Bat Activity in an Agricultural Landscape in Central Thailand

Piyaporn Suksai

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Zoology

Prince of Songkla University

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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ชื่อวิทยานิพนธ์ กิจกรรมของค้างคาวในภูมิทัศน์เกษตรในภาคกลางของประเทศไทย

ผู้เขียน นางสาว ปิยาภรณ์ สุขใส

สาขาวิชา สัตววิทยา

ปีการศึกษา 2561

บทคัดย่อ

ภูมิทัศน์เกษตรเป็นพื้นที่ที่มีการเพาะปลูกสลับกับแหล่งที่อยู่อาศัยแบบกึ่งธรรมชาติ ซึ่งลักษณะดังกล่าวสามารถพบได้ทั่วไปในภูมิภาคเอเชียเช่นเดียวกับพื้นที่ภาคกลางของประเทศไทย โดยพื้นที่การเกษตรที่มีลักษณะเหมือนๆกันส่วนใหญ่มักจะพบว่ามีผลกระทบในเชิงลบต่อความหลากหลายทางชีวภาพ เพื่อที่จะรักษาบริการของระบบนิเวศไว้ จึงจำเป็นต้องมีข้อมูลเกี่ยวกับการใช้ของที่อยู่อาศัยของสัตว์ป่าในภูมิประเทศนั้น ๆ แต่ความรู้ทางด้านการใช้ประโยชน์ของค้างคาวกินแมลงในพื้นที่เกษตรกรรมในภูมิภาคเอเชียนั้นมีน้อย การศึกษาครั้งนี้จึงมีวัตถุประสงค์เพื่อตรวจสอบกิจกรรมของค้างคาวกินแมลง และตรวจสอบความผันแปรของแต่ละฤดูกาล ในพื้นที่เกษตรกรรมโดยการใช้เครื่องบันทึกคลื่นเสียงค้างคาว โดยบันทึกเสียงค้างคาวใน 5 พื้นที่ศึกษา ประกอบด้วย นาข้าว พืชไร่ ป่า แหล่งชุมชน และแหล่งน้ำ นับชุดเสียงที่ค้างคาวบินผ่านในแต่ละพื้นที่โดยใช้โปรแกรมอ่านคลื่นเสียง สำหรับการแปลผลจะพิจารณาจากการปรากฏหรือไม่ปรากฏของค้างคาวในแต่ละชนิดในช่วงเวลาหนึ่งนาที จากการศึกษาพบเสียงของค้างคาวทั้งหมด 37,610 เสียงใน 227คืน และคลื่นเสียงแบบกำลังกินอาหารจำนวน 623 เสียง จากค้างคาวทั้งหมด 14 ชนิด โดยพบว่าแหล่งน้ำมีกิจกรรมการใช้พื้นที่สูงกว่านาข้าว พืชไร่ ป่า และแหล่งชุมชนอย่างมีนัยสำคัญ ($p < 0.001$) ซึ่งอาจจะอธิบายได้จากปริมาณของแมลงน้ำที่ปรากฏ นอกจากนี้พบว่ามีกิจกรรมค้างคาวที่สูงขึ้นอย่างมีนัยสำคัญในช่วงฤดูร้อนเมื่อเทียบฤดูหนาว และฤดูฝน ($p < 0.001$) โดยเฉพาะอย่างยิ่งในพื้นที่แหล่งน้ำ โดยรูปแบบดังกล่าวเห็นได้ชัดในค้างคาวหูหนูตีนเล็กเขี้ยวสั้น (*Myotis siligorensis*), ค้างคาวปีกถุงเคราดำ (*Taphozous melanopogon*) และค้างคาวปากย่น *(Chaerephon plicatus)* ฤดูร้อนเป็นช่วงเวลาหลักในการผสมพันธุ์ของค้างคาวส่วนใหญ่ในภูมิภาคนี้ดังนั้นกิจกรรมการกินอาหารที่สูงขึ้นในช่วงเวลาดังกล่าวอาจสะท้อนให้เห็นถึงความต้องการของสารอาหารและน้ำที่สูงขึ้นของค้างคาวในช่วงการให้น้ำนมลูก ดังนั้นการรักษาแหล่งน้ำร่วมกับการรักษาหย่อมป่ารอบ ๆ แหล่งน้ำ มีส่วนช่วยให้คงไว้ซึ่งสังคมของค้างคาวในภูมิทัศน์เกษตรได้

Thesis Title Bat activity in agricultural landscape of central Thailand

Author Miss Piyaporn Suksai

Major Program Zoology

Academic Year 2018

ABSTRACT

The agricultural landscape which is croplands mixed with semi-natural habitats, is common in Asia as well as in central Thailand. Agricultural areas with homogeneous characteristics most often found to have a negative impact on biodiversity. In order to maintain ecosystem services, we must have information about the habitat use of wildlife in the landscape. Little is known about habitat use of insectivorous bats in agricultural landscapes in Asia. The objectives of this study are determining foraging habitat and activities of insectivorous bats and to assess seasonal variation in foraging habitat and activities of insectivorous bats in an agricultural landscape central of Thailand via acoustic monitoring. Anabat Bat detector are carried out in real time with the data save to computer hard- drive in 5 land use types paddy fields, field crops, forests, settlements and water bodies for one year. During each sampling period, we detected and counted bat passes with an Analook program based upon the present or absent of a species occurrence during one- minute time interval. 37,610 one- minute interval with bat calls and 623 feeding buzzes over 227 nights, representing 14 bat species were recorded. Bats showed highest activity in water bodies, which was significantly higher than all other land use types ($p < 0.001$). This may be explained by the availability of aquatic insects. There was a significantly higher bat activity index in the hot-dry season than at other seasons ($p < 0.001$) especially over water bodies. This pattern was obvious in *Myotis siligorensis*, *Taphozous melanopogon* and *Chaerephon plicatus*. The hot-dry season is the main breeding period of most bats in this region. High feeding activity during this period could reflect higher nutrient and water demand of lactating females. Thus, maintaining water bodies and its surrounding woodlands facilitate existing of diverse bat community in agricultural landscape.

ACKNOWLEDGMENTS

This thesis would not be possible without the help and encouragement of these individuals. The person I most appreciated is the Asst. Prof. Dr. Sara Bumrungsri, my advisor who give advice, which is very useful in research and also helps solve various problems that occurred during data collection and writing phase. Thank you for the opportunity and advice throughout the study and also for giving me motivation to do research. I would like to thank Asst. Prof. Dr. Vachira Lheknim and Krongthong Lheknimto for coordinating in the field and take good care throughout in the field work.

I would like to thank thesis examining committee including, Assoc. Prof. Dr. Prateep Duengkae, Department of Forest Biology, Faculty of Forestry, Kasetsart University. Dr. Pipat Soisook, Princess Maha Chakri Sirindhorn Natural History Museum, Prince of Songkla University and Dr. Sopark Jantarit, Excellence Center for Biodiversity of Peninsular Thailand, Faculty of Science, Prince of Songkla University.

It is also thankful for supporting from our fieldwork assistants including Somsak Suksai, Teerayut Muangmanee, Panuwat Suksai, Chananchida Kwanmee and Saowaluk Binlasoi. The author wishes to thank the monks at the Khao Wongkot temple and Pathom Panich temple in Lopburi province for providing accommodation during a year of field data collection, and also the owner of paddy field, field crops and settlements for data collection. Thanks to all the people who collaborated during the bat monitoring at Lopburi, Saraburi, Sing Buriand Nakhon Sawan province.

The authors thank to the financial support from National Science and Technology Development Agency, Thailand (P14-50620) and Research Assistantship, Faculty of Science, Prince of Songkhla University and Graduate Scholarship, Prince of Songkla University.

I would like to thank all members in Small Mammals, Birds and Spiders Research Unit, Prince of Songkla University, especially, Dr. Nutjarin Petkliang, Dr. Tuanjit Sritongchuay, Miss Venus Saksongmuang, Miss Nittaya Ruadreo and Miss Kaneungnit Wayo and Miss Supawan Srilopan. And thank all friends for always encouraging.

Finally, the unforgettable person is a family member who take care, assist, encourage, understand, and always support me in learning throughout. Grateful to my boyfriend who always beside me in every moment of life.

Piyaporn Suksai

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CHAPTER 1

INTRODUCTION

1.1 General introduction

Conservation of insectivorous bats is essential to maintain a healthy habitat and suppress insect pests. Habitat use of animals is a basic requirement that responds to energy and food needs. In general, land-use study can be done in terms of spatial and temporal activity patterns (Krausman, 1999). By definition, in spatial scale refers to the fact that animals use resources in that area, both physically and biologically to be used as shelters. While temporal studies, may be based on changes in the time that affect animal behavior or behavior, or even the study of seasonal variations that affect the activity of animals. For example, the study of Ross (1967) found that the *Pipistrellus hesperus* bats eat different insects in different season. It eats leafhoppers in the spring, while it eats flying ants in the summer and small moths in the rainy season.

Since bats play an important role in the ecosystem, fruit bats pollinate and distribute seedlings (Fujita & Tuttle, 1991; Marshall, 1985), resulting in the establishment of forests in open areas. Can fly as far as 40 kilometers. (Marshall, 1985; Fleming, 1988). Insect eating bat is also important for the food chain to play a role in the transfer of energy and to help control the populations of important insects in the forest and in the agricultural areas (Boyles et al., 2011). *Chaerephon plicatus* is one of the insect-eating bats that help control insect populations, especially insect pests in paddy fields. It consumes 54.8 tons of insects per night (Leelapaibul et al., 2005).

In general, insect-eating bats tend to be more abundant in the areas where trees and water sources are present (Walsh & Harris, 1996; Vaughan et al., 1997; Brooks, 2009). They are highly active in forests or forest fragments and likewise in rural areas (Erickson & West 2003; Lumsden & Bennett, 2005), which are mostly found in the bushes and forest edges (Russ et al., 2003; Pettit & Wilkins, 2012). In addition, the activity of bats varies according to the season in response to variations in climate throughout the year (CiechanowskiI et al., 2007; Johnson et al., 2011). Some studies suggest that the physical factors affect the activity of bats, such as temperature, relative humidity and wind speed (Jonhson et al., 2011).

Information on habitat use patterns is important for conservation management in order to protect bats (Carmel & Safriel, 1998). This study aims to describe the spatial and temporal habitat use patterns of bats in central Thailand.

1.2 Literature review

1.2.1 Agricultural landscape

The agricultural landscape is characterized of interactions between farmers' efforts and the natural setting in an area (Louloudis et al., 2005). These areas cover approximately 40 % of terrestrial ecosystems (FAOSTAT, 2011), with the five billion ha of land under farming now exceeding the scope of forested (Robertson & Swinton, 2005; Power, 2010). Many researchers have shown that agricultural systems not only provide high-level biodiversity and ecosystem services. (Tilman, 1999; Foley et al., 2005; Tscharntke et al., 2005), but the characteristics of these agricultural systems may affect to the remaining natural areas. (Perfecto & Vandermeer 2010). Depending on the management of different areas, some the agriculture may use a chemical or plant genetic modification, resulting in contamination of the environment, which could impact negatively on biodiversity in many areas (Nelson et al., 2009; Power, 2010), including human health and the economy.

In tropical, agricultural expansion as a result from population growth and changes in resources use, which damage to the old forests and grasslands (Defries et al., 2010; Lambin & Meyfroidt, 2011). Other factors affecting agriculture is climate change and the need for cultural adaptation to the new environment. Many areas may not be suitable for cropping, While the weather may result in reduced yields. (Williams-Guillén et al., 2008). These trends are major convert in land-use patterns and biodiversity, which the intensive farming, forest loss have especially negative effects to species richness and abundance of bats (Fischer et al., 2009, 2010;

Jones et al., 2009). Most of the agricultural areas are close to water bodies, river or pond, an important resource for many bat species.

1.2.2 Insectivorous bats and habitat use

Bats are in Class Mammalia and Order Chiroptera. More than 750 species are in Suborder Microchiroptera. Thailand has more than 138 species bat species (Soisook, 2011). Bats are more ecologically diverse than other groups of mammals. This adaptive behavior and physiology of sensory and motor systems, allowing access bat habitats and resources in a variety of night. (Schnitzler & Kalko, 2001).

Bats drink from open water surface and many species also feed on insects emerging such as crane flies, caddis flies, midges, mosquitoes, that have aquatic larval stages. Bats may flight several kilometers for foraging across the surrounding landscape. Some bat species can use the same roost site all over the year, while, some species may be change among roosts every few nights (Linton et al., 2011).

Bats use linear habitat scenery such as woodland edge, riparian corridors, hedgerows and tree-lines as flight paths to travel through the terrain. These habitats are also of respective importance to foraging bats because they offer a high diversity and abundance of insect prey as well as appropriate foraging conditions (Linton et al., 2011).

1.2.3 Echolocation of insectivorous bats

The echolocation is the diagnosis by an animal of the echoes of its own emitted sound wave, by which it builds a sound- picture of its present environment. Many bats use high frequency sound or ultrasounds, beyond the limit of human hearing (Altringham, 1999). The sound waves of bats are specific and can be classified to species (Fenton, 1982). The role of echolocation in the foraging behaviour of aerial feeding bats appears clear and unequivocal (Fenton, 1999). Echolocation is very broad-band, audible at the times, and was picked up on the bat detector across the full scale from under 20 kHz to over 160 kHz. Bats emit echolocation sound in pulses. Two types of these pulses. Frequency modulated calls (FM), this type of sound wave is not suitable for detecting objects. Because there is less energy and are quickly transmitted through the tuner. It is suitable for monitoring the actual location of the object. Constant frequency calls (CF), this type of sound wave is suitable for detecting objects because the sound has intense energy but not suitable for accurate positioning of objects (Altringham, 1999).

1.2.4 Bat detector

In bat identification, there are a number of methods of converting ultrasound into sound we can hear. The three most common are the heterodyne method, the frequency division method, and the expansion method.

1. Heterodyning, this is the most common method. This method converts the ultrasound into a hearing sound by removing the frequency at which the detector is turned to the frequency of the incoming ultrasound. The heterodyne technique results in sensitive bat detectors. This is a simple resultant of the narrowband behavior. Because only a small part of the whole ultrasonic frequency range is made audible, only a concurrently small part of the entire full-range noise will be made audible. Therefore, the noise level will be low and the sensitivity high (Pettersson, 2004).

2. Frequency Division, this method monitors all ultrasound concurrently and uses a zero-crossing circuit which produces a square wave output with the same frequency as the fundamental of the incoming signal. A frequency division detector is less sensitive than a heterodyne detector, so may not be detected the weak calls. However, the converted signal of a frequency-division detector carries more data than that of a heterodyne detector and can be used for some types of sound analysis (Pettersson, 2004).

3. Time Expansion, this method provides the most accurate reproduction of call bats. Generally, ultrasound signals are stored digitally and send it back at a slower speed. The signal is still characteristic of the original signal. Thus, we hear calls to all as it should be sound, except that the sound frequency of less than ten times and ten times slower. Then we will be able to record this as we would hear a

sound and display a sonogram, which allow us to determine the type of species and perform analysis using computer software (Pettersson, 2004).

