BATS IN TEA: ACOUSTIC IDENTIFICATION OF BATS IN PLANTATION AGRICULTURE LANDSCAPE AND THEIR CONSERVATION MONITORING

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ABSTRACT

Due to the exponential growth of the human population, natural forests are being steadily replaced by areas devoted to agriculture. It is estimated that forty percent of our planet’s terrestrial area is allocated to agriculture, causing devastating damage to wildlife. However, on the positive side, the diverse nature of agroecosystems offers opportunities for landscape-level approaches to biodiversity conservation. Furthermore, heterogeneous agroecosystems are also known to support rich biological diversity, including bats. Insectivorous bats play a significant role in suppressing insect pests in agroecosystems all over the world. Bat insectivory in agricultural landscapes reduces harvest losses and, indirectly, pesticide use, thereby contributing to the production of healthier foods for human consumption. Hence, this study was aimed to understand the potential of insectivorous bats as insect pest control agents in the tea agroecosystem which contributes significantly to the economy of Sri Lanka. Two years of field sampling was conducted in 11 tea plantations representing major tea growing areas in Sri Lanka. Catching free flying bats and recording their echolocation sounds were employed in data collection. Results have given a very interesting insight into insectivorous bats and the tea agroecosystem in the country. Fourteen species of bats with confirmed species identification and three bat sonotypes were recorded by the present study representing seven bat families. Another important finding of this study was the discovery of *Otomops wroughtoni* (Wroughton's free-tailed bat) and *Tadarida teniotis* (European free-tailed bat) for the first time from Sri Lanka. To these new records, the country’s bat list has increased to 33 species. There were three activity peaks observed in the hourly night activity pattern of insectivorous bats in all tea plantations. Some species of bats that live sympatrically in the same habitat and that have overlapping dietary compositions displayed clear niche partitioning in temporal activity patterns. As per the results of this study, there were nine insectivorous bat species and corresponding sonotypes observed to either caught or tried to catch their prey inside tea plantations. Hence, it is very clear about the potential of insectivorous bats as natural predators of tea insect pests in Sri Lanka.

1. INTRODUCTION

Tea is an agricultural crop grown in large-scale plantations and is widespread in countries having tropical and subtropical climate (Chang, 2015). Though there are 47 tea growing countries in the world, only five countries generate 80% of the total tea production in the world. China, India, Kenya, Sri Lanka and VietNam are the largest tea producing countries, and Kenya and Sri Lanka are the world’s largest tea exporters (FAO, 2021). Tea was introduced to Sri Lanka in 1839, and the first commercial tea plantation was established in 1867 (Mohamed & Zoysa, 2008). At present, Sri Lanka is the world’s fourth largest tea producer and second largest tea exporter. As the leading plantation crop in Sri Lanka, tea accounts for 0.8% of national GDP, contributing 75 billion Rupees (US$ 0.46 billion) to the national economy in 2015 (Central Bank of Sri Lanka, 2020). Tea plantations cover 200,296 hectares and are located in fourteen administrative districts, as well as in three elevational regions-- up-country, mid-country and low-country (Watson, 2008; Central Bank of Sri Lanka, 2020). Each year, tea plantations spend over 72.9 billion Rupees (more than US$ 459.4 million) on tea cultivation and management, a substantial amount of which is used for pest control using insecticides (Central Bank of Sri Lanka, 2020; Department of Census and Statistics, 2021). Estimated crop loss due to insect pests is thought to average 8%, but severe outbreaks of certain pests cause as much as 15-25% crop loss (Cramer, 1967; Hudson, et al., 2002; Sidhakaran, 2006). Recent changes in horticultural practices in

Sri Lankan tea plantations have resulted in increased yields but have intensified pest problems.

A total of 46 species of insects have been identified as tea pests by the long-term studies in the country (Cranham, 1966; Senaratne, 2008). These could be classified in order of importance as primary, seasonal, potential and occasional pests. The primary pests include Shot-hole borer and live-wood termites; seasonal pests include most of the lepidopteran pests; potential pests include the twig and looper caterpillars, while occasional pests include White grubs, Lygus bug, Tea Mosquito Bug, Tea Leaf miners, Scale insects, Red slugs and Lobster caterpillars (Senaratne, 2008). In the recent past, major attention has been given to Integrated Pest Management (IPM) to protect the tea crop against pests (Senaratne, 2008). Before the use of IPM concept, a large number of synthetic pesticides were commonly applied (Hazarika, et al., 2009). This wanton application is a burden to planters as well as to the environment and can result in a resurgence of primary pests or mite syndrome (Cranham, 1966), secondary pest outbreak (Cranham, 1966), resistance development (Kawai, 1997), and environmental contamination, including undesirable residues on the tea itself (Chaudhuri, 1999). However, the alarming rise in resistance to chemical pesticides, together with growing concern for their environmental impact, has fosteered renewed interest in IPM to reduce the harmful effects of pesticides by reducing their application (Abrol & Shankar, 2012). The aim of this new approach is to shift management strategies so that they have less reliance on chemicals and more on the biology of pests and their interactions with crops. This system combines all approaches such as physical, cultural, chemical and biological for sustaining productivity and maintaining the health of ecosystems (Kennedy & Sutton, 2000). Biological control of agricultural pests in IPM is the use of living organisms or products to reduce the extent of problems caused by pests (Kudagamage, 2004). Natural enemies are the fundamental resource of biological control. These biological control agents (natural enemies) come from many groups, differing widely in their biology and ecology (Driesche, et al., 2009) such as parasitoids (Godfray, 1994), arthropod pathogens (Tanada & Kaya, 2012), and predators (Driesche, et al., 2009). In tea ecosystems, predators of insect pests of tea include arthropods and entomophagous vertebrates (bats, birds, amphibians, reptiles and rodents) (Driesche, et al., 2009). Many birds and bats feed on insects and have broad diets (Ye, et al., 2014). However, the role of vertebrate predators such as bats and birds has not been thoroughly studied or highlighted in integrated pest management (Maas, et al., 2016).

Bats are a group of placental mammals and they are the only group of mammals that are capable of true flight (Altringham, 2011; Fenton & Simmons, 2015). Their fore limbs are modified to form a wing (Alexander, 2015; Fenton & Simmons, 2015). Bats are nocturnal and vision is rarely used. Most bats have solved the problems of avoiding obstacles and finding their food in the dark by evolving an intricate system of echolocation or sonar (Altringham, 2011; Fenton & Simmons, 2015). Echolocation is the analysis by an animal of the echoes of its own emitted sounds, to build a sound-picture of its immediate environment. It is a complex and highly evolved process that has given bats the ability to exploit an ecological niche. For echolocation, bats use high frequency sound or ultrasound, beyond the range of human hearing (Altringham, 2011; Fenton & Simmons, 2015). Bats use acoustical signals to detect and hunt flying prey, prey moving on the water's surface and prey on substrates, general orientation, communication and access to roosts (Fenton, 2004). Most probably due to these two unique specializations - echolocation and flight, bats have become one of the most successful groups of mammals living today (Voigt & Kingston, 2016). The global distribution of bats is spreading over the Neotropical, Palaeotropical, Nearctical, and Palaearctical regions. Further some species of bats are known to spend the summer in high latitudes in both hemispheres; a few bat species are found in north of the Arctic Circle (Altringham, 2011).

Bats include at least 1447 extant species (Mammal Diversity Database, 2022), forming the second largest mammalian order and is over a fifth of the total number of mammalian species recorded so far in the world. Order Chiroptera is divided into two suborders: Yinpterochiroptera (includes seven families Pteropodidae, Hipposideridae, Rhinolophidae, Rhinonycteridae, Megadermatidae, Craseonycteridae and Rhinopomatidae) and Yangochiroptera includes 14 families (Nycteridae, Emballonuridae, Phyllostomidae, Mormoopidae, Noctilionidae, Furipteridae, Thyropteridae, Mystacinidae, Myzopodidae, Cistugidae, Vespertilionidae, Miniopteridae, Natalidae and Molossidae) (Teeling, et al., 2016). Globally 17% of bat species are threatened (Critically Endangered, Endangered and Vulnerable), 7% are Near Threatened, and nearly 18% are Data Deficient (IUCN, 2023). Nine species of bats have gone extinct in historic times (IUCN, 2023). Several anthropogenic activities, including deforestation and land conversion for agricultural use, greatly threaten bat diversity (Racey & Entwistle, 2003; Williams-Guillén, et al., 2016; Ceballos, et al., 2017).

Sri Lanka is a tropical island located near the Indian subcontinent (Survey Department of Sri Lanka, 2012). Thirty one species of bats representing 8 families have been recorded in Sri Lanka, including representatives of Pteropodidae, Emballonuridae, Megadermatidae, Rhinolophidae, Hipposideridae, Molossidae, Vespertilionidae and Miniopteridae (Kusuminda, et al., 2020). Similar to the world context, majority of Sri Lankan bat species are insectivorous including 27 species. Five bat species represent different feeding guilds, one feeding on vertebrates and four in the fruit/plant feeding guild (Yapa & Ratnavira, 2013; Yapa, 2018). Distribution of bats in Sri Lanka varies according to the species. Some species such as *Pteropus medius*, *Hipposideros speoris*, and *Cynopterus sphinx* are distributed island-wide. However, the range of some species is restricted to some ecological zones and habitats (Yapa, 2018). None of the bat species recorded from Sri Lanka was considered as threatened under the IUCN Red List (IUCN, 2023). According to the last national assessment of conservation status of bats (Ministry of Environment, 2012), 10 species are Nationally Threatened and two are Data Deficient. Bats are an understudied faunal group in Sri Lanka, and species diversity could be higher than reported. Furthermore, distribution ranges of these species are known largely from historic records and assessment of their current distribution is an urgent requirement (Yapa & Ratnavira, 2013).

Although most bat species feed on invertebrates, mainly insects, bats are members of diverse feeding guilds, including vertebrate-feeding (including fish and blood-feeding bats), omnivory (feeding on both plant and animal matter), fruit/plant feeding (including leaf, flower and bark feeding bats) and nectar/pollen feeding (Maas, et al., 2016). Studies in tropical ecosystems demonstrate the importance of bats as predators in suppressing arthropod abundance and their herbivory (Kalka, et al., 2008; Maas, et al., 2016). Biological suppression of arthropod pests is also a key ecosystem service that bats provide to agriculture (Lee & McCracken, 2005; Cleveland, et al., 2006; Wanger, et al., 2014; Puig-Montserrat, et al., 2015).

