Assessing diversity and distribution of bats in relation to land-use and anthropogenic threats in the southern Western Ghats, India

Final Report

Submitted to the Rufford Small Grants for Nature Conservation

By

Kadambari Deshpande

(Project ID: 9686-1)

The Rufford Small Grants Foundation

www.ruffordsmallgrants.org

Introduction

Occupying diverse niches in both natural and human-modified landscapes, bats provide highly important ecological services such as insect-pest predation, pollination, and seed dispersal, thus providing valuable ecosystem services (24,33). Due to these functional roles and their sensitivity to environmental change, bats are useful bio-indicators of local as well as landscape-level disturbances and change (13, 28,42). Habitat fragmentation, logging, deforestation, mining, forest loss, and encroachment of natural habitats by agricultural practices are among the major threats affecting bats, apart from direct threats such as hunting (13, 43,51). Bats, despite their tremendous importance, have been largely neglected in ecological studies and assessments of biodiversity and conservation values (36,43). Bats are the second most diverse mammalian order, with approx. 120 species found in India (3,65) and 52 species known from the Western Ghats (31,38,47,59,66). But owing to their nocturnal habits, dark dwelling places and gaps in scientific knowledge, misconceptions and social taboos are rife in India. As a result, reliable information on their ecology and conservation status is unavailable from most areas. Evaluating the status of threats to such taxa is thus of great significance for a holistic idea of conservation targets (43,59).

Land-use change and diversion of forests to commercial plantations are important threats in the tropics worldwide. A significant body of research is emerging on impacts of such widespread habitat destruction and fragmentation on a wide range of taxa, from plants and amphibians to large mammals (1,2). However, there is need for greater emphasis on threats to neglected groups such as bats that may otherwise go unnoticed due to their cryptic ecology. In the context of India, Kadambari Deshpande, 2012 rapid economic development is directly pressurizing natural resource flows in areas of rich biodiversity and unique ecosystems (29,41). The Western Ghats of India are a global biodiversity hotspot and comprise of a high diversity of flora and fauna, including several endemic species of plants, mammals, birds, reptiles, amphibians and fishes (22,45). The Western Ghats are no exception to the onslaught of land-use change for commercial conversions of tropical evergreen and deciduous forest biotopes into agroforestry plantations such as rubber, oil palm, coffee and tea (1).

The southern region of the Western Ghats, in particular, owing to its unique habitats and endemic species, is a very high-priority conservation landscape (evidenced by the numerous Protected Areas designated in this area) that is also at once, battling severe external pressures from agroforestry plantation encroachments (1,29,46,www.kfri.res.in). Yet the impacts of such conversions on ignored groups like bat communities in forested areas and neighboring unprotected areas (plantations, settlements) have not been well studied (29).

Surveys of bats conducted hitherto in the Western Ghats are few, with some identifying areas of occurrence of rare and endemic species (e.g. 66), and species checklists and inventories (31,38,47,59,66).

Although there have been a few detailed studies on the biology of some species of fruit bats in this region, the conservation ecology of insectivorous bats remains little studied. Quantitative inference on the ecological requirements of bats needs to form the basis to protect them in their changing environment. The Shenduruney Wildlife Sanctuary landscape in the southern Western Ghats of Kerala provides an ideal situation to study bat communities across a gradient of habitat modification. This landscape is a unique mosaic of different habitat types ranging from natural evergreen and semi-deciduous forests in both protected as well as adjacent unprotected areas up to monocultures of rubber or teak and eucalyptus plantations. In my study, I mainly focused on assessing diversity and distribution of insectivorous and frugivorous bat communities across a mosaic of land-use types in and around the Shenduruney Wildlife Sanctuary landscape. Based on published literature, I structured my assessment under the following questions: 1) How do different foraging guilds of bats use different habitats types? What species prefer which features in the landscape? 2) What are the local ecological and anthropogenic covariates explaining bat use of a particular habitat? 3) What are the levels of local awareness towards bat conservation? To answer these questions I collected data on bat foraging activity and species richness using a combination of echolocation recordings and roost-visits, including occasional captures of bats. Associated data on habitat features and human disturbance were also collected. Finally, I conducted detailed semi-structured interviews with local communities to understand their awareness levels, and to compile information on known bat roosts and perceptions about bats in the study area. Based on these multiple sources of data, I discuss the major threats to bat conservation in this highly human-modified forest landscape.

Shenduruney Wildlife Sanctuary

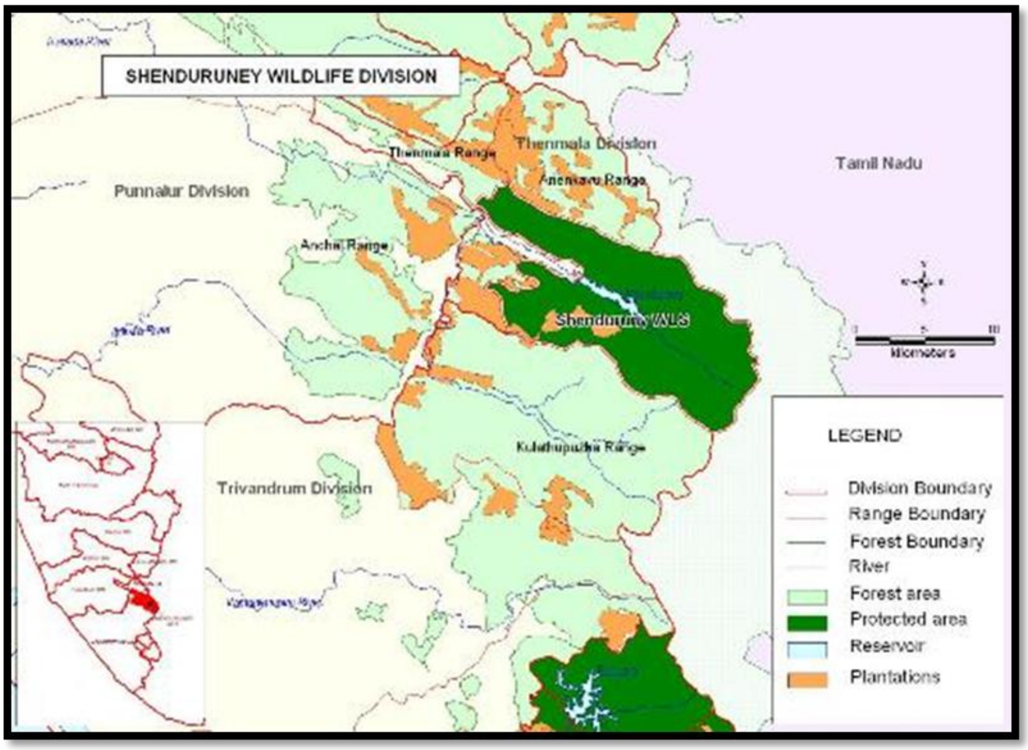
Monoculture of rubber

Methods

Study Area

The Shenduruney Wildlife Sanctuary occurs over an area of 171 sq.km tropical evergreen forests, with bamboo, reeds of *Ochlandra* and grassland patches at high elevations. It is the northwestern region of the Agasthyamalai Biosphere Reserve in the southern Western Ghats, Kollam district, Kerala, India (22, 46). The forest is located above the upstream catchment of the Kallada River on the Thenmala dam reservoir, and is bounded by the Ariankavu pass on the north, the evergreen forests of Kalakkad-Mundanthurai Tiger Reserve on the eastern reaches, the moist-deciduous forests of Kulathupuzha to the south, and a complex mosaic of highly modified landscapes comprising mainly of monoculture plantations of rubber and oil palm, with fruit orchards and human settlements, to the west (1, 22). This landscape mosaic occurs on the western slopes of the Ghats and extends up to the plains, and including lowland forest fragments. This region receives heavy annual rainfall (average 2800 mm) and has a brief summer period from February to April. These forests are rich in diversity of endemic species of plants (*Gluta travancorica*), amphibians and fishes (www.forest.kerala.gov.in/index.php). The landscape comprises of complex geomorphologic features with caves, rocky outgrowths, and also man-made tunnels, which are ideal roosting habitats of bats.

Location map of study area (source: http://www.kfri.res.in/maps.asp)



Data collection

The study was conducted from April 2011 to September 2012, of which fieldwork and interview surveys comprised of a total of 9 months (May 2011, from September'11 to November'11 and January'12 to May 2012). Data analysis and GIS work comprised of a total 4 months. Due to incessant rains in 2011, unpredictable weather and problems of logistics (e.g. unavailability of field assistants for sampling of bats in forests at night), about 6 months were lost in total (see interim report).

Habitat variables

Sites across the study area (over approx. 500 km2) were chosen based on initial ground surveys and through analysis of land-use types in a GIS (www.qgis.org). Vegetation maps and observed variations in habitats served as the basis for selection of sampling units. Sites were selected based on covariates like elevation, access, forest cover, fragmentation, land-use types, presence of water sources and settlements, and data on multiple local features within these different habitats were collected (Table 1).