1.3 Objectives

1. To determining foraging habitat use and activities of insectivorous bats in an agricultural landscape of central Thailand.

2. To investigate the seasonal variation in foraging habitat use and activities of insectivorous bats.

Supplementary notes

1.Difinition of habitats in this study

Water bodies	large bodies of water which range from artificial reservoir, major irrigation canal (width 20m), minor irrigation canal (6m width), lake. All of them were never dry in any seasons.
Paddy field	rice field which include both active rice planting period and non-rice planting period.
Field crops	area of non-rice field which farmer plant annual crops such as cassava, sugarcane, or short-term crops such as maize, millet and sunflower.
Settlements	groups of houses in rural area usually with a temple, which some are as large as rural villages. It is not including town or city.
Forest	forest patches over limestone hill. All are deciduous forest in which most trees shed leaves over hot dry season. Trees are generally small and sparsely distributed, with top canopy around 10m. Some of them are disturbed forest, and sampling site was less disturbed as possible. Bat detectors were hanging at top branches of the emergent trees.

2. note for results

Since one potential bias from overnight acoustic monitoring is calls of species that active throughout the night may outnumber other bats that active in the early night only. To verify if it occurs, data from first 3 hours (1830-2130h) was analysed. It found that results were mostly similar to whole night result (Appendix 9, 10), Bat activity was highest in water bodies and hot dry season had the highest bat activity. However, it found that cool dry season had significantly higher activity than rainy season (it was not significantly different in whole night data). So, in this thesis, result of whole night monitoring was presented in result section.

CHAPTER 2

WATER BODIES ARE A CRITICAL FORAGING HABITAT FOR INSECTIVOROUS BATS IN AGRICULTUREAL LANSCAPES OF CENTRAL THAILAND

This work was submitted to Songklanakarin Journal of Science and Technology

Water bodies are a critical foraging habitat for insectivorous bats in agricultural landscapes of central Thailand

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Abstract

Agricultural intensification and homogenization of land use are known to have a negative impact on biodiversity. Little is known about habitat use of insectivorous bats in tropical agricultural landscapes in Southeast Asia. Bat activity was determined by acoustic monitoring in five land use types included paddy fields, field crops, forests, settlements and water bodies for one year from November 2015 to October 2016. We recorded 37,610 one- minute interval with bat calls and 623 feeding buzzes, representing 14 bat species in Thailand central plain. Bat foraging activity was dominated by open space and edge space species. Bat activity was significantly higher over water bodies. However, insect biomass did not significantly different between habitats. There was a significantly higher bat activity index (two-fold) in the hot-dry season than at other times especially over water bodies. This pattern was obvious in *Myotis siligorensis*, *Taphozous melanopogon* and *Chaerephon plicatus*. High feeding activity during hot-dry season could reflect higher nutrient and water demand of lactating females. Maintaining water bodies and their surrounding woodland in agricultural landscape is important for bat conservation.

Keywords: acoustic monitoring, bat activity, habitat use, hot dry season, paddy field, water bodies

2.1 Introduction

Agricultural landscapes are mosaics of land use interspersed with few semi-natural habitats which cover approximately 40 % of terrestrial ecosystems (FAOSTAT, 2011) and will expand with increasing human population growth and resource use (FAOSTAT, 2011; Defries et al., 2010). This results in a decrease the biodiversity because of the intensification of land use mostly explained by the effect of agro-chemicals and the homogenization of the landscape ((Benton et al., 2003; Bianchi et al., 2006; Liira et al., 2008). One of the documented effects is the decline in populations of many bat species worldwide (Jones et al., 2003; Safi & Kerth, 2004). Homogenization of the agricultural matrix reduce natural structure elements which consequently remove potential habitats for bats and their prey. In addition, agro-chemicals can be directly harmful to bats and also reduce their prey availability (William-Guillen et al., 2016).

However, agricultural landscapes tend to be structurally heterogeneous (Kalda et al., 2015) most consisting of cultivated land and aquatic habitats. Several studies have highlighted the importance of these water bodies, especially for bats. They are associated with an abundance of prey (Fukui et al., 2006) and several bat species are specialized to forage in aquatic habitats (Fenton & Bogdanowicz, 2002). Many bat species also use bodies of water as landmarks for orientation and navigation (Serra-Cobo et al., 2000). For conservation of insectivorous bats, it is therefore essential to maintain a habitat and manage the area for insect resources. In general, foraging habitat can be studied both in terms of space and time. Habitat use is the way an animal uses the physical and biological resources in a habitat, for foraging, shelter, nesting, escape, or other life history traits (Krausman, 1999). While the study of temporal patterns can be observed from changes during the night, and seasonal variation. Spatially, authors reported greater bat abundance in primary forest compared to disturbed forest and agricultural land though species richness seem to be less different (William-Guillen et al., 2016; Furey et al., 2010), Activity patterns of bats may respond to a variety of factors, including the abundance of insects, air temperature, relative humidity and energetic demands imposed by pregnancy.

Factors that are correlated with activity levels differ among studies and may be area and species specific (Hayes, 1997). Season was reported to affect to bat activity pattern in temperate region (O' Donnell, 2000), but studies in tropical regions is very limited. For old world tropical bats, births were found primarily in April and May while lactation mostly present during May to July in north Vietnam (Furey et al., 2010). Theoretically, bats in this region increase foraging activity in such period to meet its energetic and nutrient requirement. In addition to foraging ground, roost is also its critical resource in agricultural landscape.

In the present study, the spatial and temporal variation in activity of insectivorous bats was examined in central Thailand where agriculture is highly intensive. Passive acoustic monitoring and insect sampling were conducted in five major habitat types including paddy field, field crops, forest over limestone hill, settlements and water bodies for one year. It is hypothesized that the foraging activity of insectivorous bats is highest in forest as it provides highest food availability and presence of complex canopy structure. In addition, bat foraging intensity is greatest during early rainy season (May-July) when it is a general breeding season in this area.

2.2 Materials and methods

2.2.1 Study area

Ours study area was located in Chao Phraya river plain which covers Lopburi, Saraburi, Nakhonsawan and Singburi provinces, Central Thailand (latitude 14°42' - 15°18'N, longitude 100°22' - 100°51'E, 400-600 m asl.). There are generally three seasons: a cool- dry season (November to February), a hot dry season (March to May) and a rainy season (June to October). In 2016, the climate in Southeast Asia was affected by El Nino and was extremely dry especially in April (Thirumalai et al., 2017). In this year, the rainy season was delayed for two months, and began in July (Figure 1), and June was classified as dry season in this study. The average ambient temperature is 28.3 ºC with an annual rainfall is about 1,147 mm. This area is generally flat as a flood plain, but limestone outcrops with caves patchily present. These caves harbour different species of bats such as *Taphozous* spp., *Rhinolophus* spp. and *Hipposideros* spp. (Figure 2).There are four cave colonies of the Wrinkle-lipped Free-tailed bats (*Charephon plicatus*) include Wat Khao Wongkot cave (15°1'N, 100°32'E), Wat Don Dueng cave (15°8'N, 100°37'E), Wat KhaoWong cave (15°10'N, 100°24'E) and Wat Suwan Khiri Pidok cave (Takra Thong) (14°49'N, 100°46'E) which habor 500,000, 100,000, 400,000 and 50,000 bats respectively (S. Binlasoi, pers. com) (Figure 2). For classifying the habitat in the study area, the positions of four colonies of *Cherephon plicatus* were located. A 25 km radius for three large colonies and 10 km radius for a smaller colony were drawn on a land use map provided by Present Land use Monitoring: PLM, Executive Information System from Land Development Department of Thailand. The major landscape features are classified into five main categories: paddy field (35% of the area), field crops (30%), forests (15%), settlements (15%), and water bodies (10%). For paddy fields, there are two planting periods: May–October, and November–April, but in the study year (2016), only one planting period took place during the rainy season due to drought caused by El Nino. Sugarcane, maize and cassava are the main field crops available year-round. For maize, after harvesting, farmers also grow sunflowers or legumes or millet depending on rainfall conditions. Most forest is mixed deciduous with bamboo, the trees of which are deciduous in the hot-dry season.

The settlements are mostly small rural communities living around the temple. For water bodies, this area is part of the irrigation system of the Chai Nat and Pa Sak rivers. A network of canals from existing rivers provide water for paddy fields. Sugar palms (*Borassus flabellifer*) which known to habour Scotophilus spp. was rare (Appendix 1).

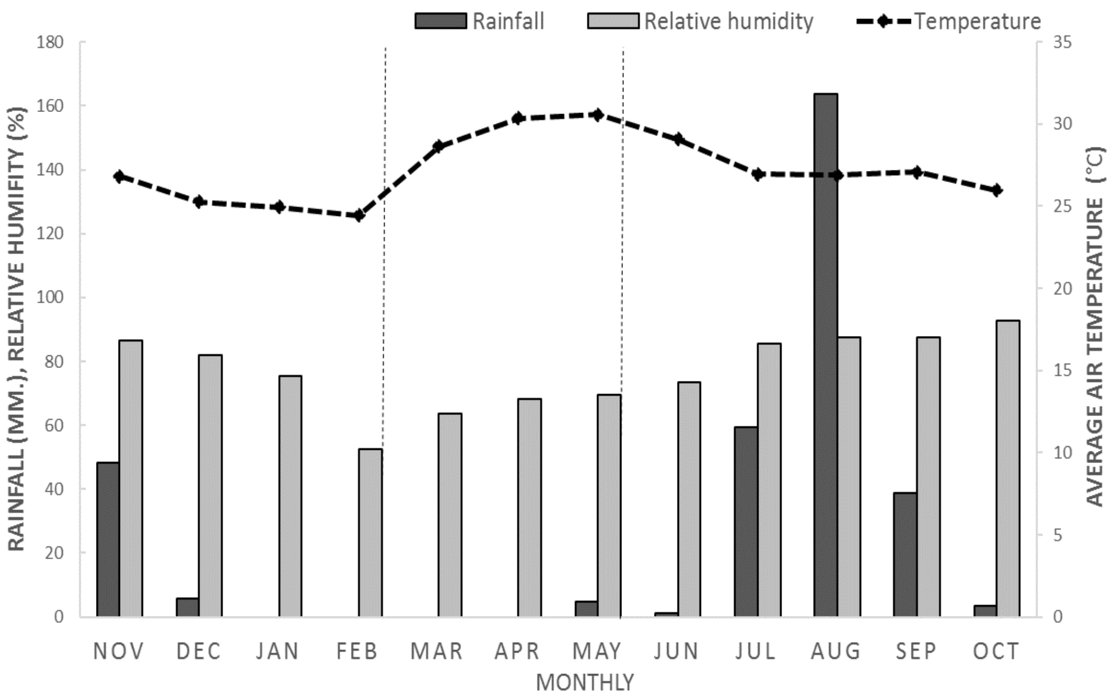

Figure 1 The climate condition (monthly rainfall (mm., grey bar), relative humidity (%, dark bar), and average air temperature (°C, dot line) in this area during November 2015- October 2016. Season was marked with line. Note that in this year, rainy season was two months delayed, so hot-dry season extends from March to May to be March to June in this year. Source: Lopburi Meteorological Station and Tak Fa Meteorological Station in 2015 to 2016.

2.2.2 Bat acoustic sampling

Data was collected every month from November 2015 to October 2016. Passive acoustic monitoring was carried out with an Anabat Bat detector (SD2, Titley Electronics) kept in a box attached to a pole at 5 m above the canopy or water surface except in forest, and tilted at approximately 45° (Avila-Flores & Fenton, 2005) and which recorded between from 18.30 h to 06.00 h.

In forest, bat detector was set at canopy level by hanging a box on the highest branches of standing trees in gaps. Thus, acoustic sampling was well represented of open space and edge space bat species while it was under representing narrow space bats which forage at understorey with faint calls. Sampling effort was in proportion to habitat contribution within the study area (Table 1). In each habitat, 5-30 nights of recording were undertaken in each season. Recording was not conducted in the same position in each season. Sampling sites in each habitat were at least 300 meters apart. Acoustic sampling in forests took place at least 150 meters from the edge. Recording stations in every habitat was far from artificial lighting as possible. Acoustic sampling was not carried out in heavy rain or during the full moon period (moon light >50%). The guild structure of insectivorous bats was categorised according to Schnitzler & Kalko (2001) and Denzinger & Schnitzler (2013) with very few species based on direct observation. These include the open space: forage in open space, high above the ground and far from vegetation, edge space: forage near the edges of vegetation, in vegetation gap, and narrow space bats: forage close to surfaces such as leaves or ground.

2.2.3 Insect sampling

Insect sampling was conducted with modified light- suction traps set randomly at 5 meters high above the canopy or water surface in each habitat. Trapping was also in proportion to habitat percentage. In each season, 3-12 traps were set in each habitat (Table 2). Insect traps were at least 50 meters from the acoustic monitoring stations. The insect traps sampled from 18.30 h to 06.00 h. Trapped insects were stored in bottles with 70% alcohol. Insect specimens were identified to the order level followings Tripplehorn & Johnson (2005). The insects are separated into 12 sizes-categories based on body length following Phommexay et al. (2011) (0.1- 2.0, 2.01- 4.00, 4.01- 6.00 till 22.01- 24.00 mm). Insect biomass were estimated with W= (0.0305) $L^{2.62}$, when W = dry mass (mg.), L = body length (mm) (Rogers et al., 1976).

