

# Urban Green Spaces and their Effect on Bat Activity in Pune, Maharashtra.

DISSERTATION SUBMITTED TO SAURASHTRA UNIVERSITY IN PARTIAL FULFILMENT OF THE  
MASTER'S DEGREE IN ORNITHOLOGY & CONSERVATION BIOLOGY  
AUGUST, 2020

By  
**SHRIRANJANI L. IYER**  
Enrolment No. 003053184

Supervisor  
Dr. MANCHI SHIRISH S.

Co-Supervisor  
Dr. ANAND KRISHNAN



Saurashtra University  
Rajkot



**Sálim Ali Centre for Ornithology and Natural History**  
(A Centre of Excellence under the Ministry of Environment, Forest and Climate Change, Govt. of India)  
Anaikatty Post, Coimbatore – 641 108, Tamil Nadu.



सालिम अली पक्षिविज्ञान एवं प्रकृति विज्ञान केन्द्र  
**SÁLIM ALI CENTRE FOR ORNITHOLOGY AND NATURAL HISTORY**  
(पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय के अधीन उत्कृष्टता का एक केंद्र, भारत सरकार)  
(A Centre of Excellence under the Ministry of Environment, Forest & Climate Change, Govt. of India)

**CERTIFICATE**

This is to certify that **Ms. Shriranjani L. Iyer** of Sálím Ali Centre for Ornithology and Natural History (SACON) has carried out an original research work titled, '**Urban Green Spaces and their Effect on Bat Activity in Pune, Maharashtra**' in partial fulfilment of the M.Sc. (Ornithology & Conservation Biology) degree of Saurashtra University, Rajkot. This investigation was carried out under my supervision from December 2019 to August 2020. I also certify that this research work has not been submitted for any other degree to any university.

Date: 31<sup>st</sup> August 2020

Place: Coimbatore

(**Dr. MANCHI SHIRISH S.**)

Principal Scientist

डॉ. मंची शिरीष एस / Dr. Manchi Shirish S  
प्रधान वैज्ञानिक / Principal Scientist  
सालिम अली पक्षिविज्ञान एवं प्रकृति विज्ञान केन्द्र  
Sálím Ali Centre for Ornithology and Natural History  
आनैकट्टी, कोयंबटूर - 641 108  
Anaikatty (Post), Coimbatore - 641 108

आनैकट्टी, कोयंबटूर - 641 108 (इंडिया)

Anaikatty (Post), Coimbatore - 641 108 (INDIA)

Tele : +91-422-2203100, 2203103, 2203109 Telefax : +91-422-2657088

E-mail : salimali@sacon.in, salimalicentre@gmail.com Website : www.sacon.in



# Indian Institute of Science Education and Research (IISER – PUNE)

IISER Campus, Dr. Homi Bhabha Road, Pashan, Pune 411 008.

**Dr. Anand Krishnan**  
**DST-INSPIRE Faculty**  
**Fellow**

## CERTIFICATE

This is to certify that **Ms. Shiranjani L. Iyer** of Sálím Ali Centre for Ornithology and Natural History (SACON) has carried out an original research work titled, '**Urban Green Spaces and their Effect on Bat Activity in Pune, Maharashtra**' in partial fulfilment of the M.Sc. (Ornithology & Conservation Biology) degree of Saurashtra University, Rajkot. This investigation was carried out under my co-supervision from December 2019 to August 2020. I also certify that this research work has not been submitted for any other degree to any university.

A handwritten signature in blue ink, appearing to be 'AK', with a long horizontal stroke extending to the right.

Date: 31 August, 2020

**(Dr. ANAND KRISHNAN)**

Place: Pune

DST-INSPIRE Faculty

## **Acknowledgements**

This dissertation is a result of the efforts of many people who have contributed discussions, encouragement, optimism and patience. I would like to thank Dr. Shirish and Dr. Anand for their guidance, discussions, feedback, patience and for being extremely supportive. I want to thank IISER-Pune for permitting me to set my study-area for this project within the campus.

I am grateful to Sálim Ali Centre for Ornithology and Natural History (SACON) for providing me with resources and opportunities in the past two years and the Ministry of Environment, Forest and Climate Change (MOEFCC) for providing my scholarship. I would like to thank Dr. Sankar, Dr. Jayapal and Dr. Babu for their guidance and patience with my batch. I would also like to thank the faculty and staff in SACON, Dr. Karunakaran, Dr. Balasubramanian for the unlimited supply of encouragement; Dr. Shomita for guidance and Touki tales; Dr. Kumara for the many interesting discussions on animal behaviour and perceptions of behaviour; Dr. R.P. Singh for his patience and enthusiastically indulging in discussion across varied topics ranging from feather structure and avian endocrine systems post-lectures; and Dr. Shirish for introducing me to cave ecosystems and the edible-nest swiftlet team for the contagious enthusiasm and fascination for cave ecosystems. I am particularly grateful to Dr. Pramod who has been a source of constant encouragement, wise words and a right dose of witty remarks over the past 12 years I have had the privilege to know and learn from him. I also want to thank Kalidas uncle and Sanjay Molur for their support and for encouraging my interests over the years. I sincerely thank Zeeshan and Rutuja for orienting me towards a path when I was lost. And Hugo, for being there for me.

I am grateful for the help and intriguing conversations with Swapna Ray, Pratik, Sethu, Divyapriya and Dhanusha; Abhilasha, for the amazing memories and generous supply of candies, chocolates, humour and support these past two years; and Subhiksha, for comic relief and entertainment. I especially thank all the security staff at SACON for their assistance in navigating through an elephant habitat at night.

This project would not have been possible without the help of members from Dr. Anand's lab; Ram, Suthirtha, Vaibhav, Nafisa, Abhinav and Dr. Rajan lab members: Shikha and Shivam for helping me out throughout the different stages of this project and beyond; Ram for teaching me 'call selection' among many other things that could not have been learnt through a book which has hopefully made me better at differentiating "Kachda calls" from others; Rohit for his feedback and discussions on everything related to bats; and Suthirta and Vaibhav for patiently helping me out with my analysis whenever my brain froze. I also want to wholeheartedly thank the Munje family and the Gupta family for hosting me and taking care of me for the short time I was with them.

I need to thank Rasika and Aditya for giving more clarity to my cluttered thoughts. Rasi especially from saving me from my R codes and for the optimism boost. I also need to thank Deepa aunty for asking me the right questions and organising my words and reasoning. Deepa Aunty and Atul for teaching me card scrabble and Sherlock.

I want to thank my family - Shrinand, Maa, Papa and Sriram for keeping me alive through the series of hospitalisations. Amamma and Thatha for reminding me of my life outside my project. Malini for being a dependable and incredible friend and for being an extraordinarily strong support-system. I cannot thank Diksha enough for keeping me as close to sanity as possible, as well as indulging in and being on par with my unhinged version.

I would like to dedicate my first formal work in this field to Thatha (the Late Lt. Col. I.S. Sundaram) who taught me math, public speaking, reading cricket scores amongst many other things and never gave up on me.

## List of Figures

Figure Title	Page No.
Figure 1.1: Study sites and acoustic transects within IISER campus, Pune, Maharashtra	11
Figure 1.2: Location of the sites of passive acoustic monitoring within the IISER campus, Pune	14
Figure 1.3: Location of passive acoustic monitoring sites and active acoustic transects in the study area	16
Figure 1.4: Call spectrograms	20
Figure 1.5: Overall bat activity in each site with the tree density	21
Figure 1.6: The activity of <i>Pipistrellus tenuis</i> in each site with the respective distance to the nearest large green patch	22
Figure 1.7: The activity of <i>Tadarida aegyptiaca</i> in each site with the respective distance to the nearest green patch	23
Figure 1.8: A boxplot of the total bat activity of all the species in each site with the distance of the detector in each site to bright artificial lighting (floodlights)	24
Figure 2.1: Species activity in the three sites	26
Figure 2.2: Hourly activity of <i>Pipistrellus tenuis</i> in each sampling site	28
Figure 2.3: Hourly activity of <i>Pipistrellus ceylonicus/Scotophilus</i> species group in each sampling site	29
Figure 2.4: Hourly activity of <i>Tadarida aegyptiaca</i> in each sampling site	30
Figure 2.5: Hourly activity of all species in site-1	31
Figure 2.6: The overnight activity of all the species in site-2	32
Figure 2.7: The overnight activity of all the species in site-3	33
Figure 2.8: Activity overlap between <i>Pipistrellus tenuis</i> and <i>Pipistrellus ceylonicus/ Scotophilus</i> species group	34
Figure 2.9: Activity overlap between <i>Tadarida aegyptiaca</i> and <i>Pipistrellus tenuis</i>	35
Figure 2.10: The activity overlap between <i>Tadarida aegyptiaca</i> and <i>Pipistrellus ceylonicus/ Scotophilus</i> species group	36
Figure 3.1: The number of <i>Pipistrellus ceylonicus/ Scotophilus</i> species group calls detected using active (transect) and PAM - Passive Acoustic Monitoring in different sites	38
Figure 3.2: The number of <i>Pipistrellus tenuis</i> calls detected using active (transect) and PAM - Passive Acoustic Monitoring in different sites	39

## List of Tables

Table Title	Page No.
Table 1.1: Summary of the distance between sampling sites	12
Table 1.2: Detector settings used for this study	13
Table 1.3: Summary of sampling time and transect length	16
Table 1.4: Summary of bat species guild and acoustic parameters	19
Table 1.5: Summary of vegetation parameters collected	20
Table 2.1: The number of detections for each species in the three sampling sites	27
Table 2.2: Detection of <i>Hipposideros speoris</i>	30
Table 3.1: The overall bat call detected using active (transect) and PAM - Passive Acoustic Monitoring in different sites	37
Table 3.2: The number of <i>Tadarida aegyptiaca</i> and <i>Hipposideros speoris</i> calls detected using active (transect) and PAM -Passive Acoustic Monitoring	39

## Contents

List of Figures .....	v
List of Tables .....	vi
Summary .....	ix
1. INTRODUCTION .....	1
1.1 BACKGROUND .....	1
1.1.1 Urban Ecology .....	1
1.1.2 Overnight Activity Patterns of Bat Species. ....	2
1.1.3 A Comparison between Active and Passive Acoustic Surveys in an Urban Area. ....	3
1.2 OBJECTIVE .....	5
1.3 LITERATURE REVIEW .....	6
1.3.1 Factors Influencing Bat Activity .....	6
1.3.2 Variation in Activity of Species .....	7
2. STUDY AREA: .....	9
3. METHODS.....	12
3.1 STUDY DESIGN.....	12
3.1.1 Passive Acoustic Monitoring.....	12
3.1.2 Active Acoustic Sampling .....	15
3.2 ACOUSTIC ANALYSIS.....	17
3.2.1 Overnight Species Activity .....	17
3.3 STATISTICAL ANALYSIS .....	17
3.3.1 Factors Influencing Bat Activity .....	17
3.3.2 Overnight Species Activity .....	18
3.3.3 Comparison of Active and Passive Acoustic Monitoring Methods.....	18

4. RESULTS.....	19
4.1 BAT SPECIES DETECTED.....	19
4.1.1 Species Call Spectrogram.....	20
4.2 FACTORS INFLUENCING BAT ACTIVITY.....	20
4.2.1 Effect of Vegetation on Bat Activity.....	20
4.2.2 Effects of Urban Lighting on Bat Activity.....	24
4.3 SPECIES ACTIVITY.....	26
4.3.1 Hourly Species Activity.....	28
4.3.2 Estimation of Species Activity Overlap.....	34
4.4 COMPARISON OF ACOUSTIC SAMPLING METHODS.....	37
5. DISCUSSION.....	41
5.1 FACTORS INFLUENCING BAT ACTIVITY.....	41
5.2 SPECIES-WISE OVERNIGHT ACTIVITY.....	45
5.3 EFFECTIVE ACOUSTIC SAMPLING METHOD.....	46
6. REFERENCES.....	48

## Summary

The increase in urbanisation over the years has affected wildlife and negatively impacted their habitats. The impact of urbanisation can be at a global-scale such as carbon emissions from cities and at a regional-scale like the effects of urban sprawl on the neighbouring habitats and species. The effect of urbanisation is often documented as negatively influencing wildlife. Although urbanisation does have a negative impact on different species, some species have learnt to tolerate and even thrive in human habitations. Such species-specific responses to different urban areas dictate which species dominate the urban ecosystem.

The aim of this study was to provide information about bat activity in urban green spaces, to understand what factors influence bat activity, to know the species-specific responses to urbanisation parameters and test the effectiveness of active and passive acoustic survey methods in an urban landscape. This study was conducted between January 2020 and February 2020. To understand the use of these green spaces by different species, variables such as green space area, edge perimeter of green space, distance to main road and distance to floodlights and vegetation parameters including canopy height, canopy cover, species richness, tree density, floristic composition of trees and shrubs, phenological state of trees and shrubs were obtained during the sampling period.

I found 3 species *Pipistrellus tenuis*, *Hipposideros speoris*, *Tadarida aegyptiaca*, and a species group *Pipistrellus ceylonicus* or *Scotophilus species* during the period of this study. There was a difference in the number of detections of bats between the study sites. From personal observations, bats foraging around floodlights in one of the sites evidently increased the bat activity in the area. The influence of vegetation parameters on bat activity was not conclusive. Size of a green patch might have an influence on the activity of *P.tenuis*. This study highlights the first information on 'light-opportunistic' bats in India. *Pipistrellus tenuis*, *Tadarida aegyptiaca*, and the species group *Pipistrellus ceylonicus* /*Scotophilus species* seem to be well-adjusted to the urban environment. It is necessary to note that although artificial lighting at night seems to positively influence the activity of these species, it could deter other 'light-shy' or 'light-averse' species which were not detected during this study. Activity patterns vary between species and the overlap is higher between the *P. ceylonicus* /*Scotophilus species*

group and *P. tenuis* than with *T. aegyptiaca*. Active monitoring (transects) detects *P. tenuis* well but misses out on rare species and underestimates *T. aegyptiaca* and *P. ceylonicus* / *Scotophilus*. The findings of this study are preliminary further studies are required to understand species-specific responses to urbanisation.

# 1. INTRODUCTION

## 1.1 BACKGROUND

### 1.1.1 Urban Ecology

Globally, expansion in urbanization has been one of the major shifts in the land-use pattern. The influence of urbanization on wildlife has mostly been negative due to the significant reduction in natural habitats and the introduction of new conditions including pollution, noise level, artificial lighting and increased temperatures, which poses a threat to many animals (Grimm *et al.*, 2008). As the boundaries of urban landscape expand, bringing the interface space of humans and wildlife closer, urban reconciliation efforts attempt to identify habitats or modify anthropogenic spaces such as to provide habitats for wildlife within human-dominated landscapes (Rosenzweig & Michael, 2003).

It is well-known that space constraint has become a universal problem. With the ever-increasing human population and its growing demand, it has become increasingly difficult to set aside undisturbed natural habitats for conservation. Resulting in the destruction of many habitats to support human communities and their needs or depriving a local human community by preserving a habitat. Either way, one side often wins while the other loses. Reconciliation ecology works a different approach to this on-going battle by providing a habitat for both wildlife and humans. Its concept stems from the idea that small habitats within a human-dominated landscape can be improved to host wildlife.

Green areas within cities are known to harbour a lot of wildlife (Avila-Flores & Fenton, 2005). Conserving wildlife in these urban pockets is a pragmatic approach towards conservation as they not only provide a habitat for resident species but also act as stepping stones that connect habitats in a human-dominated landscape. Hence, understanding urban green spaces and their impact on wildlife during rapid urbanization becomes crucial for the conservation of species and biodiversity.

Bats have long been coexisting with humans (Voigt & Kingston, 2016). Bats being nocturnal and crepuscular animals are model systems to study how urban landscapes at night influence wildlife. They are one of the most abundant and diverse groups of mammals with different species responding differently to urbanisation. While some adapt well, others are threatened

because of anthropogenic changes to the landscape (Hutson *et al.*, 2001; Russo, & Ancillotto 2015). Research shows that more than phylogenetic relationships, its the behavioural and functional morphology that dictate the extent to which a species can adjust to a changing human landscape and the levels of urbanisation intensity that allows them to thrive and when it prevents any species from surviving. Therefore, understanding the urban landscape and its impact on different species of bats is essential. As bats show species-specific responses this makes them an ideal bio-indicator to track changes of land-use over time (Watts *et al.* 2006; Kerth & Melber 2009; Jones *et al.*, 2009; Stahlschmidt & Brühl, 2012).

### **1.1.2 Overnight Activity Patterns of Bat Species.**

Urban ecosystems pose many challenges including higher predation risk, limited habitat for foraging and roosting, anthropogenic noise, pollution, warmer temperature, and diseases. (Voigt, *et al.*, 2016). Secondly, animals are limited by different morphological, physiological and behavioural constraints that make adjusting to urban ecosystems difficult ensuring that only a few species dominate this ecosystem. Urban ecosystems have often shown reduced diversity and dominance by a handful of species that have adapted well in human-modified landscapes (Tzortzakaki, *et al.*, 2019).

