THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Science (Forestry)
DEGREE

Forest Biology
FIELD

Forest Biology
DEPARTMENT

TITLE: Foraging Habitat Use by Acoustic Monitoring of *Tadarida plicata* (Buchannan, 1800) in an Agricultural Landscape, Ratchaburi Province

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THESIS

FORAGING HABITAT USE BY ACOUSTIC MONITORING OF *Tadarida plicata* (Buchannan, 1800) IN AN AGRICULTURAL LANDSCAPE, RATCHABURI PROVINCE

KESSARIN UTTHAMMACHAI

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science (Forestry)
Graduate School, Kasetsart University
2009

Kessarin Utthammachai 2009: Foraging Habitat Use by Acoustic Monitoring of *Tadarida plicata* (Buchannan, 1800) in an Agricultural Landscape, Ratchaburi Province. Master of Science (Forestry), Major Field: Forest Biology, Department of Forest Biology. Thesis Advisor: Assistant Professor Vijak Chimchome, Ph.D. 57 pages.

The objective of the study was to know the foraging habitat use and activities of *Tadarida plicata* from a large colony in Khao Chong Phran non-hunting area, Ratchaburi Province, Central Thailand. This study determined habitat use and feeding activity of *T. plicata* in an agricultural landscape including its seasonal effect. From sampling effort of 1,160 hour, The total of signal-receiving time was 69,600 minutes and 674 feeding buzzes were found. The proportion of signal-receiving time over the total recording time was measured to obtain an estimate of the relative activity of bats within 7 habitats including dry rice fields, wet rice fields, villages, sugarcane fields, forest patches, forest plantation and urban areas. *T. plicata* selected villages and dry rice fields (P<0.001). In addition, the number of feeding buzzes per unit of activity time was used to calculate an index of attack rate by bats. Feeding activity was highest in villages followed by dry rice fields (P<0.001).

There was a significant difference in mean signal-receiving time recorded between seasons (P<0.01). The highest feeding activity was in the cool and rainy season with the lowest in hot season (P>0.05). From this research, bat activity was highest when bats were young foraging (P<0.01) and it was highest in lactating and lowest in female pregnant (P<0.01). The highest bat activity was in the cool and rainy season (P<0.01). Feeding activity was highest in the cool and rainy season (P>0.05).

There were significant differences in bat activity among distance categories. The signal-receiving time was highest at 0-5 km from the Khao Chong Phran cave (P<0.001). However, there were differences among habitats in mean attack attempt (numbers of feeding buzzes per unit of activity time) between recording sessions.

Rice fields are also important target foraging areas for *T. plicata* at Ratchaburi Province in Thailand as elsewhere because the habitat of villages and dry rice fields had an intense bat activity. Finally, the result has implications directly for farmers because restricted use of pesticides in rice fields or crops may initiate a negative feedback with bats. The importance management was demonstrated in an agricultural landscape for bat conservation.

Student's signature Thesis Advisor's signature ___ / ___ / ___

ACKNOWLEDGEMENTS

I would like to grateful thank and deeply indebted to Asst. Prof. Dr. Vijak Chimchome my thesis advisor and Asst. Prof. Dr. Sara Bumrungsri my thesis co-advisor for advice, encouragement and valuable suggestion for completely writing of thesis. I would sincerely like to thank Assoc. Prof. Dr. Dokrak Marod and Assoc. Prof. Dr. Utis Kutintara from Graduate School for their valuable comments and suggestion. Thank also given to Assoc. Prof. Dr. Gunjana Theeragool (Graduate School representative) and also Assoc. Prof. Dr. Naris Bhumpakphan, Department of Forest Biology, Kasetsart University for their advice during the final examination.

I would like to sincerely thank Dr. Iain Mackie and also Dr. Jon Russ for their suggestion, encouragement and enthusiasm during study and research work. I would like to greatly indebted to Dr. Colin Catto for his advice and Mr. Adrian Hillman for his comments and English proved. I am heartfelt thank to Mr. Thawee Insura, Mr. Rawin Anurakphongsathorn and Mr. Nophakhun Suwanaphat for their assistance in data collection. Special thanks are given to Mr. Surachet Sidang, Mr. Jukrapong Buakra, Mr. Isoon Rinkame for their help in map and Ms. Ratchanu Kerdcherdchu for land use classifications data. Finally, many thanks for Mr. Prayong Phongpintukarn, Head of Ratchaburi Meteorological Station for meteorology data and KhunPiyasak with kindly help in any contact.

The financial of this research was supported by the Bat Conservation International, Texas, USA and the Darwin Initiative, UK for data collection was acknowledged.

I am especially appreciated my parents, my grandmother, my two sisters, my uncle Peter and my aunt for their continuing encouragements and moral support along this study.