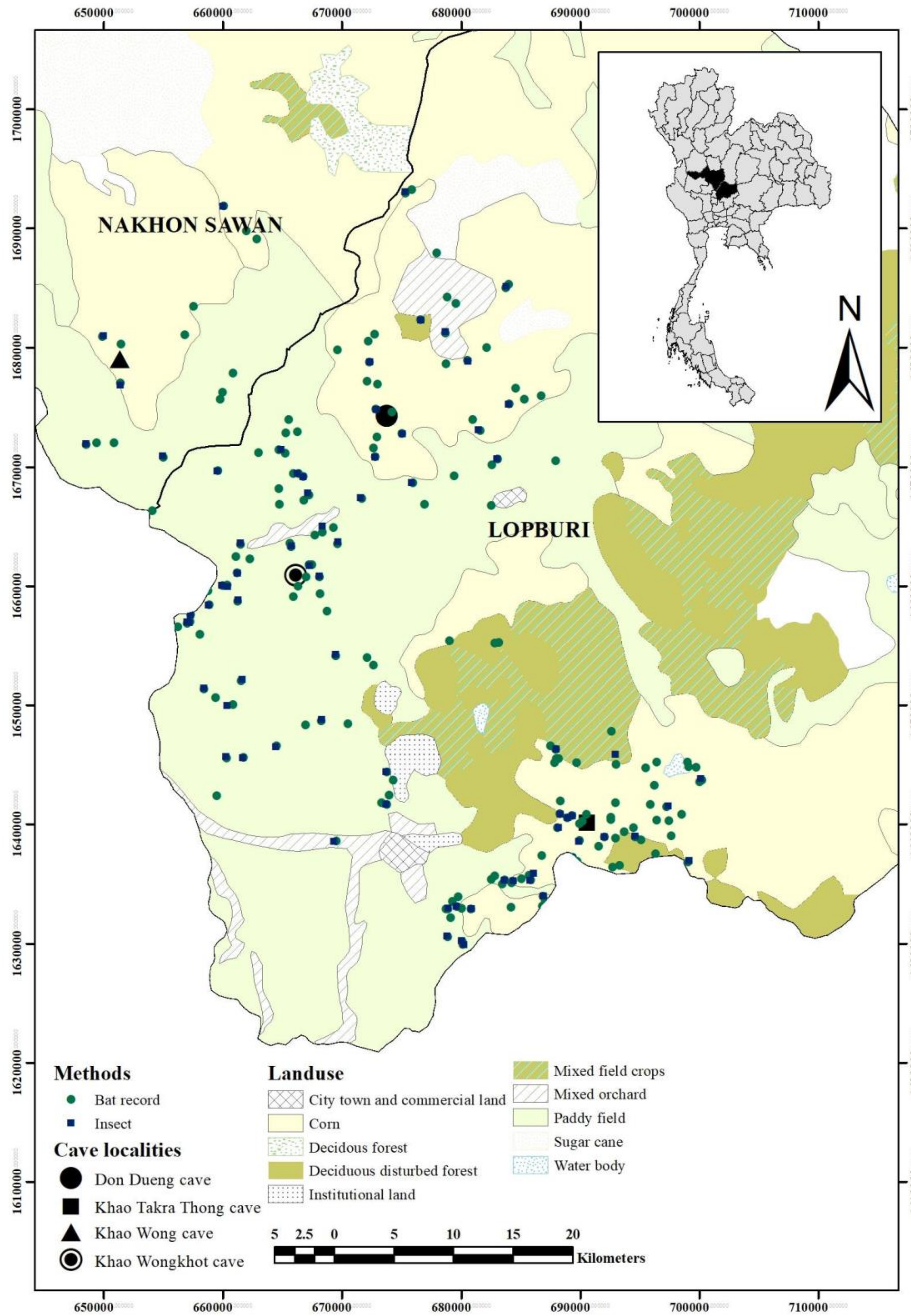

Figure 2 Distribution of bat monitoring points (n=227) (●) and insect sampling points (n=86) (■). Cave localities of four colonies of *Chaerephon plicatus* were shown.

Table 1 Sampling effort in different habitats and seasons for bats. Percent of each habitat was based on Present Land use Monitoring: Executive Information System from Land Development Department of Thailand.

Habitat/ percent	Season			Total
	Cool-dry	Hot-dry	Rainy	
Paddy fields (35%)	30	29	28	87
Field crops (30%)	21	22	20	63
Forests (15%)	10	10	9	29
Settlement (15%)	10	11	9	30
Water bodies (10%)	7	6	5	18
Total (100%)	78	78	71	227

Table 2 Sampling effort in different habitats and seasons for insect. Percent of each habitat was based on Present Land use Monitoring: Executive Information System from Land Development Department of Thailand.

Habitat/ percent	Season			Total
	Cool-dry	Hot-dry	Rainy	
Paddy fields (35%)	11	11	11	33
Field crops (30%)	6	7	7	20
Forests (15%)	5	3	4	12
Settlement (15%)	4	4	4	12
Water bodies (10%)	3	3	3	9
Total (100%)	29	28	29	86

2.2.4 Sound Analysis

The echolocation calls of bats were analysed with the AnalookW program. This study examines an acoustic activity index which is the presence/absence of species during one- minute intervals. A given night was divided into one- minute intervals, and a species was recorded as present if there were at least two calls in a series from single bat file (Miller, 2001). Feeding buzzes is rapid series of pulses were emitted when bats approached prey were also counted, when it appears in bat file. Bats are classified to species based on call characters: frequency of maximum energy, minimum frequency, and call duration by comparing the call from the call library of the Bat Research Unit, Prince of Songkhla University (Bumrungsri & Parson, 2015; Hughes et al., 2011). Although bat call references in this area were not completed and no call library for frequency division bat detector, and identification may be doubtful in some species, call character of each species used in this study was based on published reference together with call library for time expansion bat detector (Table 3). Call character use for identification of some species are overlap, it will present as a complex species such as *Rhinolophus malayanus* and *R. coelophyllus*.

2.2.5 Statistical Analysis

Zero- inflated regression tests in generalized linear regression (GLM) were used to examine variation in bat passes among habitats. Negative binomial regression in GLM was introduced to examine the differences in bat activity in each season. Quasi- Poisson regression (a type of generalized linear regression) was used to determine the insect biomass in each habitat and season. Spearman’s correlation test was used to investigate the relationship between bat passes, insect biomass and other factors. Tukey- Kramer tests were used to investigate the significant differences between pairs of groups. All statistical analysis was conducted by using R software 3.4.3 for Windows. All data were presented as mean ± SE.

Table 3 Call characters of each species found in this study based on Analook including call duration, maximum frequency, minimum frequency and time interval.

Species		Call duration	Maximum frequency	Minimum frequency	Time interval
Taphozous melanopogon	average	16.13	28.26	24.98	210
	SD	4.89	0.45	1.02	52.17
	max	21	27.6	23	107.8
	min	22	28.8	25.7	247
Taphozous theobaldi	average	8.15	25.78	17.57	-
	SD	-	-	-	
	max	-	-	-	
	min	-	-	-	
Rhinolophus coelophyllus / *malayanus*	average	31.53	80.83	66.26	87.18
	SD	7.01	1.04	5.97	32.01
	max	43.7	84	80.4	176.2
	min	13.89	78.6	54.8	38.5
Rhinolophus pusillus	average	24.55	111.66	86.08	-
	SD	7.05	1.51	3.56	
	max	38.26	115	92.40	
	min	12.55	109	76.60	

Table 3 Call characters of each species found in this study based on Analook including call duration, maximum frequency, minimum frequency and time interval. (continued)

Species		Call duration	Maximum frequency	Minimum frequency	Time interval
Rhinolophus pearsonii	average	20.5	57.73	33.02	-
	SD	-	-	-	
	max	-	-	-	
	min	-	-	-	
Hipposideros pomona	average	5.1	138.4	110.5	115.4
	SD	0.5	1.5	5.3	34.8
	max	5.7	140.4	118.4	153.0
	min	4.7	137.2	107.8	78.4
Hipposideros armiger	average	9.77	68.28	57.16	42.84
	SD	1.68	1.83	2.73	19.36
	max	13.6	71.5	64	97.8
	min	7.1	65.9	53.6	26.6
Hipposideros larvatus	average	5.72	95.98	81.88	30.68
	SD	1.15	2.37	3.02	12.56
	max	9.7	103.4	91.6	107.4
	min	3.53	89.9	76.3	15.4

Table 3 Call characters of each species found in this study based on Analook including call duration, maximum frequency, minimum frequency and time interval. (continued)

Species		Call duration	Maximum frequency	Minimum frequency	Time interval
Hipposideros diadema	average	12.41	58.17	44.81	41.01
	SD	2.05	1.28	2.28	9.47
	max	16.7	59.5	47.8	59
	min	9.6	54.6	39.7	22.9
Chaerephon plicatus	average	7.52	24.2	17.35	
	SD	-	-	-	
	max	-	-	-	
	min	-	-	-	
Myotis muricola	average	3.82	59.29	53.18	68.44
	SD	1.35	4.27	3.48	16.1
	max	1.7	53.4	47	51.1
	min	5.3	66.5	56	92.0

Table 3 Call characters of each species found in this study based on Analook including call duration, maximum frequency, minimum frequency and time interval. (continued)

Species		Call duration	Maximum frequency	Minimum frequency	Time interval
Myotis siligorensis	average	3.18	73.04	65.52	83.47
	SD	1.07	2.01	3.82	23.17
	max	1.5	70.4	59.7	38.7
	min	4.9	78.6	70.9	117.4
Scotphilus kuhlii	average	7.45	41.0	36.58	104
	SD	1.47	2.59	2.77	17.91
	max	4.7	38	34	66
	min	9.57	45.7	42.6	129
Scotphilus heathi	average	11.30	34.78	32.18	106
	SD	1.97	1.33	1.38	31.87
	max	8.3	32.2	29	49
	min	13.9	37	35	160

2.3 Results

2.3.1 Bat species composition

From 227 acoustic monitoring nights (163,440 minutes) in all habitats, 37,610 one- minute interval with bat calls and 623 feeding buzzes, representing 14 species, 6 genera, and 5 families (Table 4) were recorded. The most speciose family was the Hipposideridae (*Hipposideros pomona*, *H. armiger, H. larvatus*, *H. diadema*), followed by the Rhiniolophidae (*Rhinolophus coelophyllus* or *R. malayanus, R.pusillus* and *R. pearsonii*), and the Vespertilionidae (*Myotis muricola*, *M. siligorensis*, *Scotophilus kuhlii* and *S. heathii*), Emballonuridae (*Taphozous melanopogon* and *T. theobaldi*) and only one molossid bat (*Chaerephon plicatus*). The total number of species recorded in each habitat was similar: twelve species in settlements, Thirteen species in forests, paddy fields and water bodies and fourteen species in field crops. The five most common species were *Myotis siligorensis* (average 67.83 ± 7.23 one-minute interval with bat calls per night ± SE, 40.9%), *Chaerephon plicatus* (30.1 ± 3.8, 18.1%), *Taphozous melanopogon* (15.88 ± 3.83, 9.6%), *Myotis muricola* (12.60 ± 1.96, 7.6%), *Taphozous theobaldi* (11.34 ± 3.85, 6.8%) (Appendix 2). These species are dominant in every habitat. Based on the bat activity index, each species showed a trend in their habitat preferences. While many species prefer the water bodies including *T. theobaldi*, *C. plicatus*, *M. muricola*, *M. siligorensis*, and *S. kuhlii*, some species showed a preference for forests such as *R. pearsonii*. In addition,*T. melanopogon* showed a preference in both forest and water bodies (Table 4). Most species in this agricultural habitat were dominated by open space or edge space species.

Table 4 List of insectivorous bat species recorded in five habitats in central Thailand (Field crop, Settlement, Forest, Paddy field and Water bodies). Average number of one-minute interval with bat calls per night ± standard error (± SE), and bat functional group are shown.

Species of insectivorous bats	Average number of one-minute interval with bat calls per night (± SE)					Functional group
	Field crops (n = 63)	Settlement (n = 30)	Forests (n = 29)	Paddy fields (n = 87)	Water bodies (n = 18)	
Family Emballonuridae						
Taphozous melanopogon	6.24 ± 1.35	6.9 ± 3.32	36.8 ± 24.98	15.33 ± 4.19	33.50 ± 15.15	Open space
Taphozous theobaldi	3.40 ± 0.72	8.1 ± 1.61	14.66 ± 12.50	3.87 ± 0.84	75.28 ± 42.03	Open space
Family Rhinolophidae						
Rhinolophus coelophyllus/ malayanus	7.67 ± 1.58	0.4 ± 0.25	10.38 ± 3.41	2.74 ± 0.76	3 ± 2.09	Narrow space
Rhinolophus pusillus	1.17 ± 0.78	1.6 ± 0.67	2.68 ± 1.12	0.24 ± 0.16	1 ± 0.58	Narrow space
Rhinolophus pearsonii	1.43 ± 0.89	5.07 ± 2.14	26.21 ± 25.08	0.59 ± 0.26	5 ± 2.13	Narrow space

Table 4 List of insectivorous bat species recorded in five habitats in central Thailand (Field crop, Settlement, Forest, Paddy field and Water bodies). Average number of one-minute interval with bat calls per night ± standard error (± SE), and bat functional group are shown. (continued)

Species of insectivorous bats	Average number of one-minute interval with bat calls per night (± SE)					Functional group
	Field crops (n = 63)	Settlement (n = 30)	Forests (n = 29)	Paddy fields (n = 87)	Water bodies (n = 18)	
Family Hipposideridae						
Hipposideros pomona	0.06 ± 0.04	-	-	-	0.06 ± 0.05	Narrow space
Hipposideros armiger	0.21 ± 0.09	-	1.45 ± 1.17	0.05 ± 0.05	-	Edge space
Hipposideros larvatus	2.71 ± 0.71	7.13 ± 5.90	1.66 ± 0.73	0.60 ± 0.19	8 ± 6.32	Edge space
Hipposideros diadema	3 ± 1.31	0.1 ± 0.1	0.79 ± 0.49	5.40 ± 1.73	2.89 ± 2.18	Edge space
Family Molossidae						
Chaerephon plicatus	20.98 ± 5.30	29.27 ± 8.62	24.14 ± 11.33	33.39 ± 7.02	57.22 ± 17.0	Open space
Family Vespertilionidae						
Myotis muricola	9.67 ± 2.39	14.57 ± 4.28	4.55 ± 1.38	13.99 ± 3.32	25.89 ± 15.10	Edge space
Myotis siligorensis	40.36 ± 7.81	43.07 ± 10.70	33.45 ± 12.84	75.76 ± 10.57	222.33 ± 52.37	Edge space
Scotophilus kuhlii	5.11 ± 1.47	6.2 ± 3.40	2.28 ± 1.76	6.18 ± 1.38	30.67 ± 26.67	Open space
Scotophilus heathii	1.67 ± 0.44	1 ± 0.6	1.55 ± 0.7	5.77 ± 1.32	5.11 ± 4.37	Open space
Mean per habitat	103.68 ± 12.96	123 ± 26.53	160.59 ± 64.05	163.91 ± 21.98	469.94 ± 88.70	
Species of Bats	14	12	13	13	13	

2.3.2 Bat activity variation between habitats

Bats activity was different in all five habitat types. On average, bat activity index per night over water bodies (469.94 ± 88.70 one-minute interval with bat call, n = 18) was significantly higher than other habitats (Zero- inflated regression, $\chi^2 = 9862.27$, $p < 0.001$). Activity index in the forest (160.58 ± 64.05, n = 29) and paddy fields (163.91 ± 21.98, n = 87) does not differ significantly from each other ($p = 0.86$) but was significantly higher than those in settlements (123.40 ± 26.53, n = 30) and field crops (103.68 ± 12.97, n = 63) ($p = 0.06$) (Figure 3a). As with one- minute interval with bat call, feeding buzzes per night was significantly highest over water bodies ($p < 0.05$) (19.22 ± 7.26) while it was similar between forests (1.17 ± 0.7), paddy fields (1.67 ± 0.44), settlements (1.07 ± 0.53) and field crops (1.05 ± 0.33), respectively.