Bat community data

Bat communities were sampled across the multiple selected sites (n=157). Foraging guilds of bats were defined based on existing literature (6,7,34,55,69) as a) Rhinolophid and Hipposiderid or Constant Frequency (CF) bats (which are foliage gleaners), b) Emballonurid and Molossid or Quasi-CF bats – (open-air, above canopy feeders) and c) Vespertilionid or Frequency-Modulating (FM) bats (open air, mid-canopy feeders). Sampling involved data collection on a) species occurrence, b) foraging activity, and c) active day-roosts through field surveys and interviews with local key informants (Table 2). For fruit bats and insect bats, different sampling techniques were employed. Fruit bats were visually surveyed at each site between 1800 hrs to 2300 hrs. The only exception was the Fulvous Fruit Bat *Rousettus leschenaultii* that emitted echolocating tongue-clicks (54) and could be recorded using a bat detector. For all insectivorous bats, echolocation recording was used for species identification as well as to estimate relative foraging activity at different sites (7,14). For recording foraging call activity, multiple spatially and temporally replicated point counts were taken in adjoining habitats at almost the same times, to estimate relative time spent in activity in either habitat (7,40).

1. Acoustic sampling

Echolocation, an animal's use of echoes of its own sound to build a sound-picture of its immediate environment, is typical of insectivorous bats. Since species differ in the structure and frequency of their echolocation calls, acoustic monitoring of their ultrasonic vocalizations provides a convenient and non-invasive method for identifying and monitoring bat populations and their activity (7,14,16,18,19,49,61). Parameters like frequency with maximum energy (F-max) and call structure (constant frequency (CF)/ frequency-modulated (FM) / Quasi-constant frequency (QCF)) of individual calls recorded were analyzed (7,27,49). Assignment of acoustic signatures for each species based on unique combinations of the above parameters helped greatly in species identification. A total of about 400 recordings were conducted at 157 point-counts and 25 roosting sites (c.63.3 hours (i.e. 3800 minutes) of field recording).

Acoustic surveys of echolocating bats were conducted using a stratified random sampling scheme with spatial replicates across the study area. Harsh weather conditions limited temporal replications of most sites, however, up to 15% of sites were sampled in different seasons. Time-constrained point counts along 3-4 trails were taken for acoustic sampling of free-flying bats in the selected sites after the sunset, at two time periods (dusk and night) (58). Echolocation call recordings (49) were made with a D240X bat detector (Pettersson Elektronik AB) and a recorder (Edirol R-09). BatSound Pro v 3.32 was used to analyze individual calls with FFT size = Automatic, FFT overlap -1 and hanning window (BatSound default - provided satisfactory resolution) in 10x time expansion. Spatial locations of foraging habitats for each species were logged in a GPS and mapped using QGIS software (www.qgis.org).

2. Roost visits

Selected sites were scanned for bat roosting habitats like caves, rocky outcrops and formations, abandoned houses, trees and tree hollows, unused railway tunnels and canal tunnels. Information on roosts was also obtained from interview surveys with local key informants. A total of about 40 known roosts were estimated, but only 32 could be surveyed, and only 25 roosts had indications of presence of bats. Species were observed for peculiar morphological characteristics for identification (3,38,62). At-roost identification of bat species was done with digital photography and from available morphological keys for identification in field along with capture wherever required, with a hand-net (3,62). But trapping with harp-traps and mist-nets (17) could not be conducted systematically due to difficulties in obtaining manpower. Captured individuals were identified, their individual status (e.g. weight, sex) noted and released. Data on their echolocation were also collected for species confirmation with the help of the bat detector. Spatial locations of roosts across the area were logged in a GPS to prepare roost distribution maps.

The Lesser Woolly Horseshoe Bat *Rhinolophus beddomei* in a cave

3. Interview surveys with local people

Along with field surveys, local knowledge and awareness about bats were compiled through interview surveys across the study area. Locals were interviewed about their bat encounters, descriptions of species seen and their attitudes towards the importance of bats in nature. Local perceptions about bats, perceived trends in local bat populations, and level of knowledge about bats were noted. The interviews also led to identification of local threats and thoughts of people about the need to conserve bats.

Interview surveys with local people

Data analysis

Acoustic analysis for bat species identification: Echolocation calls of bats are species-specific and can be used in species identification. Most call signatures were identified up to species level referring to the existing data in literature from Arabia, south Asia and southeastern Asia (many species occur across these regions) and sporadic previous literature available from within India (8,10,11,25,30,56,59,60,69, www.batecho.eu/letters/tableenglishindonesianbats.xls). Ambiguous, unclear and interrupted calls were omitted and only good quality calls were considered for analysis (7). As species identification from acoustic cues is difficult, owing to the lack of detailed studies in India, some difficult-to-identify calls were assigned to individual 'morpho-species' to determine species richness, and community composition in the area. Based on frequency with maximum energy (F-max) and the call structure, each of the unidentified bat echolocation calls recorded were manually assigned a unique 'morpho-species ID' (7). These assigned morpho-species IDs were later crosschecked with existing literature and species were deduced from in the cases where call frequency and other parameters were available already from online or published resources.

Ecological data analysis: A presence-absence matrix of bat morphospecies across all sites sampled was prepared by pooling data across point counts and indexed by site. Data on bat species occurrence and foraging activity (call rates per recording) were obtained at each site, and compared across sites using basic, exploratory analyses to identify broad patterns in the dataset. To investigate relationships between ecological covariates and bat foraging activity / species richness / occurrence of individual species, generalized linear models (GLMs) as Logistic (binomial) and Poisson regressions were used. Multiple models were run for different responses of bats to the variation in habitat type, local features of different habitats, and features related to terrain, weather, seasonal changes and human disturbance effects (Table 1, Table 2). These models were compared using the Akaike Information Criterion (AIC) for model selection, and models with lowest AIC values and best fit to the data were chosen. Further, data from interview surveys on trends in bat populations, perceptions about bats and awareness levels were analyzed using simple non-parametric tests and exploratory analyses. All analyses were conducted in the software MS Excel and R-Studio 2.15.0 (53).

Results

The Shenduruney WLS landscape consisted of a diverse bat community of around 20 confirmed bat species across 7 families (Table 3), based on acoustic recordings (Fig. 1) and confirmation with photographs and captures. About 5-6 more species await confirmation and have not been reported here. Sampling effort did not show complete saturation despite the intensive effort undertaken in the study, which may be due to the inherently low detection of certain rare forest bats likely present in the landscape (Fig. 2). The distribution of species across families was as follows: Pteropodidae - 3, Rhinolophidae – 3, Hipposideridae – 1, Megadermatidae – 2, Emballonuridae – 2, Molossidae – 1, Vespertilionidae – 8. Detection probabilities of bats across most families were generally high and ranged from about 0.5 to 0.75 (Fig.3) except for Megadermatidae and Hipposideridae species. Forests had the highest overall bat activity and species richness, followed by other habitats in the order Forests >> Fruit plantations and mixed orchards >> Rubber plantations >> Settlements >> Teak and matchwood plantations (Fig. 4,5,6). Canopy density, presence of lianas and understory, and tree height emerged as important predictors of forest structure for species of Rhinolophidae as well as some species of Vespertilionid bats (57) (Table 4, Table 5). Among other variables, slope, altitude and presence of clear open areas came out as important for bat families other than Rhinolophidae. Analyzing habitat usage of Megadermatidae and Hipposideridae was not possible due to low sample sizes of these species recorded in field. Even small forest fragments outside the protected area proved to be of great importance to sustain forest-specialist bat species, providing them foraging habitats, despite the surrounding mosaic of monoculture-dominated land use. Abandoned houses, trees, tree hollows, caves, rock formations, water tunnels and railway tunnels were preferred for daytime roosting by bats. Among human disturbances, road development (district tarred roads, metaled roads and highways) was one of the most serious and unexpected threats to bats, along with night-lighting which negatively affected distribution of Rhinolophid bats near forest settlements.

Interview surveys showed that local people knew more about fruit-eating bats than about insectivorous bats. Peoples' perceptions about fruit bats were largely mixed, at one level, they considered them important as seed dispersers and aggregators, but also as pests because they damaged fruit crop by half-feeding and wasting fruits (Table 6). People mostly mentioned forest loss due to rubber plantations, and corresponding declines in fruit production as the main reasons for declines in bat abundance. However, both fruit bats and small-sized bats were being regularly hunted in large numbers often, for food and medicinal uses (unproved treatment of asthma and bronchitis) (Table 6). Direct killing, hunting and disturbing bats from roosts, for sport, were the largest direct threat to their survival, apart from the widespread indirect threat of habitat loss. People interviewed at locations near the protected areas perceived bat abundance to be increasing over the past decade due to protection of forests, whereas in contrast, people living in rubber plantations and settlement areas mentioned that bats had declined considerably over the same time period (Table 6). Most people were hardly concerned with possible local extinction of bats. It was, however, worth noting that people showed signs of curiosity towards bats, and most people were not averse to bats due to misconceptions. My surveys mainly identified the need to educate people furthermore on the ecological importance of bats, as pollinators, seed dispersers and bio-control agents of agricultural pests, with a special focus on insectivorous bats, and to specifically focus on reduction in hunting of bats through active protection to bat roosts (10).