The time of emergence varies for each species. Broadly, the temporal activity of animals are categorised into diurnal, crepuscular and nocturnal (Bennie *et al.*, 2014). Further degrees of temporal partitioning occurs when the time of emergence of each species varies. Bats are broadly classified as nocturnal and each species has a different time of emergence: at dusk, after midnight, before sunrise. These patterns are influenced by various regional factors including prey availability, temperature, noise, competition and predation risk. (Rydell *et al.*, 1996; Ostwald & Siemers 2008; Siemers & Schaub 2010).

Urban landscapes often have a limited area available for foraging. This increases competition for resources. Species that are in the same foraging guild are likely to have higher competition. Temporal partitioning is one mechanism which animals use to reduce competition. Observing the temporal patterns of bat activity will reveal the behavioural characteristics that allow species to coexist in this ecosystem.

### **1.1.3 A Comparison between Active and Passive Acoustic Surveys in an Urban Area.**

Acoustic surveys can record species richness and activity levels and are very useful, especially for nocturnal taxa like bats, which can have cryptic species and cannot be detected easily otherwise. Acoustic detectors can also be deployed and can store large quantities of data, which makes it effective for monitoring of biodiversity. Additionally, acoustic monitoring is a non-invasive approach to monitor wildlife. Acoustic monitoring can broadly be of two types- active, where the observer is present along with the detector and is generally mobile and passive, where the detector is deployed and the observer is not present during the sampling (USFWS 2014). The active acoustic monitoring surveys can be done either using a vehicle or on foot where the observer covers a certain distance within a particular time. One of the main benefits of this method is that it covers a larger area for monitoring. However, this can also be a drawback as this large area is covered within a short duration of time and hence does not capture the diversity and the pattern of activity.

Passive acoustic monitoring (PAM) does not cover a larger area, but it captures variation over time and has been proven to be better at capturing diversity, including the rare species than active acoustic surveys (Coleman *et al.*, 2014; Braun de Torrez *et al.*, 2017; Teet *et al.*, 2019). One study (Johnson *et al.*, 2002) that contradicts this detection rate reasons that the rate of recording and storing of acoustic data on a tape-recorder (passive detector) and compares it with that of a computer (active detector connected to the computer). It needs to be noted that the equipment used these days are more advanced and the appropriate data transfer rate of the memory cards resolves this issue.

This study aims to document the variations in the activity of different species in urban areas, to understand what factors influence bat activity, to know the species-specific responses to urbanisation parameters and test the effectiveness of active and passive acoustic survey methods in an urban landscape to inform conservation planning and monitoring in urban areas.

In countries like India, where urban sprawl is growing at a rapid pace, information on urban wildlife and planning has become increasingly important. Green spaces in urban areas provide

habitats for wildlife (Rosenzweig & Michael, 2003) and are one of the few spaces that can be managed in urban areas to improve these habitats to accommodate more wildlife.

## 1.2 OBJECTIVE

1. To understand the distribution of insectivorous bats within the green spaces in an urban matrix in order to answer the following questions:

- a) How are patterns of bat detections influenced by vegetation structure? and

- b) How does the presence of artificial lighting at night influence bat detections?

2. To observe the activity pattern of insectivorous bats overnight in different species.

How does bat activity vary overnight in different species?

3. To determine the most effective survey method for detecting insectivorous bats in an urban area.

How does the detection of bat species vary in active and passive acoustic surveys?

## 1.3 LITERATURE REVIEW

### 1.3.1 Factors Influencing Bat Activity

Vegetation areas (green spaces) offer prey and hence function as foraging grounds. Therefore, they are an essential factor in structuring the bat assemblages (Avila-Flores & Fenton, 2005). Vegetation structure is one such factor that affects bat diversity (Lintott & Park, 2015; Kalko & Handley, 2001). Vegetation structure is known to influence insectivorous bats more than vegetation composition. Canopy cover, canopy height, tree density, bushland size are some of the variables that generally have a positive influence on bat diversity and activity (Kalko & Handley, 2001; Basham *et al.*, 2010; Parkins & Clark, 2015; Moretto & Francis, 2017; Rodríguez-Aguilar *et al.*, 2017; Gallo *et al.*, 2018; Straka *et al.*, 2019). The availability of water bodies and distance to water bodies from foraging grounds are known to attract many bat species, thereby increasing the species richness of bats in and around water bodies (Vaughan *et al.*, 1997; Lintott & Park, 2015). It is because of their flying requirements and physiology that bats tend to lose more water from their bodies (Chew & White, 1960).

It is well-known that urban landscapes are often well-illuminated after sunset. Lighting is a critical component to urban environments and this also alters the habitat for wildlife in urban areas. Stone *et al.* (2009) found that the impact of street lighting on bats varied between species. They observed that while some species avoided using well-lit spaces, a few species preferred to forage near well-illuminated spaces by preying on insects that were attracted to the artificial light.

Within urban landscapes, Siemers and Schaub (2010) and Ostwald and Siemers (2008) observed that traffic noise seems to affect the foraging ability of bats. It was found that traffic noise overshadowed the acoustic signature of prey, thereby making the detection of prey by eavesdropping-bats increasingly difficult in urban landscapes. Another study that looked at traffic as an influencing factor found that bats avoid areas where the amount of traffic volume in terms of the number of vehicles being used in the area is high (Zurcher *et al.*, 2010). Berthinussen and Altringham (2012) provided further support for this negative interaction of roadways and bat diversity and observed that bat diversity was lower closer to major roads and increased with the distance from them.

Several related studies are available explaining the different urban variables that affect bat diversity. However, most studies isolate a determinant and study its influence on bats. Only a few studies looked at green spaces and the effect of all the determinants in relation to each other. Green spaces within the cities can be managed effectively to make urban landscapes a better habitat for bats. Further studies on factors affecting bats within these green spaces are required. Based on the literature surveyed, the present study was designed to understand the distribution of bats within such green spaces in the urban landscape.

This study generates a basic understanding of the factors affecting insectivorous bat activity in urban green spaces. Green spaces are defined as any patch or strip of vegetation such as gardens, public parks or roadside vegetation. This study also helps to understand a little about the habitat requirements of different bat species within cities, specifically, in developing tropical countries like India. Since urban green spaces are one of the few spaces in the city that can be altered and managed, the information generated can be directly used to manage green spaces better to provide more suitable foraging habitat for bats in urban landscapes. There are a few studies around the world that try to understand how urban landscapes affect bats and fewer still that look at green spaces within the cities that might inform urban green spaces can be improved to form better habitats. This study looks at the factors influencing bat activity in urban green spaces and how such responses vary between species.

### **1.3.2 Variation in Activity of Species**

Species tend to have different temporal activity patterns as a response to temperature, prey availability, competition, noise, species-specific behaviour, and predation risk (Rydell *et al.*, 1996; O'Farrell & Bradley, 1970; Schaub *et al.*, 2008; Siemers & Schaub, 2010; Schimpp *et al.*, 2018). Predation risk is often inter-linked with daylight hours. The decrease in daylight also decreases the risk of predation from diurnal predators who use visual cues to locate and capture prey. Morphological constraints on wing and body weight dictate the flight patterns of different species such as fast and slow flight speed and agility, this influences the risk of predation by avian predators. These risks are different for each species. Research shows that in islands, in the absence of avian predators, certain species of bats tend to be diurnal (Russo *et al.*, 2011). Hence, temporal activity in bats seems to be influenced by predators.

The availability and type of insect prey also play a crucial role in the patterns of bat activity. Foraging guilds such as aerial or trawling insectivore, flutter-detecting insectivore and gleaning insectivore influences insect prey selection (Denzinger *et al.*, 2016). Therefore, the emergence of bat species varies with the foraging guild and type and availability of insect prey (Jones & Rydell, 1994).

Urbanisation effects such as an increase in temperature and traffic noise are also known to influence the activity of bats. Warmer temperatures are known to increase activity levels of animals. Cities are warmer than non-urban landscapes as anthropogenic changes increase the heat in an area this is often referred to as the 'urban heat effect' (Voigt *et al.*, 2016). Noise from human activities is a unique issue found only in urban and other human-modified environments. The effects of noise on wildlife have generally been negative as the species either try to avoid the area with noise (Siemers & Schaub, 2010) or alter their behaviour by calling at a different frequency (Slabbekoorn & Peet, 2003) or at a different time (Fuller *et al.*, 2007) or increase the amplitude of their call (Brumm, 2004). The latter is also known as the 'Lombard effect' (Lombard, 1911; Zollinger *et al.*, 2011). These responses have been documented in birds (Slabbekoorn & Peet, 2003; Fuller *et al.*, 2007) and mammals (Parks *et al.*, 2007; Schaub *et al.*, 2008; Siemers & Schaub, 2010; Schimpp *et al.*, 2018). The effects of urbanisation on bats can vary regionally and are more studied in temperate regions and developed countries (Voigt *et al.*, 2016) with very little known in the tropics and developing countries. This study was conducted in Pune city as it is one of the most populous cities in India and has a call library to aid acoustic identification of bats.

## 2. STUDY AREA:

This study was conducted in Pune city. Pune is the second-largest city in Maharashtra, India. It is the ninth most populous city in India, with a total human population in the district equaling to 9426259 (District Census Department Population Data, 2011). This city is considered important for its economic and industrial growth and is also viewed as culturally significant. It lies at an average of 600 m above sea level. This district receives an average rainfall of 650 mm. The daily temperatures during winter vary between 8°C and 25°C (Government Of India <<https://pune.gov.in/>>).

Previous surveys conducted were related to bat diversity in and around Pune. They do not look at bats in green spaces within an urban context but provide baseline information on the diversity of bat species in the region. One survey estimates nine species of bats from in and around Pune, of which three are Megachiroptera and the rest belong to Microchiroptera. The Microchiroptera bat species include; Schneider's Leaf-nosed Bat (*Hipposideros speoris*), Egyptian Free-tailed Bat (*Tadarida aegyptiaca*), Asiatic Greater Yellow House Bat (*Scotophilus heathii*), Kuhl's Pipistrelle (*Pipistrellus kuhlii*), (*Pipistrellus tenuis*), (*Pipistrellus ceylonicus*) (*Anand lab call library*), Savi's Pipistrelle (*Hypsugo savii*) and Greater False Vampire (*Megaderma lyra*). The Megachiroptera bat species include; Fulvous Fruit Bat (*Rousettus leschenaultia*), Greater Short-nosed Fruit Bat (*Cynopterus sphinx*) and Indian Flying Fox (*Pteropus giganteus*) (Gaikwad *et al.*, 2012). These bat species recorded are not protected under the Wildlife Protection Act of India (1972).

IISER campus in Pune has an area of 98 acres. The vegetation spaces in the study site are diverse, ranging from small ornamental gardens, lawns to patches of natural vegetation occurring in stretches along road and path edges.

Three bat detectors (SM4BAT FS) were deployed and set to record simultaneously at the three sites (one detector at each site). Detectors were placed at three sites within the institute and set to record overnight for 12 hours from sunset to sunrise, to study the influence of factors affecting bat activity (USFWS 2014). Three night-replicates were done to collect 12 hours of data from each site for each night. The detectors were set to record between 6:00 PM to 6:00 AM on the first night, and 7:00 PM to 7:00 AM on the second and third night replicates. The

timing was changed because the data from night one did not show any bat activity around 6:00 PM. These sampling sites were selected based on a pilot sampling session in the green spaces available in IISER campus.

Site-1 is a relatively undisturbed green patch along the roadside with ornamental bushes and a few trees along one side and overgrown, dense, dry undergrowth inside the patch. However, this patch is not a disconnected green patch. It is adjacent to a larger green patch in a neighbouring campus which is covered with trees and undergrowth on both sides of the road. The species of plants found within the sampling site include Dwarf poinciana (*Caesalpinia pulcherrima*) and Gum Arabic tree (*Acacia nilotica*). Some of these plants were fruiting and flowering during sampling. *Prosopis juliflora* and *Tecoma stans*, ornamental bushes Copper-leaf (*Acalypha wilkesiana*) were seen in the vicinity and long dried grass covered the ground. The coordinates of the location of the sampling were Latitude: 18° 32' 21.732" N and Longitude: 73° 48' 31.14" E.

Site-2 is a maintained lawn lined with ornamental plants like Copper-leaf (*Acalypha wilkesiana*) and Royal Palm (*Roystonea regia*) on one end. It also has floodlights that are near a flag post. These floodlights attract a lot of insects, which in turn attracts bats in the area. It is an open area with short grass. The coordinates of the location of sampling were Latitude: 18° 32' 52.188" N and Longitude: 73° 48' 22.247" E.

Site-3 predominantly has teak trees arranged in rows. The ground is generally covered in leaf litter or grass. There are a few bamboo stumps and neem (*Azadirachta indica*) in the vicinity. Most of the plants were vegetative and not flowering or fruiting during sampling. The coordinates of the location of sampling were Latitude: 18° 32' 56.184" and N Longitude: 73° 48' 22.859" E.

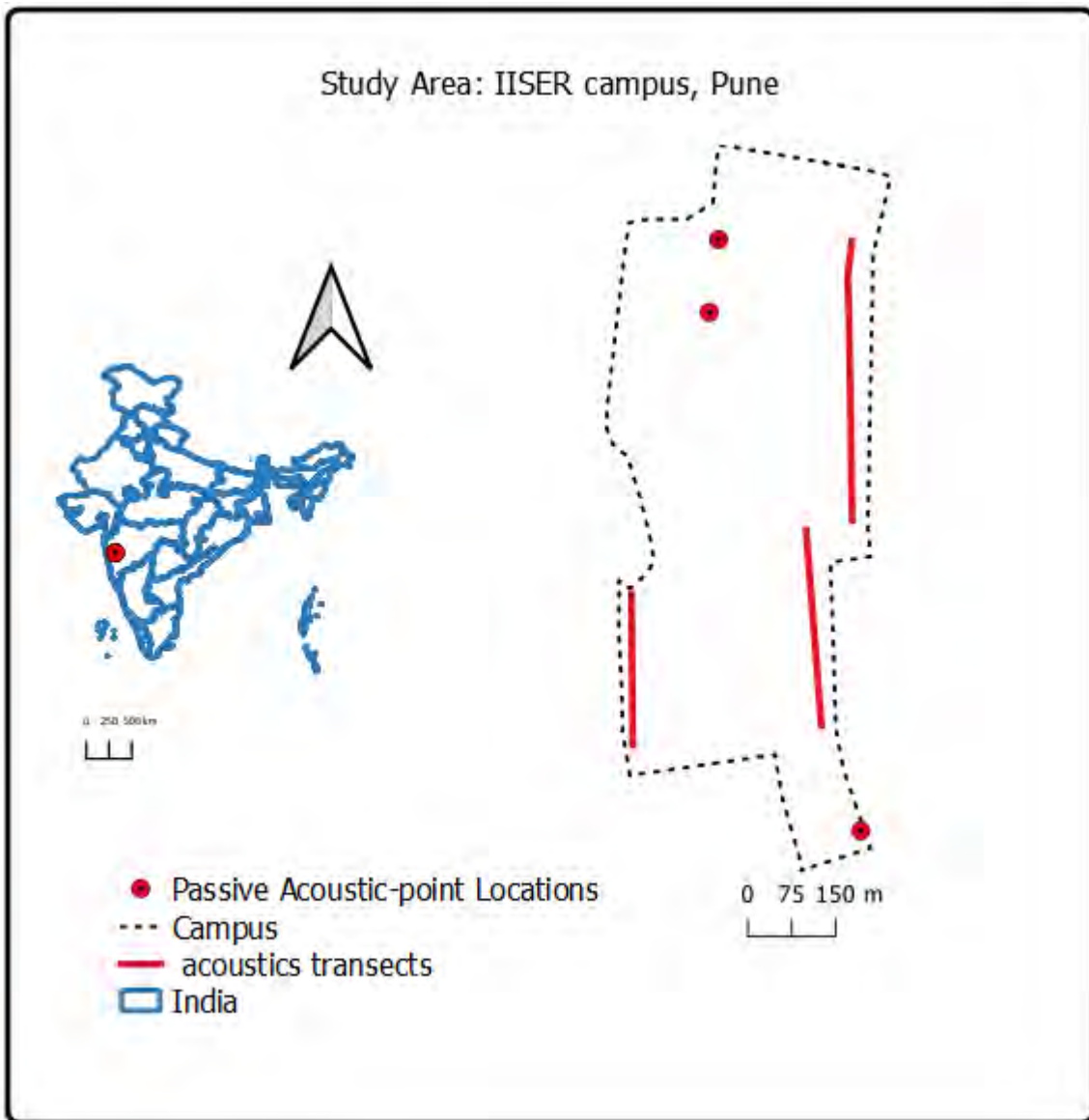


Figure 1.1 Study sites and acoustic transects within IISER campus, Pune, Maharashtra. Map created using QGIS and Google Earth Pro.