Increasing research in tropical ecosystems demonstrates the importance of bats as predators in controlling arthropods, and resultant biological control of arthropod pests is a key ecosystem service that bats provide to agriculture (Kalka, et al., 2008; Maas, et al., 2016). The economic impacts of their insectivory on agricultural pests can be enormous (Cleveland, et al., 2006; Boyles, et al., 2011; Kunz, et al., 2011; Wanger, et al., 2014). Insect pest control service of bats has been studied for diverse crops in a range of agricultural landscapes (Leelapaibul, et al., 2005; Federico, et al., 2008; Johnson, et al., 2010; Puig-Montserrat, et al., 2015; Kemp, et al., 2019; Cohen, et al., 2020). However, no any study was addressed the insect pest control service of bats in tea plantations in the world. Similarly, information on the insect pest control service of bats in any agricultural crops of Sri Lanka is very limited (Yapa, 2012). Hence, here I developed this research to fulfill that knowledge gap of the country and the world.

1.1. OBJECTIVES

1. Strengthen the existing bat call library and make it publicly available. Then, it will useful for researchers in Asian region to species identification. Because, all species recorded so far from Sri Lanka are well distributed in many parts of Asia.
2. Assess the species diversity of bats along an agro-ecological gradient and quantify temporal activity pattern of sympatric species using passive acoustic monitoring techniques. Further, I will be identifying species of bats foraging inside tea plantations using feeding buzzes.
3. Examine the importance of local landscape features such as surrounding habitat of tea plantation, size of the tea plantation, availability of bat roosting sites adjacent to tea plantation and its effects on activity of bats. These will give useful insights about how tea planters can maximise ecosystem services by bats in their plantations.
4. Building capacity of field assistance and university students at sampling sites to operate passive acoustic bat detectors, data processing and data analysis for continued long-term monitoring.
5. Create a bat acoustic baseline data and assessing effect of anthropogenic pressure on trends in species distributions and abundance in tea plantations using multi-year dataset to provide conservation recommendations.

2. METERIAL AND METHODS

Study sites

Field data were collected in 11 tea plantations (Table 1) representing tea growing ecological regions (Watson, 2008), such as the low-country wet zone (WL), mid-country wet zone (WM), up-country intermediate zone (IU), and up-country wet zone (WU) (Figure 1). At proposal stage, we planned to survey 14 tea plantations and started field work in seven tea plantations in 2019. However, due to some logistic problems and funding limitations, we only surveyed 11 tea plantations and had to change few surveyed tea plantations at first.

Table 1. Agroecological zone of sampling sites surveyed for bats.

	Name of tea plantation	Tea growing ecological regions	Elevation region	Province & District
1	Drayton Estate, Kotagala	WU	Low-upper elevation	Central – Nuwara Eliya
2	Oliphant Estate, Nuwara Eliya	WU	High-upper elevation	Central – Nuwara Eliya
3	Loolecondera Estate, Deltota	WU	Low-upper elevation	Central – Kandy
4	Gammaduwa Tea Estate, Knuckles	IU	Low-upper elevation	Central - Matale
5	Udaveriya Estate, Ohiya	IU	High-upper elevation	Uva - Badulla
6	Bio tea garden, Idulgashinna	IU	High-upper elevation	Uva - Badulla
7	Pingarawa Estate, Namunukula	IU	Low-upper elevation	Uva - Badulla
8	Small holder tea land, Manikkawatta, Rakwana	WM	Mid elevation	Sabaragamuwa - Ratnapura
9	Pettigala Estate, Balangoda	WM	Mid elevation	Sabaragamuwa - Ratnapura
10	Enasaldola Estate, Kotapola	WL	Low elevation	Sabaragamuwa - Galle
11	Ransiri tea Estate, Homadola, Udugama	WL	Low elevation	Southern - Galle

Data collection and analysis

Field work was conducted in 2021 and 2022 years. The survey effort was 24 sound-recording hours per site. The Passive bat survey recorded sounds of free flying bats within the tea plantations. Suitable bat sound recording sites with potential flight paths in each tea plantation were identified using an Android-compatible active bat sound recorder (Echo Meter Touch 2 Pro). After that, two passive bat sound recorders (Songmeter SM4Bat FS detectors) fitted with high sensitivity ultrasonic microphones (SMM-U2) were mounted on the shade trees of tea plantations (Figure 2); individual recorders were positioned at least 500 m apart. One bat sound recorder was located near the edge of the tea plantation and the other was located towards the center of the tea plantation. Sound recording was conducted for one night at each site. The Microphone of each sound recorder was mounted 1.5 m above ground to reduce noise from tea bushes and the ground. Bat sounds were recorded from sunset to sunrise to cover the full nocturnal activity of bats (Skalak, et al., 2012). The settings of the sound recorders were as follows; gain – 12dB, 16K high filter – off, sample rate – 500kHz, minimum duration – 0.5 ms, max duration – none, minimum trigger frequency – 10 kHz, trigger level – 12dB, trigger window – 5 sec and maximum length – 5 sec.

Recorded sound files were processed using Kaleidoscope Pro software. Noise sound files were removed and 26,480 bat sound files were separated during batch process in initial stage of analysis. After that, Cluster analysis function of the Kaleidoscope Pro software was used to cluster the similar bat sounds. Then, the key call parameters were measured from these clusters separately to species identification. These key call parameters are minimum frequency (Fpmin), maximum frequency (Fpmax), frequency at maximum energy (Fppeak), Call duration (Dur), Time between two calls (TBC) and band width (BW). Above all six parameters were measured from spectral analysis for frequency modulating calls and only Fppeak and Dur were measured for constant frequency calls (Figure 3). Species identification was done manually by comparing measured sound parameters with reference sound parameters (Kusuminda et al., 2017, 2019a, 2019b, 2019c) or published for the region (Hughes, et al., 2011; Phauk, et al., 2013; Wordley, et al., 2014; Deshpande & Kelkar, 2015; Kusuminda & Yapa, 2017; Chakravarty, et al., 2020; Raman & Hughes, 2020). Echolocation calls of several species could not be identified to species due to overlap of their echolocation call parameters. Therefore, those similar echolocation calls were conservatively identified as sonotypes. Pulses with narrowband multi harmonic FM calls without a distinct CF component (band width: 5-16 kHz; maximum energy in 2nd harmonic) were identified as one sonotype -Emballonuridae, representing three species in the family Emballonuridae. Another sonotype was designated as *Pipistrellus ceylonicus/Scotophilus heathii* for narrowband FM pulses with QCF tail, FmaxE between 33–43 kHz and Fmin between 30-38 kHz. A third sonotype included *Miniopterus phillipsi/Pipistrellus coromandra/Pipistrellus tenuis*, with narrowband FM pulses with a QCF tail, FmaxE between 48–60 kHz and Fmin between 43-53 kHz representing three species in the families Vespertilionidae and Miniopteridae.

Species richness and composition

The number of bat species recorded in different tea plantations and the number of tea plantations each species was recorded were displayed in a bar chart using Microsoft Excel 2010. The community composition of bats recorded in different tea plantations were compared by Non-metric multidimensional scaling (NMDS) using PAST 3.33 software (Hammer, et al., 2001). For this analysis, presence/absence data of different species and sonotypes in different sampling sites were grouped by ecological and elevation regions. Sampled tea plantations were categorized into different ecological regions (Table 1) including low-country wet zone (WL), mid-country wet zone (WM), up-country intermediate zone (IU) and up-country wet zone (WU) following Watson (2008). In addition, sites were categorized into different elevation regions (Table 1) including low elevation (<600 m.a.s.l.), mid elevation (600-1200 m.a.s.l.), low-upper elevation (1200-1500 m.a.s.l.) and high-upper elevation (>1500 m.a.s.l.) based on major elevation regions and natural vegetation types in different elevations (Ashton, et al., 1997; Mohamed & Zoysa, 2008). Concentration ellipses of 75% were created around the centroid of different groups to see overlaps. The significance of the distances between different groups were calculated using a one-way analysis of similarity (ANOSIM) in PAST. The Jaccard index was used as the distance metric in both NMDS and ANOSIM in PAST. Uncorrected *p*-values less than 0.05 were considered as significant.

Temporal night activity

Bat activity was considered as the number of bat passes per hour and night. A bat pass was defined as a 5 sec sound recording that contained at least two search-phase calls characteristic of a bat species (de Oliveira, et al., 2015; Appel, et al., 2019; López-Baucells, et al., 2022). Temporal activity of all bats was calculated by adding all bat passes emitted by different bat species in different hours of the night. Then those counts were plotted as interquartile range box with outlier symbols using Minitab 17 software (Minitab, LLC., 2023). Hourly night activity of bat communities in different elevation regions were also plotted as interquartile range box with outlier symbols using same software. Addition to that, hourly night activity pattern of different bat species within their genus or family or functional group was assessed by line charts with standardized activity data which was subtract mean and divide by stand deviation.

Bats associated with tea agroecosystem

Species of insectivorous bats recorded in sound recorders thet were fixed inside tea plantations at least more than 50 m away from the nearest boundary of the tea plantation were considered here. Data from one or both sound recorders set at Kotagala (1), Idalgashinna (2), Kotapola (1), Nuwara Eliya (2), Balangoda (1), Namunukula (2) and Ohiya (1) were selected based on the above criteria. However, data from one recorder each from Kanneliya (48 m) and Loolecondera (45 m) were also used due to the closeness of the above criterion.

Effect of landscape and weather variables on activity and richness of insectivorous bats in tea agroecosystem

GPS coordinates of all sound recording sites were documented using Garmin eTrex 20x hand-held GPS receiver. For each bat sound recorded site, the following geospatial variables were estimated: mean elevation (m), road density within a 200-m radius around the sampling point (m^2), density of river segments within a 200-m radius around the sampling point (m^2), distance to nearest impervious surfaces (m), number of different land-cover types within a 200-m radius around the sampling point, the predominant land-cover type within a 200-m radius around the sampling point, distance to nearest forest edge (m) and distance to nearest village (m). Zonal statistics tool of the ArcGIS Pro version 3.0 (ESRI, Redlands, CA) was used for all geospatial estimations. The elevation at sampling point was extracted from the Digital Elevation Model developed from NASA's Suttle Radar Topography mission (NASA Land processes Distributed Active Archive Center, 2016). The road and river density were estimated from the Open Street Map and the Geospatial ToolKit (National Renewable Energy Laboratory, and et. al., 2010). All the land-cover variables were estimated from Global Land Cover dataset (ESA, 2017).