Discussion

The commercial agroforestry sector in tropical regions across the world has shown tremendous expansion over the past 5 decades (29). In southern Kerala, the rate of expansion (over 500% land conversion to rubber) has inevitably come at the unaccounted cost of biodiversity loss through forest destruction (1). Studies on impacts of rubber and associated plantations surrounding remnant forest areas have indicated their negative effects on data-rich taxa such as birds, large mammals, butterflies and herpeto-fauna (2). Most studies have stressed the value of remnant forests for several taxa and the need for effective landscape-level management of these multiple-use systems. This study finds similar patterns for bats, which seems counterintuitive considering their widely assumed ability to tolerate habitat changes (4,23,26,35). Further, this study emphasizes the need for more detailed studies on these small taxa across multiple gradients of habitat change and forest destruction (35,43).

Natural forests in the Shenduruney landscape, along with mixed fruit plantations and groves, recorded considerably higher bat diversity than rubber plantations and teak-eucalyptus-matchwood plantations (as in 9,52). Even forest fragments surrounding rubber plantations recorded occurrence of forest-dwelling Rhinolophid bat species that require clutter (understory, shrub etc.) to feed on insects (55). Natural evergreen forests were often highly structured and with multiple layers of stratification. Even in disturbed forest fragments the incidence of such understory was high, leading to distribution with strong co-occurrence of the three Rhinolophid species found. Forest fragments outside the Protected Area

(Sanctuary) were also thus of high value for these species (2,64). A similar pattern was found for Emballonurid and Molossid bats, which although found occasionally in rubber plantations, seemed to prefer settlements (open areas) and hill forests, also foraging over tea plantations with uniform leveling of shoot tops (48). However, the Vespertilionid bats of the genus *Pipistrellus* occurred throughout the different habitat types, and although their activity was considerably higher in open areas and forest edges (21,37), they also did use rubber plantations with settlements considerably (26). These results largely agree with similar studies on bat communities (12,52,67,68) in the paleotropics, where it was found that rubber plantation and other monocultures had considerably lower bat diversity, activity and abundance than adjoining forests. This study thus provides complementary evidence about the negative impacts of rubber and matchwood plantations on even small mammals such as bats (23,35,52,67), information that may be vital for rubber eco-certification and biodiversity value assessments (15,35).

It is relevant here to discuss, therefore, the mechanisms by which forest conversion to plantations may be reducing bat activity and diversity in the latter. Insect biomass is known to typically determine bat foraging activity, and rubber plantations seem to have lower insect abundance than forests (23,52). The lack of understory in managed rubber plantations might be a factor driving insect abundance. Also, the canopy level in rubber plantations is highly uniform and homogenous, with little stratification, and this might lead to lower habitat structure than natural forests (23,57). While the impacts of rubber are clear and obvious, what was surprising was the low preference of bats for teak and matchwood plantations. These habitats were often strongly associated with linear forest edges and riparian reaches which bats are known to strongly use (21,37,50) (unlike rubber plantations which form polygonal patches within the forest matrix) (36). The structural complexity of the teak secondary growth is also considerably higher than rubber, yet bats seem to not prefer teak forests much. I believe that this may be due to seasonality of teak-associated secondary forests, and the strong effect on seasonal change in structure from leaf fall due to a dominance of deciduous trees (37). More data from these areas will be required round the year to test if bat habitat use intensity follows seasonal changes in resource abundance in secondary forests. This is important as most remnant evergreen forest fragments are gradually being encroached by secondary deciduous growth.

Pipistrelle species were found to be highly generalist and apparently tolerated wide range of habitats. These results need to be treated with caution as these bats, like Molossids and Emballonurids, are open-area feeders, and may not directly be affected by forest structure. The positive effect of ‘settlements’ indicates actually the effect of ‘open areas’. Despite this, overall pipistrelle activity was highest in forests, perhaps owing to higher insect abundance. Apart from the broad land-use types, many effects of human disturbance were evident. Interestingly, one of the most serious impacts on almost all bat species was that of road development. Bats tend to use edge habitats in forests and occur across forest tracks, small roads commonly (5,12,21,43). In fact, these paths recorded substantially higher (by almost 80%) call activity of bats than forest or plantation interiors. However, roads larger than village dirt tracks or forest paths had significant negative effects on foraging activity. Development of district roads and state highways (metaled and tarred roads) for faster transport seems to have negatively affected bats across different foraging guilds (5,36,43) (Table 5). The roads may affect bats through higher noise, and also by accelerating the spread of invasive plant species along wide linear intrusions (12,43). Roads are known to affect larger animals, but their impact on volant mammals such as bats may be an important finding. Apart from roads, disturbances such as night-lighting and noise might affect forest bat species (32,63,70).

This leads us to also clearly separate effects of habitat and disturbance on foraging and roosting of bats. Bat roosts may often be located in close proximity to human settlements due to the higher availability of structure: rock-cut caves, blasted rocks, tunnels, abandoned buildings and so on. In my study area I found many species living in rather close proximity to human settlements and even in rubber plantations, besides their natural habitats in forests. As bats roost in human-dominated areas, they also become vulnerable to many threats such as hunting for food and medicines. In this area people regularly hunt bats for their meat and blood, believed to cure asthma and bronchitis. Other threats to roosting bats include destruction of rocky structures and toxic fumigation by plantation managers for ground leveling, blasting of tunnels for placing of railway lines, and boulder quarrying.

Along with forests, mixed plantations and fruit orchards provided an excellent habitat for multiple species of bats. Banana plantations appear to be very important, but bat activity even in spice groves (e.g. clove) and fruit orchards (mango, jackfruits, papaya) was fairly high. Yet, the increasing demand for commercial rubber plantations is also leading to drastic declines in fruit crop production, limiting it to merely subsistence levels. Maintenance of fruit plantations as a source of subsidiary income might in the process also benefit bat communities in the area. As fruit crops are on the decline, local perceptions about bats as pests are increasing. Although there is some local recognition that fruit bats act as seed dispersers and seed aggregators, increasing negative perceptions seem to be nullifying this recognition too (e.g., 20,24,33,39).

In this human-dominated landscape mosaic of forests and plantations, it is clear that threats to bats have a much larger origin and history. Bats are unfortunately still on the 'vermin' list in the schedules of the Wildlife Protection Act (1972), Government of India (44). They need to be given strict state- or local-level protection through active involvement and awareness of environment protection agencies. Long term disturbance such as deforestation, use of pesticides, and mining should be controlled and measures must be taken to rehabilitate bats. Hunting and disturbing bats for food, medicine, ritual or sport must be prevented and discouraged wherever and whenever possible. It is necessary to ban the currently extensive bat hunting in the landscape, which is quite extensive at present. Known roosts like caves, tunnels, abandoned houses need to be actively protected. Trees, old or decaying stands of wood, abandoned buildings should be carefully checked for presence of bats before destroying them. Roosting sites of bats need to be occasionally monitored by the local forest department staff in order to control wanton disturbance by people (10). Long-term monitoring of bat communities in the region is also essential to know variations across seasons and changing local conditions in terms of habitat alteration, disturbance, climate and people's perceptions. Research needs to be continued to build on knowledge on species distribution and ecology, and recognize unknown threats. The most important need of the time is to disseminate awareness about bats, their ecology, and importance, to clarify misconceptions. Bat conservation has to be increased among forest dwelling tribes, settlements, tourists as well as the supporting staff of forest departments (10). Educational and outreach materials in the form of posters, pamphlets should be displayed and distributed in the forest departments, among locals and in tourism zones. This study marks the initiation of this process by undertaking ecological surveys and engaging in the process of local conservation education.

Future plans as follow-up to this project

1. Working with local contacts in the landscape, and also with officials and ground staff of the Kerala forest department to spread information on the ecological importance of bats, and to control local threats.
2. Scientific paper(s) to be published in peer-reviewed journals.
3. Detailed surveys through echolocation recordings and establishment of a reference call database for bat species in the Western Ghats. Studies on ecological preferences of bats across a range of similar sites to inform landscape-level management plans for the Western Ghats.

Acknowledgements

I sincerely thank the Rufford Small Grants Foundation, UK who funded this project that took me through a very important learning experience. I thank the Kerala Forest Department for providing me research permits to study bats in the Shenduruney Wildlife Sanctuary (WLS) and neighboring areas. I sincerely thank the Divisional Forest Officers at Shenduruney WLS - Shri K.I. Pradeep Kumar and Smt. S. Lekshmi, for their constant help and support. They made all my ventures in and around the protected areas very easy and comfortable. I also thank forest department staff for their support in bat surveys and the help they provided in field. People at Ottakkal, Thenmala, and Edapalayam were always very kind and helped in various ways. Thanks to Shri Sayed and family, Ottakkal and Shri Neelambaran, RB Kuttalam, who provided accommodation and helped greatly in facilitating fieldwork and logistics, and to Sivadas, Goban, Selvi chechi and Quader bhai along with all the auto-rickshaw people at Ottakkal. Special thanks to Mr. Shinu Jacob of Edapalayam, without whose help fieldwork would have virtually been impossible. I thank him and his family for all the efforts they took for me. I also thank my transient field assistants who helped in the project initially. I am thankful to Dr. Mahesh Sankaran for his support, encouragement and help with institutional facilities and equipment. Special thanks to Dr. Neil Furey for his valuable suggestions and guidance. Pipat Soisook helped me with selection, purchase and usage of harp-traps. I am also thankful to Dr. Ajith Kumar, Prof. Bhagyashri Shanbhag, Dr. Sanjay Molur, Srinivas V., Robin Abraham, Aditya Gangadharan, Sneha Dharwadkar and Rutuja Dhamale for their help and support. I particularly thank Atul Joshi for his constant help off field, for productive discussions and support. I cannot express my feelings in words to thank my parents and brother for believing in me and standing by me in both happy as well as difficult times. Had they not been so supportive, liberal and reassuring all throughout, I would not have reached this stage. I also thank my in-laws for their constant moral support, love and encouragement. I take this opportunity to express my love and gratitude towards my husband Nachiket for his constant moral support, for giving me confidence in tough times, his help in field, during statistical analyses, and keep me going on in all ups & downs. It’s because of him that I could complete this project successfully through all hurdles. Finally, I genuinely thank the people in the Shenduruney landscape for their constant curious questions on bats, responding to my interviews, for their love & care for me, and for a warm welcome into their culture and lives.