### 3. METHODS

Bat species in the green spaces within IISER campus in Pune city were recorded using bat detectors (SM4BAT FS). Data was collected using passive acoustic monitoring (PAM) and active acoustic sampling (transects). Acoustic data was collected to identify bat species and activity in the study sites. Data from PAM was used in the analysis of factors influencing bat activity and overnight activity patterns of species. Data from PAM and active acoustic sampling were used to compare the methods.

#### 3.1 STUDY DESIGN

##### 3.1.1 Passive Acoustic Monitoring

The acoustic sampling was done in green spaces for which three sites were chosen for passive acoustic monitoring. Three bat detectors (SM4BAT FS) were deployed and set to record overnight simultaneously at the three sites (one at each site). The detectors were attached to trees or a pole at a height of 1.6 m above ground (USFWS 2014). Three repetitive sampling sessions were done per sampling site to replicate the acoustic sampling. The passive acoustic monitoring point counts were done during the dates 27th, 28th and 29th January 2020. Seventy-two hours of data were collected for each of the three sites. A total of Two hundred and sixteen hours of point count data (PAM) was collected. Out of which, seventy-two (Twenty-four hours of data from each site) was used for analysis.

The distances between the sampling sites are given in Table 1.1.

The distance between site-1 and site-2	970 m approximately
The distance between site-2 and site-3	131 m approximately
The distance between site-1 and site-3	1900 m approximately

Table 1.1: Summary of the distance between sampling sites.

For passive acoustic monitoring, the bat detectors (Model: SM4BAT) were placed at the sampling site on a tree or a pole to record calls of different bat species from dusk to dawn. The equipment was set to record for a minute with a 4 minutes interval.

SM4Bat (FS) settings used:

Start time	1800 hours on 27th January 2020 1900 hours on 28th January 2020
End time	0700 hours
Gain	12 dB
Trigger level	6 Db
Trigger window	1 second
Trigger frequency	16 kHz
Sampling rate	384
Minimum duration	1.5 ms
Raven Pro setting	Default window frame 512

Table 1.2: Detector settings used for this study.

Vegetation Data: Vegetation plots were laid within a 15 m diameter circular plot with the bat detector placed as the centre. The vegetation plot included the collection of the following data: Canopy height, canopy cover using a mobile app (CanopyApp version 1.04 - University of New Hampshire), tree and shrub density within the 15 m plot, the composition of trees and shrubs and their current state of phenology were recorded. The evaluation of phenology of the trees and shrubs was repeated on the days of acoustic sampling.

The size of the green space, the edge perimeter of green spaces, was calculated using Google My Maps and Google Earth Pro (version 7.3).

Urbanisation Parameters: The distance to the main road from the sampling sites and distance to floodlights were estimated using Google My Maps and Google Earth Pro (version 7.3).

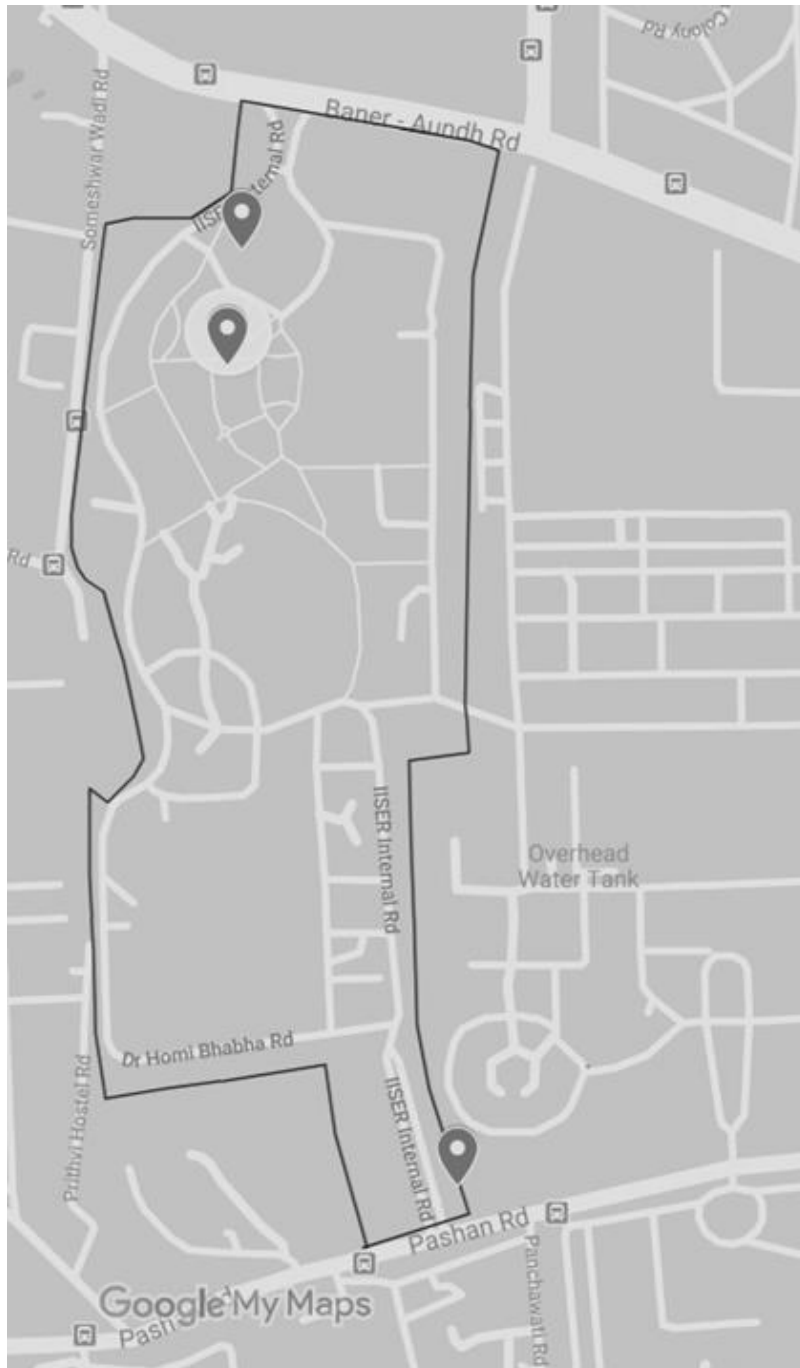


Figure 1.2: Location of the sites of passive acoustic monitoring within the IISER campus, Pune. Created using Google My Maps.

### 3.1.2 Active Acoustic Sampling

Active surveys are defined as acoustic surveys where an observer moves around with the bat detector whereas, in PAM, the bat detectors are stationary as they are attached to poles or trees at a height of 1.6 meters above ground level and not being held by the observer (Coleman *et al.* 2014). The study area (IISER campus) is a very open space with a very sparse canopy. Therefore, no separate detectors were placed for recording at canopy height as high flying bats could be detected with the same detectors in the open environment.

Three transects were selected and seven replicates were done for each of these transects (Figure 1.3). These transects were laid after a pilot survey. The transect surveys were conducted during the following days 25th January 2020, 3rd February 2020, 4th February 2020, 5th February 2020 and 8th February 2020. Transect data collected sum up to Two hundred and ten minutes in total. Out of which, ninety minutes of data was used for analysis (Table 1.3).

For active acoustic monitoring, each transect was walked while holding a bat detector (Model: SM4BAT FS). These transects were walked slowly with the detector microphone angled slightly upwards, to record the bat calls from all directions. The surveys were conducted between 7:00 PM and 9:00 PM. This time period was chosen as the pilot survey showed a dip in the first bout of bat activity post 9:00 PM.

The bat detectors were set to record from dusk to dawn for 12 hours (from 7:00 AM to 7:00 PM). Out of which 90 minutes of data was used for comparison. The subsampling was done within the time period of 7:00 PM to 9:00 PM to account for the influence of time and match the sampling effort (number of minutes). In this study, a single “bat pass” is defined as a series of pulses recorded within a timeframe of 1 minute. Any bat pulses that were more than a minute apart were considered a separate bat pass. The detector was set to trigger at or above 18 kHz and record for a minute, thereby making one-minute files. The detector setting used is presented in table 1.2.

Transects	Distance	Sampling date	Sampling time
T1	352 m	04-02-2020	1915 hrs to 1925 hrs & 2019 hrs to 2029 hrs
T2	271 m	04-02-2020	1857 hrs to 1915 hrs & 2030 hrs to 2040 hrs
T3	504 m	25-1-2020 & 3-2-2020	1959 hrs to 2023 hrs & 1900 hrs to 1918 hrs

Table 1.3: Summary of sampling time and transect (active acoustic) length.



Figure 1.3: Location of passive acoustic monitoring sites and active acoustic transects in the study area.

## **3.2 ACOUSTIC ANALYSIS**

All acoustic data was visualised in Raven Pro software (version 1.5, Cornell Laboratory of Ornithology, Ithaca, NY, USA). The peak frequency and call type (CM, FM, QFM) in the recordings were compared to an existing call library (Krishnan Lab) to identify bat species. The number of detections (number of bat passes) and the presence and absence of bat calls in the recording were sub-sampled in each hour for the entire night at all sites. The sub-samples of 5-minute intervals used for analysis were 0-5 minutes, 15-20 minutes, 30-35 minutes, 45-50 minutes (Krishnan, 2019). Data from PAM was used to analyse data in analysis of: 1. Determinants of bat activity and 2. Overnight activity patterns and 3. To compare between methods. Active acoustic data (transect) was used only to compare between the methods.

In this study, bat detections are the number of bat passes. Bat pulses recorded within a minute are considered as a single bat pass. Bat pulses recorded with a one-minute gap in between them were considered as two separate bat passes.

### **3.2.1 Overnight Species Activity**

The overnight recordings from the passive acoustic data were used to analyse the species-wise overnight activity patterns. The detections of bat passes were classified into different species by comparing the call type and peak frequency with an existing call library (Dr. Anand Krishnan Lab). The number of bat passes and presence and absence data were collected within these sub-sampling intervals: 0-5 minutes, 15-20 minutes, 30-35 minutes, 45-50 minutes (Krishnan, 2019).

## **3.3 STATISTICAL ANALYSIS**

### **3.3.1 Factors Influencing Bat Activity**

The number of bat detections data points from each site were bootstrapped to create 500 data points per site. The bat detections data on site-3 was not normal. The Kruskal-Wallis test (Hollander & Wolfe, 1973) was used to analyse the difference in mean detections between sites. Visualisation using bar graphs was done to investigate the pattern between bat detections and vegetation and urbanisation parameters. Non-parametric analysis Kruskal-Wallis test was done using the R studio (Version 3.6.1 R core team).

### **3.3.2 Overnight Species Activity**

For visualising the activity patterns, the number of detections (number of bat passes) was used. Visualisation using line and bar graphs was done to visualise the overnight activity patterns of each species. The number of detections was summed hourly from all the temporal replicates for each site and species. This data was plotted against time.

Species Overlap Estimation: For the estimation of species activity overlap, the presence data was used. The overlapping activity coefficient Delta-hat ( $\Delta^{\wedge}$ ) was estimated. The value of delta hat (D-hat) ranges from 0 to 1. The value closer to zero indicating less overlap and the value closer to one indicating high overlap of species activity. The estimation of activity overlap between species was done using the R studio (Version 3.6.1 R core team) using the overlap package.

The overlap package is based on fitting kernel density functions to the timing of animal detections and is usually used on camera trap data. This method was presented by Ridout and Linkie (2009) (Meredith & Ridout, 2020).

### **3.3.3 Comparison of Active and Passive Acoustic Monitoring Methods**

The preliminary analysis to compare the methods (active and passive acoustic) was done using bar graphs. The number of detections from the temporal and spatial replicates was summed from transect data for each species to compare with similarly combined data from passive acoustic monitoring. For comparing with passive acoustic survey data, the time of the detections was subsampled from the passive acoustic data to a similar time frame from 7:00 PM to 9:00 PM. Such that the sampling time between both methods compared was similar in terms of sampling effort (minutes of recording). However, the active acoustic monitoring data and passive acoustic monitoring data were not collected simultaneously on the same days and were collected a few days apart, this might have an effect on the results.

## 4. RESULTS

### 4.1 BAT SPECIES DETECTED

I obtained 2434 total bat passes from 72 hours of data from all the three sites using Passive Acoustic Monitoring (PAM). A total of three bat species and one species group were identified. These were Least Pipistrelle (*Pipistrellus tenuis*), Schneider's Leaf-nosed Bat (*Hipposideros speoris*), Egyptian Free-tailed Bat (*Tadarida aegyptiaca*), and a species group which could either be another species of *Pipistrellus ceylonicus* or a *Scotophilus species*. Two species and one species group were identified in all the three sites. *Hipposideros speoris* was detected only on two occasions, once on site-1 and site-2. Summary of the foraging guild and foraging habitat type of the bat species detected and their acoustic parameters are provided in Table 1.4.

Common name	Scientific name	Foraging guild	Foraging habitat type	Av. Peak freq. (Hz)	Min. peak freq. (Hz)	Max peak freq. (Hz)	Total call pulses
Least Pipistrelle	<i>Pipistrellus tenuis</i>	Aerial/trawling insectivore	Open area & edge	50000.1	47500		
Schneider's Leaf-nosed Bat	<i>Hipposideros speoris</i>	Flutter-detecting insectivore	Cluttered space & edge	123916.67	123000	125250	10
Egyptian Free-tailed Bat	<i>Tadarida aegyptiaca</i>	Aerial insectivore	Open area	18173.08	17250	24000	27
Kelaart's Pipistrelle / yellow Bat	<i>Pipistrellus ceylonicus</i> / <i>Scotophilus species</i>	Aerial insectivore	Open area & edge	36300.3	31500	45750	737

Table 1.4: Summary of bat species guild and acoustic parameters. Guild information from Denzinger *et al.* (2016)

### 4.1.1 Species Call Spectrogram

The call spectrogram of these bat species Least Pipistrelle (*Pipistrellus tenuis*), *Pipistrellus ceylonicus*/ *Scotophilus* species group and Schneider’s Leaf-nosed Bat (*Hipposideros speoris*) were observed (Figure 1.4.)

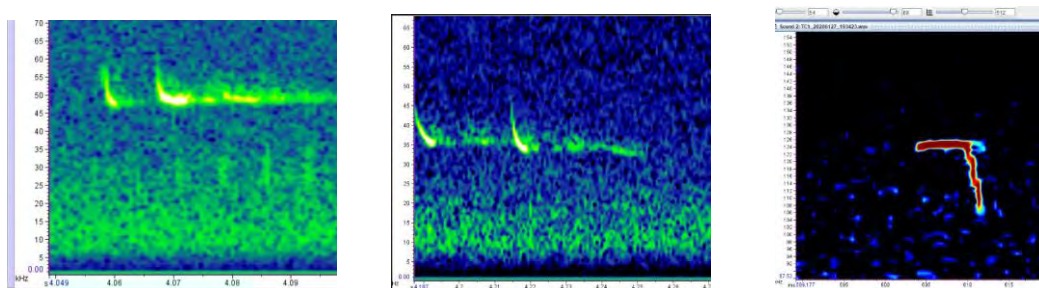


Figure 1.4: Call spectrogram of (from left to right) *Pipistrellus tenuis*, *Pipistrellus ceylonicus*/ *Scotophilus* species group and *Hipposideros speoris*. Image for representation only.

## 4.2 FACTORS INFLUENCING BAT ACTIVITY

### 4.2.1 Effect of Vegetation on Bat Activity

The results show that the influenced by vegetation parameters such as vegetation species richness and canopy height on bat activity was inconclusive at the scale of sampling that is, 15 m radial plots (Table 1.5). However, the presence of artificial lighting such as bright floodlights seemed to have influenced the bat activity in site-2 (lawn).

Vegetation parameters	Site 1	Site 2	Site 3
Canopy cover	24.25%	0.25%	35%
Canopy height	5.75 feet	1.5 feet	4 feet
Leaf litter	100%	6%	74.50%
Bush species richness	4	4	3
Tree species richness	4	1	4
Total bat detections	712	1419	303

Table 1.5: Summary of vegetation parameters collected within a circular plot of 15 m diameter around the detectors in each site.

Studies show that vegetation structure influences bat activity in natural and urban ecosystems positively (Kalko & Handley, 2001; Basham *et al.*, 2010; Threlfall *et al.*, 2012). However, another study reported that vegetation cover did not influence the bat activity in

areas of varying degrees of urbanisation (Tzortzakaki *et al.*, 2019). In this study, exploratory analysis using bar graphs and boxplot were made to observe patterns of bat activity and individual vegetation parameters. The data from Table 1.5 was also included in this analysis. Considering that there were only three sampling sites and therefore only three data points, no clear patterns in bat activity was observed (Figure 1.5). Perhaps, increasing the number of spatial replicates might provide insights into the influence on bat activity. In this study, the number of spatial replicates (sampling sites) did not bring out any patterns that could suggest the influence of vegetation parameters on bat activity and thus was inconclusive.