Weather parameters, including rainfall, temperature (minimum & maximum) and relative humidity (minimum & maximum), which can affect the activity of bats, were recorded by the same custom made weather logger every 5 minutes from sunset to sunrise of surveyed nights. Average night temperature (Temp Avg.), maximum night temperature (Temp Max), minimum night temperature (Temp Min), temperature difference between Temp Max and

Temp Min (Temp Diff), average night relatve humidity (RH Avg.), maximum night RH (RH Max), minimum night RH (RH Min), RH difference between RH Max and RH Min (RH Diff) and total night rainfall (RF) was calculated from the weather data recorded at all sound recording sites. The strength of relationship between all log-transformed predictor variables on the scaled bat species richness values was measured using the Partial linear correlation coefficient in PAST (Hammer, et al., 2001), while controlling for the effect of other variables. Subsequently, predictor variables with correlation coefficient > ±0.500 were selected for the preliminary stage to test multiple effects of those variables on the response variables.

Stepwise multiple regression analysis was conducted using the above selected predictor variables and response variables in Minitab 17 software to find the best model to explain interaction of those predictor variables on the bat activity and bat species richness.

Species of bats that forage in tea plantations

Generally, insectivorous bats use echolocation to search their prey by producing sounds at a low repetition rate (10–20 clicks/sec) (Figure 4A). After detecting a potential prey, those bats increase the rate of pulses, ending with the terminal buzz or feeding buzz, at rates as high as 200 clicks/sec (Figure 4B) (Altringham, 2011). This special call pattern is widely used to identify and record foraging activity of bats (Wickramasinghe, et al., 2003; Boonchuay & Bumrungsri, 2022). The species of bats forage in tea plantations were identified using these special feeding calls “feeding buzzes”.

Insectivorous bat species that hunted insects inside tea plantations were identified by counting feeding buzzes of the particular species (Boonchuay & Bumrungsri, 2022). Then, the total feeding activity of bats was assessed by counting the feeding buzzes of each particular bat species. In addition, the number of tea plantations in which each species foraged were assessed. These feeding activities were displayed in bar charts using MS Excel 2010.

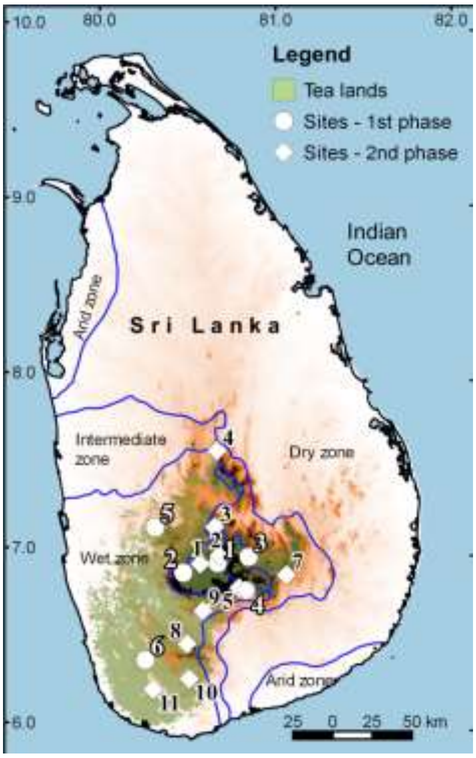

Figure 1. Sampling sites surveyed. Bat boacoustic survey conducted in 2nd phase.

Figure 2. Bat sound recording devices mounted on a shade tree in a tea plantation.

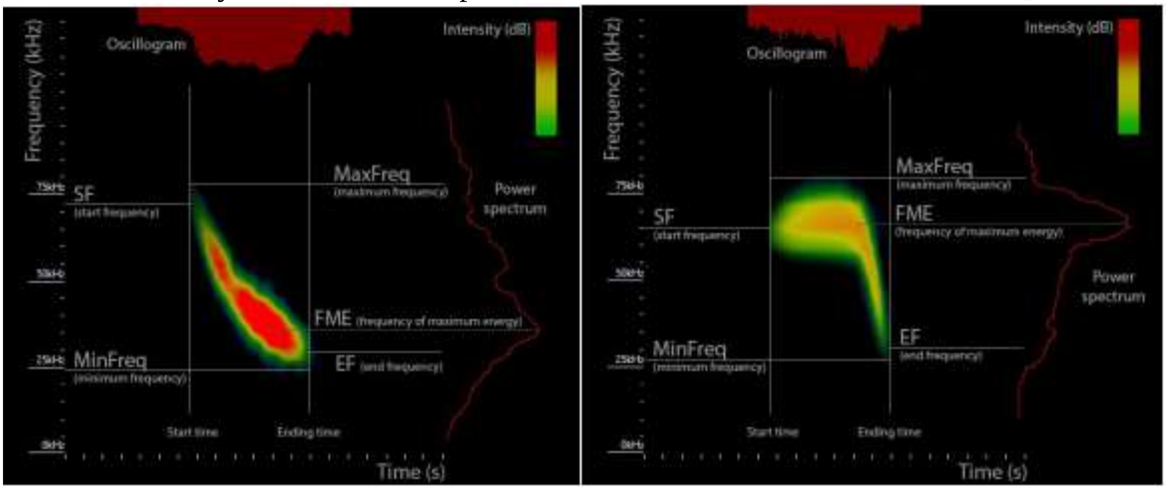

Figure 3. Key call parameters of a bat sound. A. Frequency modulated (FM) call, B. Constant frequency (CF) call (Adapted from López-Baucells, et al., 2016).

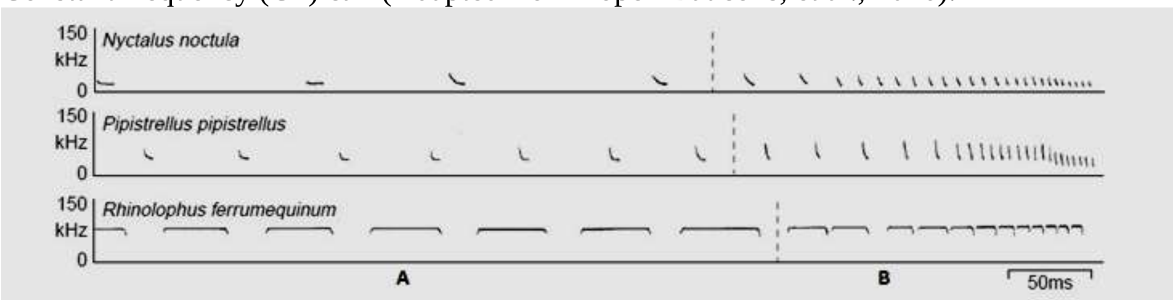

Figure 4. Call structures of three different bat species. A. Search calls, B. Feeding buzzes (Modified from Schnitzler, et al., 2003).

3. RESULTS

Objective 1: Bat call library

Echolocation calls of twenty seven bat species in Sri Lanka were able record representing eight bat familes. Echolocation call characteristics of all these bats were extracted and preparing to publish as a scientific publication and making to publicly available through a website. Seven species including genera *Hipposideros* and *Rhinolophus* were having calls with a significant constant frequency (CF) component (Figure 5). Four species having multi harmonic (> two harmonics) frequency modulating calls were recorded representing genera Megaderma, Lyroderma, Saccolaimus and Taphozous (Figure 6). Sixteen species of bats having frequency modulating echolocation calls with less than two harmonics were recorded representing generas *Tadarida, Otomops, Mops, Scotophilus, Pipistrellus, Miniopterus, Hesperoptenus, Kerivoula, Murina, Myotis* and *Rousettus* (Figure 7).

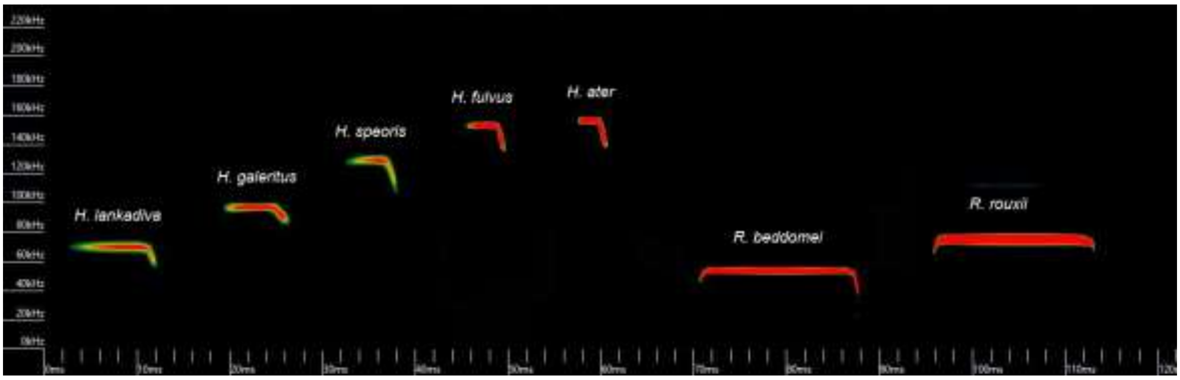

Figure 5. Echolocation call spectrograms of constant frequency call emitting bats.

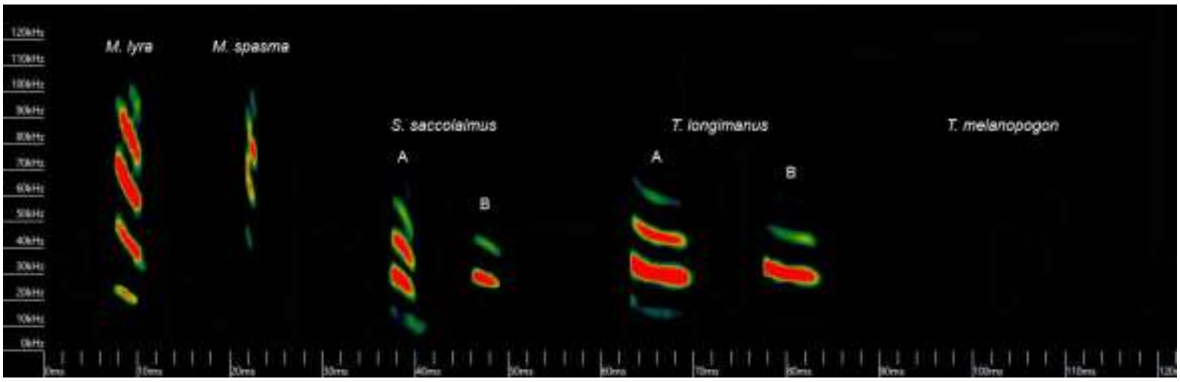

Figure 6. Echolocation call spectrograms of multi harmonic frequency modulating call emitting bats.