Tables

Table 1. Details of habitat variables recorded in the study.

Variable Name	Type	Description	Method of recording / measurement
Locational Information	Basic description of recording points	GPS location (latitude, longitude), date and time, season	Direct observations
Altitude	Continuous	Meters above sea-level	From GIS elevation models
Slope, Ruggedness, Aspect	Continuous	Slope: degrees, ruggedness: %, aspect: 0-360 degrees	Extracted from terrain models in GIS
Habitat type	Categorical	Habitat classified as Forest, Mixed fruit Plantation, Rubber, Teak and Settlement area	From ground surveys and toposheets compiled in a GIS
Surrounding habitat type	Categorical	As above	Direct field observations
Presence of settlement	Binary	Presence/Absence	Direct field observations
Roads	Ordinal	1-mud road, 2-village road, 3-district road (tarred), 4-metalled road (highway)	Direct field observations
Stream order	Ordinal	Stream order estimated from toposheets of scale 1:25000 (Survey of India-1987 topo maps)	GIS, Direct field observations
Stagnant water	Ordinal	1-ditch/pond, 2-village tank, 3-large storage tank, 4-dam reservoir	Direct field observations
Forest structure: presence of understory, liana, fruiting trees	Binary	Presence/Absence recorded	Direct field observations
Canopy height, canopy density, connectivity	Continuous, %, ordinal	Canopy height (m), Canopy density (%) Connectivity (ranked from 1-low to 3-high)	Field measurements, observations
Protection status	Categorical	PA-protected area, NPA-non-protected area, RF-reserve forest area	GIS and field surveys
Disturbance Index and Night lighting	Ordinal and Binary	Disturbance (hunting, logging, presence of power lines and other intrusions) ranked from 1 to 4, from low to high; night lighting presence/absence recorded	Interviews and direct observations on threats to bats

Table 2. Parameters of bat species distribution recorded in the study.

Variable of interest	Parameter(s) recorded / Classification details	Field sampling techniques used	Relevance
Bat species richness	Species identity, no. of species	Echolocation recording, roost surveys, capture and measurement, visual surveys of fruit-bats	For correct recording of species richness
Bat foraging activity	CPTM (# calls per ten-minute point count)	Echolocation recording with time-restricted point-counts, visual sightings of fruit-bats passing	Provides a measure of habitat use by all bat species
Foraging Guilds	Above-canopy open-area feeders (Emballonuridae and Molossidae), Near-canopy open-area feeders (Vespertilionidae), Foliage gleaners (Rhinolophidae and Hipposideridae), multiple feeding strategies (Megadermatidae)	Echolocation type (FM-CF bats: open area (near-canopy) feeders, QCF bats: open area (above-canopy) feeders, CF bats: foliage gleaners) Fruit-eating bats do not echolocate (except 1 species), and were recorded visually.	Families associated with different call types may have different foraging requirements, and hence different habitat preferences
Bats trespassing habitats without actually 'using' those areas	Initial calls of bats not accompanied by complete, actual calls	Echolocation recordings (used only for insectivorous bats)	Initial calls are feeble signals recording from bats surveying an area before actually starting to echolocate fully on prey (foraging)
Bat roost sites	Abundance, species composition	Interview surveys, key informant surveys, roost visits	For confirmation of species and to observe roosting requirements of different species

Table 3. List of bat species with sighting details, habitat and threats recorded in the study area including Shenduruney WLS and surrounding unprotected areas.

Species	Common name	Family	Sighting & identification details	Habitat and occurrence	Direct threats
Pteropus giganteus	Indian Flying Fox	Pteropodidae	Rst, flt	Sacred groves, orchards	H
Cynopterus sphinx	Short-nosed Fruit Bat	Pteropodidae	Rst	Palm trees	H, S, D
Rousettus leschenaultii	Fulvous Fruit Bat	Pteropodidae	Rst, flt, echolocation	Caves, tunnels	H, S, D
Megaderma lyra	Greater False Vampire	Megadermatidae	echolocation	Forest, settlements	U
Megaderma spasma	Lesser False Vampire	Megadermatidae	Rst, echolocation	Abandoned houses, caves, tree hollows	H, D

				(recorded throughout)	
Taphozous melanopogon	Black-bearded Tomb Bat	Emballonuridae	Rst, echolocation	Caves, throughout	H, S, D
Saccolaimus saccolaimus	Pouch-bearing Bat	Emballonuridae	Flt, echolocation (P)	Secondary forest	U
Rhinolophus lepidus	Blyth's Horseshoe Bat	Rhinolophidae	Rst, Flt, echolocation	Caves, Forests (recorded throughout in forests)	H, D
Rhinolophus rouxii	Rufous Horseshoe Bat	Rhinolophidae	Rst, Flt, echolocation	Caves, tunnels, Forests (recorded throughout in forests)	H, RT
Rhinolophus beddomei	Lesser Woolly Horseshoe Bat	Rhinolophidae	Rst, echolocation	Caves, Tunnels, Forests	H, RT
Hipposideros pomona	Andersen's Leaf-nosed Bat	Hipposideridae	Rst, echolocation	Tunnels, Scrub	H, RT
Tadarida aegyptiaca	Egyptian Free-tailed Bat	Molossidae	echolocation	Open hilly forested areas	H
Pipistrellus cf. ceylonicus	Kelaart's Pipistrelle	Vespertilionidae	echolocation (P)	Recorded throughout	H
Pipistrellus cf. coromandra	Indian Pipistrelle	Vespertilionidae	echolocation (P)	Recorded throughout	H
Pipistrellus cf. tenuis	Indian Pygmy Bat	Vespertilionidae	echolocation	Recorded throughout	H
Scotozous cf. dormeri	Dormer's Bat	Vespertilionidae	echolocation	Recorded throughout	H
Miniopterus schreibersii	Schreiber's Long-fingered Bat	Vespertilionidae	Rst, echolocation	Caves, tunnels (Recorded throughout)	H, D
Miniopterus pusillus	Nicobar Long-fingered Bat	Vespertilionidae	echolocation	Recorded throughout	H
Myotis horsfieldii	Horsfield's Bat	Vespertilionidae	Rst	Tunnels	H, D
Scotophilus heathii	Asiatic Greater Yellow House Bat	Vespertilionidae	Rst, echolocation (*)	Tunnels	H, RT

KEY: Sighting details - Rst = Roosts, Flt = seen in Flight, Cal = sound (Call) of free flying bats recorded in bat detector; (P) = Probable and not yet confirmed; (*) Found an injured bat near Ariankavu. Direct threats – H = Hunting for food or medicine, S = Sport killing, D = Direct physical disturbance to bat or to roosting site, RT = Railway Tunnel construction, U = Unknown threats.

Table 4. List of ecological and anthropogenic disturbance variables with positive and negative effects on bat habitat use (foraging, echolocation activity) and species richness, identified from Generalized Linear Models.

Bat families (functional groups)	**Positive effects**	**Negative effects**
Foraging activity and bat species richness		
Rhinolophidae	Slope, Canopy Density, Forest Cover, Protected Area, Understory, Lianas	District roads and highways, ruggedness of terrain, tree height, rubber plantations, settlements with night-lighting, forest fragmentation
Emballonuridae	Settlements, open areas	Forest cover, tree height, rubber plantations
Molossidae	Altitude and hilly terrain, settlements (open areas), tree height, forest cover	District roads and highways
Vespertilionidae	Settlements, rubber plantations, open areas, canopy density, understory	District roads and highways, slope
Pteropodidae	Fruit plantations, secondary forests, settlements	Protected Area avoided by Flying Foxes, smaller fruit bats occur throughout, tree height
Megadermatidae	Abandoned houses, settlements, secondary forests	-

Table 5. Summaries of best Generalized Linear Regression models for predicting probability of presence of habitat generalist bat species and forest-specialist bat species in relation to habitat characteristics.