From five insect order found in the study sites, Lepidoptera account for the highest biomass (177.69 ± 25.98 mg, 48% of total insect biomass), followed by Coleoptera (73.05 ± 20.57 mg, 20%), Diptera (61.51 ± 23.10 mg, 17%), Hymenoptera (35.60 ± 48.0 mg, 9%), Hemiptera 19.45 ± 11.30 mg, 5%) and others was 1.69 ± 2.50 mg (1%) (Appendix 3). The insect biomass per night did not show significant variation between each habitat (Quasi- Poisson regression, $\chi^2 = 4.49$, $p > 0.05$). Insect biomass over water bodies (532.80 ± 400.25 mg, n = 9), field crops (361.86 ± 150.79 mg, n = 20) and paddy fields (262.35 ± 72.47 mg, n = 33) was slightly higher than settlements (206.33 ± 177.99, n = 12) and forests (130.59 ± 69.75, n = 12) (Figure 3b). No correlation between bat activity and insect biomass was found ($r = -0.03$, $p > 0.05$). Whilst, the bat activity index was negatively correlated with relative humidity ($r = -0.35$, $p < 0.001$), the number of insects was significantly and positively correlated with relative humidity ($r = 0.28$, $p < 0.01$) and negatively significant with temperature ($r = -0.22$, $p < 0.05$).

When divided bats into functional groups, water bodies had a significantly higher number of bat activity index than others habitat in every guild (GLM,χ^2= 9553.54, $p < 0.001$) (Appendix 4). Foraging activity index of open space bats over water bodies, in forests and paddy fields was significantly higher than in settlement areas and field crops ($p < 0.001$). For edge space bats, their activity over water bodies was very high and significantly different from other habitats. Although narrow space bats showed similar foraging activity across all habitats but their activities also differ between some habitats.

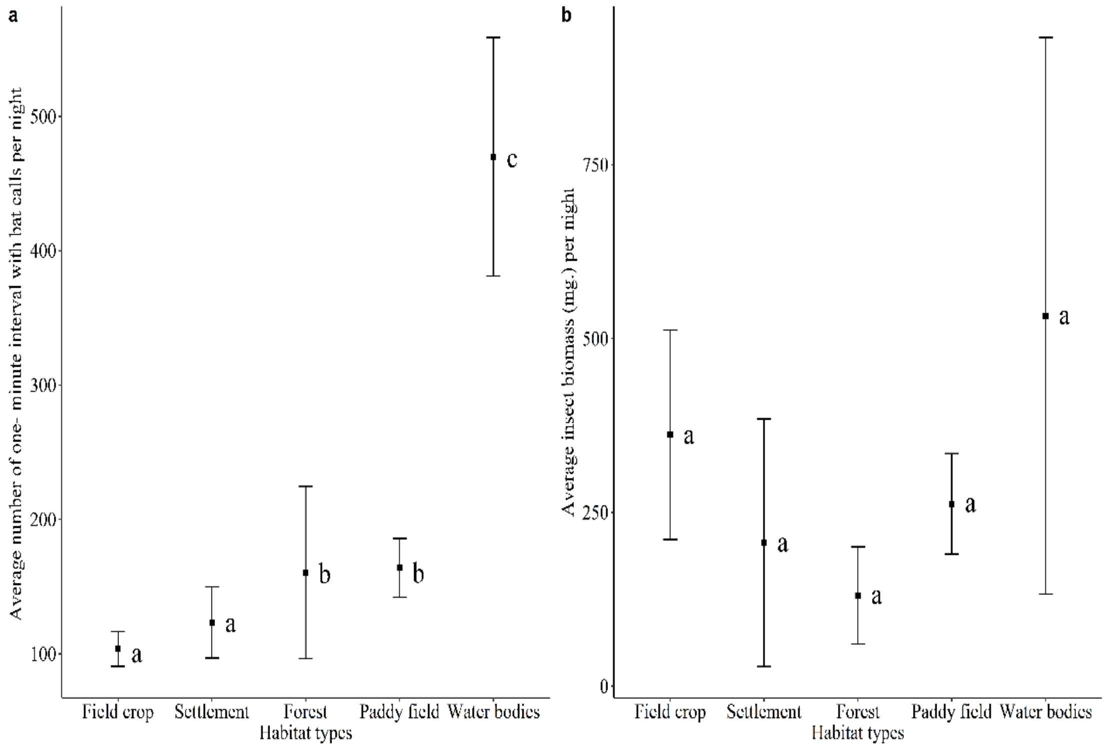

Figure 3 Average number of one- minute interval with bat calls per night (± SE) (a), average insect biomass (mg.) per night (± SE) (b) in five habitat types in Lopburi. Different letter means statistically different.

2.3.3 Seasonal variation in bat activity

Bat activity generally varies between seasons. In the hot dry season, there was a significantly higher bat activity index (241.74 ± 28.17, n = 78) than other seasons (Negative binomial regression, $\chi^2 = 17.50$, $p < 0.001$) whilst it was not much different between rainy (114.82 ± 24.98, n = 71) and cool-dry seasons (135.92 ± 25.85, n = 78) ($p > 0.05$) (Figure 4a). Specifically, most activity was recorded from March to April (296.63 ± 53.83) while it was lowest from September to October (103.77 ± 45.33). The foraging activity over water bodies was increased in the hot-dry season (682.17 ± 161.67, cool- dry season: 335.14 ± 103.04, and rainy season: 404 ± 194.7) (Appendix 5). *Myotis siligorensis, C. plicatus*, *T. melanopogon* increased their activity in hot- dry season. Feeding activity varied between seasons. Again, average feeding buzz was significantly higher in the hot- dry season ($p < 0.05$) (7.67 ± 1.34 buzzes) followed by the cool- dry season (3.42 ± 1.44 buzzes), and lowest in the rainy season (0.75 ± 0.30 buzzes).

2.3.4 Seasonal variation in insect biomass

The average nocturnal insect biomass per night was highest in the cool-dry season (516.73 ± 0.14 mg, n = 29) followed by the hot dry season (220.43 ± 89.15, n = 28) and the rainy season (123.31 ± 33.91, n = 29). There was a statistically significant difference (Quasi- Poisson regression, $\chi^2 = 8.61$, $p < 0.01$) in biomass between the cool- dry and rainy seasons (Figure 4b). The bat activity index in each season was not correlated with insect biomass ($p > 0.05$). Different groups of insects dominated in different habitats and these patterns changed in different seasons except for Diptera which were always dominant over water bodies in every season. Their biomass contributes 60-90% of total insect biomass in this habitat in every season (Appendix 6). Diptera contribute 90% of insect biomass in the hot-dry season over water bodies when bat foraging activity was highest.

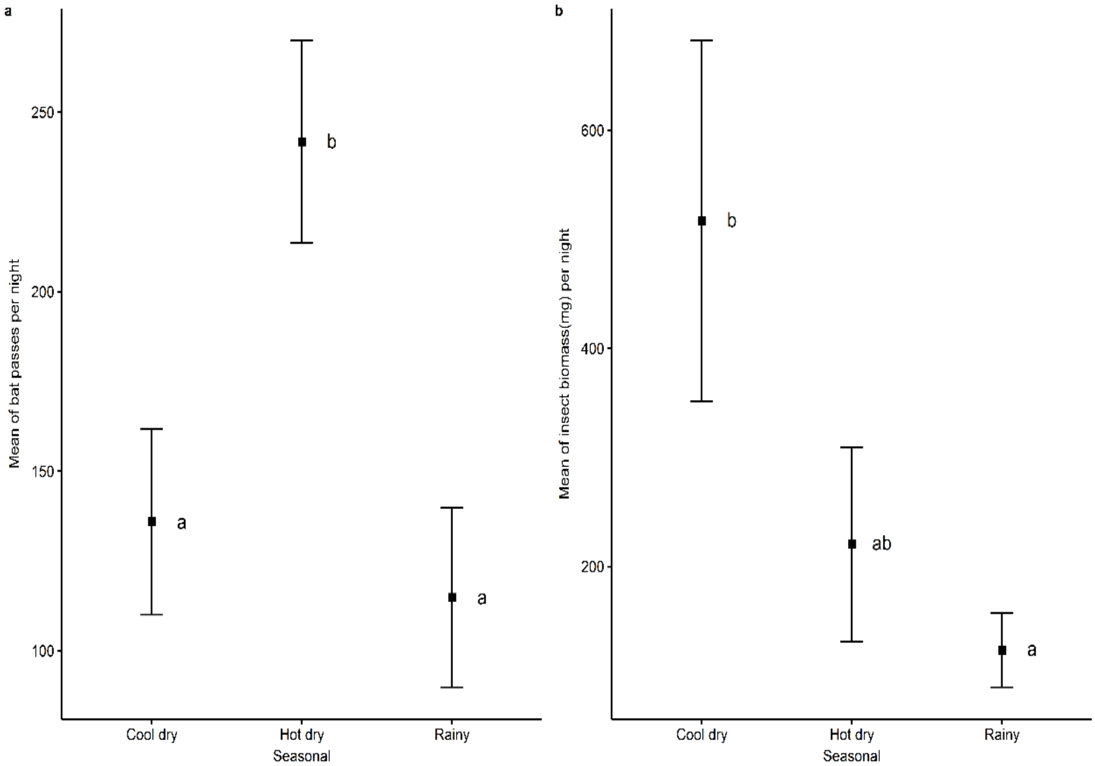

Figure 4 Seasonal activity patterns of insectivorous bats, average number of one-minute interval with bat calls per night (± SE) (a) and average insect biomass (mg.) per night (± SE) (b) in each season.

2.4 Discussion

2.4.1 Habitat use and activity of bats

Based on these results, this study highlights the importance of water bodies as foraging grounds in a tropical agricultural landscape. Water bodies are suggested as important foraging habitats for many insectivorous bat species (Fukui et al., 2006). Since bodies of water were shown to provide higher biomass of emergent adult aquatic insects, previous authors reported that the pond or stream has positive effects on the foraging activity of bats (Racey et al., 1998). In addition, aquatic insects have less well-developed flight ability compared to terrestrial insects (Brodsky, 1994) thus it is easier for bats to capture them. For water bodies, surrounding vegetation and size can be important factors determining insect biomass and consequently to bat foraging activity. The presence of trees around water bodies also impacts insect abundance as trees can create a shelter against wind, rain and predators more than in the open space (Zahn & Maier, 1997). For bats, trees along water bodies also reduces the intensity of light that lead to lower predation risk (Rydell et al., 1996). In aquatic habitats, wind can be an important factor for foraging bats. In windy conditions, trawling bats like *Myotis* spp. are less active, presumably because wind reduces the insect abundance and made ripples on the surface of the water, thus reducing the detection ability of targets (Russo & Jones, 2003). In contrast, smooth water surfaces provide a less cluttered acoustic return from the echolocation pulses for detecting and recognizing prey (Greif & Siemers, 2010). The size of aquatic habitats also influences the diversity of feeding bats in arid and semi-arid areas. Razgour et al., (2010) found that the activity of bats in the Negev Desert increased significantly according to the size of the pond. Wider ponds provide greater densities of insect prey and having the capacity to support more insect species offering productive and predictable foraging opportunities for bats (Racey et al., 1998).

Different bat species show variations in habitat preference. Most dominant species, which are open space and edge space foragers, prefer water bodies and paddy field. These open space bats are characterised by long and narrow wings, and are adapted for fast but relatively unmaneuverable flight in open places (Altringham, 1999). Their low echolocation frequencies allow them to detect pray at some distance, so they can hunt insects in uncluttered space, high above the ground or above the canopy (Schnitzler & Kalko, 2011). Based on this study, a particular species of bat showed strong habitat preference, for example *M. siligorensis*. *Myotis siligorensis* preferentially forage over water bodies or reservoir and scattered secondary grow deciduous trees including a sugar cane field in Thailand. The bats hunted in open foraging areas over land usually they hunted 2-5 m above the ground or over water surface and at least some meters away from the nearest vegetation (Surlykke et al. 1993). Rhinolophid bats have been known as forest specialists, their winsg and echolocation calls are suited to such highly cluttered habitats (Schnitzler & Kalko, 2011; Denzinger & Schnitzler, 2013).

2.4.2 Seasonal variation in bat activity

Season affects tropical bat activity and the present study indicated that bat activity index and feeding buzzes were significantly higher in the hot-dry season. This pattern mostly resulted from increasing activity of three bat species namely, *M. siligorensis*, *C. plicatus* and *T. melanopogon* over water bodies. Such increase may result from breeding nutrient requirement and the availability of Diptera, the dominant diet of these bats, in this habitat. These bats are known to be pregnant, giving birth during March to May (*C. plicatus*: Leelapaibul et al., 2005; Hillman, 1999; Furey et al., 2018 and *T. melanopogon*: Badwaik, 1988, Lim et al., 2018). Though there is no study of diet of *M. siligorensis* but they have known this species are smaller body size, lower ratio of wing length to wing width and lower wing loading which are adapted to fly slower but are more maneuverable (Wei et al., 2006), so we presume that species suited to forage for small insects. Vaughan, (1997) showed that another riparian bat, *Myotis daubentonii*, feeds mainly on aquatic Diptera, mostly soft- bodied Chironomidae. *Taphozous* spp. are opportunistic feeders, and authors showed that they also consume large amounts of Diptera (Srinivasulu & Srinivasulu, 2005; Wei et al., 2008; Weterings et al., 2015). For *C. plicatus*, Thonjued et al., (2018) using direct PCR-DGGE techniques, revealed that it feeds mostly on dipterans in central Thailand. During lactation, females adjust foraging activity to meet their energy demand (Barclay, 1989; Adams & Hayes, 2008). Insect-eating bats increase foraging time (Barclay, 1989) but reduce home range size (Henry et al., 2002) during lactation in respond to increase of 25% of body mass in milk. Lactating females showed significant more feeding bouts compared to pregnant females (Henry et al., 2002). In seasonal tropical regions, high temperatures and low relative humidity in the hot- dry season will causes high rates of evaporative water loss in reproductive females. Lactating bats need to drink more water as Adams & Hayes, (2008) found that lactating female bats visited water resources 13 times more compared to non-breeding adult females. Milk is composed of 72–76% water and body water flux increased significantly during lactation (Kunz et al., 1983; Wilde et al., 1995). So, bats need to fly to drink more often mostly in the evening and at dawn.

The ability of successful reproductive effort in female insectivorous bats is related directly to water availability (Adams & Hayes, 2008).

In this study, some inherently biases need to be noted. First, the detectability of each insectivorous species is unequal. Those open space bats and edge space bats have higher intensity call, thus are more detectable by bat detector. Consequently, result of this study including the dominant species, seasonal variation in habitat use tend to be represent of these groups. Regarding narrow space bats, further study using direct capture could complement acoustic study especially in forest. In Southeast Asia, limestone outcrop with patches of forest is common within agricultural landscape. This forested habitat is known to support bat diversity and important in terms of bat conservation (Furey et al.,2010). The second limitation of this study is the lack of inter-annual variation. In the study year, dry period was two months longer due to El Nino, thus limit of rain could affect to insect as well as bat behaviour. Future study should be also conducted in non-El Nino year before rigid conclusion can be made.