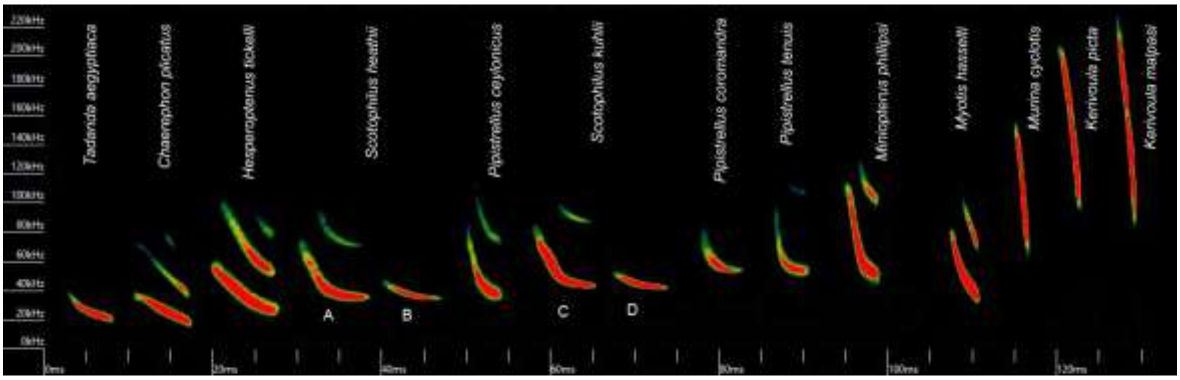

Figure 7. Echolocation call spectrograms of frequency modulating (<2 harmonic) call emitting bats.

Note: Echolocation call spectrograms of two newly recorded molossid bats and *Rousettus* species were not included into the Figure 7.

Objective 2: Species richness, temporal activity pattern and foraging bats

Species richness

During this study, the presence of at least 20 different bat species was detected within Sri Lanka's tea agroecosystems. I was able to confidently identify twelve of those to species level by their unique echolocation call characters. Another eight bat species could be identified to three sonotypes because of overlapping echolocation call parameters. *Pipistrellus ceylonicus* and *Miniopterus phillipsi* appeared acoustically as multi-species sonotypes. However, these two species were also captured in mist nets inside tea plantations. Therefore, a total of fourteen species were recorded with confirmed species identification. Those identified insectivorous bat species represented all seven insectivorous bat families in Sri Lanka: Hipposideridae, Rhinolophidae, Megadermatidae, Molossidae, Emballonuridae, Miniopteridae and Vespertilionidae (Figure 8).

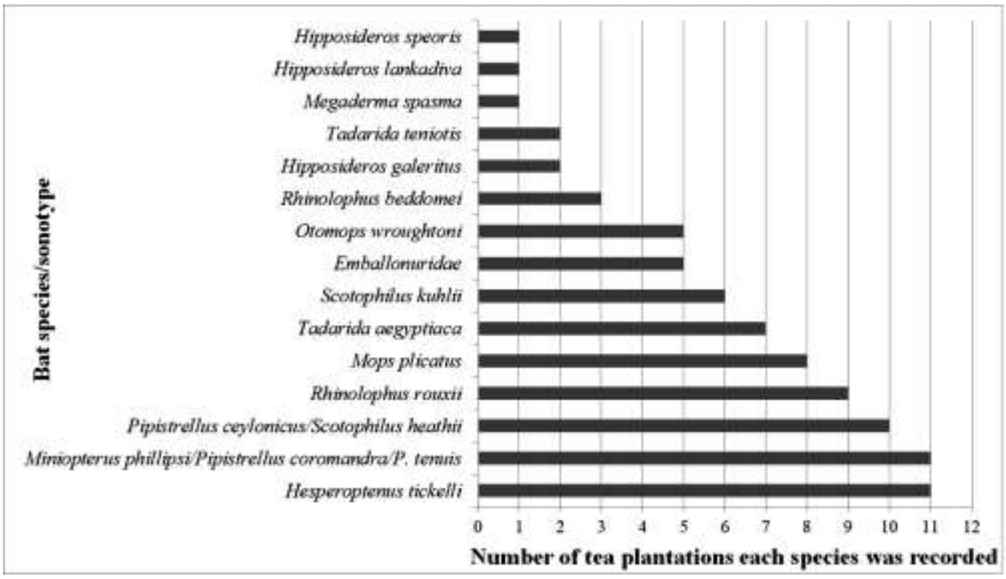

Figure 8. Insectivorous bat species and sonotypes recorded in different tea plantations of Sri Lanka.

The tea plantation at Kotapola (206 m) had the highest bat richness (12 species) and the tea plantation located at Nuwara Eliya had the lowest bat richness (4 species). It is very interesting that the lowest bat richness was recorded in a tea plantation (Nuwara Eliya) located at the highest elevation (2138 m) of tea agroecosystems in the country. Similarly Idalgashinna (1592 m) and Ohiya (1656 m) tea plantations also had lower bat richness and were situated in high upper elevation regions (Figure 9). However, the bat richness in low upper elevations was considerably higher and closer to bat richness at low elevation sites. Although the Homadola tea plantation (163 m) was located in a low elevation region, its bat richness was lower than at mid elevation and low upper elevation sites (Figure 9).

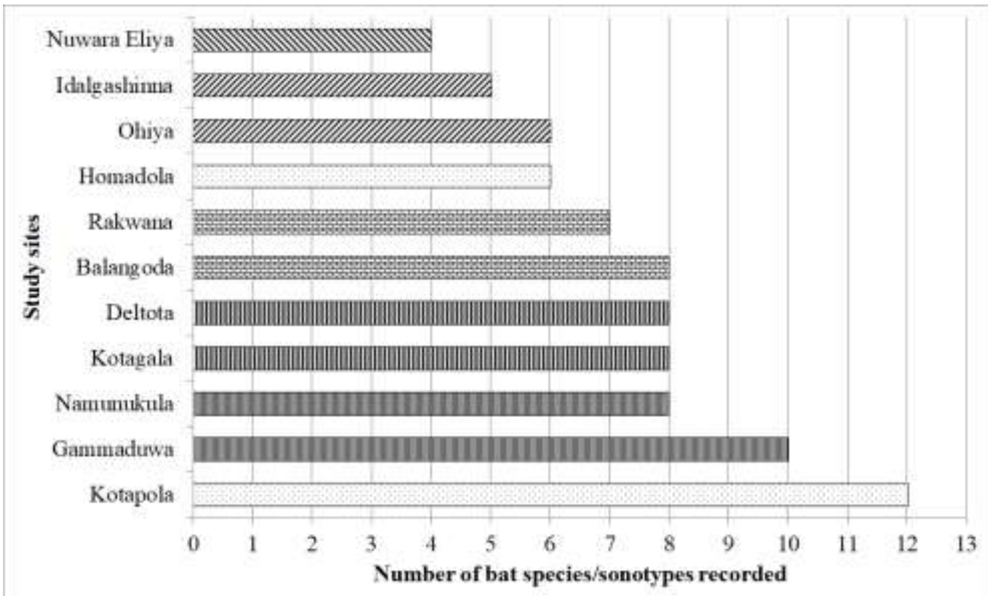

Figure 9. Number of bat species and sonotypes recorded in different tea plantations of Sri Lanka. Pattern of the bars indicate its relevant ecological and elevation category; right angle lines: high upper elevation wet climate; left angle lines: high upper elevation intermediate climate; vertical lines: low upper elevation wet climate; shaded bars: low upper elevation intermediate climate; brick pattern: mid elevation wet climate; light spotted pattern: low elevation wet climate.

Another important finding of this study was the discovery of Wroughton's free-tailed bat (*Otomops wroughtoni*) and European free-tailed bat (*Tadarida teniotis*) for the first time from Sri Lanka. Echolocation calls of *Otomops wroughtoni* were recorded from four locations including Kotagala, Gammaduwa, Kotapola, and Balangoda. It emitted shallow frequency-modulated echolocation calls (Figure 10) with low mean peak frequency (16.16 kHz, range 14.1-18.0 kHz) and other distinctive call parameters (Table 2). Echolocation calls of *T. teniotis* were recorded from Kotagala and Nuwara Eliya. It emitted shallower frequency-modulated echolocation calls than *O. wroughtoni* (Figure 11) with lower mean peak frequency (12.51 kHz, range 11.2-13.6 kHz) (Table 2). In addition, most useful sound parameters (peak frequency and minimum frequency) to distinguish four species of molossids in South Asia (Deshpande & Kelkar, 2015), were compared here with available recent publications (Table 3).

Table 2. Echolocation call characters of four bat species including two newly recorded bat species. Number of calls: *n*, values in the cells shown as mean (range). Abbreviations are: maximum frequency (Fmax), start frequency (Fstart), minimum frequency (Fmin), end frequency (Fend), frequency at maximum energy (FPeak), call duration (Dur), and band width (BW).

Species	***n***	**Fmax (kHz)**	**Fstart (kHz)**	**Fmin (kHz)**	**Fend (kHz)**	**FPeak (kHz)**	**Dur (ms)**	**BW (kHz)**
T. teniotis	19	13.85 (11.9-15.4)	13.35 (11.4-14.6)	11.42 (10.4-12.7)	11.76 (10.6-12.6)	12.51 (11.2-13.6)	27.06 (11.2-49.8)	2.42 (1.4-3.5)
O. wroughtoni	9	19.67 (17.5-25.4)	19.26 (17.0-24.7)	13.99 (12.3-14.8)	14.35 (12.3-15.2)	16.16 (14.1-18.0)	12.26 (7.7-18.5)	5.68 (2.8-10.5)
T. aegyptiaca	14	20.38 (17.7-23.2)	19.74 (17.1-22.3)	16.68 (15.3-18.2)	16.96 (15.5-18.8)	18.48 (17.0-20.5)	15.46 (8.5-21.1)	3.69 (1.3-6.6)
M. plicatus	15	28.69 (26.7-30.7)	27.99 (25.7-30.4)	23.08 (21.1-24.4)	23.55 (21.3-25.3)	24.77 (23.9-25.8)	16.31 (12.3-21.8)	5.61 (3.3-9.5)

Table 3. Two newly recorded molossids in Sri Lanka compared with same data of recently published studies in its range. Number of calls: *n*, values in the cells shown as mean (range). Abbreviations are: end frequency (Fend), and frequency at maximum energy (FPeak).