Species (Family)	**Expected habitat preference based on previous studies**	**Important variables and response directions for the best selected GLM**	**Best model (parameter estimates) Mean (SD) in brackets)**	**Inference**
Rhinolophus lepidus (Rhinolophidae)	Forests	Canopy Density (+) Tree height (-) Lianas (understory clutter structure) (+) Co-occurrence with *Rhinolophus beddomei / R.rouxi* (+) Nightlighting at settlements (-)	(Intercept) -1.56 (0.97), p=0.11* 0.035 (0.013), p=0.00892** -0.139 (0.053) p=0.009 ** 1.74 (0.94), p=0.06350* 4.34 (1.55), p=0.00514** -2.095 (1.224), p=0.08703*	Strong preference for forests. Sensitive to human disturbance and other land-uses. Co-occurs often with other Rhinolophid species.
Rhinolophus rouxii (Rhinolophidae)	Forests	Canopy density (+)	(Intercept) -4.454 (0.92), p=1.23e-06 *** 0.0334 (0.014), p=0.0199 *	Strong preference for forests.
Tadarida aegyptiaca (Molossidae)	Open areas, hill forests	Altitude (+) Settlement (proxy for open areas) (+) Tree height (+) Altitude: Settlement interaction (-)	(Intercept) -7.64 (1.79), p=1.99e-05 *** 0.0054 (0.0015), p=0.00028 *** 3.533 (1.414), p=0.012470 * 0.089 (0.038),	Common in open hilly areas but no strong association with either forests or plantations

			p=0.020109 * -0.0047 (0.0026), p=0.067984*	
Taphozous melanopogon (Emballonuridae)	Open areas	Settlement (proxy for open areas) (+)	(Intercept) -1.705 (0.3138) p=5.57e-08 *** 0.69 (0.40) p=0.0883*	Habitat generalist, but stronger preference to wide open areas
Rousettus leschenaultii (Pteropodidae)	Fruit orchards	Tree height (-)	(Intercept) -0.90 (0.54879), p=0.101* -0.065 (0.03), p=0.030 *	Preference for banana plantations may explain negative relationship with tree height
Miniopterus schreibersii (Vespertilionidae)	Open areas	Slope (-) Understory (+)	(Intercept) -2.47 (1.098), p=0.0243 * -0.125 (0.054), p=0.0199 * 1.606 (1.067), p=0.1322_	Seems to forage at short distances up to near-canopy levels, prefers flat terrains.
Miniopterus pusillus (Vespertilionidae)	Open areas	Canopy Density (+) District roads and Highways (-)	(Intercept) -1.364 (0.644) p=0.0341 * 0.0177 (0.009), p=0.0491 * Village road -0.696 (0.533), p=0.1915 NS District Road -1.326 (0.627) p=0.0345* Highway -1.434 (0.84) p=0.0872 .	Strong avoidance of large linear intrusions like roads. Prefers shaded canopy forests.
Pipistrellus cf. coromandra (Vespertilionidae)	Open areas	Canopy Density (+)	(Intercept) -6.998 (SD 1.904) p=0.000238 *** 0.065 (0.0257), p=0.011620 *	At canopy foraging, forest/grove dwelling pipistrelle species
Pipistrellus cf. ceylonicus and Pipistrellus cf. tenuis (Vespertilionidae)	Open areas	Uniform response to diverse habitat conditions	NS	Total habitat generalists, adaptable to any habitats

Table 6. Perceptions and attitudes of interview respondents about bats and their ecological importance and threats to their conservation.

Perceptions of interview respondents (proportion data)						
Have bats increased or decreased?	Increased	Decreased	Can't Say			
	0.35	0.43	0.22			
Reasons for increase in bat abundance	Good habitat	Roosting sites	Food availability	Reduced disturbance	Reproductive ability	Immigration
	0.12	0.017	0.034	0.085	0.1	0.033
Threats causing declines in bats	Habitat Loss	Hunting	Climate / Weather Change	Loss of fruit trees	Mining	
	0.41	0.46	0.135	0.27	0	
Are bats useful	Useful	Harmful	Cant Say/Both			

or harmful to man?								
	0.203	0.305	0.492					
Are bats important in nature?	Yes	No						
	0.68	0.32						
Why important?	Seed aggregation	Seed dispersal	Forest regeneration	Insect pest control	Pollination	Aesthetic value	Medicines	Food
	0.32	0.203	0.068	0.2	0.017	0.15	0.44	0.29
Why harmful?	Fruit plantation damage	Dirt/Smell	Noise	Bites/Injury				
	0.42	0.033	0.051	0.101				

Figures

Figure 1. Acoustic signatures of representatives of insectivorous bat families identified in the study.

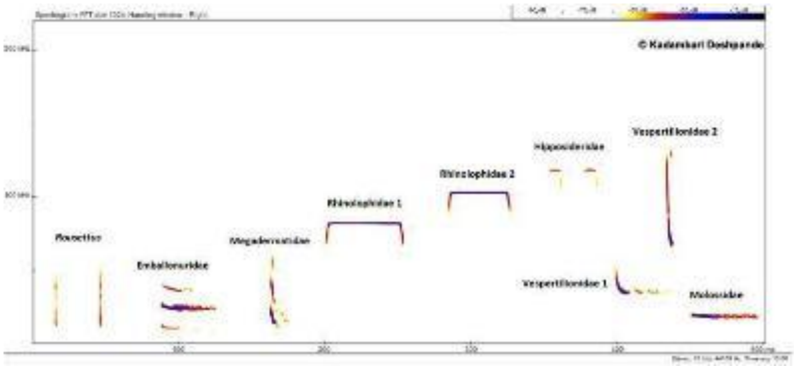


Figure 2. Species-accumulation curve with increasing survey coverage. Rare bats such as small forest Verspetilionids and Hipposideridae are often difficult to detect in field and this may have caused the curve to not saturate even after sampling 157 individual sites.

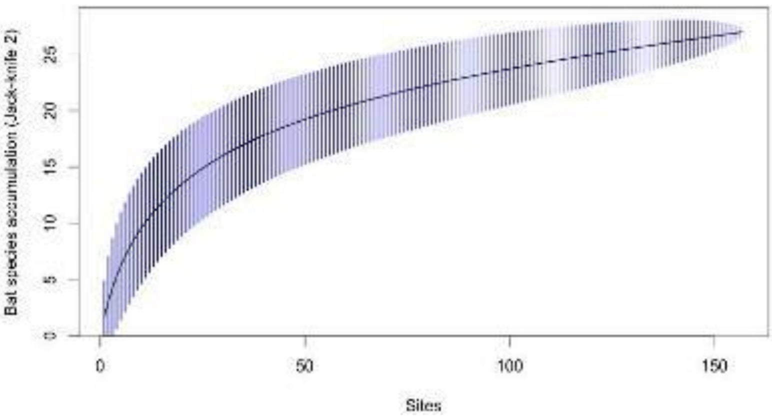


Figure 3. Detection probabilities estimated for common species of 5 families (range: 0.45-0.72). RoL =*Rousettus leschenaultii*, TM = *Taphozous melanopogon*, RL = *Rhinolophus lepidus,* TA = *Tadarida aegyptiaca*, MS = *Miniopterus schreibersii*, PC = *Pipistrellus cf. ceylonicus*.

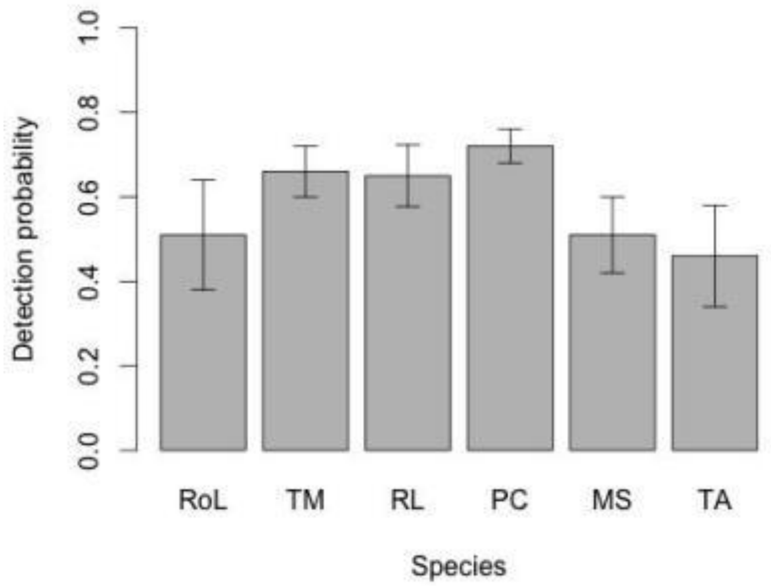
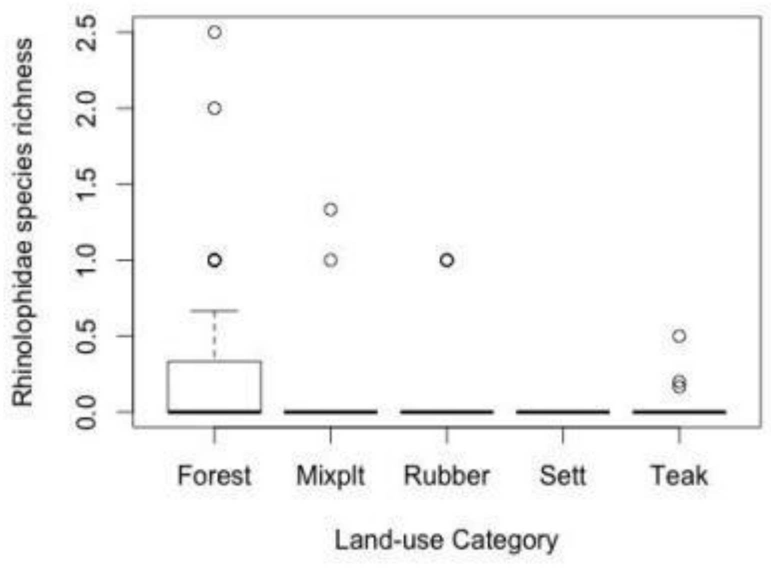
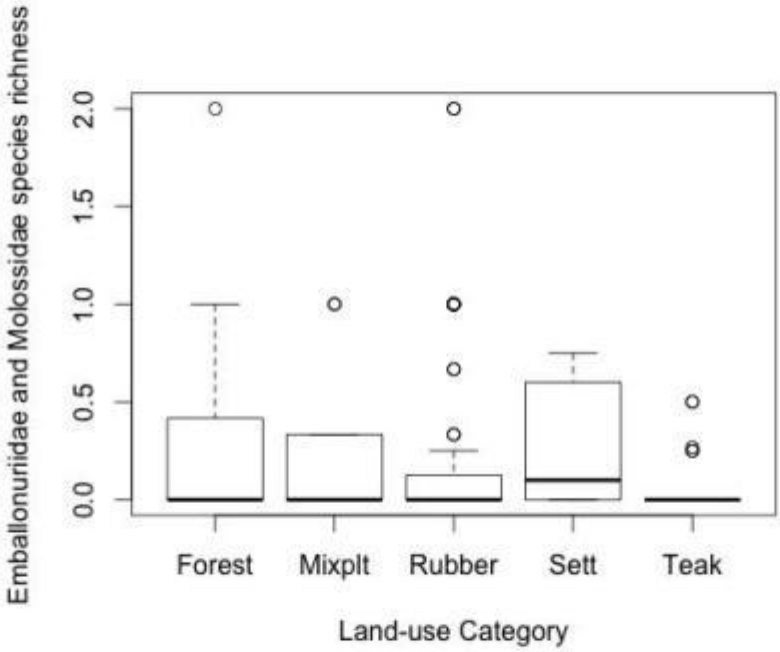