2.4.3 Conservation implication

The present study emphasizes the importance of the water bodies to bats in tropical agricultural landscape. To conserve bat populations, it is important to maintain the water bodies, including ponds, rivers and streams. Additionally, it is also vital to protect woodlands surrounding water bodies. In addition to harboring wildlife, such woodland can buffer aquatic ecosystems from chemical spray and extreme weather. However, most farms in Southeast Asia tend to clear such vegetation. Water bodies are critical habitats during the breeding period of bats, thus maintaining water bodies consequently helps to maintain populations of pest suppresser agents such as *C. plicatus* and other bats that known to consume planthoppers (Leelapaibul et al., 2005; Srilopan et al., 2018).

2.5 Acknowledgements

The authors wish to thank Khao Wongkot temple and Pathom Panich temple in Lopburi province for researcher accommodation. We would like to thank Asst. Prof. Dr. Vachira Leknim and and Krongthong Leknim to help coordinate in the field. We are also thankful for support of our field assistants Somsak Suksai, Teerayut Muangmanee, Panuwat Suksai, Chananchida Kwanmee and Saowaluk Binlasoi. The authors thank to the financial support from National Science and Technology Development Agency, Thailand and Research Assistantship, faculty of science, Prince of Songkhla University.

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CHAPTER 3

CONCLUSION

Our study highlights the importance of the water bodies in agriculture landscape components. To conserve bat diversity, one must maintain a diversity of ponds, river, stream or water bodies as these will be used differently by species with different physiological and morphological characteristics. These habitats are importance to foraging bats because they high diversity and abundance of insect prey particularly, availability of Diptera in water bodies. Bats in different functional groups will use different ways across the seasons, most dominant species of bats, which are used open space and edge space foragers. In hot- dry season indicated that the high bat activity index based on this study. This pattern mostly resulted from increasing activity of three bat species namely, *M. siligorensis, C. plicatus* and *T. melanopogon* in water bodies. Consequential, bats are most active during March to May, is the main breeding period. High feeding activity during this period could reflect higher nutrient and water demand of lactating females. Thus, the availability of water appears to have a strong positive influence on species of bats richness and activity in landscape characteristics of the surrounding farmland.

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APPENDICES

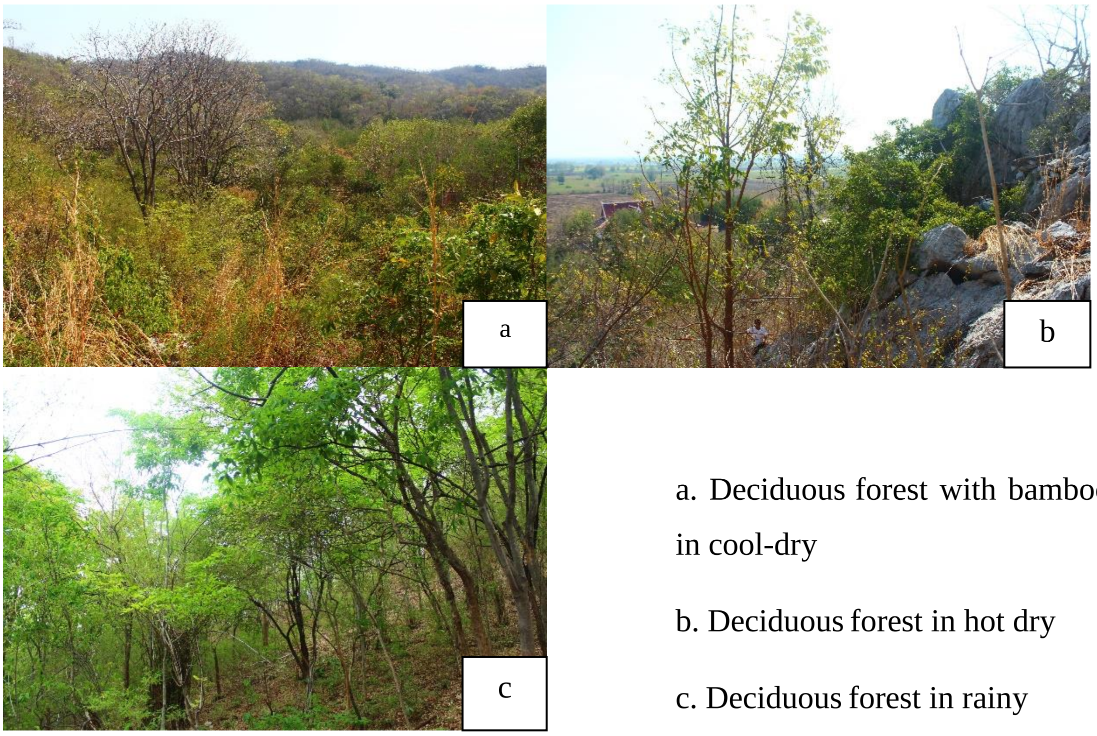
Appendix 1 The habitat types in the central of Thailand.

1). Paddy fields

2). Field crops

a.	Sugarcane	b.	Corn
c.	Sunflower	d.	Cassava
e.	Millet		

3). Forests



a. Deciduous forest with bamboo in cool-dry

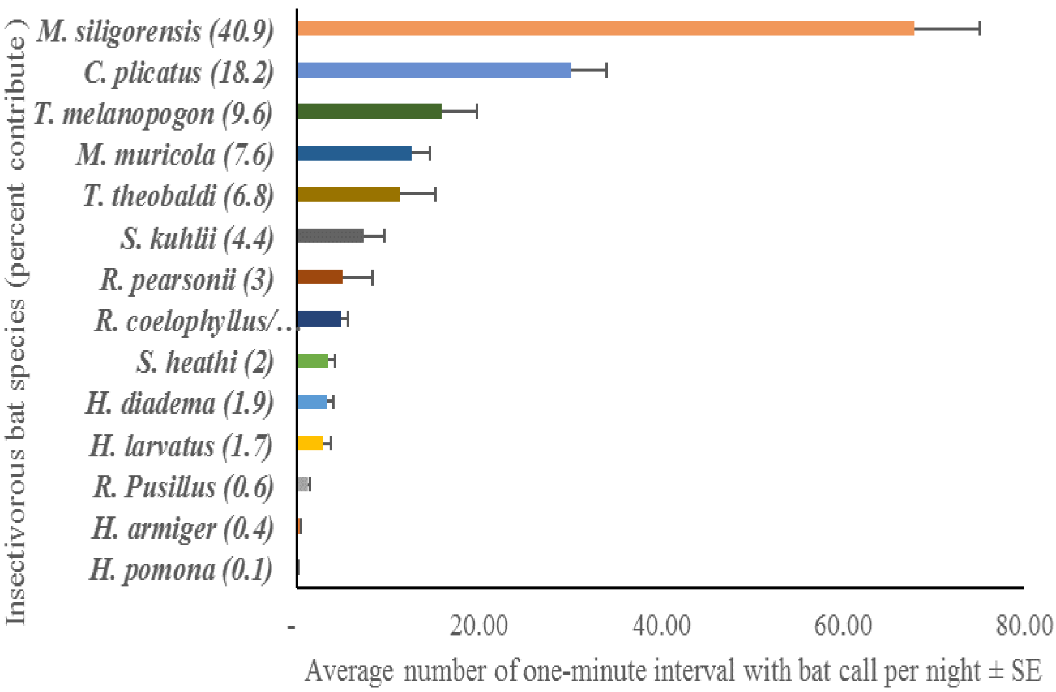
b. Deciduous forest in hot dry

c. Deciduous forest in rainy

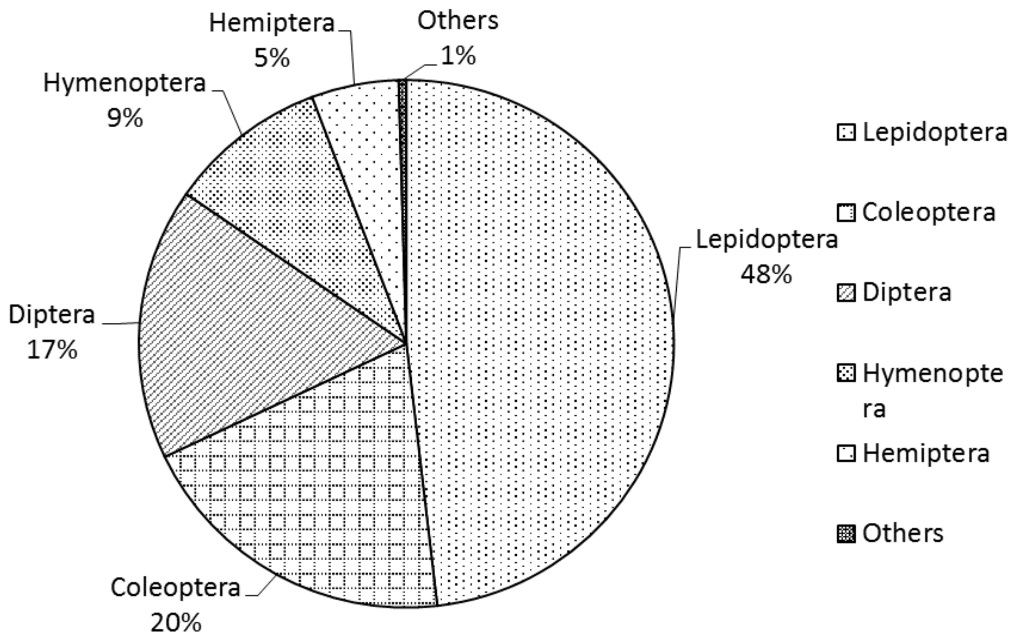
4). Settlements

5). Water bodies

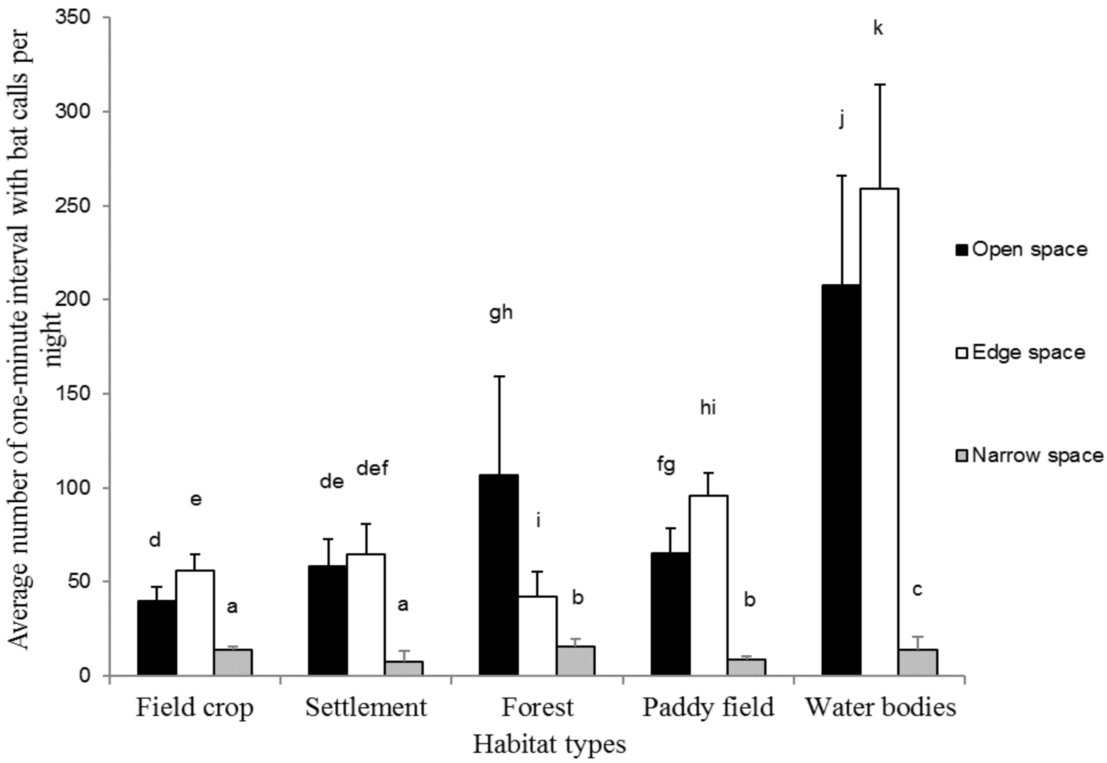
Appendix 2 List of insectivorous bat species record in Central of Thailand, average number of one-minute interval with bat calls per night ± standard error.



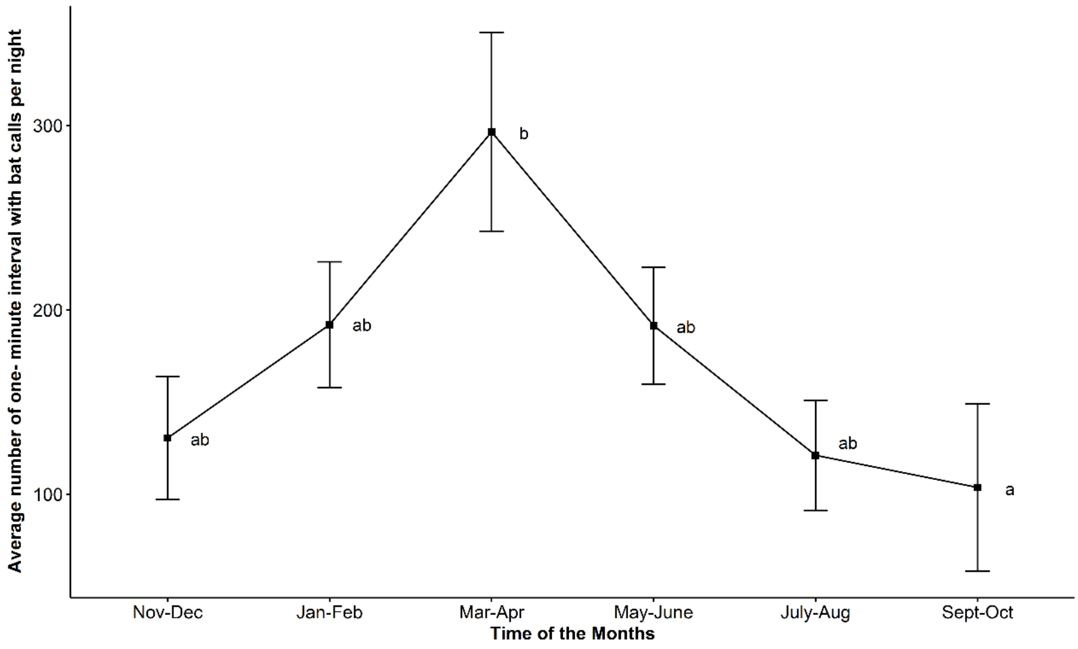
Appendix 3 The percentage of insect orders found in the all study sites.