Effect of tree density on overall bat detections: Although the number of trees is higher in site-3 (24 trees), the bat activity was the lowest in that site. The bat activity was highest in site-2 which has 7 trees, followed by site-1, which has 3 trees. Looking at the data and the pattern obtained the influence of the number of trees on bat activity was inconclusive.

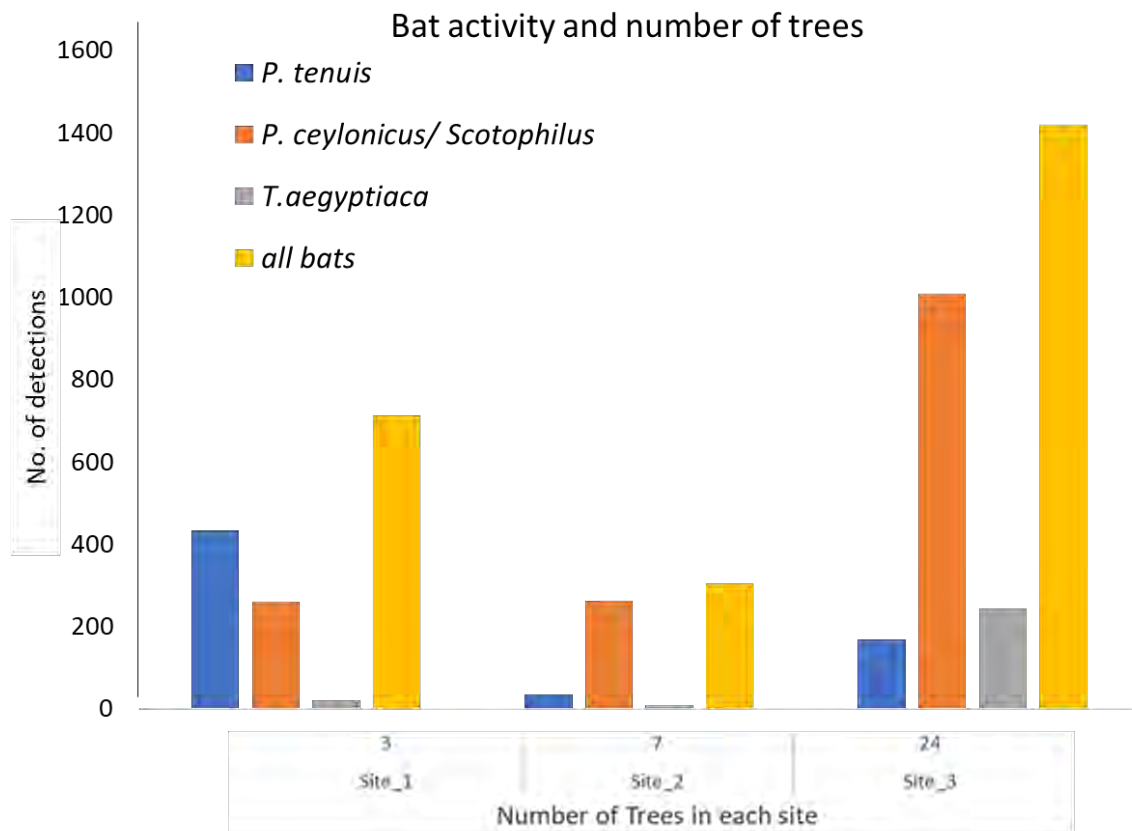


Figure 1.5: Overall bat activity and the number of trees in each site. The values indicated below the bar represent the number of trees.

Effect of distance to the nearest largest green patch on *Pipistrellus tenuis* detections: *P. tenuis* was detected the most in site-1 (Figure 1.6), which is adjacent to a large green patch. However, this pattern of distance from a large green patch does not entirely apply to all the sites as the detections in site-3, which is closer to a large green patch, is lower than in site-2, which is slightly away from a large green patch. It is probably because site-2 has artificial lighting that increases the activity of *P. tenuis* and other bat species in the area.

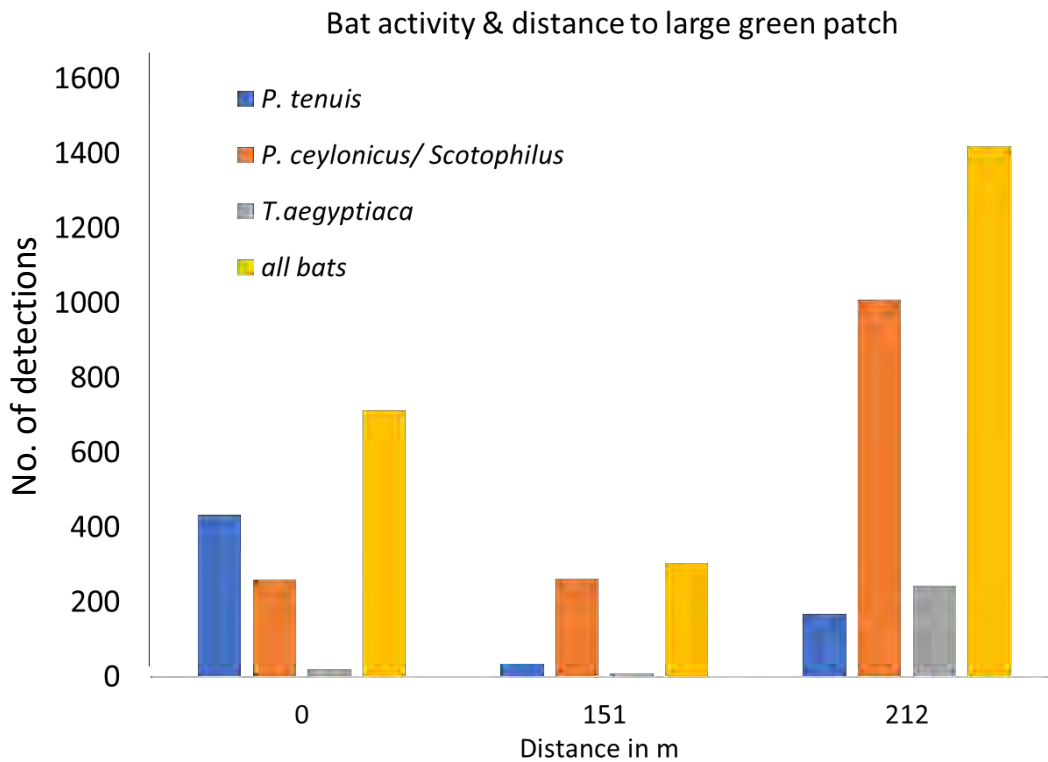


Figure 1.6: The activity of each species in each site with the respective distance to the nearest large green patch from each site indicated below the bar. The values above the bar indicate the distance to the nearest large green patch.

Effect of the distance to the nearest green patch on *Tadarida aegyptiaca* detections: *Tadarida aegyptiaca* was detected the most in site-2, which has the shortest distance to a neighbouring green patch than site-1 and site-3 (Figure 1.7). However, the scale in the distance is very small, and the difference between the distances is also too small to influence the activity of this species.

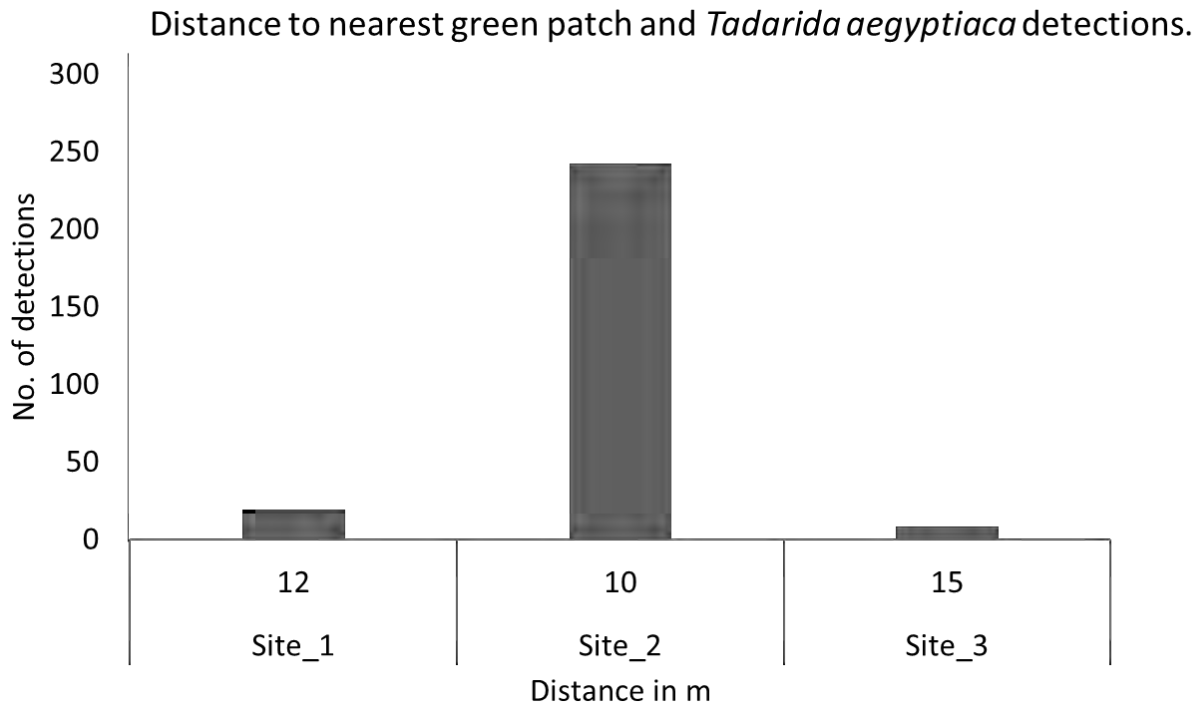


Figure 1.7: The activity of *Tadarida aegyptiaca* in each site with the respective distance to the nearest green patch from each site indicated below the bar. The values above the bar indicate the total number of bat detections for that site.

#### 4.2.2 Effects of Urban Lighting on Bat Activity

Effect of floodlight on bat detections: The highest bat detections were recorded in site-2, which is in very close proximity to bright artificial lighting – floodlights (Figure 1.8). Although the figure shows that the activity is higher in site-1 than site-3, this is due to the influence of other site-specific characteristics such as neighbouring large green patch and the presence of street lights near site-1.

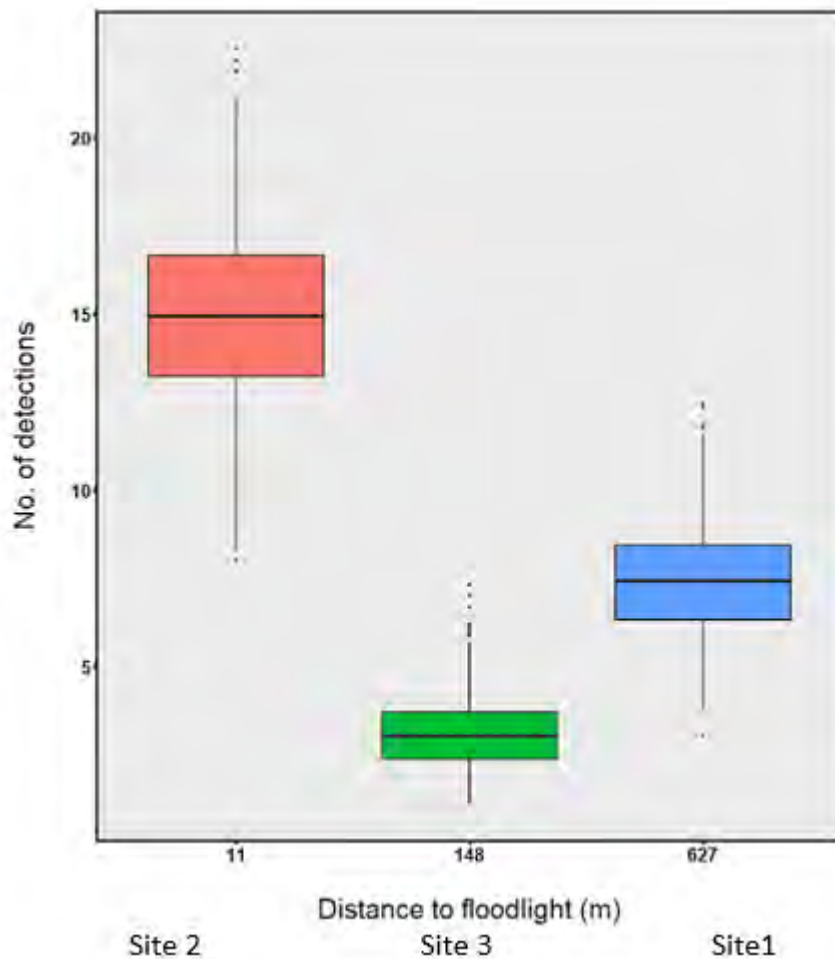


Figure 1.8: A boxplot of the total bat activity of all the species in each site with the distance of the detector in each site to bright artificial lighting (floodlights). The bootstrapped values of 500 mean values/ site were used in this boxplot.

The Kruskal-Wallis test values for the difference in the bat detections between sites gave the following results:

chi-squared = 1309.6, df = 2,  $p < 0.01$

It shows that there is a significant difference observed in the detections of bats (bat activity) between the three sites. It indicates the site-specific influence of the habitat characteristics on the bat activity. From personal observations at the sampling site, bats were foraging around the floodlights, which seemed to have increased the bat activity in site-2. However, the sample size used for this analysis is small as it is based only on 3 sites. Therefore, these results are to be considered as preliminary findings and more data is required to observe any relationship or influence.

### 4.3 SPECIES ACTIVITY

The results show that the overall bat activity was higher in site-2, with 1419 total number of detections of all species across nights. Site-3 had very low bat activity with 303 total detections (total bat passes) of all species across nights when compared to the other two sites (Figure 2.1 and Table 2.1).

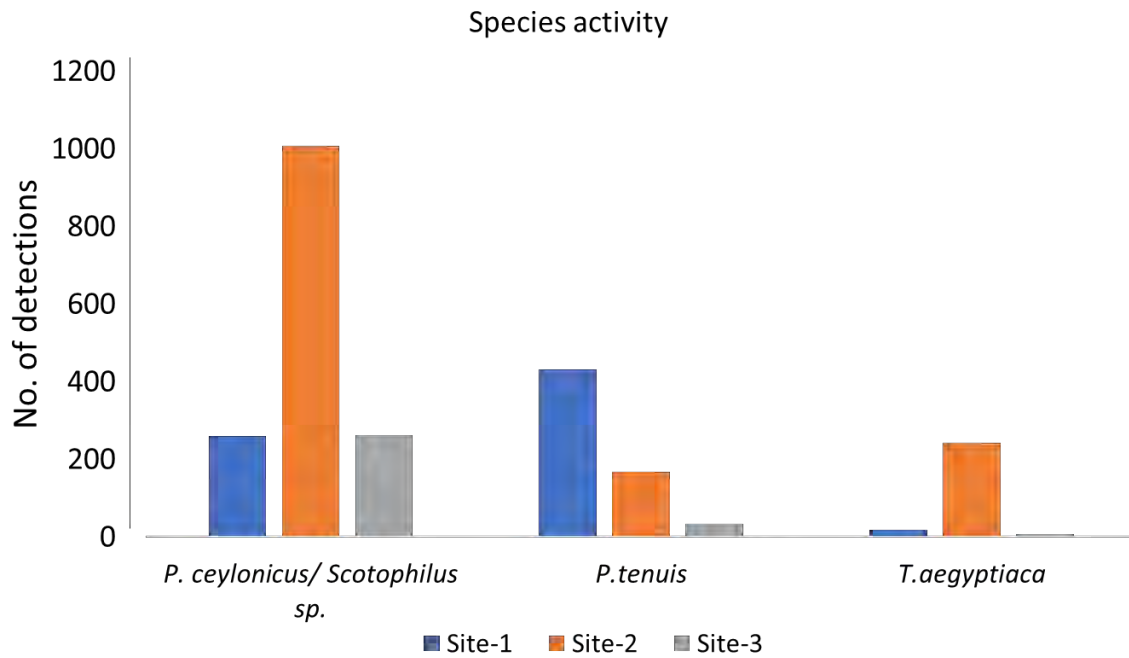


Figure 2.1: Species activity in the three sites.

Site	<i>Hipposideros speoris</i>	<i>Pipistrellus ceylonicus/Scotophilus sp.</i>	<i>Pipistrellus tenuis</i>	<i>Tadarida aegyptiaca</i>	total detections
Site-1	1	260	432	19	712
Site-2	1	1008	168	242	1419
Site-3	0	262	33	8	303

Table 2.1: The number of detections for each species in the three sampling locations.

### 4.3.1 Hourly Species Activity

Although the *Pipistrellus ceylonicus*/*Scotophilus species* cluster (group) was more frequently detected during the sampling period, in site-1 *Pipistrellus tenuis* was the most frequently detected species (total detections over 2 nights = 432). *Pipistrellus tenuis* was also detected in site-2 (total detections = 168) and site-3 (total detections = 33) but the detections were relatively lower than in site-1 (Figure 2.1). The hourly activity of this species differed slightly between the nights (Figure 2.2). This could be an indication of the species could be moving between these sites.