Figure 4. Species richness of bat functional guilds a) Rhinolophidae, b) Emballonuridae and Molossidae, and c) Vespertilionidae, in major land-use categories across the study area.




Emballonuridae and Molossidae species richness
0.0
0.5
1.0
1.5
2.0
Forest
Mixplt
Rubber
Sett
Teak
Land-use Category

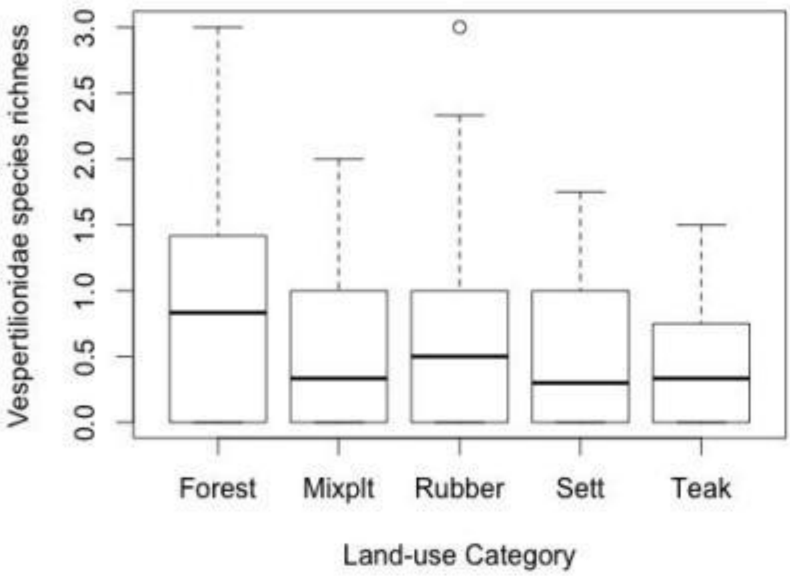
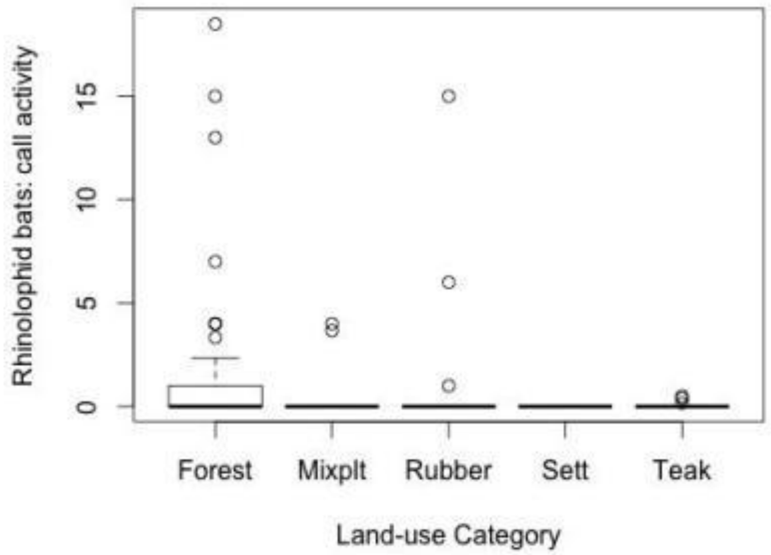
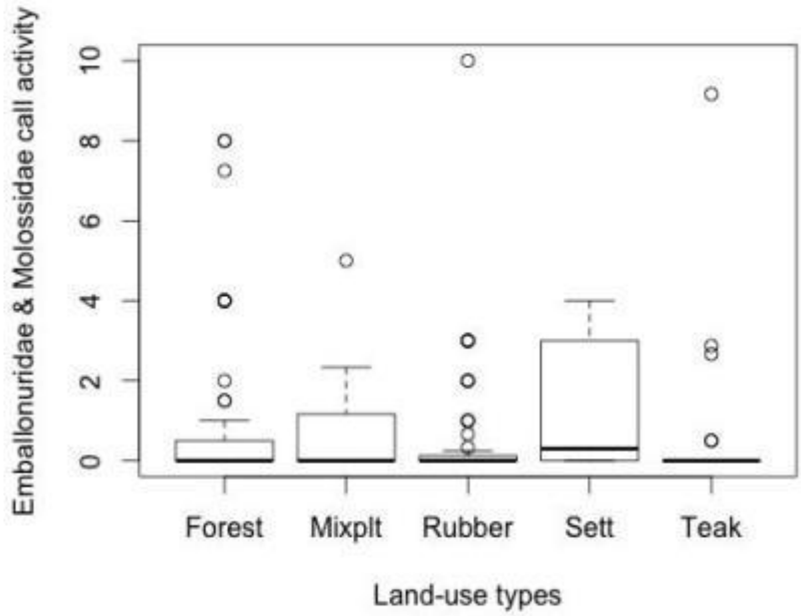

Vespertilionidae species richness
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Forest
Mixplt
Rubber
Sett
Teak
Land-use Category

Figure 5. Patterns in call activity of bat functional guilds, a) Rhinolophidae, b) Emballonuridae and Molossidae, and c) Vespertilionidae, in rubber, fruit plantations, teak and forest patches adjoining each other.