Species	**Fend (kHz)**	**FPeak (kHz)**	***n***	**Country of origin**	**Data source**
T. teniotis	11.76 (10.6-12.6)	12.51 (11.2-13.6)	19	Sri Lanka	This study
	10.9	13.0	420	Nepal	Sharma, et al., 2021
	12.70	14.89	34	India	Chakravarty, 2017
	10.11	12.8	67	India	Deshpande and Kelkar, 2015
	11.75	11.35	-	Crimea	Uhrin, et al., 2009
O. wroughtoni	14.35 (12.3-15.2)	16.16 (14.1-18.0)	09	Sri Lanka	This study
	13.0	16.15	310	India	Deshpande and Kelkar, 2015
	12.4	15.3	-	India	Ruedi, et al., 2014

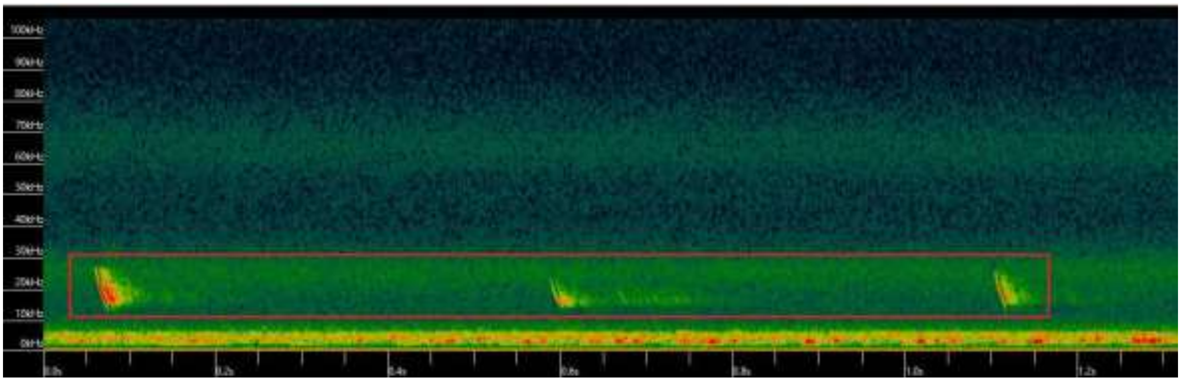

Figure 10. Spectrogram of the echolocation call of *Otomops wroughtoni*.

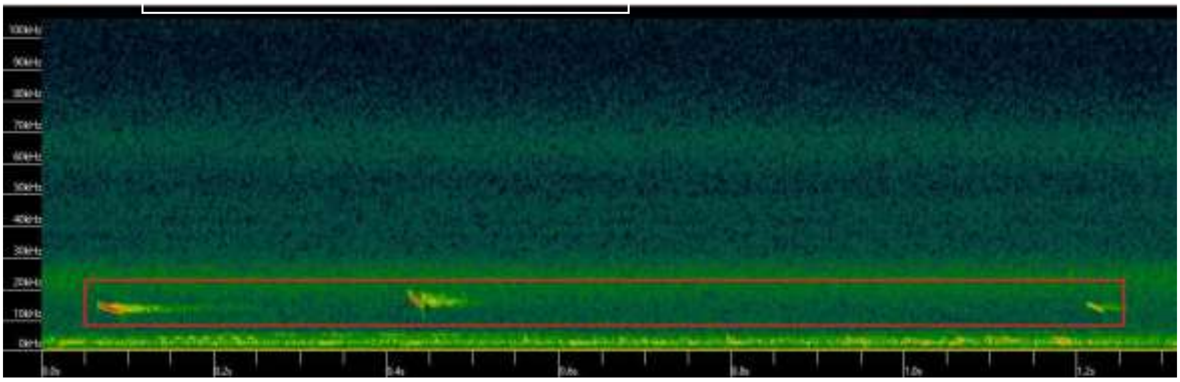

Figure 11. Spectrogram of the echolocation call of *Tadarida teniotis*.

Community composition of insectivorous bats

Insectivorous bat communities in the tea agroecosystem are very important to understand. Since the study sites were from different ecological regions as well as from different altitudes, it is important to understand the effects of these in overall distribution of bats. Therefore, as a first step, insectivorous bats were grouped based on the ecological regions they found. According to the nonmetric multi-dimensional scaling (NMDS) results, all bat communities were in the ordination plot with slightly to completely overlapping 75% concentration ellipses (Figure 12). However, the goodness of fit is poor (Stress = 0.25). Bat communities of low-country wet zone (WL) slightly overlapped those of up-country wet zone (WU) and up-country intermediate zone (IU). But the WL community significantly differed from WU and IU communities (p = 0.0098 and 0.0212 in ANOSIM). All other bat communities did not significantly differ from each other (p = 0.0845-0.5582).

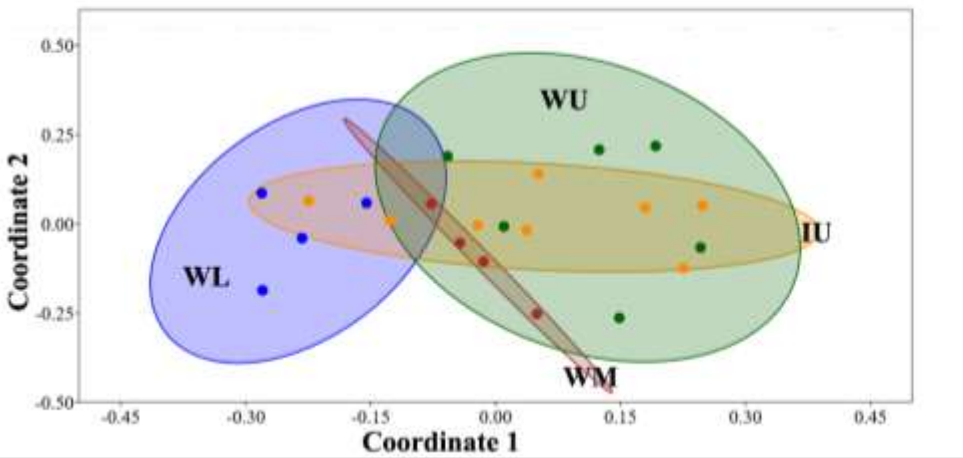

Figure 12. NMDS scatter plot of insectivorous bat communities in different ecological regions. Different clusters were labeled in the plot by respective ecological region names.

In addition, insectivorous bat communities in different elevational regions were also tested for their similarities without regard to ecological regions. As per the results of NMDS, bat communities showed different similarity levels on ordination plot with no overlap, slight overlap and complete overlap of their 75% concentration ellipses (Figure 13). However, the goodness of fit is poor (Stress = 0.2472). Bat communities of high upper elevation (HUE) did not overlap with low (LE) and mid elevation (ME) communities with significant differences (p = 0.0058 and 0.016 respectively in ANOSIM). The HUE bat community significantly differed (p = 0.0264 in ANOSIM) from low upper elevation (LUE) bat community, despite some overlap of their 75% concentration ellipses. All other bat community interactions such as LE and ME, LE and LUE, ME and LUE did not significantly differ from each other (p = 0.0817, 0.1126 and 0.7792 respectively).

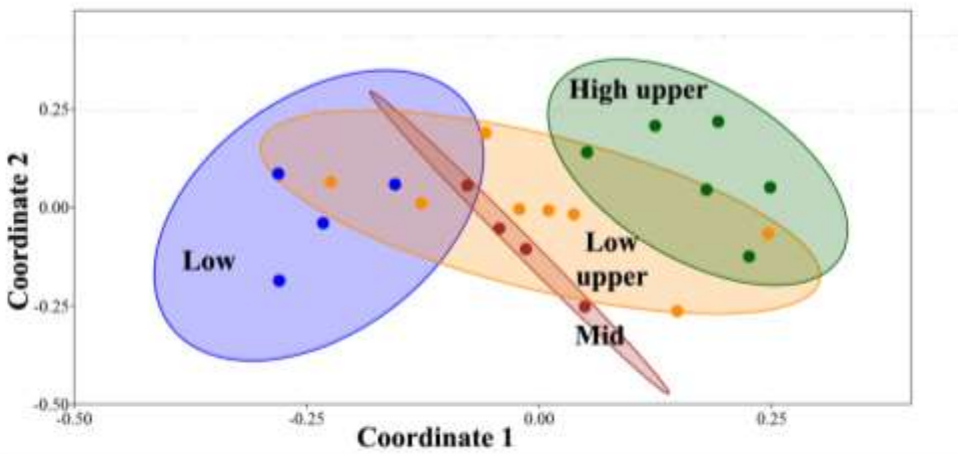

Figure 13. NMDS scatter plot of insectivorous bat communities in different elevation regions. Different clusters were labeled in the plot by respective elevational region names.

Temporal night activity patterns of insectivorous bats

Echolocation calls of fifteen insectivorous bat species and corresponding sonotypes were recorded inside tea agroecosystems of Sri Lanka. There were three activity peaks observed in the temporal activity pattern of insectivorous bats in all tea plantations. The first activity peak occurred after sunset between 18:00-19:00 hrs. A second activity peak occurred at

01:00-02:00 hrs. The third activity peak was observed before sunrise between 05:00-06:00 hrs. Activity was lower between 20:00-24:00 hrs and 02:00-05:00 hrs (Figure 14).

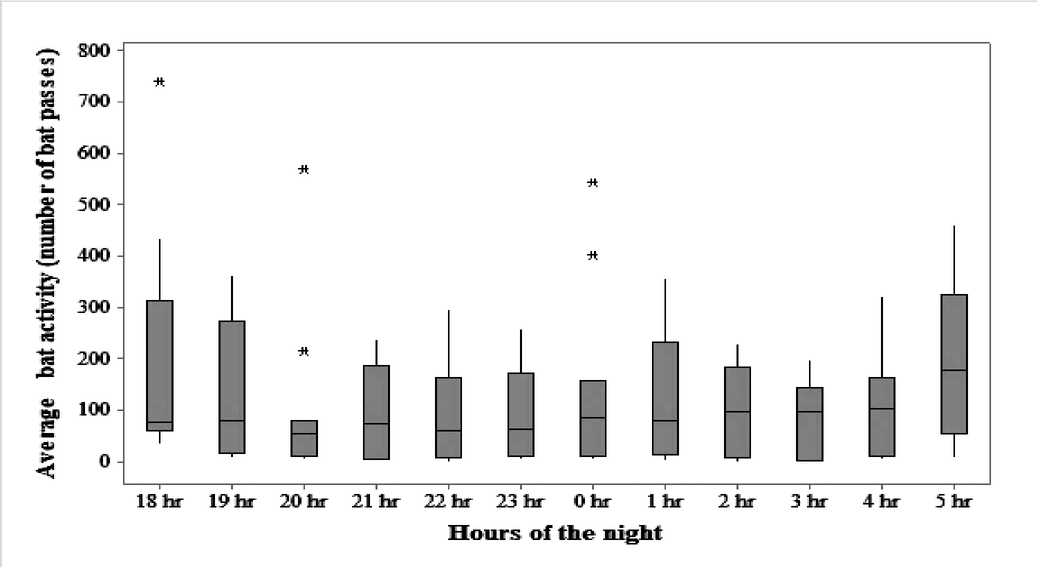

Figure 14. Temporal activity of insectivorous bats in night time at all tea plantations of Sri Lanka.