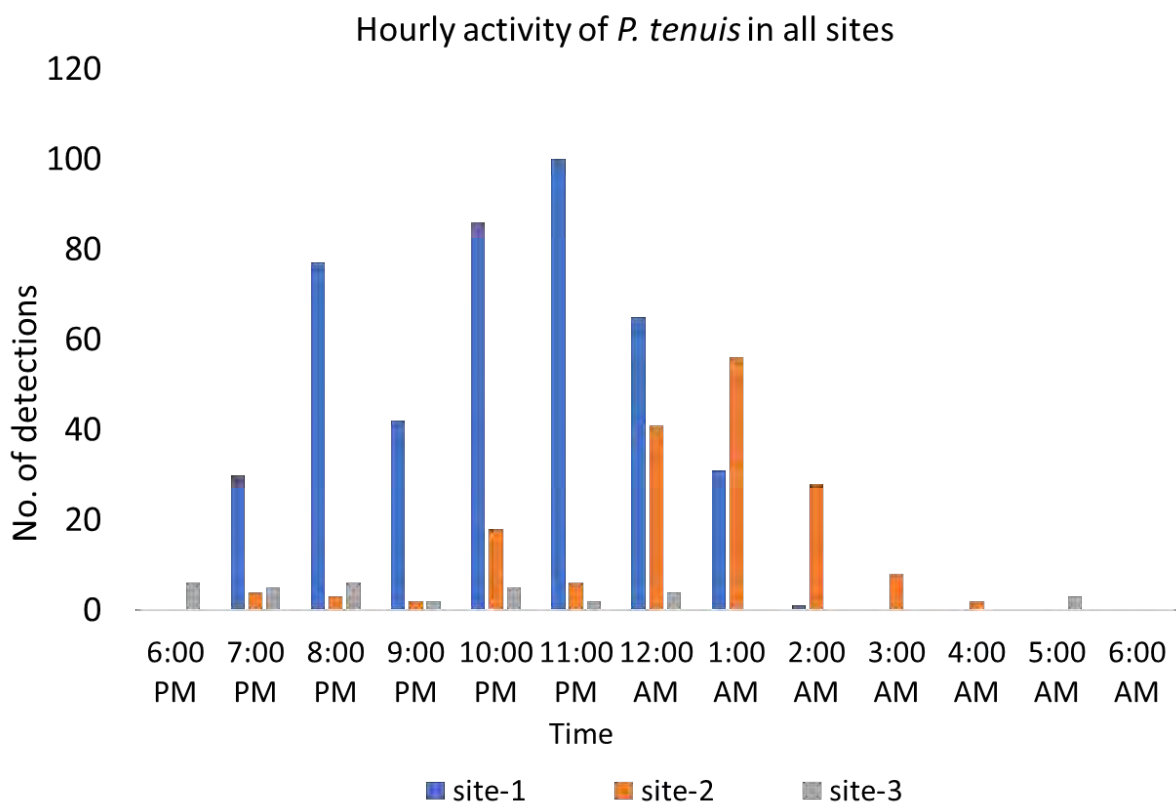


Figure 2.2 Hourly activity of *P. tenuis* in each sampling site.

*Pipistrellus ceylonicus/Scotophilus* species group was the most frequently detected species during the sampling period (total detections = 1530). *Pipistrellus ceylonicus/Scotophilus* species group was more active in site-2 (total detection = 1008) than in site-1 (total detections = 260) and site-3 (total detections = 262). Although the total detections in site-1 and site-3 indicate that *Pipistrellus ceylonicus / Scotophilus* species cluster activity was similar in both sites, the hourly activity of this species varies in both the sites (Figure 2.3). This species was the most frequently detected in site-2 indicating a strong site preference. The activity of this species in site-2 was throughout the night, whereas in site-1 and site-3 the activity peaks during certain hours and then dips (Figure 2.3).

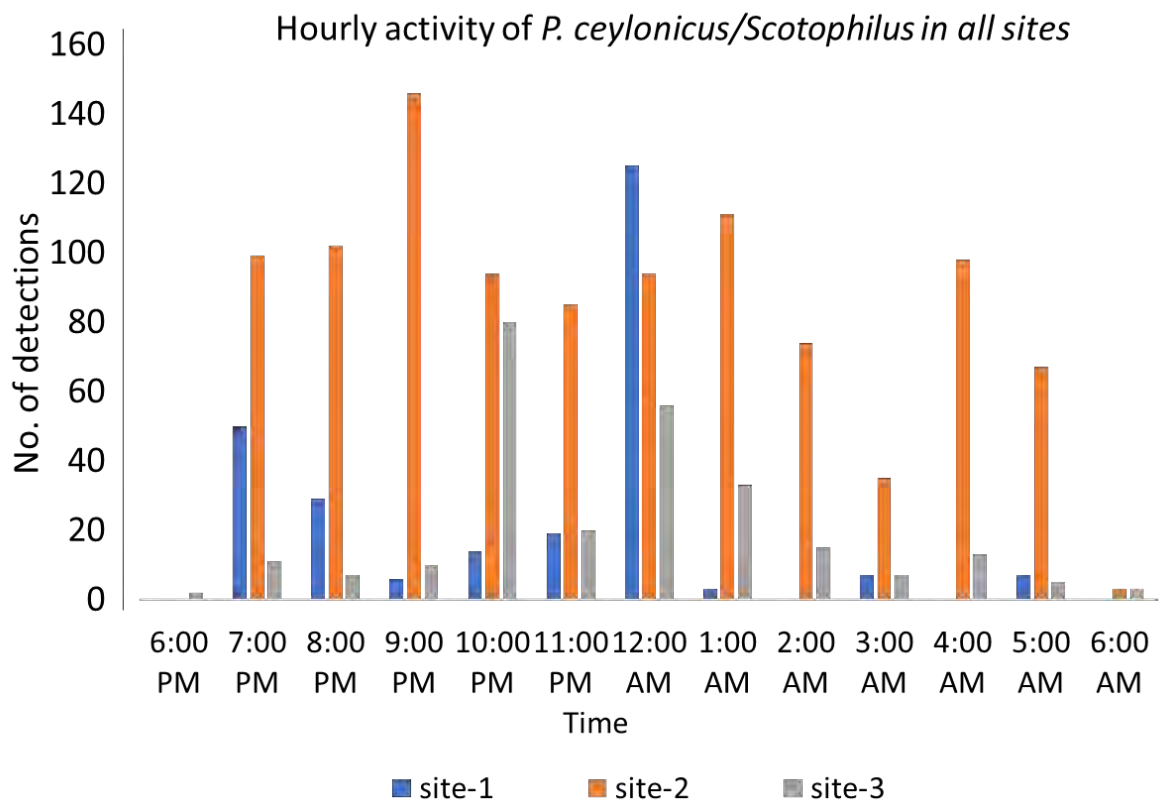


Figure 2.3 Hourly activity of *Pipistrellus ceylonicus/Scotophilus* species group in each sampling site.

*Tadarida aegyptiaca* was detected less frequently when compared to *Pipistrellus ceylonicus*/*Scotophilus* species group and *Pipistrellus tenuis*. It was detected more frequently in site-2 (total detections = 242) than in site-1 (total detections = 19) and site-3 (total detections = 8). The hourly activity pattern shows that this species is mostly activity in site-2 between the 2:00 AM and 5:00 AM (Figure 2.4). This activity pattern of this species does not seem to overlap highly with the other species (*Pipistrellus ceylonicus*/*Scotophilus* species group and *Pipistrellus tenuis*).

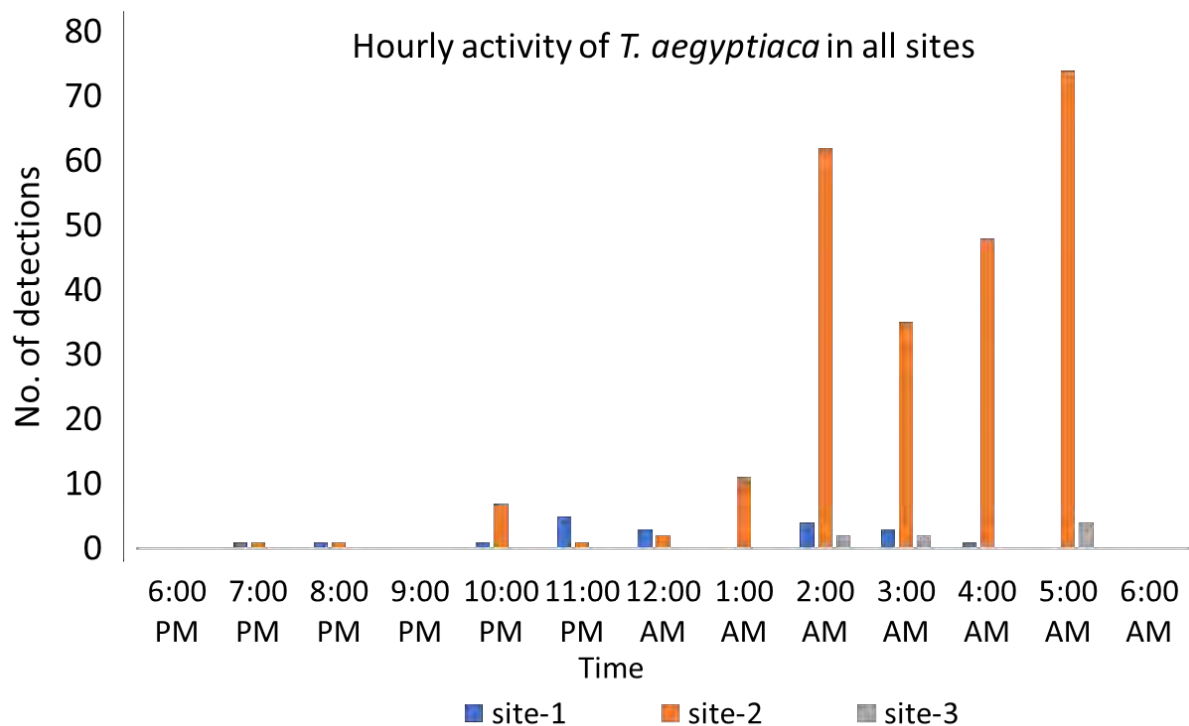


Figure 2.4 Hourly activity of *Tadarida aegyptiaca* in each sampling site.

Detections of <i>Hipposideros speoris</i> in the three locations				
Time	Pt_1	Pt_2	Pt_3	Total detections
7:00 PM	1	1	0	2

Table 2.2 *Hipposideros speoris* was detected only once from both site-1 and site-2. It was not detected in site-3. The detection of this species was rare.

In site-1, the highest detections peaked between 12:00 AM and 1:00 AM. During this period, the activity of 3 species (*Pipistrellus tenuis*, *Pipistrellus ceylonicus*/*Scotophilus* species group and *Tadarida aegyptiaca*) was at the highest. Bats were generally not detected at the beginning of the sampling time around 6:00 AM but after 7:00 PM a sudden rise in bat activity was detected from *Pipistrellus ceylonicus*/*Scotophilus* species group and *Pipistrellus tenuis*. Post this, the activity of these two species seemed to have an interesting pattern where the number of detections of *Pipistrellus ceylonicus*/*Scotophilus* species group began to dip around the same time the detections of *Pipistrellus tenuis* began to rise and vice-versa and this trend does not seem to be maintained overnight (Figure 2.5). It could be due to the interaction between these two species or just a species-specific behaviour. *Pipistrellus tenuis* was found to be most active at site-1 followed by *Pipistrellus ceylonicus*/*Scotophilus* group. *Hipposideros speoris* was detected once during sampling during the early hours of sampling (Table 2.2). *Pipistrellus ceylonicus*/*Scotophilus* species group was active throughout the night in site-2 but was observed to have varying activity patterns of temporal use of site-1 and site-3 (Figure 2.5, Figure 2.6 and Figure 2.7).

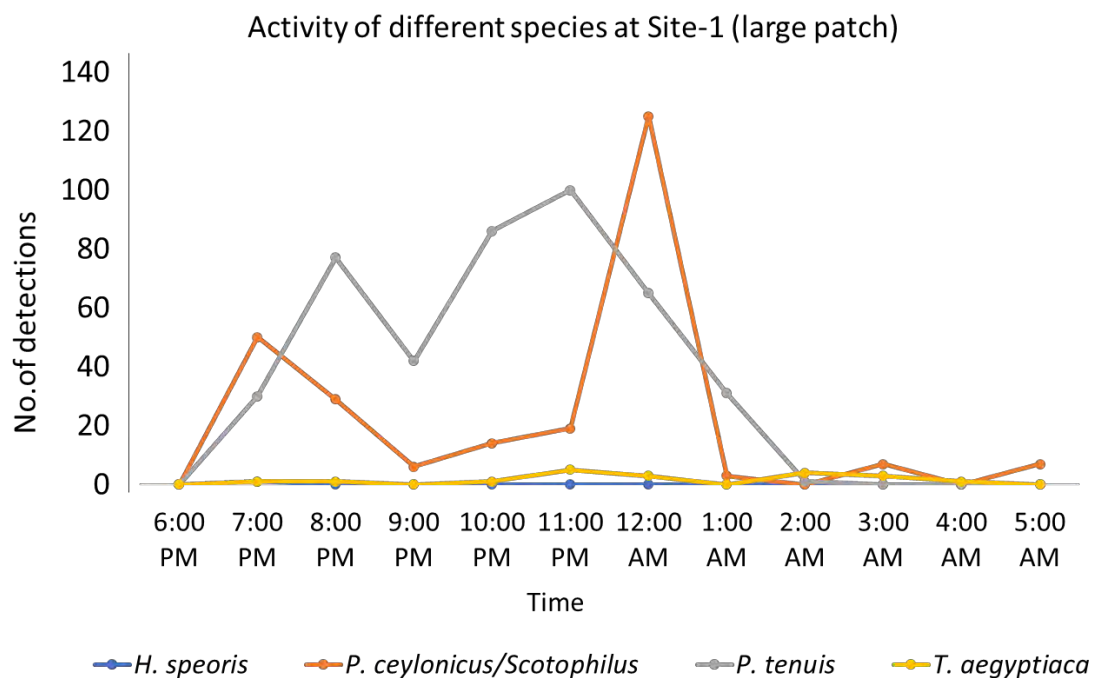


Figure 2.5 Hourly activity of all species in site-1. The line in blue refers to the activity of *Hipposideros speoris*. The line in orange refers to the activity of *Pipistrellus ceylonicus*/*Scotophilus* species group. The grey line refers to the activity of *Pipistrellus tenuis* and the line in yellow refers to the activity of *Tadarida aegyptiaca*.

The highest detections in site-2 were observed between 1:00 AM and 2:00 AM (total detections = 178). The activity of *Tadarida aegyptiaca* began to peak during 2:00 AM and 5:00 AM. Interestingly, the activity of *Pipistrellus ceylonicus/Scotophilus* species group and *Pipistrellus tenuis* were observed to decline during the same time.

Around 3:00 AM the activity of all these three species seems to reduce and then increase at different hours later into the night. The activity of *Pipistrellus ceylonicus/ Scotophilus* species group and *Pipistrellus tenuis* in site-2 was different from the pattern observed in site-1 in that, the general activity of *Pipistrellus tenuis* in site-2 is relatively lower and the peak in the activity overlaps with that of the activity of *Pipistrellus ceylonicus/ Scotophilus* species group for only a few hours.