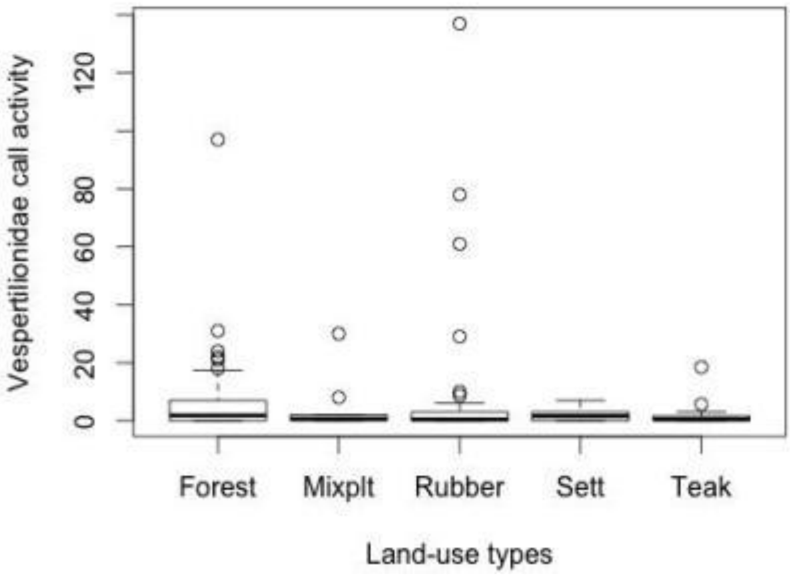
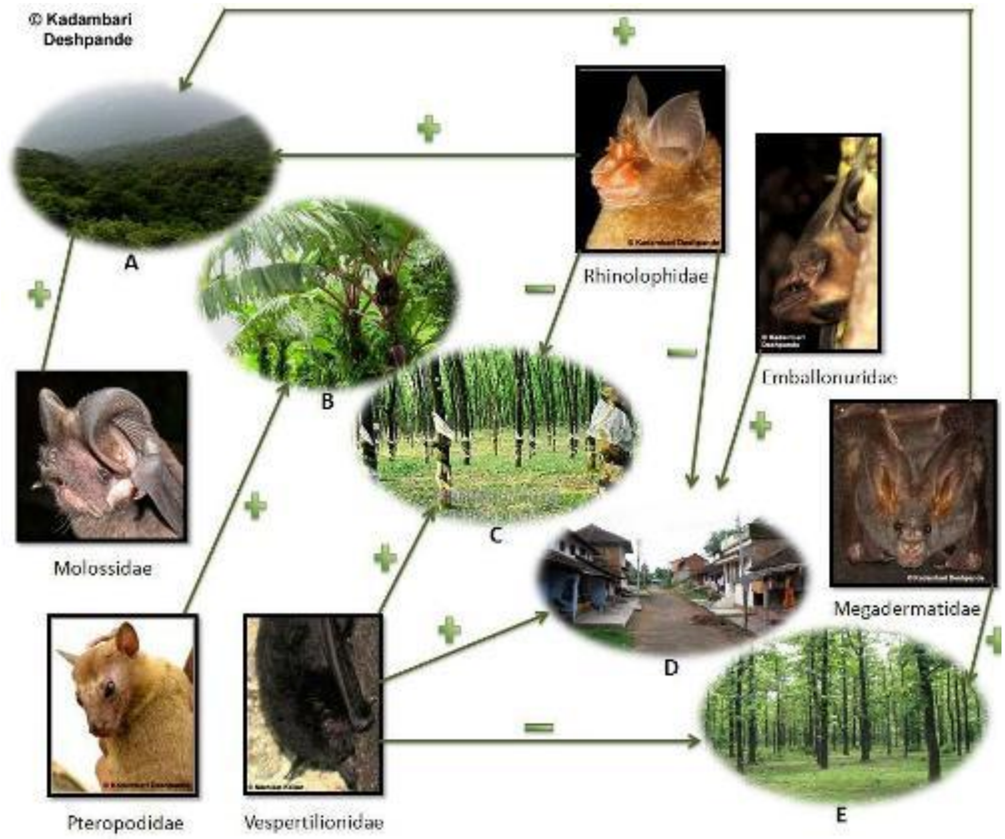


Figure 6. Summary diagram showing responses of bat families to dominant land-use types in the landscape. The habitats shown (top left to bottom right) are placed in ranked order of preference by different species: A) Forests, B) Fruit plantations, C) Rubber plantations, D) Settlements and E) Teak and matchwood secondary forest and plantations. (Picture of Molossid bat courtesy of http://www.bio.bris.ac.uk.)



References

1. Abraham, R.K., & Kelkar, N. (2012). Do terrestrial Protected Areas conserve freshwater fish diversity? Results from the southern Western Ghats, India. *Oryx*, 46, 544-553.
2. Anand, M. O., Krishnaswamy, J., Kumar, A., & Bali, A. (2010). Sustaining biodiversity conservation in human-modified landscapes in the Western Ghats: Remnant forests matter. *Biological Conservation*, *143*, 2363–2374. doi:10.1016/j.biocon.2010.01.013
3. Bates, P. J. J. and Harrison, D. L. (1997). Bats of the Indian subcontinent. Harrison Zoological Museum, Kent, U.K.
4. Bernard, E., and Fenton, M.B. (2007). Bats in a fragmented landscape: species composition, diversity and habitat interactions in savannas of Santare´m, Central Amazonia, Brazil. Biological Conservation, 134, 332-343.
5. Berthinussen, A., & Altringham, J. (2012) The effect of a major road on bat activity and diversity. *Journal of Applied Ecology*, 49, 82-89.
6. Bogdanowicz, W., Fenton, M. B., & Daleszczyk, K. (1999). The relationships between echolocation calls, morphology and diet in insectivorous bats. *Journal of Zoology*, *247*, 381–393.
7. Brigham, R. M., Kalko, E. K. V., Jones, G., Parsons, S., Limpens, H. J. G. A., & Parsons, S. (Eds.). (2004). *Bat Echolocation Research: tools, techniques and analysis.* (p. 171). Austin, Texas: Bat Conservation International.
8. Davis, L. (2007). *An Introduction to the Bats of the United Arab Emirates* (p. 24). Polmont, Scotland.
9. Davy, C. M., Russo, D., & Fenton, M. B. (2007). Use of native woodlands and traditional olive groves by foraging bats on a Mediterranean island: consequences for conservation. *Journal of Zoology*, *273*, 397–405. doi:10.1111/j.1469-7998.2007.00343.x
10. Deshpande, K. (2012). *Diversity and distribution of bats in the Shenduruney wildlife sanctuary landscape, Kerala Inputs on bat diversity and conservation for the management plan of the Forest Department*, Shenduruney WLS, Thenmala, Kollam, Kerala. Pp 13.
11. Dietz, C. (2005). *Illustrated identification key to the bats of Egypt* (p. 36). Tuebingen, Germany.
12. Duchamp, J. E., & Swihart, R. K. (2008). Shifts in bat community structure related to evolved traits and features of human-altered landscapes. *Landscape Ecology*, *23*(7), 849–860. doi:10.1007/s10980-008-9241-8
13. Fenton, M.B., Acharya, L., Audet, D., Hickey, M. B. C., Merriman, C., Obrist, M.K., and Syme, D. M. (1992). Phyllostomid bats (Chiroptera: Phyllostomidae) as indicators of habitat disruption in the neotropics. *Biotropica*, 24, 440-446.
14. Fenton, M.B., and Bell, G.P. (1981). Recognition of species of insectivorous bats by their echolocation calls. *Journal of Mammalogy*, 62, 233-243.

15. FERAL-INDIA (2011) Exploring Sustainable Land-use Practices in Rubber Plantations in a Critical Wildlife Corridor. Http://www.feralindia.org/drupal/content/exploring-sustainable-landusepractices-rubber-plantations-critical-wildlife-corridor [accessed 5 March 2012].
16. Flaquer, C., Torre, I., & Arrizabalaga, A. (2011). Comparison of sampling methods for inventory of bat communities. *Journal of Mammalogy*, *88*(2), 526–533.
17. Francis, C.M., (1989). A comparison of mist-nets and two designs of harp-traps for capturing bats. *Journal of Mammology*, 70, 865-870.
18. Furey, N. M., Mackie, I. J., and Racey, P. A. (2009). The role of ultrasonic bat detectors in improving inventory and monitoring surveys in Vietnamese karst bat assemblages. *Current Zoology*, 55, 327-341.
19. G Cristina Macswiney, M., Clarke, F. M., & Racey, P. A. (2008). What you see is not what you get: the role of ultrasonic detectors in increasing inventory completeness in Neotropical bat assemblages. *Journal of Applied Ecology*, *45*, 1364–1371. doi:10.1111/j.1365-2664.2008.01531.x
20. Goveas, S. W., Miranda, E. C., Seena, S., & Sridhar, K. R. (2006). Observations on guano and bolus of Indian flying fox, Pteropus giganteus. *Current Science*, *90*(2), 7–9.
21. Grindal, S. D., Morissette, J. L., & Brigham, R. M. (1999). Concentration of bat activity in riparian habitats over an elevational gradient. *Canadian Journal of Zoology*, *977*(1989), 972–977.
22. Gunawardene, N.R.,Dulip Daniels, A.E., Gunatilleke, I.A.U.N., Gunatilleke, C.V.S., Karunakaran, P.V., Nayak, K.G. et al. (2007) A brief overview of the Western Ghats–Sri Lanka biodiversity hotspot. *Current Science*, 93, 1567–1572.
23. Harvey, C. A., & Gonzalez Villalobos, Æ. J. A. (2007). Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. *Biodiversity & Conservation*, *16*, 2257–2292. doi:10.1007/s10531-007-9194-2
24. Hodgkison, R., & Balding, S. T. (2003). Fruit Bats (Chiroptera : Pteropodidae) as Seed Dispersers and Pollinators in a Lowland Malaysian Rain Forest. *Biotropica*, *35*(4), 491–502.
25. Hughes, A. C., Satasook, C., Bates, P. J. J., Soisook, P., Sritongchuay, T., Jones, G., & Bumrungsri, S. (2011). Using echolocation calls to identify Thai bat species: Vespertilionidae, Emballonuridae, Nycteridae and Megadermatidae. *Acta Chiropterologica*, *13*(2), 447–455. doi:10.3161/150811011X624938
26. Johnson, J. B., Gates, J. E., & Ford, W. M. (2008). Distribution and activity of bats at local and landscape scales within a rural–urban gradient. *Urban Ecosystems*, *11*, 227–242. doi:10.1007/s11252-008-0055-x