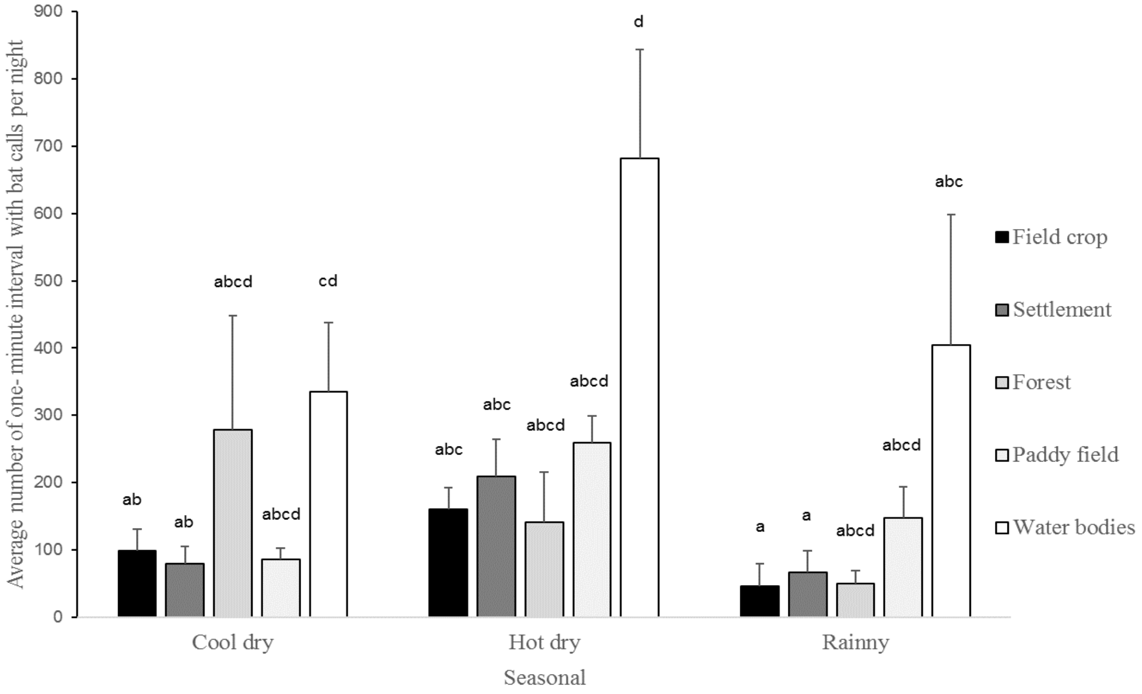
Appendix 4 Average number of one- minute interval with bat calls (± SE) of the three functional groups of insectivorous bats in each habitat.



Appendix 5 Average number of one-minute interval with bat calls per night in each month from November 2015 to October 2016.



Appendix 6 Seasonal activity in each habitat types, the average number of one-minute interval with bat calls per night (± SE).



Appendix 7 The insect orders found in the study sites in each season and habitat type. Average insect biomass ± standard error (± SE).

Season	Insect orders	Habitat types (average insect biomass ± SE))				
Cool- dry		Field crop	Settlement	Forest	Paddy fields	Water bodies
	Coleoptera	79.89± 35.01	6.70± 2.61	2.36± 1.28	165.37± 75.90	139.95± 87.73
	Diptera	127.26± 88.20	4.70± 4.70	17.05± 16.99	71.79± 24.53	655.09± 601.55
	Hemiptera	32.18± 20.04	0.18± 0.18	1.30± 1.29	100.10± 89.02	33.08± 32.48
	Hymenoptera	484.40± 480.44	1.38± 1.38	1.13± 0.71	3.07± 1.91	0.54± 0.38
	Isoptera	-	-	-	-	-
	Lepidoptera	45.90± 32.66	6.45± 3.32	225.78± 157.85	83.85± 30.36	260.05± 151.89
	Odonata	-	-	-	-	-
	Orthoptera	-	-	-	0.19± 0.18	9.20± 9.15

Appendix 7 The insect orders found in the study sites in each season and habitat type. Average insect biomass± standard error (± SE). (continued)

Season	Insect orders	Habitat types (Average insect biomass± SE)				
Hot dry		Field crop	Settlement	Forest	Paddy fields	Water bodies
	Coleoptera	9.29± 5.26	498.56± 496.36	1.98± 1.07	61.29± 41.22	1.85± 0.22
	Diptera	4.96± 4.07	0.83± 0.52	1.98± 0.99	15.86± 8.59	29.27± 18.83
	Hemiptera	8.01± 7.48	-	1.97± 1.12	13.49± 11.34	1.05± 1.05
	Hymenoptera	2.15± 1.16	-	0.17± 0.15	14.13± 12.82	-
	Isoptera	0.07± 0.07	2.49± 2.49	-	-	-
	Lepidoptera	107.75± 105.54	40.78± 40.78	19.55± 19.30	151.20± 72.45	-
	Odonata	7.68± 7.68	-	-	3.34± 3.34	-
	Orthoptera	-	-	-	-	-

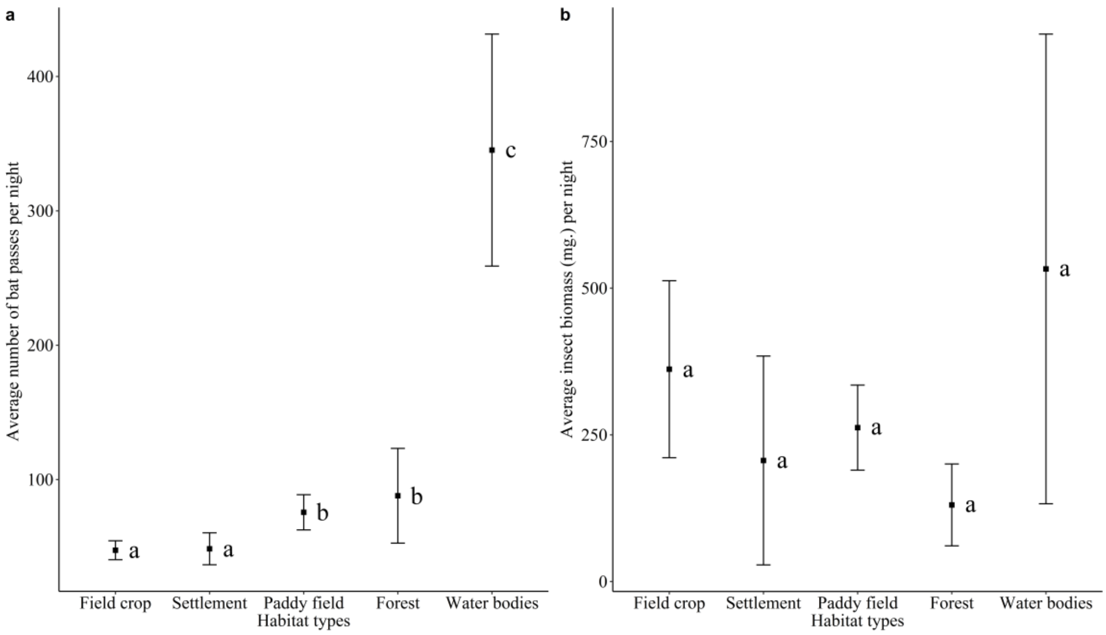
Appendix 7 The insect orders found in the study sites in each season and habitat type. Average insect biomass ± standard error (± SE). (continued)

Season	Insect orders	Habitat types (Average insect biomass± SE)				
Rainy		Field crop	Settlement	Forest	Paddy fields	Water bodies
	Coleoptera	33.08± 19.07	1.15± 0.62	0.59± 0.35	2.38± 1.29	3.15± 1.06
	Diptera	35.81± 14.42	43.80± 21.41	8.06± 2.29	46.29± 11.55	98.21± 54.14
	Hemiptera	7.33± 2.19	0.66± 0.26	1.66± 0.83	5.46± 3.21	1.98± 1.00
	Hymenoptera	0.30± 0.19	0.10± 0.10	0.83± 0.83	0.87± 0.54	0.69± 0.69
	Isoptera	-	-	-	-	-
	Lepidoptera	157.63± 115.52	3.55± 2.01	62.03± 36.79	47.83± 25.28	8.32± 8.33
	Odonata	-	-	-	-	-
	Orthoptera	-	-	-	-	-

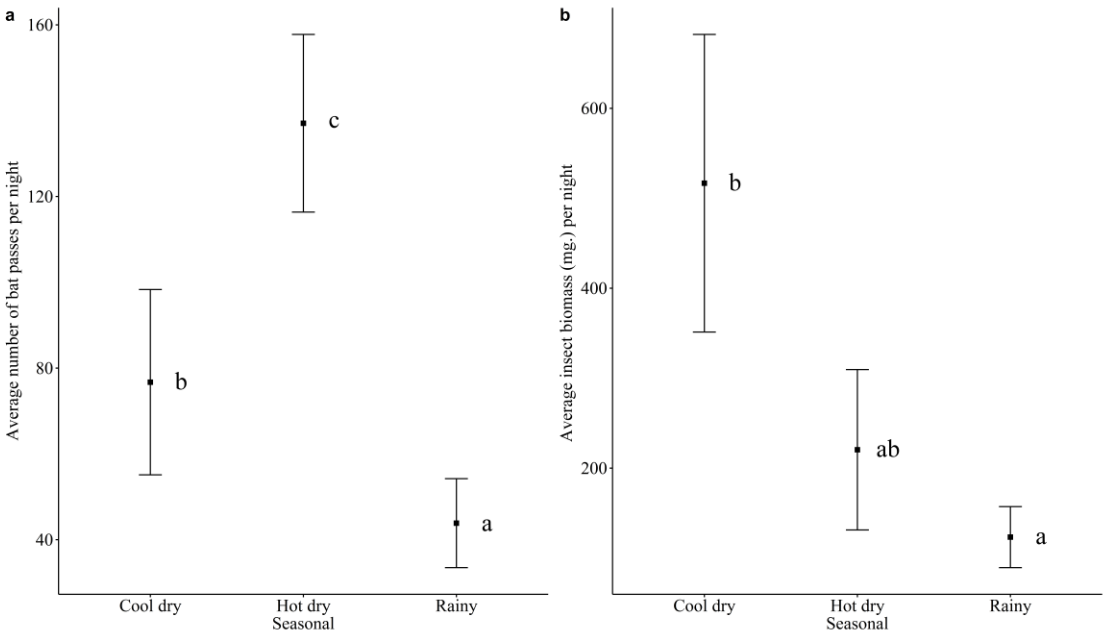
Appendix 8 The list of insectivorous bats found in the study sites in each season, Average number of one- minute interval (AI) with bat calls per night ± standard error (± SE).

Species of bats	Seasonal (Average of AI ± SE)		
	Cool- dry n = 78	Hot- dry n = 78	Rainy n = 71
Chaerephon plicatus	19.85 ± 4.88	46.82 ± 5.30	23.02 ± 2.73
Hipposideros diadema	1.96 ± 0.90	4.56 ± 0.51	3.19 ± 0.37
Hipposideros larvatus	0.74 ± 0.25	5.57 ± 0.63	1.91 ± 0.22
Hipposideros armiger	-	0.58 ± 0.06	0.18 ± 0.02
Hipposideros pomona	-	0.01 ± 0.01	0.05 ± 0.01
Myotis siligorensis	53 ± 7.71	111.44 ± 12.61	36.21 ± 4.29
Myotis muricola	6.29 ± 1.14	17.74 ± 2.00	13.88 ± 1.64
Rhinolophus coelophyllus / malayanus	5.32 ± 1.47	4.55 ± 1.15	4.49 ± 1.13
Rhinolophus pusillus	1.26 ± 0.46	1.5 ± 0.67	0.33 ± 0.19
Rhinolophus pearsonii	11.35 ± 1.28	2.08 ± 0.23	1.32 ± 0.15
Scotphilus heathi	1.83 ± 0.20	5.98 ± 0.67	2.31 ± 0.27
Scotphilus kuhlii	8.98 ± 1.01	7.79 ± 0.88	5 ± 0.59
Taphozous melanopogon	9.62 ± 1.09	26.15 ± 2.96	11.45 ± 1.35
Taphozous theobaldi	15.69 ± 1.77	6.91 ± 0.78	11.42 ± 1.35

Appendix 9 Average number of bats passes per night (± SE) (a), average insect biomass (mg.) per night (± SE) (b) between 18.30 h and 21.30 h in five habitat types in Lopburi.

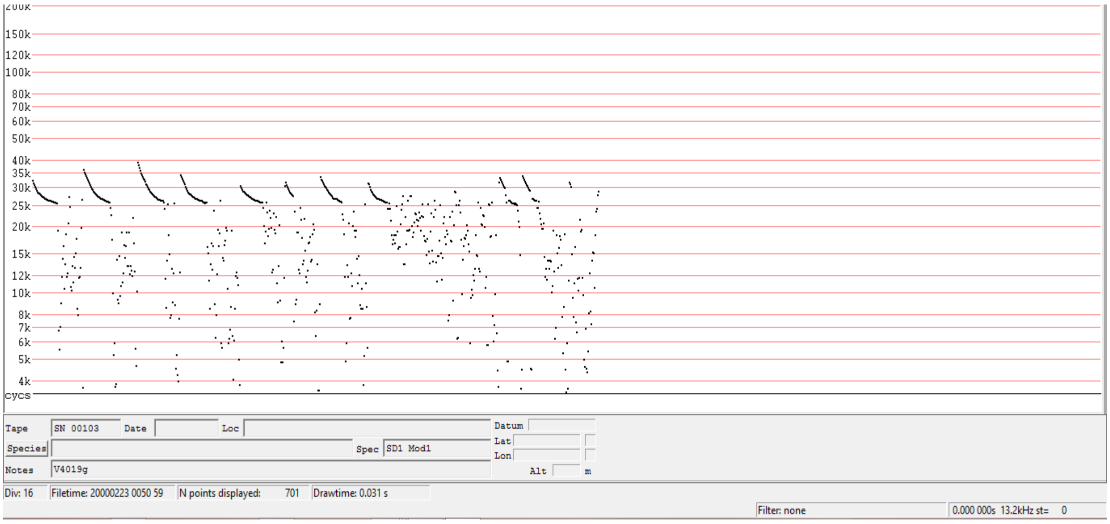


Appendix 10 Seasonal activity patterns of insectivorous bats, average number of bats passes per night (± SE) (a) and average insect biomass (mg.) per night (± SE) (b) between 18.30 h and 21.30 h in each season.

