calculated.

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Among different variables measured in roost site compared between forest and non forest, distance to human settlement and distance to road was significantly higher in forest area. Bat species such as *Megaderma spasma*, *R. beddomei*, *R. lepidus*, *R. rouxii* recorded from abandoned buildings, rock caves, tunnel and unused wells. *P. giganteus* roosted only on trees and there were substantial variation in roost tree selection. Among roost site characteristics, roost temperature and altitude varied across species.

Three species of Rhinolophidae call parameters such as duration, interval, start and end frequency, FMAX and bandwidth were analysed and found that all parameters varied significantly. Call parameters of *R. pusillus* is reported for first time. Call parameters have reported to vary in different localities, method of call recording and thus it is essential to study call parameters from Wayanad region. In the present study calls were measured at the roost site when the bats were flying without any constraints. The call parameters of three Rhinolophid species were classified with 100% certainty using discriminate function analysis.

A total of 120 droppings of frugivorous bat *C. brachyotis* were analyzed (both frequency and volume were estimated) and 12 different species of fruits were identified. Plant species belongs to 10 genera and eight families were identified as food plants. *Ficus* sp. had the highest frequency (46.5%) followed by *Psidium guajava* (26.7%), *Ficus callosa* (18.9%) and other species. Diet composition based on volume was different with *Gnetum* sp. had the highest volume (50.9%) followed by *Cinnamomum* sp. (12.2%), *Ficus* sp. (7.5%) and other species. There was significant difference between the volume of fruit and frequency.

Diet composition of two Rhinolophid bat species (*R. beddomei* and *R. rouxii*) were compared. The major insect prey was similar for both species with Coleoptera, Lepidoptera and Diptera were constituted 80% and 88% in *R. beddomei* and *R. rouxii* respectively. Prey species diversity was higher for *R. beddomei* than *R. rouxii*. Diet niche overlap based on prey species was 98% similar. Though both species feed on same niche, same insect prey item, morphological differences of bat species, foraging methods and insect prey abundance could enable both species to co-exist in the similar environment

KERALA VETERINARY AND ANIMAL SCIENCES UNIVERSITY
Faculty of College of Veterinary and Animal Sciences
**PROGRAMME OF RESEARCH WORK FOR DISSERTATION FOR
MASTERS**

DEGREE

(Vide Rule 25(b) of Post Graduate Regulations 1998)

1. Title of Dissertation

Abundance, roost characteristics,
acoustics and diet composition of
selected bat species in South Wayanad
Forest Division

**2a. Title of departmental/KVASU
research project of which this forms a
part**

Nil

**2b. Code No. if any, and order by
which the departmental/KVASU
research project is approved**

Nil

3b. Admission No:

15-02MS-003

**4a. Name of the Major Advisor
(Guide):**

Dr. Abdul Azeez C.P.

4b. Designation

Assistant professor

KVASU- Centre for Wildlife Studies

College of Veterinary and Animal

Sciences

Pookode, Wayanad

3a. Name of the student:

Bibin Paul M.

5. Objectives of the study

1. To estimate bat species abundance, diversity and species composition in different habitats of South Wayanad
2. To study the roost characteristics and preferences of different bat species in the landscape
3. To find out the diet composition of selected bat species in the landscape
4. To develop a baseline data on acoustic sampling for selected species of microchiropterans

6. Practical/Scientific utility

Ability to fly and highly mobile nature of bats makes difference from other mammals. They found in worlds different habitats. About 1100 species of bats found in world and are second only to rodents in their diversity (Simmons, 2005). Bats use echoes of sounds they produce and to locate objects in their

paths and this process is called 'echolocation'.

Comparison of bat diversity in different habitats showing which species prefers which habitat. Habitat use pattern of bats also consider in this study. Habitat have a great role in the species richness and foraging. Many bats species seen in the common habitats. Habitat have crucial role in the survival of bats. Habitat quality is important in the case of frugivorous bats. Difference in vegetation controls bats population and occupancy. Variables such as canopy cover and water availability influences the bat distribution (Amelon *et al.*, 2014). Some variables like water, altitude also causing habitat preference in bats. Pollination and nutrient enrichment in the habitat increase by bats. Bats are highly adaptable mammal. Coffee plantation is the human altered habitat, comparison of this habitat with forest habitat indicating which habitat prefers more by bats.

Occurrence of bats varies with location, habitat type and the landscape cover of the area. Fragmentation and deforestation causing bat diversity. Abundance of bat species associated with forest cover, patch size and patch density (Gorresen & Willing 2004). Roosting of bats inside the natural forest or any area is related with habitat quality.

Bat echolocation call recording and identification is very important. Different bat species have different call frequency. Bat detectors can survey bat species by non invasively (Russo and Voigt, 2016). Acoustic recording of echolocation calls helps for monitoring bat activity or habitat use over time and space (Frick, 2013).

Bats diet includes insects, pollen, fruits, flowers, flesh and blood (Gillette ,1975). Insectivorous bats helps in pest control in coffee and other cultivating lands. They consuming great amount of insects. Affect of bats population in a particular area also affects insect's population. Fruiting plants near the coffee plantation or

inside the coffee plantation affects frugivorous bat foraging behaviour.

Different types of habitats present in Wayanad district, so the data collection from these study area is relevant. Majority of bat species included in vermin's. This study helps to show real status of bats and affect of human altered habitat in bat diversity.