27. Jones, G. (1999). Scaling of echolocation call parameters in bats. *Journal of Experimental Biology*, *3367*, 3359–3367.
28. Jones, G., Jacobs, D. S., Kunz, T. H., Willig, M. R., & Racey, P. A. (2009). Carpe noctem: the importance of bats as bioindicators. *Endangered Species Research*, *8*, 93–115. doi:10.3354/esr00182.
29. Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits : an overview. *Agroforestry Systems*, *76*, 1–10. doi:10.1007/s10457-009-9229-7.
30. Kingston, T., Francis, C. M., Akbar, Z., & Kunz, T. H. (2003). Species richness in an insectivorous bat assemblage from Malaysia. *Journal of Tropical Ecology*, *19*, 67–79.
31. Korad, V., Yardi, K., and Raut, R. (2007). Diversity and distribution of bats in the Western Ghats of India. *Zoos' Print Journal*, 22, 2752-2758.
32. Kuijper, D. P. J., Schut, J., Dullemen, D. V., Toorman, H., Goossens, N., Ouwehand, J., & Limpens, H. J. G. A. (2008). Experimental evidence of light disturbance along the commuting routes of pond bats (Myotis dasycneme). *Lutra*, *51*(1), 37–49.
33. Kunz, T. H., de Torrez, E. B., Bauer, D., Lobova, T., & Fleming, T. H. (2011). Ecosystem services provided by bats. *Annals of the New York Academy of Sciences*, *1223*(1), 1–38. doi:10.1111/j.1749-6632.2011.06004.x
34. Kusch, J., & Schotte, F. (2007). Effects of fine-scale foraging habitat selection on bat community structure and diversity in a temperate low mountain range forest. *Folia Zoology*, *56*(3), 263–276.
35. Lane, D. J. W., Kingston, T., & Lee, B. P. Y. (2006). Dramatic decline in bat species richness in Singapore, with implications for Southeast Asia. *Biological Conservation*, *131*, 584–593. doi:10.1016/j.biocon.2006.03.005
36. Lentini, P.E., Gibbons, P., Fischer, J., Law, B., Hanspach, J., & Martin, T. G. (2012) Bats in a farming landscape benefit from linear remnants and unimproved pastures. *PLoS One*, 7, e48201-e48213.
37. Lloyd, A., Law, B., & Goldingay, R. (2005). Bat activity on riparian zones and upper slopes in Australian timber production forests and the effectiveness of riparian buffers. *Biological Conservation, 129, 207-220.*
38. Madhavan, A. (2000). A catalogue of bats recorded in Thrissur district , Kerala. *Zoos' Print Journal*, *15* (September), 355-358.
39. Mahmood-ul-Hassan, M., Ur-Rehman, F., & Salim, M. (2011). Public perceptions about the fruit bats in two horticulturally important districts of Pakistan. *The Journal of Animal and Plant Sciences*, *21*(2), 135–141.
40. Martin, C., & Andreas, Z. (2008). Foraging habitats preferences of bats: new question in interpretation of bat detector data. *Vespertilio*, *12*, 3–9.

41. Mcdonald, R.I., Green, P., Balk, D., Fekete, B.M., Revenga, C., Todd, M. & Mark Montgomery, M. (2011) Urban growth, climate change, and freshwater availability. *Proceedings of the National Academy of Sciences (USA)*, 108, 6312–6317.
42. Medellin, R. A., Equihua, M., and Amin, M. A. (2000). Bat diversity and abundance as indicators of disturbance in neotropical rainforests. *Conservation Biology*, 14, 1666-1675.
43. Mickleburgh, S. P., Hutson, A. M., & Racey, P. A. (2002). A review of the global conservation status of bats. *Oryx*, *36*(1), 18–34. doi:10.1017/S0030605301000011.
44. Ministry of Environment and Forests, Government of India. 1972. The Indian Wildlife (Protection) Act, (1972). URL: http://moef.nic.in/modules/rules-and-regulations/wildlife/# Accessed on 20/11/2010.
45. Myers, N., Mittermier, R.A., Mittermier, C.G., Da Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, 403, 853–858.
46. Nair, S.C. (1991) Southern Western Ghats. Indian National Trust for Art and Cultural Heritage (INTACH), New Delhi, India.
47. Nameer, P. O., Molur, S., & Walker, S. (2001). Mammals of Western Ghats: a simplistic overview. *Zoos' Print Journal*, *16*(November), 629–639.
48. Noer, C. L., Dabelsteen, T., Bohmann, K., & Monadjem, A. (2012). Molossid bats in an African agro-ecosystem select sugarcane fields as foraging habitat. *African Zoology*, *47*(April), 1–11.
49. O'Farrell, M. J., and Gannon, W.L. (1999). A comparison of acoustic versus capture techniques for the inventory of bats. *Journal of Mammology*, 80, 24-30.
50. Obrist, M. K., Rathey, E., Bontadina, F., Martinoli, A., Conedera, M., Christe, P., & Moretti, M. (2011). Response of bat species to sylvo-pastoral abandonment. *Forest Ecology and Management*, *261*(3), 789–798. doi:10.1016/j.foreco.2010.12.010
51. Peters, S. L., Malcolm, J. A. Y. R., & Zimmerman, B. L. (2006). Effects of selective logging on bat communities in the southeastern Amazon. *Conservation Biology*, *20*(5), 1410-1421. doi: 10.1111/j.1523-1739.2006.00526.x.
52. Phommexay, P., Satasook, C., Bates, P., Pearch, M., & Bumrungsri, S. (2011). The impact of rubber plantations on the diversity and activity of understorey insectivorous bats in southern Thailand. *Biodiversity & Conservation*, *20*, 1441–1456. doi:10.1007/s10531-011-0036-x
53. R Development Core Team (2012) R: A Language and Environment for Statistical Computing. Vienna, Austria. http://www.r-project.org [accessed September 2012].
54. Raghuram, H., Gopukumar, N., & Kandula, S. (2007). Presence of single as well as double clicks in the echolocation signals of a fruit bat, *Rousettus leschenaulti* (Chiroptera: Pteropodidae). *Folia Zoology*, *56*(1), 33–38.

55. Rainho, A., Augusto, A. M., & Palmeirim, J. M. (2010). Influence of vegetation clutter on the capacity of ground foraging bats to capture prey. *Journal of Applied Ecology*, *47*, 850–858. doi:10.1111/j.1365-2664.2010.01820.x
56. Ratcliffe, J. M., Raghuram, H., Marimuthu, G., Fullard, J. H., & Fenton, M. B. (2005). Hunting in unfamiliar space : echolocation in the Indian false vampire bat, Megaderma lyra, when gleaning prey. *Behavioral Ecology and Sociobiology*, *58*, 157–164. doi:10.1007/s00265-005-0912-z
57. Russo, D., Cistrone, L., Jones, G., & Napoli, I.-P. (2007). Emergence time in forest bats: the influence of canopy closure. *Acta Oecologica*, *31*, 119–126. doi:10.1016/j.actao.2006.11.001
58. Rydell, J., Entwistle, A., & Racey, P. A. (1996) Timing of foraging flights of 3 species of bats in relation to insect activity and predation risk. *Oikos*, 76, 243-252.
59. Sankaran, M., Deshpande, K. Foui, E., & Mudappa, D. (2011). Diversity of insectivorous bats in four protected areas of Kerala. Status report submitted to the Kerala Forest Department, p.16. Project funded by Critical Ecosystem Partnership Fund (CEPF) and Ashoka Trust for Research in Ecology and the Environment (ATREE). Western Ghats Small Grants Program, Bangalore, India.
60. Schuller, G. (1980). Hearing Characteristics and Doppler Shift Compensation in South Indian CF-FM Bats. *Journal Of Comparative Physiology*, *356*(430), 349–356.
61. Sherwin, R. E., Gannon, W. L., & Haymond, S. (2000). The efficacy of acoustic techniques to infer differential use of habitat by bats. *Acta Chiropterologica*, *2*(2), 145–153.
62. Srinivasulu, C., Racey, P. A., & Mistry, S. (2010). A key to the bats (Mammalia: Chiroptera) of South Asia. *Journal of Threatened Taxa*, *2*(July), 1001–1076.
63. Stone, E. L., Jones, G., & Harris, S. (2009). Street lighting disturbs commuting bats. *Current Biology*, *19*, 1–5. doi:10.1016/j.cub.2009.05.058
64. Struebig, M. J., Kingston, T., Zubaid, A., Mohd-adnan, A., & Rossiter, S. J. (2008). Conservation value of forest fragments to Palaeotropical bats. *Biological Conservation*, *141*, 2112–2126. doi:10.1016/j.biocon.2008.06.009
65. Talmale, S.S. & Pradhan, M.S. (2009) *A checklist of valid Indian bat species (Chiroptera: Mammalia)*. Zoological Survey of India Report. p. 17.
66. Vanitharani, J. (2006). Conservation status of bats in the Agasthiyar Hill Range in the Western Ghats, India, with particular reference to Salim Ali's fruit bat (*Latidens salimalii*). Report submitted to the Rufford Small Grants for Nature Conservation, The Rufford Maurice Laing Foundation. p. 7.
67. Wickramasinghe, L. P., Harris, S., Jones, G., & Vaughan, N. (2003). Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. *Journal of Applied Ecology*, *40*, 984–993.

68. Williams-Guille, K., & Perfecto, I. (2011). Ensemble Composition and Activity Levels of Insectivorous Bats in Response to Management Intensification in Coffee Agroforestry Systems. *PLoS One*, *6*(1), e16502–16512. doi:10.1371/journal.pone.0016502.
69. Neuweiler, G., Singh, S. & Sripathi, K. (1984) Audiograms of a south Indian bat community. *Journal of Comparative Physiology*, 154, 133-142.
70. Schaub, A., Ostwald, J., & Siemers, B.M. (2008). Foraging bats avoid noise. *The Journal of Experimental Biology*, 211, 3174-3180.