Temporal activity patterns varied in different elevation regions. Temporal activity patterns of bats in high upper elevation and low elevation regions were similar to overall activity pattern with two peak activities after sunset and before sunrise (Figure 15). However, activity level (number of bat passes) is higher at low elevations than upper elevations. In low upper elevations and mid elevations, first peak activity occurred in 19:00-20:00 hrs and 20:00-21:00 hrs respectively. Third peak activity of the mid elevation bat community was at 04:00-05:00 hrs.

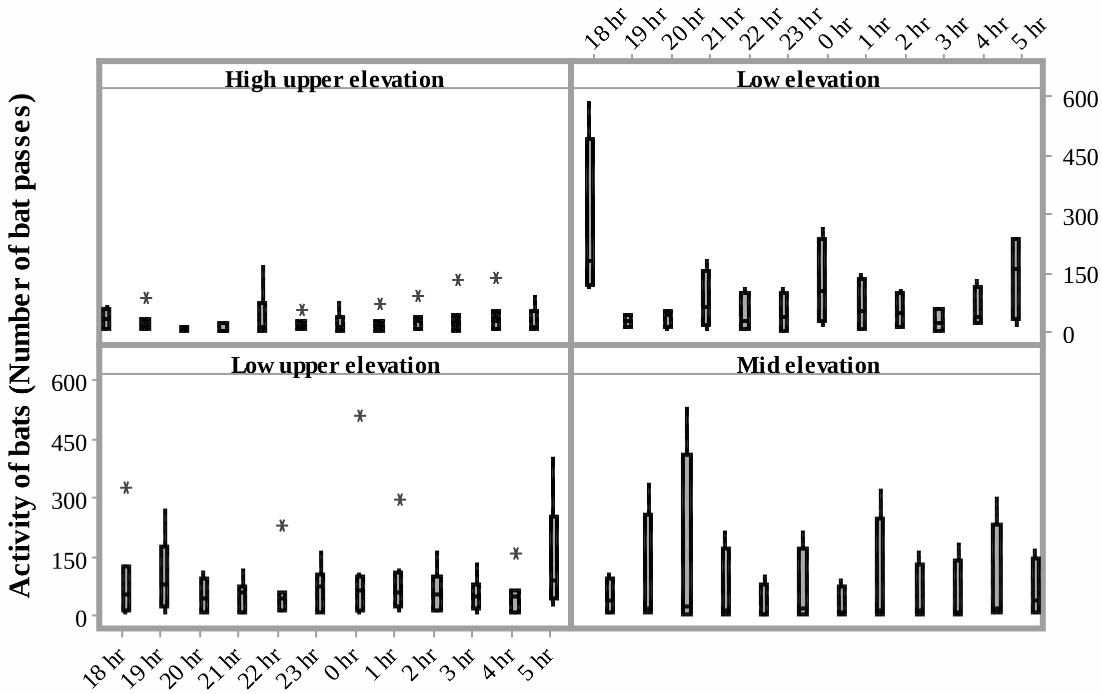

Figure 15. Temporal activity of insectivorous bats at tea plantations at different elevations of Sri Lanka.

Variation of temporal night activity pattern of insectivorous bats within their genus, family and functional group was assessed. Species of Hipposideridae and Rhinolophidae, adapted for echo-clutter habitats, were assessed by family for their temporal activity pattern. Overall activity level of *R. rouxii* is higher than *R. beddomei*. There was a very clear temporal niche partitioning between the two species (Figure 16). Slight temporal niche partitioning was observed in three species of hipposiderids (Figure 17). *Hipposideros speoris* and *H. lankadiva* had their highest activity just after sunset. However, *H. galeritus* was not active until 20:00 hr. *Hipposideros lankadiva* had another two activity peaks before midnight and then its activity ceased. *Hipposideros speoris* had three activity peaks after sunset and its activity increased at midnight. *Hipposideros galeritus* had only three activity peaks and highest activity peak was recorded around 01:00 hr.

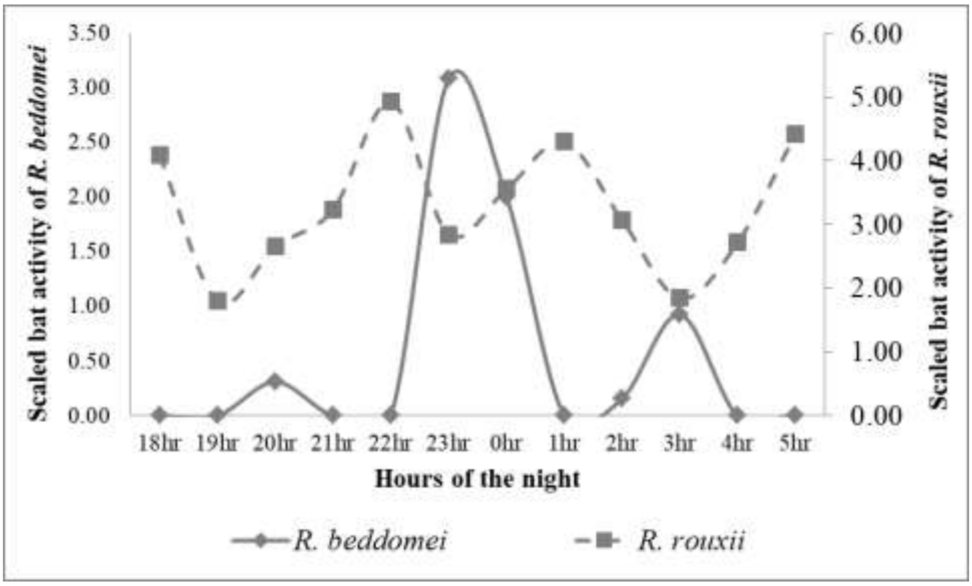

Figure 16. Temporal night activity of *Rhinolophus beddomei* and *Rhinolophus rouxii*.

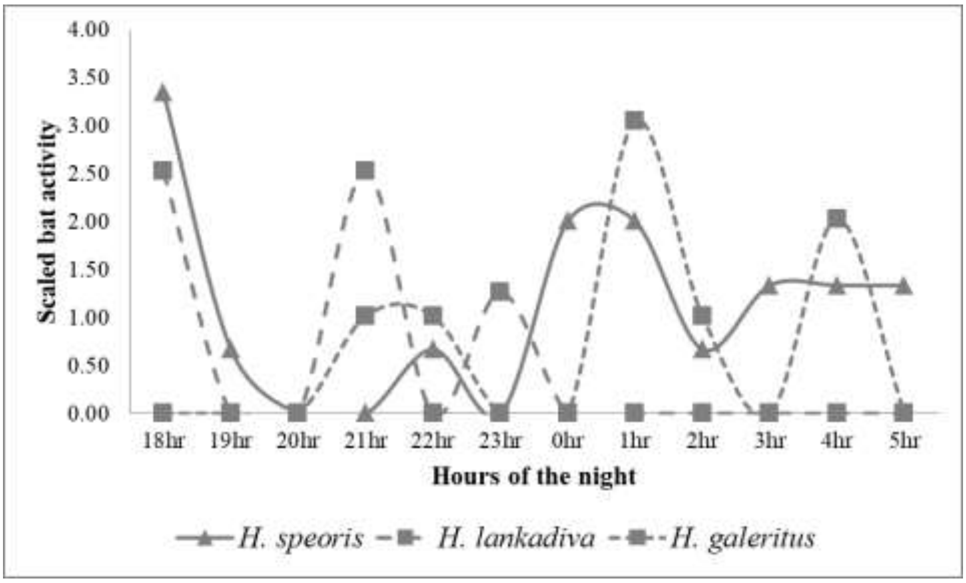

Figure 17. Temporal night activity of *Hipposideros speoris, Hipposideros lankadiva*, and *Hipposideros galeritus*.

Bats in the families Vespertilionidae and Miniopteridae are aerial hawking bats that feed in "edge habitats". Therefore, all bat species in the above two families were studied together for their temporal activity patterns (Figure 18). Activity of all of those bats increased after sunset around 18:00 hr. Except for *Pipistrellus ceylonicus/Scotophilus heathii*, all reduced their activity around one hour after the sunset. However, *Pipistrellus ceylonicus/Scotophilus heathii* remained active for around two hours after sunset. Activity level of *Miniopterus phillipsi/Pipistrellus coromandra/Pipistrellus tenuis* was higher than all other recorded edge-habitat bats. In addition, it was active between 19:00-21:00 hrs when other bats were less active. Activity of *Hesperoptenus tickelli* gradually reduced towards 22:00 hrs and again gradually increased towards sunrise of the next day. *Scotophilus kuhlii* had the lowest activity than the other three species in edge habitat. Except for *S. kuhlii*, all other bat species were moderately active around mid-night (Figure 18).

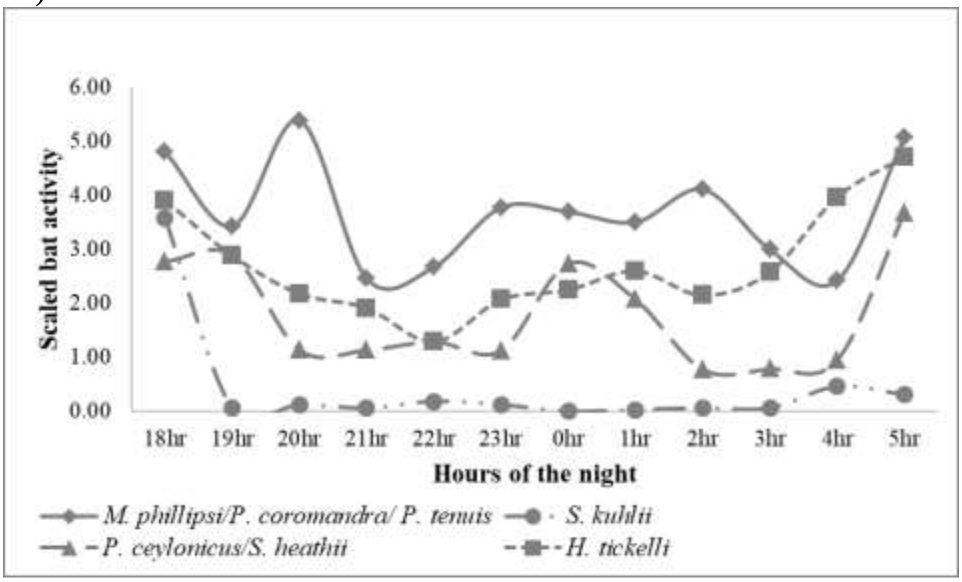

Figure 18. Temporal night activity of *Miniopterus phillipsi/Pipistrellus coromandra/ Pipistrellus tenuis*, *Scotophilus kuhlii*, *Pipistrellus ceylonicus/Scotophilus heathii*, and *Hesperoptenus tickelli*.