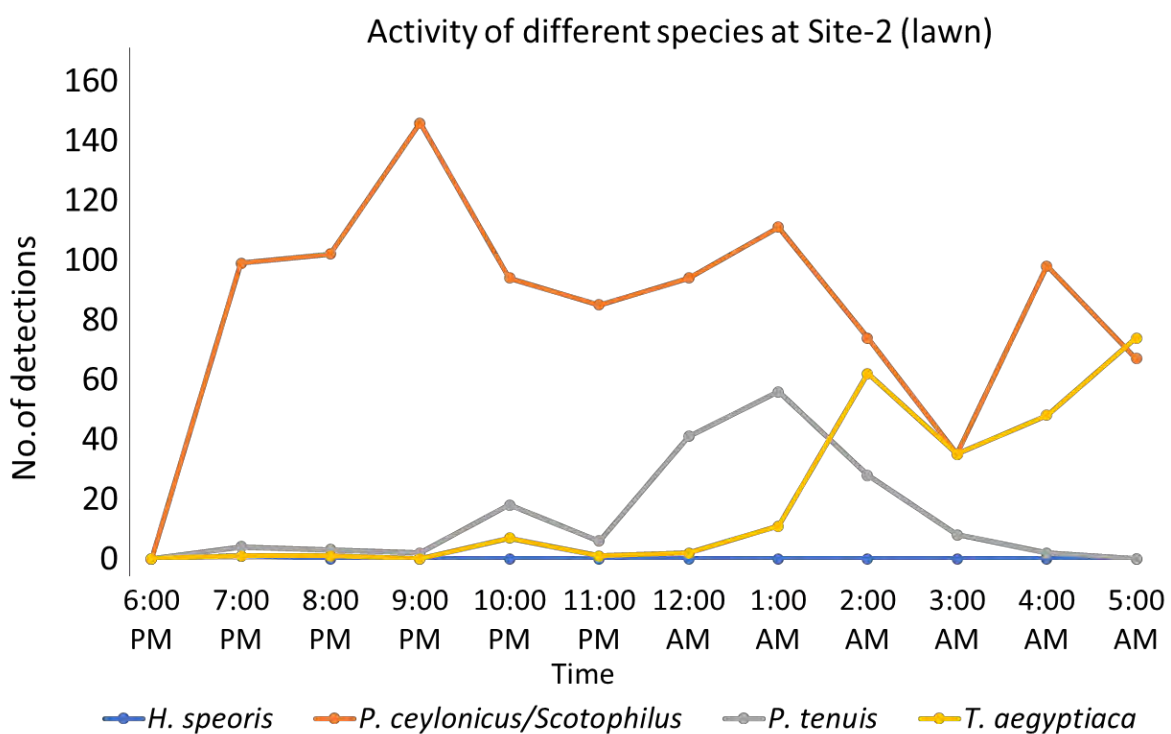


Figure 2.6: The overnight activity of all the species in site-2. The line in blue refers to the activity of *Hipposideros speoris*. The line in orange refers to the activity of *Pipistrellus ceylonicus/ Scotophilus* species group. The grey line refers to the activity of *Pipistrellus tenuis* and the line in yellow refer to the activity of *Tadarida aegyptiaca*.

Site-3 was observed to have low bat activity when compared to site-1 and site-2. *Tadarida aegyptiaca* was detected during 2:00 AM and 5:00 AM, *Tadarida aegyptiaca* detections in site-1 and site-2 were also observed during this time. Additionally, only a few detections of this species between the hours of 10:00 PM and 12:00 AM were observed and these were only recorded in site-1 and site-2.

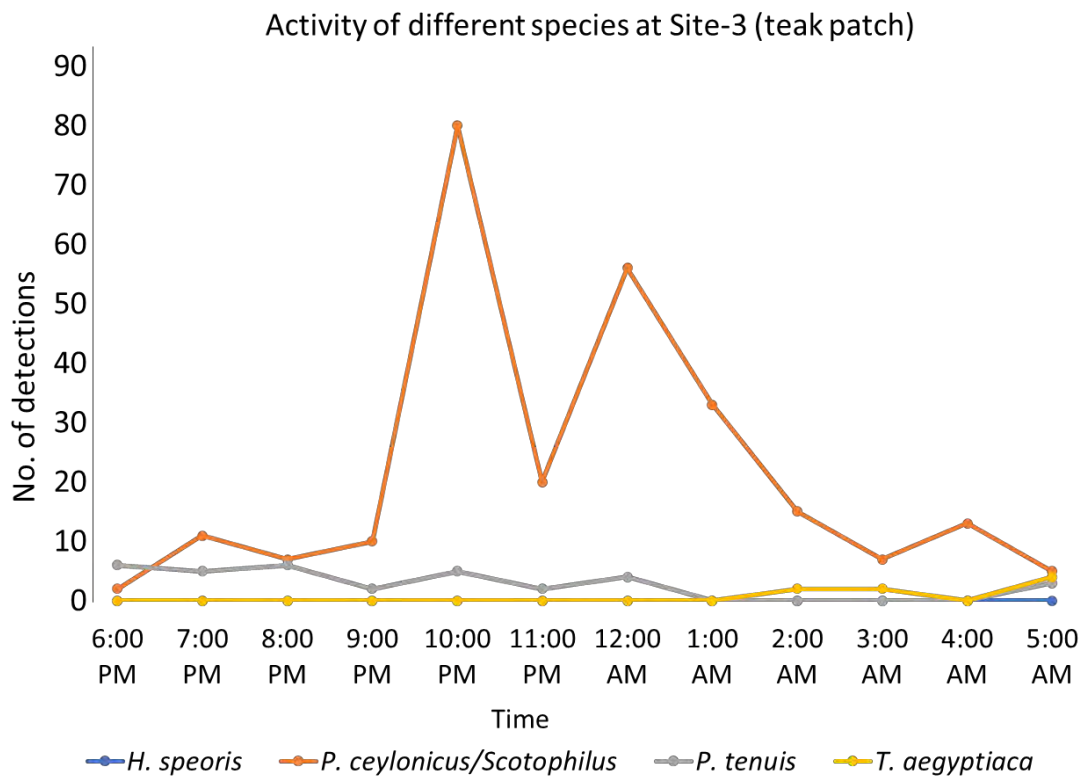


Figure 2.7: The overnight activity of all the species in site-3. The line in blue refers to the activity of *Hipposideros speoris*. The line in orange refers to the activity of *Pipistrellus ceylonicus/ Scotophilus* species group. The grey line refers to the activity of *Pipistrellus tenuis* and the line in yellow refers to the activity of *Tadarida aegyptiaca*.

### 4.3.2 Estimation of Species Activity Overlap

The activity of *Pipistrellus tenuis* species highly overlaps with *Pipistrellus ceylonicus*/*Scotophilus* species group. The overlap coefficient ( $\Delta^{\wedge}$ ) between these species is equal to 0.8224576 and the Confidence interval lower limit is 0.74 upper limit equals to 0.93 (Figure 2.8).

**Pipistrellus tenuis and Pipistrellus ceylonicus/Scotophilus activity overlap (presence)**

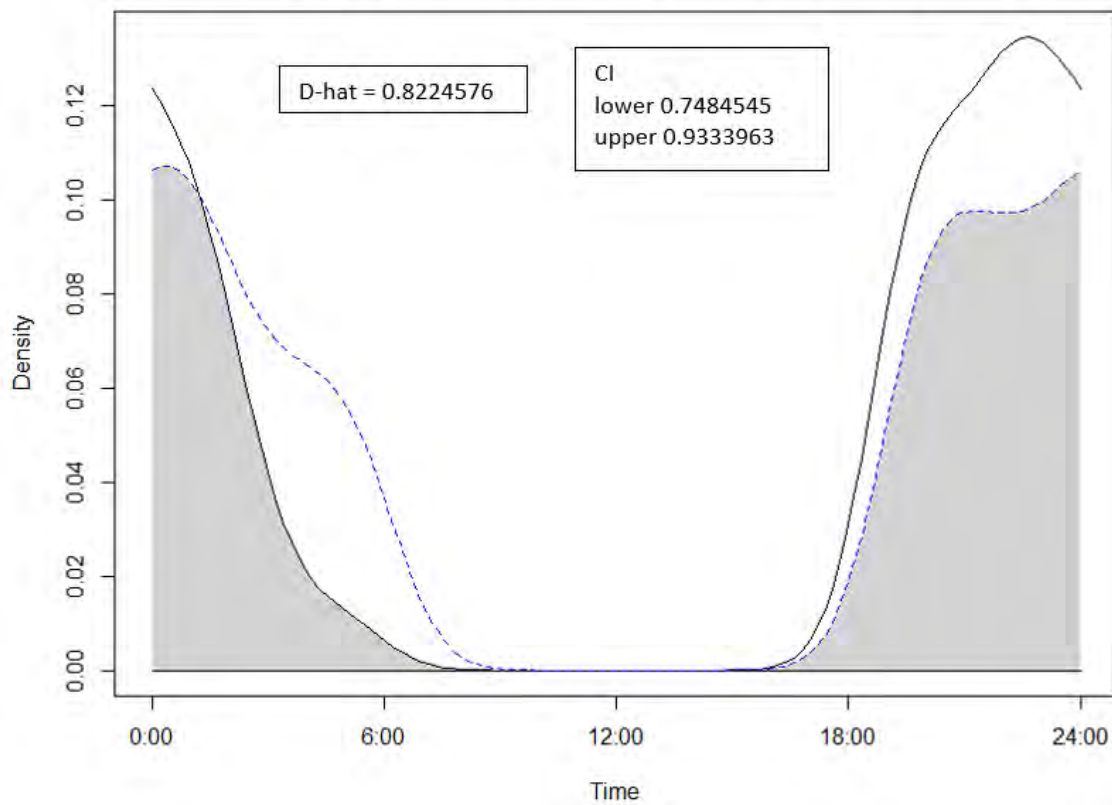


Figure 2.8: The activity overlap between *Pipistrellus tenuis* (solid line) and *Pipistrellus ceylonicus*/*Scotophilus* species group (dotted line).

The activity of *Pipistrellus tenuis* overlaps minimally with the activity of *Tadarida aegyptiaca*. The overlap coefficient ( $\Delta^{\wedge}$ ) between these species is equal to 0.5354377 and the Confidence interval lower limit 0.34 upper limit equal to 0.62 (Figure 2.9).

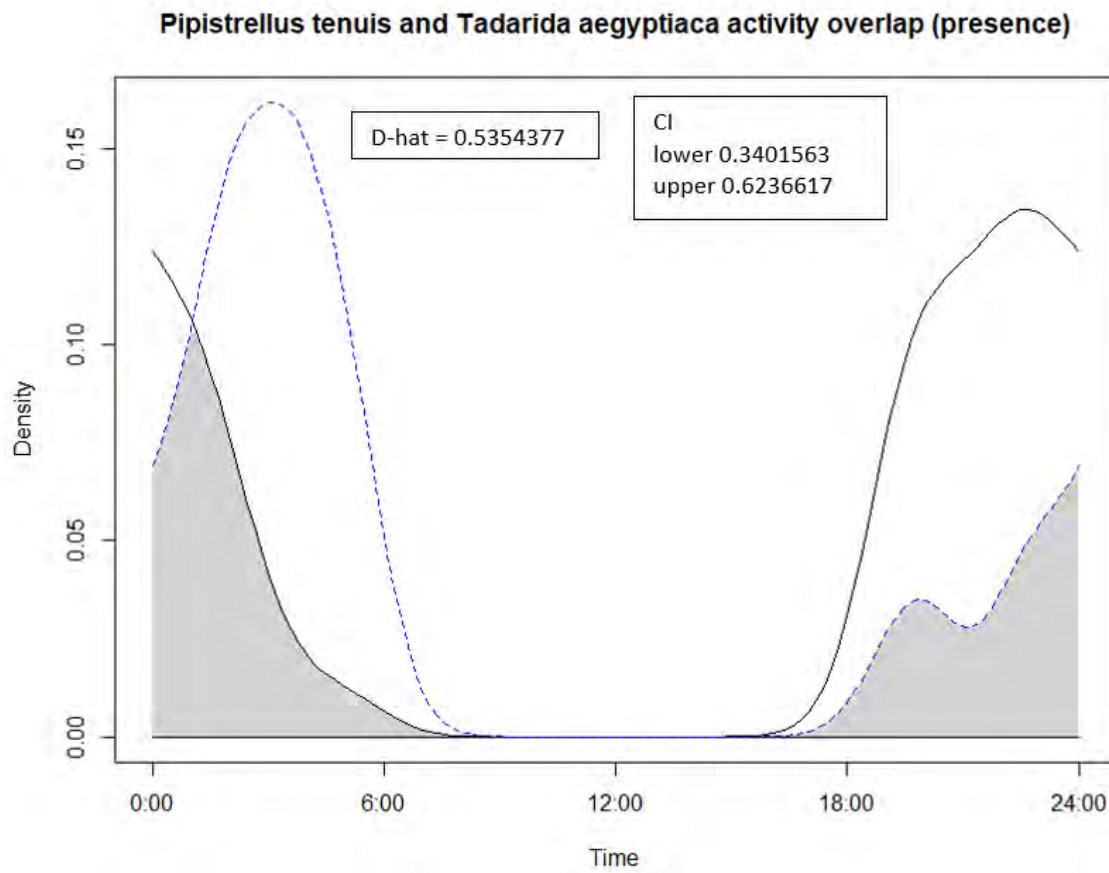


Figure 2.9: The activity overlap between *Tadarida aegyptiaca* (dotted line) and *Pipistrellus tenuis* (solid line).

The activity of *Pipistrellus ceylonicus/ Scotophilus sp.* group overlaps minimally with the activity of *Tadarida aegyptiaca*. The overlap coefficient ( $\Delta^{\wedge}$ ) between these species is equal to 0.6926573 and the Confidence interval lower limit 0.53 upper limit equal to 0.79 (refer figure 2.10).

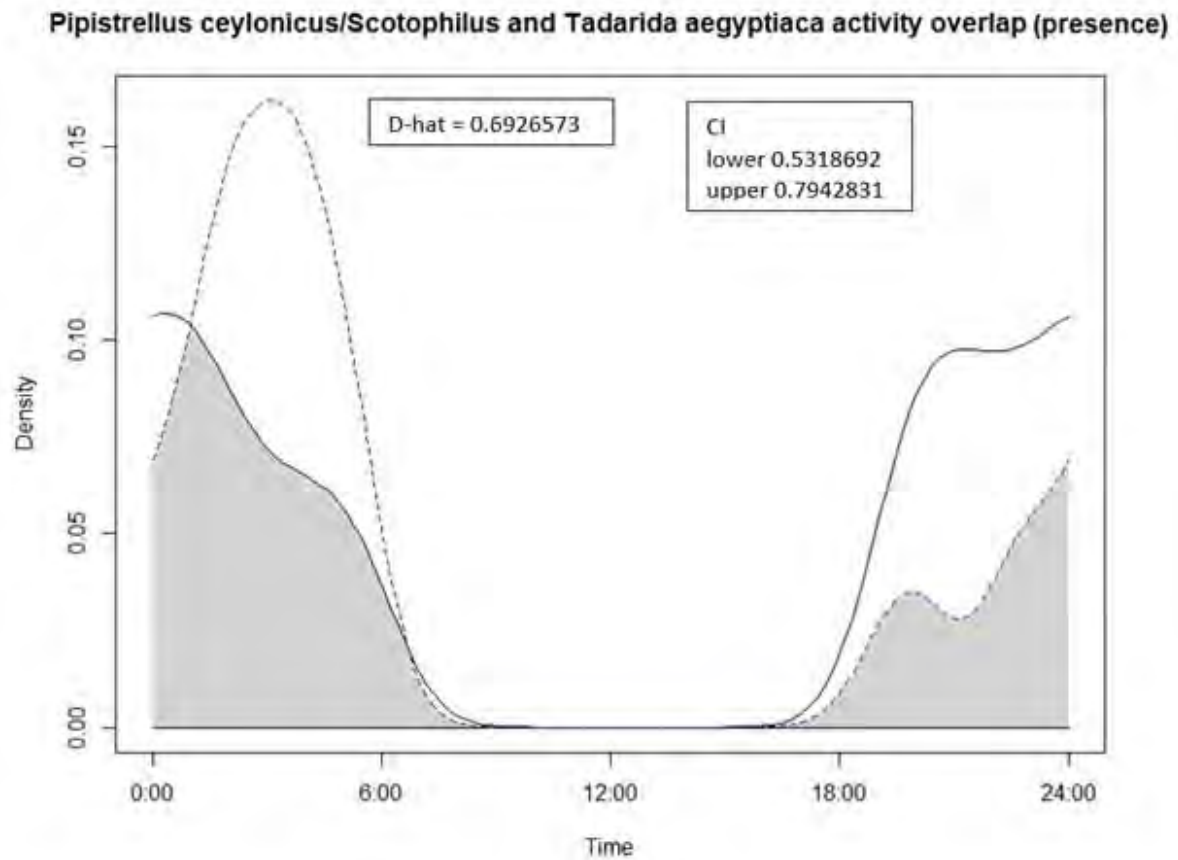


Figure 2.10: The activity overlap between *Tadarida aegyptiaca* (dotted line) and *Pipistrellus ceylonicus/ Scotophilus* species group (solid line).

#### 4.4 COMPARISON OF ACOUSTIC SAMPLING METHODS

The overall detection of bats in transects and PAM does vary a little between sites, but there is only a slight difference in detections of bat species in general between the methods (Table 3.1).

All species				
Sampling method	Site1	Site-2	Site-3	Total detections
PAM	17	22	9	48
Transect	30	14	18	62

Table 3.1: The overall bat call detected using active (transect) and PAM - Passive Acoustic Monitoring in different sites.

The detection rates of *Pipistrellus ceylonicus/ Scotophilus species group* vary between sites. Overall, the detection of this species in PAM is a little higher than in transects (Figure 3.1).