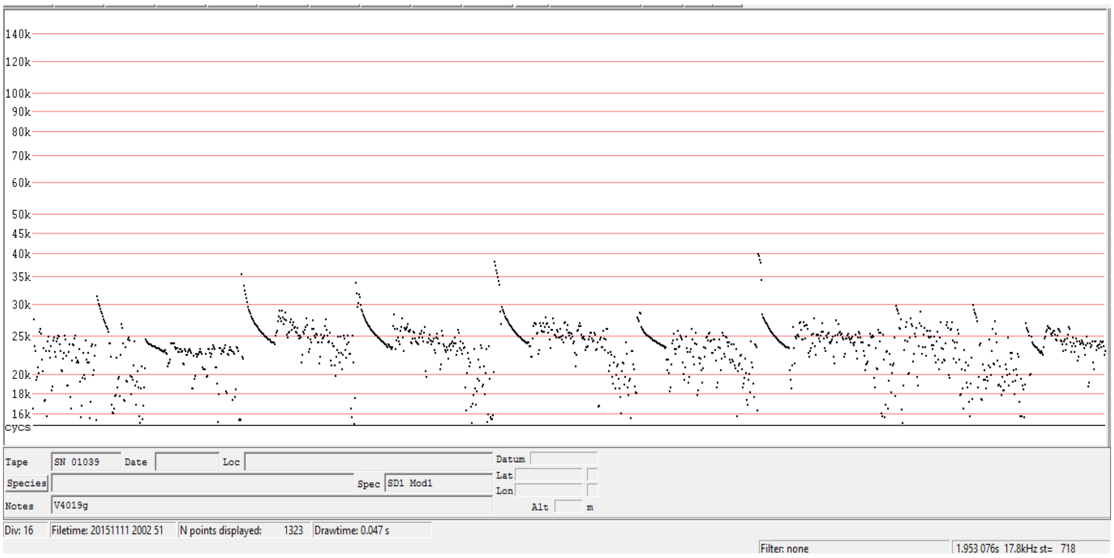


Appendix 11 The echolocation call of bats with Analook W program was record in Central of Thailand.