Bats in the family Molossidae feed in open habitats and are very fast flyers. *Mops plicatus* and *Otomops wroughtoni* exhibited similar activity patterns before midnight (Figure 19). However, they are very different in size and their prey size also differs, reducing inter-species competition. Later, the activity of *O. wroughtoni* was reduced whereas that of *M. plicatus* increased around mid-night. Interestingly, activity of all molossids except *M. plicatus* started to reduce towards sunrise. *Tadarida aegyptiaca* is the only molossid species having its highest peak activity around 19:00 hr (vs. others around 18:00 hr) and had clear temporal niche partitioning. Next species *T. teniotis* had its highest peak activity around 21:00 hr and was not active after 02:00 hr (Figure 19).

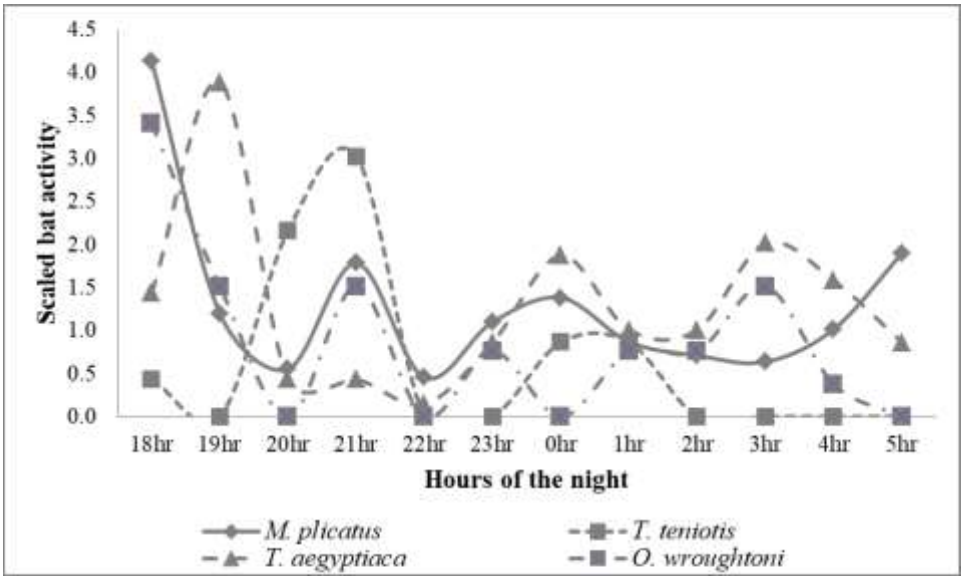

Figure 19. Temporal night activity of *Mops plicatus*, *Tadarida teniotis*, *Tadarida aegyptiaca* and *Otomops wroughtoni*.

Bats associated with tea agroecosystem

Of all bat species and sonotypes recorded, it is certainly vital to recognize the species of insectivorous bats which forage in tea plantations. Therefore, we investigated the bat species recorded inside tea plantations. Surprisingly, all bat species and sonotypes recorded except *Megaderma spasma* were also recorded at the center of tea plantations. Additionally, those species represented the three main functional groups and all six other bat families.

Species of bats that forage in tea plantations

Species of insectivorous bats foraged in the tea agroecosystem were studied based on their feeding-related acoustic signals. According to the results of this study, there were nine insectivorous bat species and corresponding sonotypes observed to either caught or tried to catch their prey inside tea plantations (Figure 20). Those species represented molossids and emballonurids, which prefer to forage in open habitats, vespertilionids, which forage in edge habitats, and rhinolophids, which are adapted to forage in echo-cluttered habitats. *Hesperoptenus tickelli* is the most commonly detected bat species which is found to prey in all ten tea plantations. Highest feeding activity was recorded from *Pipistrellus ceylonicus/Scotophilus heathii* (188) in all surveyed tea plantations. *Miniopterus phillipsi/P. coromandra/P. tenuis* (110), *H. tickelli* (82), and *Rhinolophus rouxii* (53) have shown subsequently higher feeding activities (Figure 21).

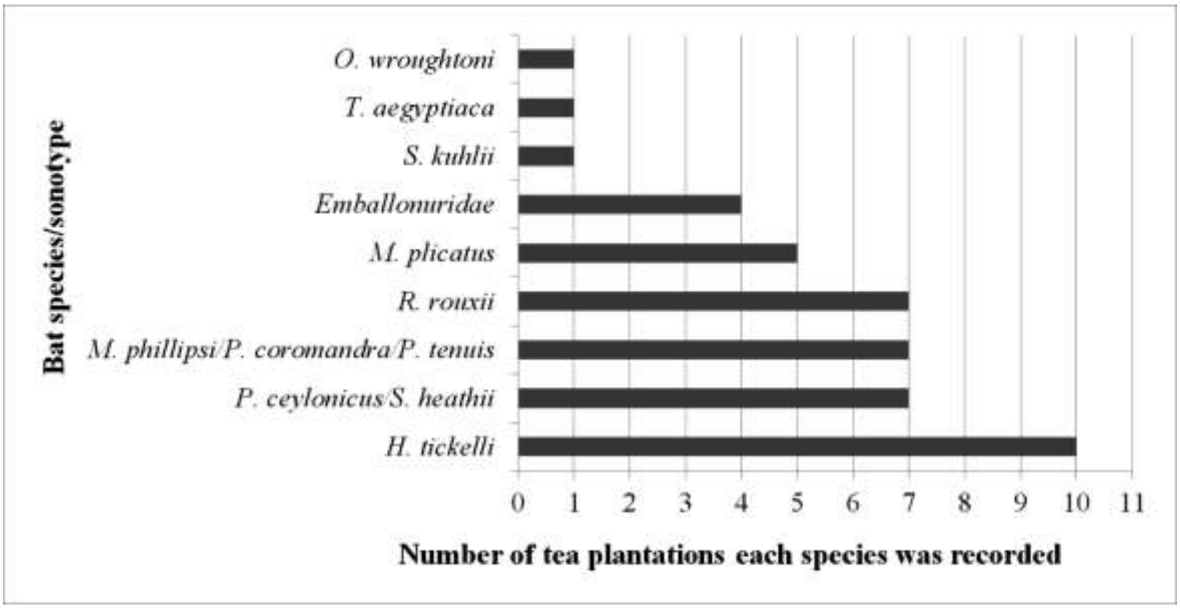

Figure 205. Insectivorous bat species and sonotypes recorded foraging in different tea plantations of Sri Lanka.

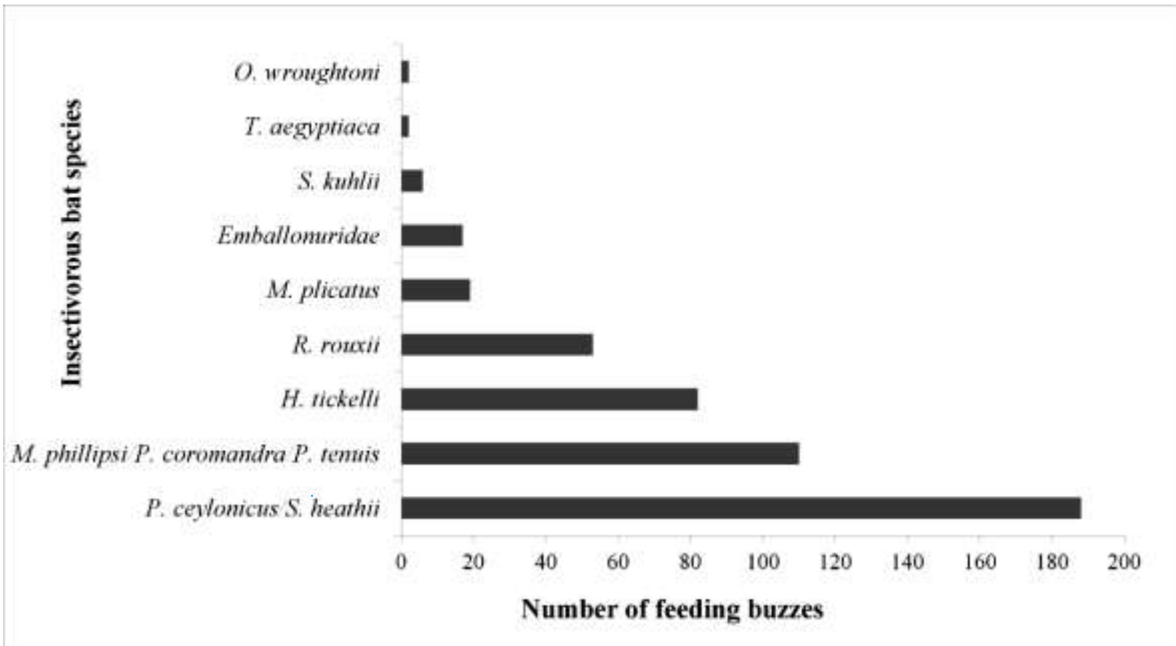

Figure 21. Number of feeding attempts of different insectivorous bat species in all tea plantations.

Objective 3: Importance of local landscape and weather variables for bats

Tea plantations are intensively managed agricultural habitats spread over heterogeneous landscapes in Sri Lanka. Moreover, tea plantations in different agroecological regions experience different weather conditions. Variation in landscape and weather conditions affects the richness and activity of insectivorous bats in tea agroecosystems. To understand that, we have studied the effect of different landscape and weather conditions on the richness and activity of insectivorous bats.

Relationship of landscape and weather variables on activity of bats

Partial linear correlation analysis was used to assess bat activity and associated landscape and weather variables. Mean elevation, distance to nearest forest, distance to nearest village, number of land cover types, minimum temperature, temperature difference and relative humidity difference all had negative relationships with bat activity (Table 4). All other variables were positively related to bat activity (Table 4). However, the number of land cover types, average temperature, maximum temperature, minimum temperature, temperature difference and minimum relative humidity had strong relationships (> ±0.75) with bat activity. Further, only minimum temperature had a significant relationship with bat activity (Table 4).

Table 4. Partial linear correlation coefficients between predictor variables and bat activity were mentioned below. Significant *p* values (< 0.05) were bold faced.