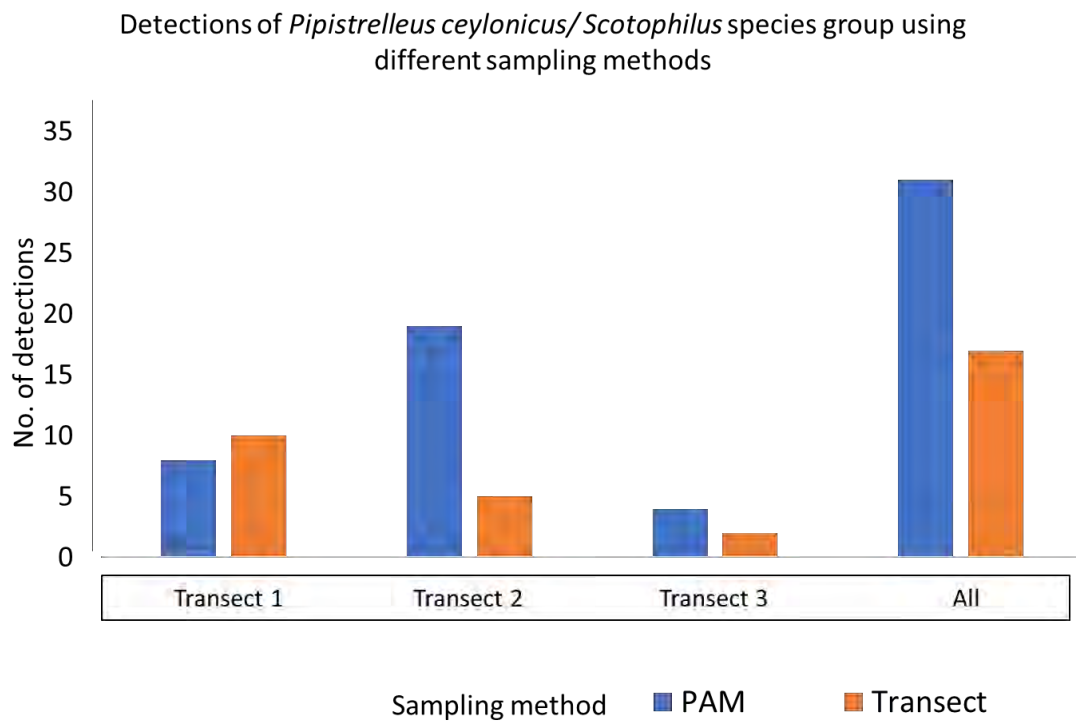


Figure 3.1: The number of *Pipistrellus ceylonicus/ Scotophilus species group* calls detected using active (transect) and PAM - Passive Acoustic Monitoring in different sites.

The detection rates of *Pipistrellus tenuis* vary between sites. Overall, the detection of this species in transects is higher than in PAM (Figure 3.2). Transects could be more useful when this species is the focus of a study.

Detections of *Pipistrellus tenuis* using different sampling methods

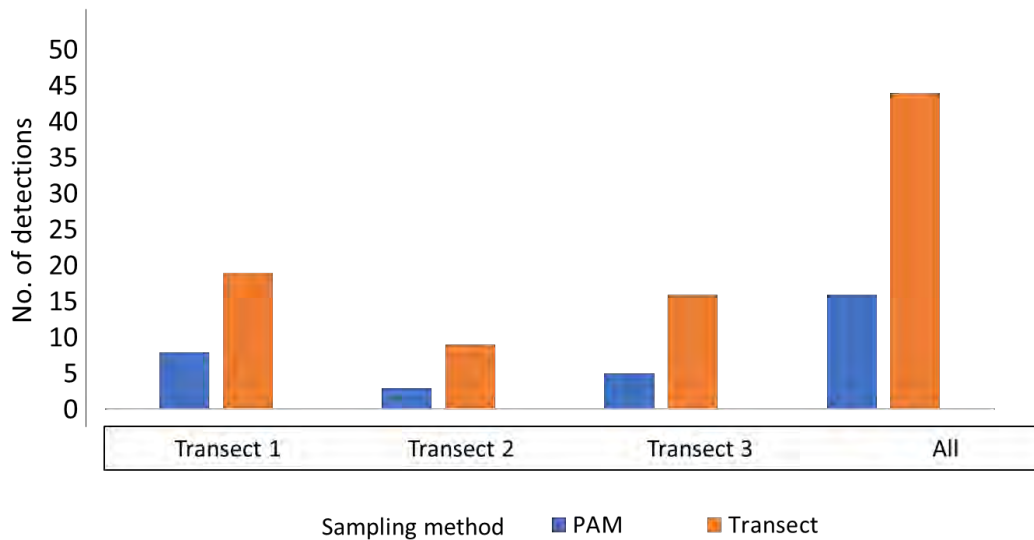


Figure 3.2: shows the number of *Pipistrellus tenuis* calls detected using active (transect) and PAM - Passive Acoustic Monitoring in different sites.

Sampling method	<i>Tadarida aegyptiaca</i>	<i>Hipposideros speoris</i>
PAM	1	2
Transect	1	0

Table 3.2: The number of *Tadarida aegyptiaca* and *Hipposideros speoris* calls detected using active (transect) and PAM - Passive Acoustic Monitoring.

The detection rates of *Tadarida aegyptiaca* during the sampling hours of 1900 hours and 2100 hours is low in both the sampling methods with just one detection during this time (Table 3.2). It could mean that the sampling time might not be suitable for this species, regardless of the sampling method used. It could apply to other species that have similar activity patterns. Sampling during different hours of the night or overnight to get the activity of different species would lead to a more appropriate estimate of activity for such species.

*Hipposideros speoris* was only detected in two sites and only using the PAM method. Since they were not detected in any of the transects, this could mean that such species which are not detected frequently, are more likely to get detected using the PAM method and missed out during transect surveys.

## 5. DISCUSSION

### 5.1 FACTORS INFLUENCING BAT ACTIVITY

The responses to different factors in an urban area is often species-specific. There could be many reasons for such species-specific responses, including behavioural responses, morphological constraints (wing type), call types that limit species foraging habitat type and foraging guilds (Denzinger *et al.*, 2016). The results of this study support the conclusions of other studies that responses to urbanisation are species-specific (Avila-Flores and Fenton, 2005; Russo & Ancillotto, 2015; Voigt *et al.*, 2016). Generally, the two species *P. tenuis* and *T. aegyptiaca* and one species group *P. ceylonicus/ Scotophilus species* seem to have adjusted well to an urban ecosystem in this region. Bat activity in site-2 (lawn) was observed to be higher than the other sites. One species, in particular, *Pipistrellus ceylonicus/ Scotophilus* group, tends to be active throughout the night in this lawn site. In contrast, its peak activity in the other sites is limited to a few hours, followed by a dip in the activity. It could be because of the presence of floodlights in site-2 (lawn), which attracts insects, providing prey for bats throughout the night. Some species of bats have been observed and are known to forage around artificial lighting for insects (Stone *et al.*, 2015; Stone *et al.*, 2012; Spoelstra *et al.*, 2017; Rydell *et al.*, 2017; Rowse *et al.*, 2017). Although such species-specific responses have not yet been documented from India, and hence this study provides the first insight into the responses of different species to artificial lighting in this region.

My results suggest that artificial lighting at night (ALAN) influences the activity of all the species recorded in this study, especially the species group *Pipistrellus ceylonicus/ Scotophilus* species group. These findings indicate that this species group seems to not only tolerate but thrive in well-lit areas. Such species are called “light-opportunistic” species (Spoelstra *et al.*, 2017; Rowse *et al.*, 2018; Voigt *et al.*, 2019). The other two species *Pipistrellus tenuis* and *Tadarida aegyptiaca*, also seem to have adjusted well to an urban ecosystem. Since very little is known about urban bats in India, this study provides preliminary findings about the impacts of artificial lighting on urban bat species in India.

The recorded activity of *Tadarida aegyptiaca* is also higher in site-2 (lawn) and is recorded mostly between 2:00 AM and 5:00 AM in all the sites. Similar species with a lower call frequency are also known to be more active in areas away from the road to avoid traffic noise, which could mask its low-frequency call (Schaub *et al.*, 2008; Siemers & Schaub, 2010; Bunkley *et al.*, 2015). But in this study, the activity of *Tadarida aegyptiaca* is relatively higher in site-1 (large green patch) than site-3 (teak patch), even though site-1 is closer to the main road. Site-3 is a small patch of teak monoculture plantation. Studies have shown monoculture plantations have relatively lower bat activity and diversity (Phommexay *et al.*, 2011). Site-1 is adjacent to a larger green space and that probably provides more habitat that might compensate the disturbance from the road. *Tadarida aegyptiaca* is an open area forager, a fast flyer (Monadjem, 2017), perhaps this aids in foraging in a large green patch despite its proximity to the main road. The specific time of activity between 2:00 AM and 5:00 AM could also just be a species-specific behaviour. This time coincides with the time of low traffic which could mean that this species avoids foraging at peak traffic hours. It could also be a response of these bats to the varying insect abundances in different sites. Future research aimed towards understanding insect diversities and abundances in urban spaces is an essential factor for bat activity and diversity.

The size of the green space also seems to influence the activity of *P. tenuis*, as the detection of this species is relatively higher in site-1, which is adjacent to a large green patch than in site-2 (lawn with floodlights). Though this species seems to be 'light-opportunistic' because of its activity in site-2 (lawn with floodlights), its overall activity is relatively higher in site-1 (large green patch), which could be because of habitat characteristics of site-1. The size of the green space is known to positively influence bat activity (Tena *et al.*, 2020). At the scale of this study, the size of the sampling green space did not seem to have any conclusive effect. Another study on bats in an urban landscape showed that vegetation cover did not influence bat activity in high and low urbanisation areas (Tzortzakaki *et al.*, 2019). Further studies are required to determine if larger green spaces or types of plantations have a positive or negative impact on bat activity in urban areas. Additionally, information on the effects of vehicular noise and proximity of roads on bats in the India is needed.

Artificial lighting at night, also abbreviated as ALAN (Haddock, 2018; Rowse *et al.*, 2018; Straka *et al.*, 2019; Voigt *et al.*, 2019) in urban areas has been documented to influence nocturnal fauna in urban areas. The influence of ALAN on bat activity has been reported in other parts of the world. However, the adverse effects of lighting are more well-documented than the positive impacts. Responses to artificial lighting is often a species-specific response and hence can have positive as well as negative consequences based on the behaviour and morphology of different species. The *Pipistrellus* species in this study seem “light opportunistic” and similar findings have been observed of species in this genus in Europe (Spoelstra *et al.*, 2017; Rowse *et al.*, 2018; Straka *et al.*, 2019). Although, this cannot be considered a phylogenetic ability to adapt because different species within the same families and genus are known to respond differently to the effects of urbanisation in different regions of the world (Watts *et al.*, 2006; Voigt & Kingston, 2016; Straka *et al.*, 2019).

Studies show that “light-averse” or “light-shy” bat species like the *Myotis species* in Europe (Spoelstra *et al.*, 2017; Rowse *et al.*, 2018; Straka *et al.*, 2019) generally avoid such areas and hence not detected in well-lit landscapes and the absence of such species can indicate that urban habitat is not suitable for all species. One of the explanations for avoiding well-lit areas by such light-averse species includes the risk of predation, as such species are generally heavier and have a slow flight, increasing the risk of predation (Spoelstra *et al.*, 2017). A similar species encountered during this study is the *Hipposideros speoris*, species of this genus are generally not known to forage in well-lit areas and this could explain why this species was encountered only twice in the study area. The impact of urbanisation on such species is largely not studied in India, but in other countries, especially in temperate regions, these species-specific responses are well-documented (Russo & Ancillotto, 2015; Stone *et al.*, 2015; Rydell *et al.*, 2017; Spoelstra *et al.*, 2017; Haddock, 2018; Ancillotto *et al.*, 2019; Voigt *et al.*, 2019). Experimental studies have also been conducted in other countries to investigate remedial measures to improve habitat for such species in an urban area. These measures include the use of different types of lights, red lights and trees to mask the effect of bright white lights (Rowse *et al.*, 2018; Straka *et al.*, 2019) and creating green roofs (covering rooftops with vegetation cover) to provide more habitat (Parkins & Clark, 2015).

Vegetation in urban environments provide habitat for wildlife and the structure and composition of vegetation are vital as they alter the local species pool. Vegetation structure is often considered more important for insectivorous bats than vegetation composition (Kalko & Handley, 2001; Basham *et al.*, 2010; Parkins & Clark, 2015; Moretto & Francis, 2017; Rodríguez-Aguilar *et al.*, 2017; Gallo *et al.*, 2018; Straka *et al.*, 2019). Vegetation composition and phenology are essential for fruit-eating bats. They indirectly can affect insectivorous bats activity by attracting insects, but vegetation structure primarily influences bat activity and diversity in natural and urban ecosystems (Kalko & Handley, 2001; Basham *et al.*, 2010). The vegetation parameters in this study did not seem to confluence bat species and their activity and that could be a result of short sampling time, season and the scale (Gallo, *et al.*, 2018) at which these parameters were measured and the bat activity was recorded. Broad-scale investigation on bat activity and vegetation structure are needed in urban ecosystems to fill these knowledge gaps.

With the increase in urbanisation, especially in countries like India, these ecosystems are relatively new and growing. More studies are required to investigate how species respond to these changes and adjust to such environments. This study documents baseline information on factors such as light and vegetation structure and its effects on bats. However, artificial lighting that seems to impact most of the species positively does not necessarily imply brightening up urban areas is beneficial to bats in general. The present study indicates that artificial lighting is useful to these species of bats when supplemented with the necessary green cover for foraging. More research is required to ascertain the impact on “light-averse” bat species, and how urban areas can be improved to accommodate them better. It becomes even more critical to study the impact of various artificial lighting as 57000 LED street lights have been installed all around the Pune city and there are ongoing plans on replacing 77800 conventional street lights with LED lights (Smart city Pune <<https://punsmartcity.in/project/smart-street-lighting/>>). It offers an opportunity to study the effects of different types of lightings on urban ecosystems. This study provides preliminary work for further investigations into such species-specific responses to light in the urban ecosystems of India. More information related to how light-shy species could be accommodated in urban areas in India will be needed to better inform urban planning.

## 5.2 SPECIES-WISE OVERNIGHT ACTIVITY

Very little is known about the behavioural information on the overnight activity of different species of bats. This study gives the preliminary data on overnight activity patterns of two species and one species group. These patterns can help plan acoustic surveys in an urban ecosystem. Overnight activity patterns show the behavioural variation between species within the same habitat. In this study, one species *P. tenuis* and one species group, *P. ceylonicus/ Scotophilus* species group are generally highly active, especially from dusk to midnight. *P. ceylonicus/ Scotophilus* species group is the most frequently detected species. This could indicate its adaptability to an urban environment. *P. ceylonicus/Scotophilus* species group was the most commonly recorded in two out of three sites. Urban ecosystems often tend to support a few species which dominate the ecosystems (Tzortzakaki *et al.*, 2019). This species group showed hourly variation in activity peaks and low activity throughout the night. These patterns varied between site-1 (large green patch) and site-3 (teak patch) whereas the activity in site-2 (lawn) was high throughout the night from dusk till dawn. The influence of artificial lighting (floodlights) in site-2 explain this behaviour, as the lights attract plenty of insects especially *Dipterans* throughout the night.

In site-1 (large green patch), *P. tenuis* was the most frequently detected species, indicating the influence of site-specific characters. The hourly patterns of activity of this species in all sites vary, this could mean that this species was moving between these sites at different hours of the night. The activity of this species was high from dusk till midnight and dipped post 12:00 AM and the activity was very little during early morning hours. This could be because of species-specific foraging behaviour or prey availability in sites (Schimpp *et al.*, 2018).

The activity of *P. tenuis* and *P. ceylonicus/ Scotophilus* species group overlap highly. Considering these are both aerial insectivores and adapted to forage in open and edge habitats, this increases the competition for resources. These species are known to be “early flyers” because their activity begins early during dusk (Srinivasulu *et al.*, 2019; Srinivasulu & Srinivasulu, 2019). Additionally, both species are well-adjusted to artificial lighting at night (ALAN) in urban environments. ALAN attracts plenty of insects and thereby increases prey availability for these species.

*Tadarida aegyptiaca* was detected relatively less than the other two species and seemed to be more active between the hours of 2:00 AM and 5:00 AM, contrasting the pattern of the other two species. The overlap coefficient is relatively higher with *P. tenuis* and *P. ceylonicus/ Scotophilus* species group. These species are known to be a 'late flyer' in the sense that the active hours are later into the night (Monadjem *et al.*, 2017). *Tadarida aegyptiaca* has a low-frequency call and is likely to be masked by traffic noise. The active hours of this species coincide with the time when traffic volume is relatively lower than during dusk (Pune Cycle Plan-Traffic Volume Count survey 2017). Further studies that look into the seasonal activity and the effect of noise on different foraging species are needed. The behavioural variation in species can inform urban bat monitoring.

### **5.3 EFFECTIVE ACOUSTIC SAMPLING METHOD**

Although the overall detection of bats between 7:00 PM and 9:00 PM was slightly higher in active surveys (62 detections) than in PAM (48 detections), the species-wise detections reveal that acoustic surveys miss detecting rare species like the *Hipposideros Speoris* in this study and underestimate the activity of *Pipistrellus ceylonicus/ Scotophilus* species group.