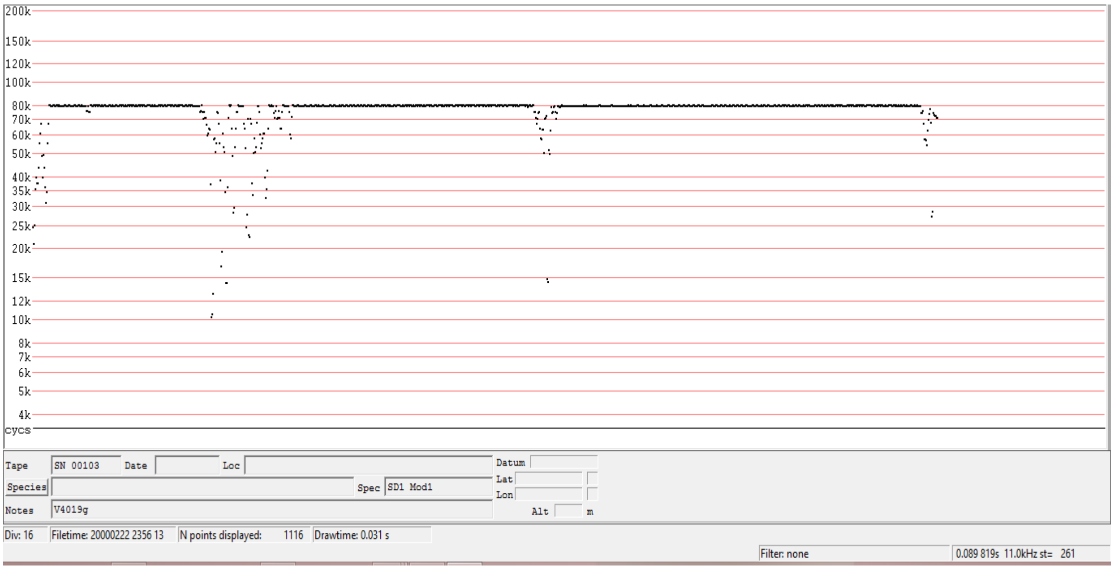
1. *Taphozous malonopogon*

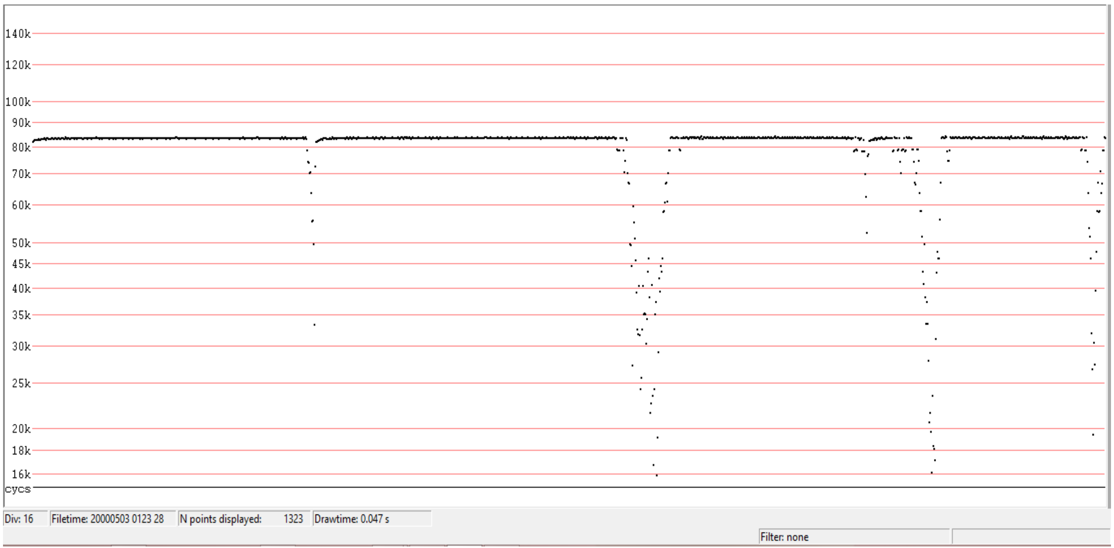


2. *Taphozous theobaldi*

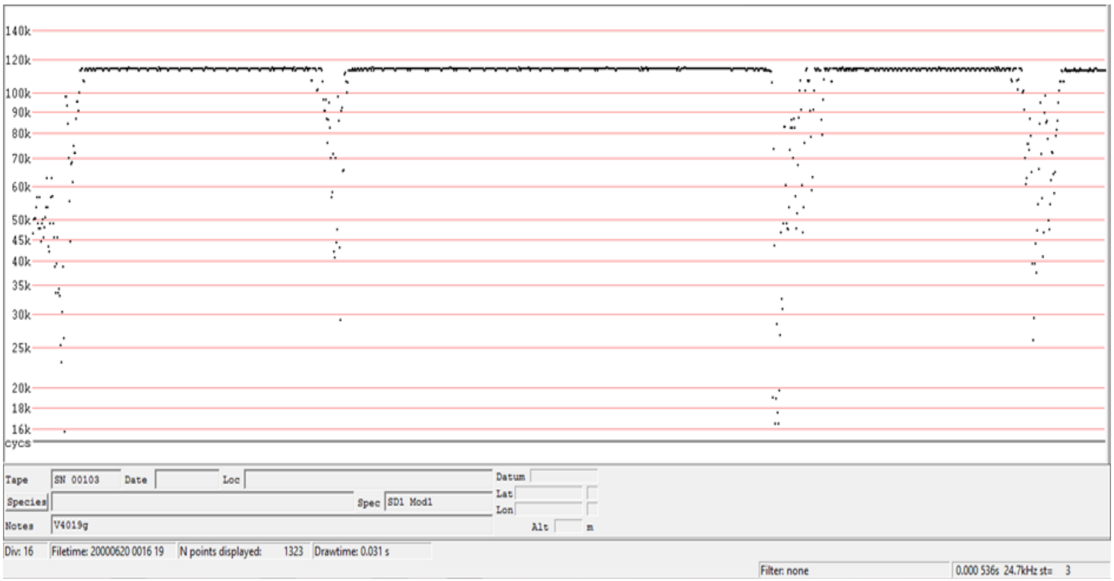


3. *Rhinolophus coelophyllus* / *Rhinolophus malayanus*

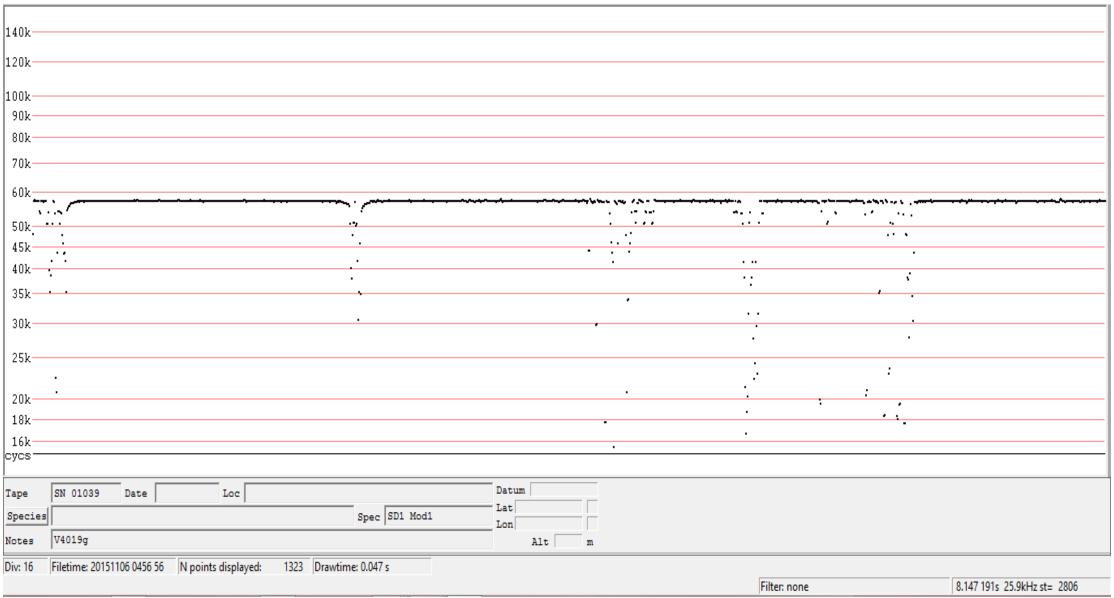




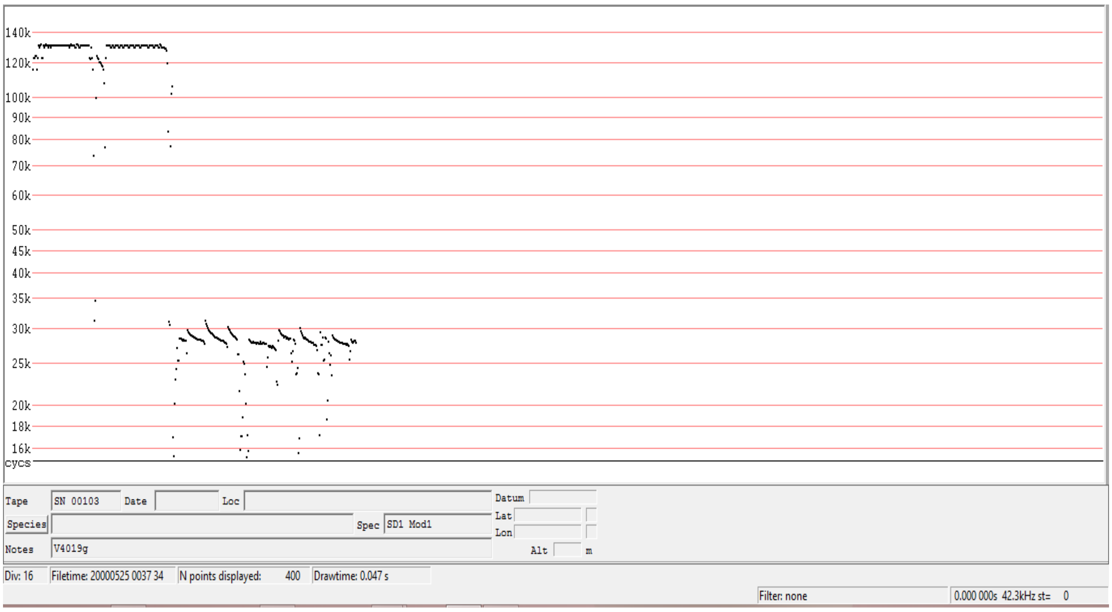
4. *Rhinolophus pusillus*



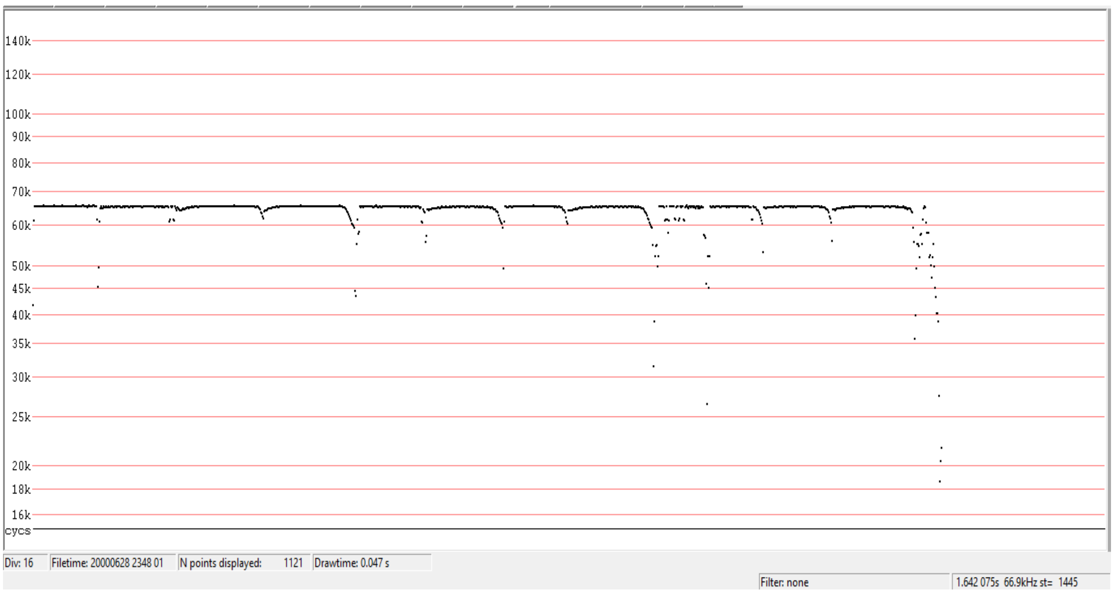
5. *Rhinolophus pearsonii*



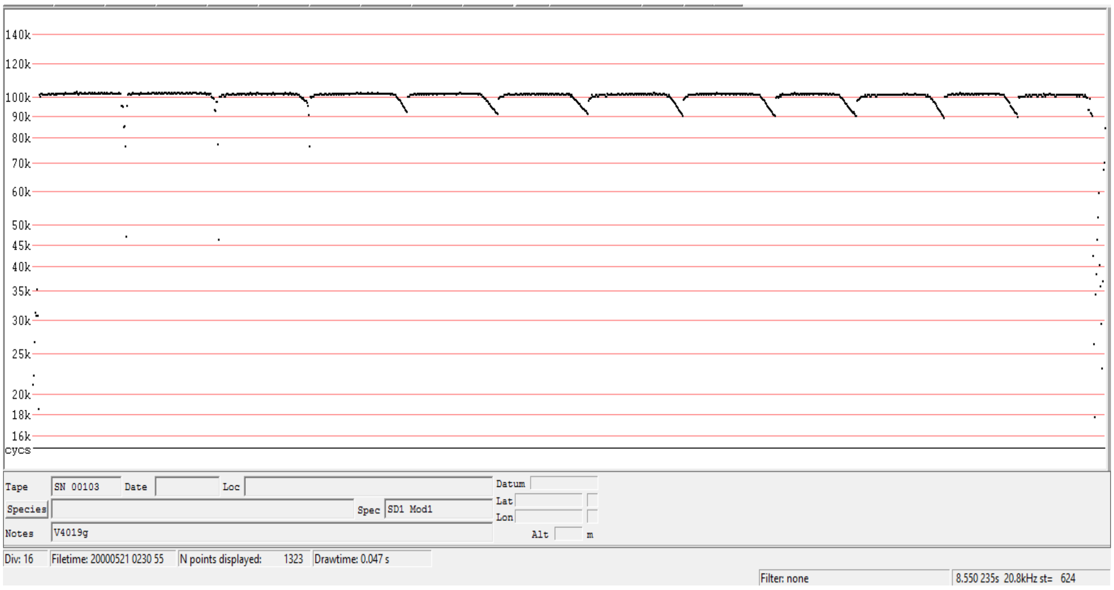
6. *Hipposideros pomona*



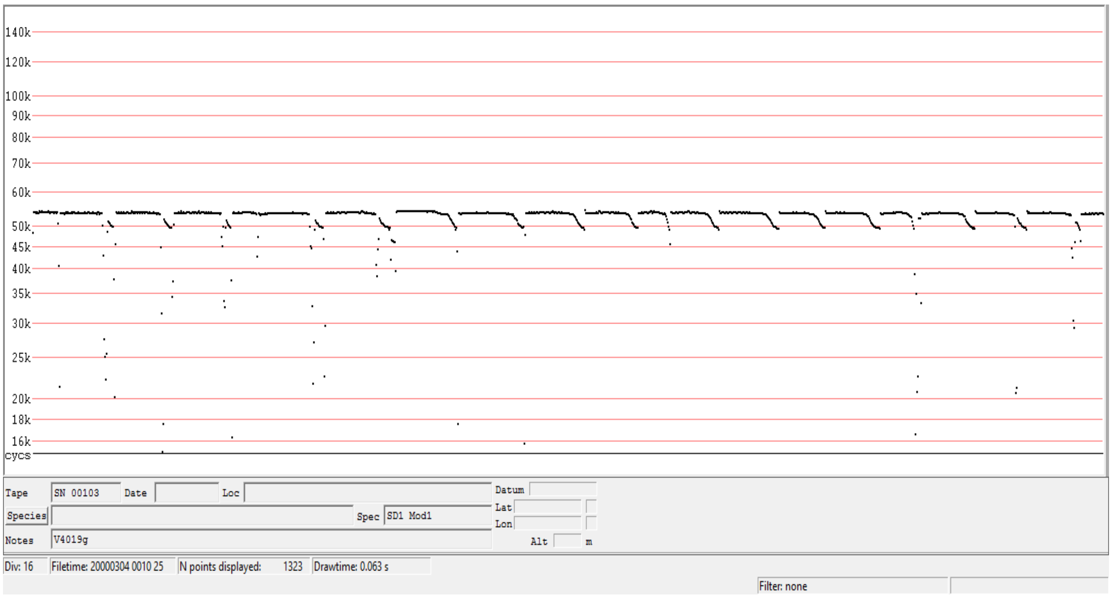
7. *Hipposideros armiger*



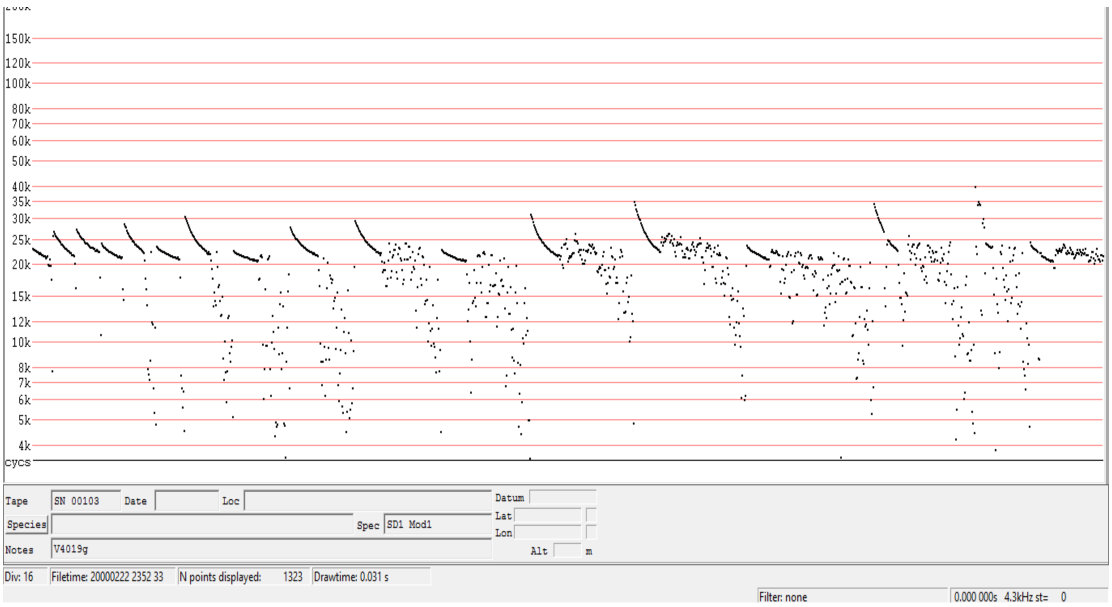
8. *Hipposideros larvatus*



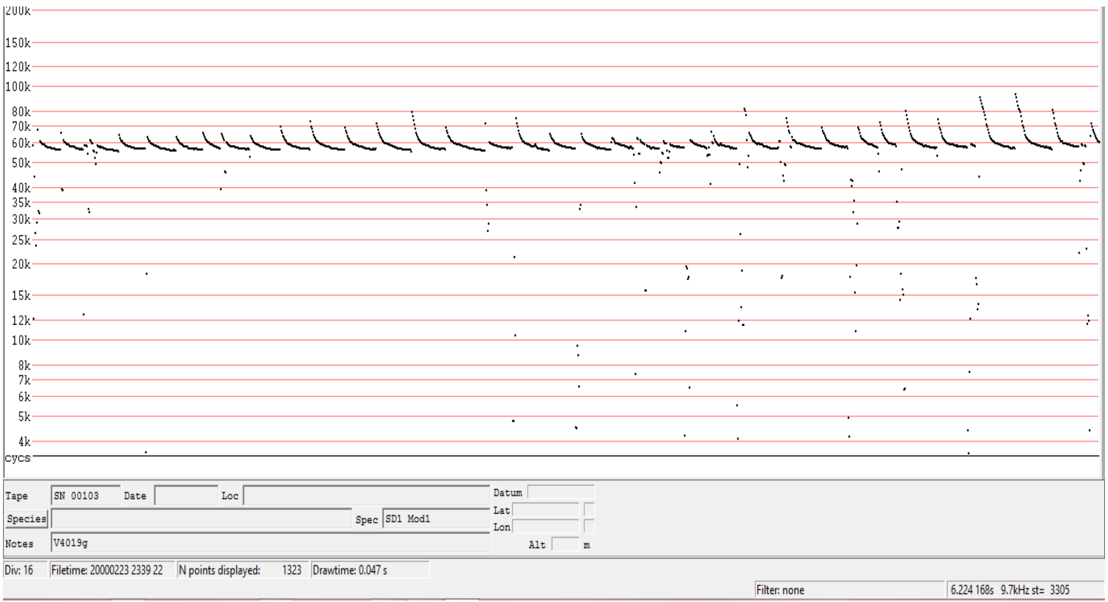
9. *Hipposideros diadema*



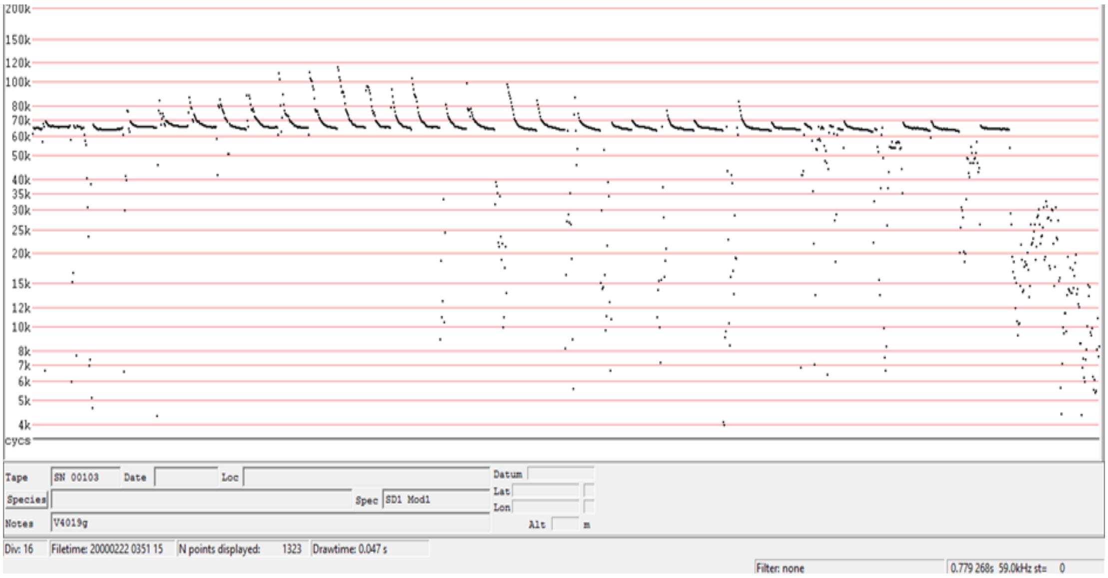
10. *Chaerephon plicatus*



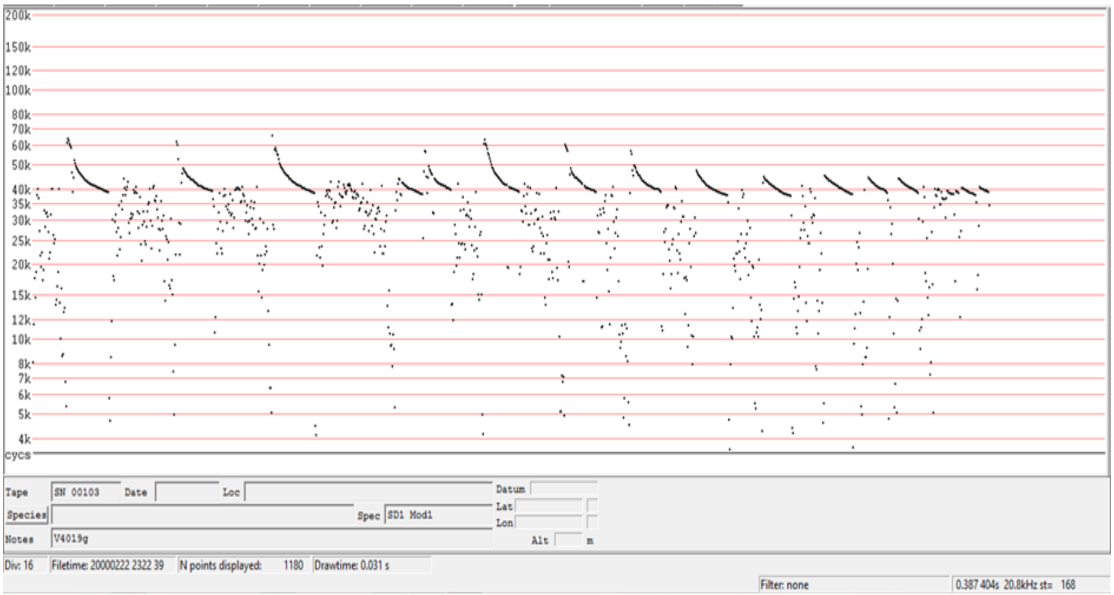
11. *Myotis muricola*



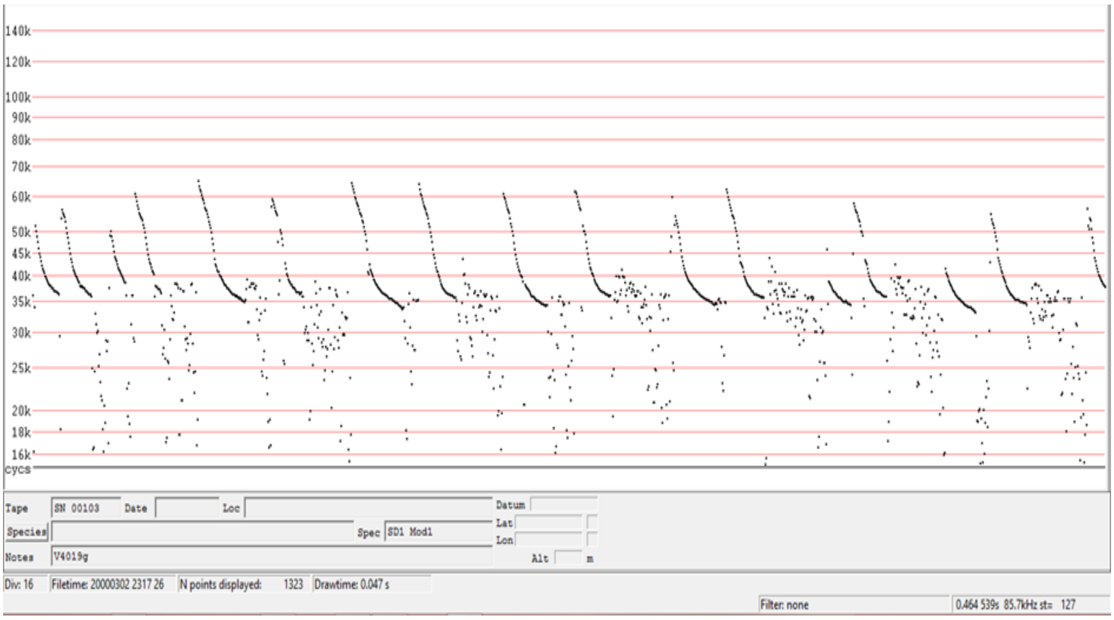
12. *Myotis siligorensis*



13. *Scotphilus kuhlii*



14. *Scotphilus heathi*



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List of Publication and Proceeding

Suksai, P., Bumrungsri, S. (2018). Water bodies are a critical foraging habitat for insectivorous bats in agricultural landscapes of central Thailand. Songklanakarin Journal of Science and Technology (Summited on November)