7. Important publications on which the study is based

Korad *et al.* (2007) studied the diversity and distribution of bats in the Western Ghats of India. They compiled species checklist from published literature. They recorded 52 species of bats included in 8 families. They found that *Latidens salimalii* is endemic to the Western Ghats. They suggested that 35% of the bat fauna of the Western Ghats are threatened globally or nationally.

Almeida *et al.* (2014) conducted a study on habitat characteristics and insectivorous bat activity. Two types of comparison were observed in this study:

first between forest, forest edge, and open habitat and second between open habitat with and without water body nearby. This study showed that insectivorous bat activity in the neotropics is also influenced by spatial complexity of vegetation and the presence of water bodies.

Divakar (2015) carried out a study on diversity, habitat preference and feeding habits of chiropterans in Wayanad Wildlife Sanctuary. He recorded 10 bat species, which belonged to 6 families and 8 genera. He examined guano samples of *Pteropus giganteus*, *Rhinolophus rouxii* and *Megaderma spasma*. Mixed species roosting also reported in his study.

Raghuram *et al.* (2006). recorded the echolocation calls of 13 microchiropteran species from Kudremukh National Park in the Western Ghats of Karnataka, of which the calls of *Pipistrellus coromandra*, *Pipistrellus affinis*, *Pipistrellus ceylonicus* and *Harpiocephalus harpia* were recorded for the first time. They

conducted study by using standard techniques, including mist netting acoustical and roost surveys. Their study indicated that the echolocation calls could be used successfully for non-invasive acoustic surveys and monitoring of bat species in the future.

Wordley *et al.* (2014) recorded echolocation calls of 15 bat species from the Valparai plateau in the Anamalai Hills, southern Western Ghats of India. They got first record of *Barbastella leucomelas darjelingensis* in south India. This study revealed that the call frequencies for some species (*Rhinolophus rouxii* and *Hipposideros pomona*) that differ from those published from other parts of the species ranges.

Shetty (2013) studied the prey and nutritional analysis of *Megaderma lyra* from the west coast of Karnataka, India. The percent volume and percent frequency of food items present were also determined and were classified as basic food, constant food, supplementary food and chance food. They identified 15 insect orders from study area. They

showed that Coleopterans formed the major food items in all the three seasons (pre monsoon, monsoon and post monsoon) and Hemipterans formed the constant food in all the three seasons.

McAney *et al.* (1991) made a key for the identification of Arthropoda from bat droppings. Their study gave instructions on how to collect and prepare droppings for examination. They found only one bat fly in the 1894 bat droppings. They described variety of prey remains and drawings also helped for the identification.

8. Outline of the technical programme

The study area will consist of the forest and non forest areas of South Wayanad Forest Division. South Wayanad Forest Division is dominated by evergreen and semi evergreen vegetation.

Tree holes, caves, tunnels, bridges, buildings, wells, bamboo clumps and all potential roosting sites will be screened for the presence of bats.

Direct and indirect signs of bat species will be observed to confirm the presence. Roost count will be taken for population estimation. Bat species will be identified by published keys (Srinivasulu and Bates). Photos of the entire colony and individuals will be taken during roost sampling. Identification also will be done by comparing the photos with useful field guides. Different variables will be recorded from roost sites and compared among different bat species. Habitat utilization of bats will be enumerated based on roosting sites, foraging sites and bat detector data. Habitat variables such as tree cover, slope, altitude, canopy cover, and shrub and tree density will be determined (Ford *et al.*, 2006). Distance to human habitation, roads will also be measured.

Bat echolocation calls will be recorded using a Pettersson D200 ultrasound detector with a sampling rate range from 10-120 KHz will be recorded into WAV file format. Calls will be analyzed by using bat sound software.

Guano samples of three bat species will be collected from the bat roosting sites. Samples will be identified using microscopic examination. The remnants of prey species will be identified by using insect identification keys (Shetty and Sreepada, 2013).

9. Main items of observations to be made

1. Species inventory of number of species and richness and diversity of bat species in Wayanad.
2. Acoustic analysis of three bat species calls
3. Diet analysis of three bat species
4. Management implication on how human influence on habitat affects bat species composition and diversity.

10. Facilities

a. **Existing:** Camera, Vernier caliper

b. Additional facilities required:

Bat detector, Field guide/Tracker

11. Duration of study: One Semester

12. Financial estimate

Bat detector	-	Rs 45000
Trackers	-	Rs 20000
Miscellaneous	-	Rs 4000
Total	-	Rs 69000

13. Signature of student

14. Signature of Major Advisor

Place:

Date:

15. Name, designation and signature of members of the Advisory Committee

1. Dr. Abdul Azeez C.P. (Major advisor)

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KVASU- Centre for Wildlife Studies
College of Veterinary and Animal
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Pookode, Wayanad

2. Dr. George Chandy (Course Director)

Officer in Charge,
Centre for Wildlife Studies, College of
Veterinary and Animal
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3. Dr. Biju S. (Member2)

Assistant professor
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Appendix I

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Appendix -2

Time frame of work

Semester IV

1. Roost sampling and data collection
2. Guano collection and analysis
3. Acoustic analysis
4. Interpretation of results
5. Dissertation writing

CERTIFICATE

Certified that the research project has been formulated observing the stipulations laid down under the Prevention of Cruelty to Animals Act (Amendment, 1998).

Place:

Dr. Abdul Azzez C.P.

Date:

Guide

CURRICULUM VITAE

Name of the Candidate : Bibin Paul M

Date of Birth : 21/7/1995

Place of Birth : Irinjalakuda

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Publication Made : Nil

Membership in Professional Bodies : Nil