Since the time of the active acoustic survey was limited, it massively underestimated the activity of *Tadarida aegyptiaca*, as this species is active post 2:00 AM. Such species-specific behaviour can be missed out or underestimated in transect surveys. Few other studies comparing active and passive acoustic monitoring arrive at the same conclusion that active acoustic surveys are more cost-effective but miss out detecting rare species and underestimate the activity of a few others (Braun de Torrez *et al.*, 2017). Coleman *et al.* (2014) counter the cost-effectiveness of active acoustic surveys and argue that their cost-analysis reveals that passive acoustic surveys are more cost-effective than active surveys.

The activity of *P. tenuis* was the only species for which the active survey seemed effective. However, determining how each species behaves and the detection rates captured by active surveys, requires a lot more information and can still tend to be difficult to predict. Despite these drawbacks, active acoustic surveys can be used in pilot studies, which would be followed by passive acoustic surveys. Information on the species behaviour which can only be gotten from passive acoustic monitoring. Teets *et al.* (2019) conclude that the method of acoustic monitoring - active acoustic surveys or passive acoustic surveys can have very

different effects on the detection probabilities of species and recommend using passive acoustic surveys to monitor bats to make comparisons between surveys and studies simple. To conclude, the results of this study are in agreement with the perception that passive acoustic sampling is better at detecting diversity and recording activity trends, although it must be noted that the data used in this study is not sufficient and further studies looking at the probability of detection of different species is required.

The findings of this study are preliminary. The influence of vegetation parameters was inconclusive. This could be because of the short sampling time, the season of sampling, the scale of this study. More spatial and temporal replicates are needed to understand the influence of different factors on bat activity and the appropriate survey method. Data collection for active monitoring (transects) and PAM were not simultaneous and hence, the results could not have accounted for the other variations that could influence the detection of these species in both the methods.

Increasing the suitability of urban landscapes to bat species could be useful to bats and humans. As bats are important predators of insects in urban and other human-modified landscapes. Hence, they are essential for conservation from an ecological and economic point of view. Bats are diverse in their foraging and contribute to ecosystem services, including pollination, seed dispersal and insectivory. Nocturnal insects are primarily predated upon by bats (Zinn & Humphrey 1976; Kalko 1995), which in turn also benefits the human economy (Boyles *et al.* 2011). Bats also impact human health as they predate on insects, reduce the amount of disease-carrying vectors such as mosquitoes and indirectly contribute to disease control (Reiskind & Wund 2009). Hence, providing habitats for bats in an urban environment becomes directly beneficial.

## 6. REFERENCES

1. Ancillotto, L., Bosso, L., Salinas-Ramos, V. B., and Russo, D. 2019. The importance of ponds for the conservation of bats in urban landscapes. *Landscape and Urban Planning*, 190,103-607.
2. Avila-Flores, R., and Fenton, M.B. 2005. Use of spatial features by foraging insectivorous bats in a large urban landscape. *Journal of Mammalogy*, 86, 1193–1204.
3. Basham, R., Law, B., and Banks, P. 2010. Microbats in a “leafy” urban landscape: Are they persisting, and what factors influence their presence? *Austral Ecology*, 36, 663–678.
4. Bennie JJ, Duffy JP, Inger R, and Gaston KJ .2014. Biogeography of time partitioning in mammals. *Proceedings of the National Academy of Sciences of the United States of America*. 111, 13727–13732.
5. Berthinussen, A., and Altringham, J. 2012. The effect of a major road on bat activity and diversity. *Journal of Applied Ecology*, 49, 82-89.
6. Boyles, J.G., Cryan, P.M., McCracken, G.F. and Kunz, T.H. 2011. Economic importance of bats in agriculture. *Science*, 41-42.
7. Braun de Torrez, E. C., Wallrichs, M. A., Ober, H. K., and McCleery, R. A. 2017. Mobile acoustic transects miss rare bat species: implications of survey method and spatio-temporal sampling for monitoring bats. *PeerJ*, 5, e3940.
8. Brumm H. 2004. The impact of environmental noise on song amplitude in a territorial bird. *Journal of Animal Ecology*. 73, 434–440.
9. Bunkley, J. P., McClure, C. J. W., Kleist, N. J., Francis, C. D., and Barber, J. R. 2015. Anthropogenic noise alters bat activity levels and echolocation calls. *Global Ecology and Conservation*, 3, 62–71.
10. Chew, Robert M, and White, Harold E., 1960. Evaporative Water Losses of the Pallid Bat, *Journal of Mammalogy*, 41(4), 452-458.
11. Coleman, L. S., Ford, W.M., Dobony, C. A., Britzke, E. R. 2017. A Comparison of Passive and Active Acoustic Sampling for a Bat Community Impacted by White-Nose Syndrome. *Journal of Fish and Wildlife Management*; 5 (2): 217–226.
12. Denzinger A., Kalko E.K.V., Tschapka M. and Grinnell A.D., Schnitzler HU. 2016. Guild Structure and Niche Differentiation in Echolocating Bats. In: Fenton M., Grinnell A., Popper A., Fay R. (eds). *Bat Bioacoustics*. Springer Handbook of Auditory Research, vol 54. Springer, New York, 141-166 pp.
13. Fuller R. A., Warren P. H. and Gaston K. J. 2007. Daytime noise predicts nocturnal singing in urban robins. *Biology Letters*. 3, 368-370.
14. Gaikwad, M., Narwade, S., Fartade, K., and Korad, V. 2012. A review of the distribution of bats in southwestern region of Deccan, Maharashtra-India and conservation recommendations. *The Journal of Asian Biodiversity*, 41, 4-25.

15. Gallo, T., Lehrer, E. W., Fidino, M., Kilgour, R. J., Wolff, P. J., and Magle, S. B. 2018. Need for multiscale planning for conservation of urban bats. *Conservation Biology*, 32(3), 638–647.
16. Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., and Briggs, J. M. 2008. Global change and the ecology of cities. *Science*, 319.5864, 756-760.
17. Grinnell A., Popper A., Fay R. (eds) *Bat Bioacoustics*. Springer Handbook of Auditory Research, vol 54. Springer, New York, NY. 141-166 pp.
18. Haddock, J. K. 2018. *Effects of artificial lighting on insectivorous bat communities in urban ecosystems*. (PhD. thesis). Retrieved from ses.library.usyd.edu.au.
19. Hollander, M., and Wolfe, D.A. 1973. *Nonparametric Statistical Methods*. New York: John Wiley and Sons. 115-120 pp.
20. Hutson, A.M., Mickleburg, S.P., and Racey, P.A. 2001. *Microchiropteran bats: Global status survey and conservation action plan*, vol. 56. IUCN.
21. Johnson, J., Menzel, M., Edwards, J., and Ford, W. 2002. A Comparison of 2 Acoustical Bat Survey Techniques. *Wildlife Society Bulletin*, (1973-2006), 30(3), 931-936.
22. Jones, G., and Rydell, J. 1994. Foraging strategy and predation risk as factors influencing emergence time in echolocating bats. *Philosophical Transactions of the Royal Society: Biological Sciences*, 346(1318), 445–455.
23. Jones, G., Jacobs, D. S., Kunz, T. H., Willig, M. R., and Racey, P. A. 2009. Carpe Noctem: the importance of bats as bioindicators. *Endangered species research*, 81-2, 93-115.
24. Kalko, E. K. V., and Handley, C. O. 2001. Neotropical bats in the canopy: Diversity, community structure, and implications for conservation. *Plant Ecology*, 153(1–2), 319-333.
25. Kalko, E.K.V. 1995. Insect pursuit, prey capture and echolocation in *Pipistrelle* bats Microchiroptera. *Animal Behavior*, 50, 861-880.
26. Kerth, G., and Melber, M. 2009. Species-specific barrier effects of a motorway on the habitat use of two threatened forest-living bat species. *Biological Conservation*, 142(2), 270-279.
27. Krishnan, A. 2019. Acoustic community structure and seasonal turnover in tropical South Asian birds. *Behavioural Ecology*, 30(5), 1364–1374.
28. Lintott, P. R., Bunnefeld, N., and Park, K. J. 2015. Opportunities for improving the foraging potential of urban waterways for bats. *Biological Conservation*, 191, 224-233.
29. Lombard, E. 1911. Le signe de l'élévation de la voix. *Annales des Maladies de L'Oreille et du Larynx*. 37, 101–119.
30. Meredith, M. and Ridout. M. 2020. *Overview of the overlap package*. URL: [URL: <https://cran.rproject.org/web/packages/overlap/vignettes/overlap>](https://cran.rproject.org/web/packages/overlap/vignettes/overlap)

31. Monadjem, A., Jacobs, D., Cotterill, W., Hutson, A.M., Mickleburgh, S., Bergmans, W. and Fahr, J. 2017. *Tadarida aegyptiaca*. The IUCN Red List of Threatened Species 2017: e.T21312A22115459.
32. Moretto, L., and Francis, C. M. 2017. What factors limit bat abundance and diversity in temperate, north American urban environments? *Journal of Urban Ecology*, 3(1), 1–9.
33. O'Farrell, M. J. and Bradley, W. G. 1970. Activity Patterns of Bats over a Desert Spring. *Journal of Mammalogy*, 51(1), 18–26.
34. Parkins, K. L., and Clark, J. A. 2015. Green roofs provide habitat for urban bats. *Global Ecology and Conservation*, 4(July 2015), 349–357.
35. Parks S. E., Clark C. W. and Tyack P. L. 2007. Short and long-term changes in right whale calling behavior: the potential effects of noise on acoustic communication. *Journal of the Acoustical Society of America*, 122, 3725–3731.
36. Phommexay, P., Satasook, C., Bates, P., Pearch, M., and Bumrungsri, S. 2011. The impact of rubber plantations on the diversity and activity of understorey insectivorous bats in southern Thailand. *Biodiversity and Conservation*, 20(7), 1441–1456.
37. Pune City Census Department. 2011. Pune Municipal Corporation Report, 12-13 pp.
38. Pune Cycle Plan-Traffic Volume Count survey. 2017. Pune Municipal Corporation, i Trans, PDA Pune, CEE. 16 pp.
39. Pune District, National Informatics Centre, Ministry Of Electronics and Information Technology, Government Of India URL: <<https://pune.gov.in/>>
40. Reiskind, M.H. and Wund, M.A. 2009. Experimental assessment of the impacts of northern long-eared bats on ovipositing *Culex* (*Diptera: Culicidae*) Mosquitoes. *Journal of Medical Entomology*. 465:1037-1044.
41. Ridout, MS. and Linkie, M. 2009. Estimating overlap of daily activity patterns from camera trap data. *Journal of Agricultural, Biological, and Environmental Statistics*, 14(3), 322–337.
42. Rodríguez-Aguilar, G., Orozco-Lugo, C. L., Vleut, I., and Vazquez, L. B. (2017). Influence of urbanization on the occurrence and activity of aerial insectivorous bats. *Urban Ecosystems*, 20(2), 477–488.
43. Rosenzweig, M. L., and Michael, L. 2003. Win-win ecology: how the earth's species can survive in the midst of human enterprise. Oxford University Press on Demand. 224 pp.
44. Rowse, E. G., Harris, S., and Jones, G. 2018. Effects of dimming light-emitting diode street lights on light-opportunistic and light-averse bats in suburban habitats. *Royal Society Open Science*, 5(6), 180-205.
45. Russo, D., and Ancillotto, L. 2015. Sensitivity of bats to urbanization: A review. *Mammalian Biology*. 803, 205-212.

46. Russo, D., Maglio, G., Rainho, A., Meyer, C. F. J., and Palmeirim, J. M. 2011. Out of the dark: Diurnal activity in the bat *Hipposideros ruber* on São Tomé island (West Africa). *Mammalian Biology*, 76(6), 701–708.
47. Rydell, J., Eklöf, J., and Sánchez-Navarro, S. 2017. Reply to ‘Comment on age of enlightenment: Long-term effects of outdoor aesthetic lights on bats in churches’ by T. Onkelinx. *Royal Society Open Science*, 4(12), 1–8.
48. Rydell, J., Entwistle, A., and Racey, P. 1996. Timing of Foraging Flights of Three Species of Bats in Relation to Insect Activity and Predation Risk. *Oikos*, 76(2), 243–252.
49. Schaub, A., Ostwald, J. and Siemers, B. M. 2008. Foraging bats avoid noise. *Journal of Experimental Biology*, 21119, 3174–3180.
50. Schimpp, S.A., Li, H. and Kalcounis-Rueppell, M.C. 2018. Determining species specific nightly bat activity in sites with varying urban intensity. *Urban Ecosystem*, 21, 541–550.
51. Siemers, B. M., and Schaub, A. 2010. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. *Proceedings of the Royal Society: Biological Sciences*, 278, 1646–1652.
52. Slabbekoorn H. and Peet M. 2003. Birds sing at a higher pitch in urban noise. *Nature*. 424(6946), 267–267.
53. Smart City. URL: <https://punsmartcity.in/project/smart-street-lighting/>
54. Spoelstra, K., van Grunsven, R. H. A., Ramakers, J. J. C., Ferguson, K. B., Raap, T., Donners, M. and Visser, M. E. 2017. Response of bats to light with different spectra: Light-shy and agile bat presence is affected by white and green, but not red light. *Proceedings of the Royal Society: Biological Sciences*, 284(1855), 11–15.
55. Srinivasulu, B. and Srinivasulu, C. 2019. *Pipistrellus ceylonicus*. *The IUCN Red List of Threatened Species* 2019: e.T17332A22130600.
56. Srinivasulu, B., Srinivasulu, C. and Kruskop, S.V. 2019. *Pipistrellus tenuis*. *The IUCN Red List of Threatened Species* 2019: e.T17368A22123869.
57. Stahlschmidt, P., and Brühl, C. A. 2012. Bats as bioindicators—the need of a standardized method for acoustic bat activity surveys. *Methods in Ecology and Evolution*, 33, 503–508.
58. Stone, E. L., Jones, G., and Harris, S. 2009. Street lighting disturbs commuting bats. *Current biology*, 1913, 1123–1127.
59. Stone, Emma L., Jones, G., and Harris, S. 2012. Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. *Global Change Biology*, 18(8), 2458–2465.
60. Stone, Emma Louise, Harris, S., and Jones, G. 2015. Impacts of artificial lighting on bats: A review of challenges and solutions. *Mammalian Biology*, 80(3), 213–219.

61. Straka, T. M., Wolf, M., Gras, P., Buchholz, S., and Voigt, C. C. 2019. Tree cover mediates the effect of artificial light on urban bats. *Frontiers in Ecology and Evolution*, 7, 91.
62. Teets, Katherine D., C., Susan, David, Loeb, and Jachowski S. 2019. Detection Probability of Bats Using Active Versus Passive Monitoring. *Acta Chiropterologica*, 21(1), 205-213.
63. Tena, E., Fandos, G., de Paz, Ó., de la Peña, R., and Tellería, J. L. 2020. Size does matter: Passive sampling in urban parks of a regional bat assemblage. *Urban Ecosystems*, 23(2), 227–234.
64. Threlfall, C., Law, B. and Banks, P. 2012. Sensitivity of insectivorous bats to urbanization: Implications for suburban conservation planning. *Biological Conservation*, 146. 41–52.
65. Tzortzakaki, O., Papadatou, E., Kati, V. and Giokas, S. 2019. Winners and losers in an urban bat community: a case study from southeastern Europe. *Hystrix*. 30(2), 825-5272.
66. USFWS United States Fish and Wildlife Service 2014. Range-wide Indiana bat summer survey guidelines. Reference URL: <<http://www.fws.gov/midwest/endangered/mammals/inba/surveys/pdf/2014IBatSummerSurveyGuidelines13Jan2014.pdf>>
67. Vaughan, N., Jones, G., and Harris, S. 1997. Habitat use by bats (Chiroptera) assessed by means of a broad-band acoustic method. *Journal of Applied Ecology*, 34(3), 716–730.
68. Voigt, C. C., and Kingston, T., Jung, K.G. and Threlfall, C. 2016. *Bats in the Anthropocene: Conservation of Bats in a Changing World* (Voigt C. C. and Kingston, T. eds.). Springer International Publishing. 571–595 pp.
69. Voigt, C. C., Scholl, J. M., Bauer, J., Teige, T., Yovel, Y., Kramer-Schadt, S., and Gras, P. 2019. Movement responses of common noctule bats to the illuminated urban landscape. *Landscape Ecology*, 35, 189–201.
70. Watts, I., Walls, S., and Jones, G. 2006. Differential habitat selection by *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus* identifies distinct conservation needs for cryptic species of echolocating bats. *Biological Conservation*, 133, 118-127.
71. Zinn, L., and Humphrey, S. R. 1976. Insect communities available as prey and foraging of the southeastern brown bat. Proceedings 7th Annual North American Symposium on Bat Research, unpublished paper presented at symposium.
72. Zollinger, Sue A. and Brumm, H. 2011. The Lombard Effect. *Current biology*: CB. 21. R614-5.
73. Zurcher, A. A., Sparks, D. W., and Bennett, V. J. 2010. Why did the bat not cross the road? *Acta Chiropterologica*, 122, 337-340.