Predictor variable	**Correlation coefficient**	**Uncorrected *p* value**
Mean elevation (m)	-0.284	0.643
Mean road density (m^2)	0.115	0.854
Mean river density (m^2)	0.576	0.309
Distance to impervious surfaces (m)	0.133	0.831
Distance to nearest forest (m)	-0.120	0.848
Distance to nearest village (m)	-0.045	0.942
Number of land cover types	-0.787	0.114
Temp Avg. (°C)	0.777	0.122
Temp Max (°C)	0.833	0.080
Temp Min (°C)	-0.966	**0.007**
Temp Diff (°C)	-0.800	0.104
RH (%)	0.503	0.388
RH Max (%)	0.125	0.841
RH Min (%)	0.859	0.062
RH Diff (%)	-0.590	0.295
RF (mm)	0.734	0.158

Relationship of landscape and weather variables on bat species richness

According to the partial linear correlation analysis results between bat species richness and associated landscape and weather variables, mean elevation, distance to nearest forest, number of land cover types, minimum temperature, temperature difference and RH difference had negative relationship with bat activity (Table 5). All other variables had a positive relationship with bat activity (Table 5). However, average temperature, maximum temperature, minimum temperature, temperature difference, minimum relative humidity and rainfall had strong relationships (> ±0.75) with bat species richness. Relationships of maximum temperature, minimum temperature and minimum relative humidity with bat species richness were significant (Table 5).

Table 5. Partial linear correlation coefficients between predictor variables and bat species richness were mentioned below. Significant *p* values (< 0.05) were bold faced.

Predictor variable	Correlation coefficient	Uncorrected *p* value
Mean elevation (m)	-0.716	0.174
Mean road density (m^2)	0.094	0.880
Mean river density (m^2)	0.089	0.887
Distance to impervious surfaces (m)	0.209	0.736
Distance to nearest forest (m)	-0.295	0.629
Distance to nearest village (m)	0.473	0.421
Number of land cover types	-0.744	0.150
Temp Avg. (°C)	0.875	0.052
Temp Max (°C)	0.924	**0.025**
Temp Min (°C)	-0.967	**0.007**
Temp Diff (°C)	-0.859	0.062
RH (%)	0.517	0.372
RH Max (%)	0.180	0.772
RH Min (%)	0.894	**0.041**
RH Diff (%)	-0.700	0.188
RF (mm)	0.774	0.125

Multiple effect of landscape and weather variables on the activity of bats

Nine predictor variables having moderately strong to very strong relationships with bat activity were selected to test their multiple effects on the bat activity. Those selected variables are mean river density, number of land cover types, average temperature, maximum temperature, minimum temperature, temperature difference, average relative humidity, minimum relative humidity and rainfall. During the stepwise multiple regression analysis, maximum temperature was identified as the only variable which was appropriate for the regression model for bat activity (but not significant, p = 0.056) and all other variables were eliminated (Table 6). Further results showed that, selected predictor variable was not correlated (VIF = 1.00) with other predictor variables (Table 7). However, the present regression model didn't explain the total variance of bat activity and maximum temperature only explained a low percentage of variance (R^2 = 18.88%) of the bat activity (Table 8).

Table 6. Stepwise multiple regression results: analysis of variance. Abbreviations are: adjusted sum of squares (Adj SS), adjusted mean squares (Adj MS), *p* value less than 0.05 is considered as significant.

Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
Regression	1	1.085	1.0845	4.19	0.056
Temp Max	1	1.085	1.0845	4.19	0.056
Error	18	4.660	0.2589		

Total	19	5.745				

Table 7. Stepwise multiple regression results: coefficients. Abbreviations are: coefficients (Coef), standard error of coefficient (SE Coef), *p* value less than 0.05 is considered as significant.

Term	**Coef**	**SE Coef**	**T-Value**	***p*-Value**	**VIF**
Constant	2.627	0.114	23.09	0.000	
Temp Max	0.239	0.117	2.05	0.056	1.00

Table 8. Stepwise multiple regression results: model summary. Abbreviations are: R-square (R-sq), R-square adjusted [R-sq(adj)], R-square predicted [R-sq(pred)].

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
0.508813	18.88%	14.37%	5.60%

The regression equation to measure the relationship between bat activity and maximum temperature is given below.

Bat activity = 2.627 + 0.239 Temp Max

Multiple effect of landscape and weather variables on the bat species richness

Ten predictor variables having moderately strong to very strong relationship with bat species richness were selected to test their multiple effect on bat activity. Those selected variables are mean elevation, number of land cover types, average temperature, maximum temperature, minimum temperature, temperature difference, average relative humidity, minimum relative humidity, relative humidity difference and rainfall. During the stepwise multiple regression analysis, mean elevation, rainfall, and relative humidity difference were selected for the regression model for bat species richness and all other variables were eliminated (Table 9). However, only mean elevation (p = 0.000), and rainfall (p = 0.000) were significantly supported for the regression model while relative humidity difference (p = 0.091) wasn't supported significantly. Further results showed that, selected predictor variables were not correlated (VIF = 1.47-1.78) with other predictor variables (Table 10). Interestingly, the three-variable regression model explained a high percentage of variance (R^2 = 75.51%) of bat species richness (Table 11).

Table 9. Stepwise multiple regression results: analysis of variance. Abbreviations are: adjusted sum of squares (Adj SS), adjusted mean squares (Adj MS), *p* value less than 0.05 is considered as significant.

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	***p*-Value**
Regression	3	0.24830	0.082767	16.45	0.000
Mean elevation	1	0.15811	0.158113	31.42	0.000
RF	1	0.15111	0.151114	30.03	0.000
RH Diff	1	0.01623	0.016234	3.23	0.091
Error	16	0.08051	0.005032		
Total	19	0.32881			

Table 10. Stepwise multiple regression results: coefficients. Abbreviations are: coefficients (Coef), standard error of coefficient (SE Coef), *p* value less than 0.05 is considered as significant.

Term	**Coef**	**SE Coef**	**T-Value**	***p*-Value**	**VIF**
Constant	0.7612	0.0159	47.74	0.000	

Mean elevation	-0.1196	0.0213	-5.61	0.000	1.78
RF	-0.1152	0.0210	-5.48	0.000	1.67
RH Diff	-0.0355	0.0197	-1.80	0.091	1.47

Table 11. Stepwise multiple regression results: model summary. Abbreviations are: R-square (R-sq), R-square adjusted [R-sq(adj)], R-square predicted [R-sq(pred)].

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
0.0709368	75.51%	70.92%	54.06%

The regression equation describing the relationship between bat species richness and three predictor variables is given below.
Bat species richness = 0.7612 - 0.1196 Mean elevation - 0.1152 RF - 0.0355 RH Diff

Objective 4: Capacity building

During the field works, our field assistants Chamara Amarasinghe, Mathisha Karunarathna and Sameera Suranjan were trained well about bat research (Figure 22). Now, they are well-trained not only in setting up bat detectors but also in identifying different genera of bats from sound recordings.

Figure 22. Chamara is learning to operate Echo meter touch 2 pro.

Objective 5: Bat acoustic baseline data for mult-year bat monitoring

Bat activity data generated through this study from 11 tea plantations in Sri Lanka will be used as baseline data for the multi-year bat monitoring program. However, this proposed project is awaiting financial support to conduct field bat monitoring surveys.

4. CONCLUSIONS AND RECOMMENDATION

In conclusion, the tea agroecosystem of Sri Lanka harbors comparatively rich bat fauna with notable taxonomic and functional diversity. Many insectivorous bat species found in this ecosystem actively forage on nocturnal aerial insects, including several pests of tea cultivation. This suggests promising potential for utilization of insectivorous bats as natural predators of insect pests in the tea agroecosystems. Our main recommendation is to promptly develop an integrated pest management plan for different tea growing regions of the country incorporating the findings of this research. As part of the pest management program, the introduction of different types of bat houses to attract various bat species into tea plantations is crucial.

5. PROJECT OUTCOMES

I. Results of this project were shared with the Forest Department, Department of Wildlife Conservation, and the tea industry in Sri Lanka.

II. Echolocation calls of twenty seven bat species in Sri Lanka were record representing eight bat familes. Echolocation call characteristics of all these bats will be available to public through a website very soon.

III. This project is part of my PhD research and it helped me to successfully complete my PhD research. Further, three PhD students were trained through this project including Chamara Amarasinghe, Sahan Siriwardhana and Sameera Karunarathna of University Colombo.

IV. Research Publications

- Kusuminda, T., Amarasinghe, C., Mannakkara, A., Patterson, B.D., Yapa, W.B. (*In Review*). First record of the Wroughton's free-tailed bat (*Otomops wroughtoni*) and the European free-tailed bat (*Tadarida teniotis*) from Sri Lanka. **Mammal Study**.

- Kusuminda, T., Mannakkara, A., Amarasinghe, C., Karunarathna, M., Patterson, B.D., Yapa, W.B. (*In Prep*). Echolocation calls of Sri Lankan Bats: A bat call library for their effective monitoring.

- Kusuminda, T., Mannakkara, A., Amarasinghe, C., Siriwardhana, S., Patterson, B.D., Yapa, W.B., Surasinghe, T. (*In Prep*). Effect of landscape and weather on the activity and richness of bats in a tropical agricultural landscape.

- Kusuminda, T., Mannakkara, A., Amarasinghe, C., Patterson, B.D., Yapa, W.B., Surasinghe, T. (*In Prep*). Temporal activity patterns and feeding activity of insectivorous bats in a tropical agricultural landscape.

V. Outreach Activities

- Resource Person: Invited online public talk on “Introduction to Bat World” organized by Turtle Conservation Project Sri Lanka, 09th Mar 2024.

- Resource Person: Invited online public talk on "Bat diversity of Sri Lanka" organized by Faculty of Agricultural and Plantation Management Nature Team, Wayamba University of Sri Lanka, 29th Jan 2023.
- Main Resource Person: Two day workshop on "Bat diversity and their significance" organized by The Youth Exploration Society of Sri Lanka. Peradeniya, Sri Lanka, 29-30th Oct 2022.
- Resource Person: Invited online talk on "Bat diversity of Sri Lanka" organized by program coordinator of Advance certificate course in wildlife conservation and management, Open University of Sri Lanka, 05th Jul 2022.
- Resource Person: Invited public talk on "Bats of Sri Lanka" organized by Young Zoologists' Association of Sri Lanka. Attidiya, Sri Lanka, 30th Nov 2019.
- Resource Person: Invited talk on "Diversity and Ecosystem services of bats in Sri Lanka" organized by Association of Young Biologists of Rajarata University of Sri Lanka. Mihintale, Sri Lanka, 31st May 2018.

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