Kessarin Utthammachai

March 2009

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LIST OF ABBREVIATIONS

KCP	=	The Khao Chong Phran cave, Ratchaburi Province
DRF	=	Dry rice fileds
WRF	=	Wet rice fields
V	=	Villages
SCF	=	Sugarcane fields
FPa	=	Forest patches
FPl	=	Forest plantations
UA	=	Urban areas

FORAGING HABITAT USE BY ACOUSTIC MONITORING OF *Tadarida plicata* (Buchannan, 1800) IN AN AGRICULTURAL LANDSCAPE, RATCHABURI PROVINCE

INTRODUCTION

Critical information concerning the economic and ecological importance of insectivorous bats was needed to further their conservation in developing countries. The wrinkle-lipped free-tailed bat (*Tadarida plicata*) is an insectivorous cave dwelling species, sometimes found roosting in very large colonies of several millions, and is distributed throughout Southeast Asia. They inhabit often become economically important to the local community as the bat droppings (guano) are collected and used as agricultural fertilizer. A recent study demonstrated that *T. plicata* is a major predator of nocturnal insects and has the potential to act as a biological pest control agent in farmlands (Leelapaibul *et al*., 2005). Biological pest control involves suppressing pest population densities to levels lower than they would otherwise be (Van Driesche and Bellows, 1996). Thus, large colonies of *T. plicata* may result in the large-scale depletion of pest insects in areas surrounding the cave roosts such as rice fields. Quantifying the feeding rate and habitat use of *T. plicata* in relation to insect availability, particularly pest species, will demonstrate the important role of them on natural and cultivated ecosystems.

Knowledge about foraging behavior and habitat use of the bats is of primary importance to establish conservation practices for endangered species (Stebbings, 1988). Using this knowledge, one can manage nature reserves to increase the extent of these habitat types, and protect them (Carmel and Safriel, 1998). Thus, conserving of the population of natural biological control agents should be a priority. Most of the previous work on the ecology of bats has been conducted in caves or human-made structures and very little is known about foraging behaviour. For example, bats may be important in controlling insect populations (Machmer and Steeger, 1995).

Grindal (1996) explained that roosting and foraging habitat are two basic requirements of bats. Roosting habitat provides areas for reproduction and daytime shelter, whereas foraging habitat fulfills obvious energy and nutrient requirements. In Thailand, the bats are threatened by pressures such as caving, tourism, mining and harvesting. Direct economic benefits from guano collection at caves are available to a few individuals but more widespread interest in bat conservation will result from evidence of agricultural benefits.

OBJECTIVES

1. Determining foraging habitat use and activities of *Tadarida plicata* in an agricultural landscape.

2. Assessing seasonal effect in foraging habitat use and activities of *Tadarida plicata*.

LITERATURE REVIEW

1. Wrinkle-lipped free-tailed bat (*Tadarida plicata*)

Free-tailed bats are widely distributed family of bats which occurs both in the Old World in Africa, southern Europe, southern Asia and Australia and in the New World in North, Central and South America. According to Corbet & Hill (1992), it is comprised of 13 genera and around 89 species. They are small or medium-sized insectivorous bats with a stout tail projects conspicuously beyond the narrow interfemoral membrane. The ears are variable in form, usually freshly, sometimes joined across the forehead; the tragus of each ear is rudimentary and the antitragus is usually large. Genus *Tadarida* has an essential characters of the genus are as in the Family Molossidae. These bats are adapted for swift flight with the downwardly facing ears contributing towards their aerodynamic profile. Two subgenera are recognized in the Indian Subcontinent. Members of the subgenus Chaerephon (*T. C. plicata*) are distinguished by the premaxillae (in the skull) which are usually fused and have palatal branches isolating the two small palatal foramina.

Tadarida (Chaerephon) plicata (Buchannan, 1800) common name is wrinkle-lipped free-tailed Bat (see Appendix Figure 1). Bates and Harrison (1997) reported that it is the smallest species of *Tadarida* known from the region with an average forearm length of 46.3 mm (43.1-50.2 mm). It is superficially similar to *Tadarida aegyptiaca*. However, unlike this species and *Tadarida teniotis*, the ears are connected by a membrane across the forehead. The pelage is soft, dense and very short. On the dorsal surface, it is usually dark clove brown: it is paler on the ventral surface. The skull is smaller than that of *T. aegyptica* with an average condylo-canine length of 16.6 mm (15.9-17.1 mm). Unlike *T. teniotis* and *T. aegyptica*, the premaxillary bones are complete on the palatal side in consequence the deep notch extending behind the upper incisors is absent. Usually the two premaxillae are fused with the surrounding bones, leaving two small foramina at the end of the pellate, or a very small notch in front of the incisors. The rostrum is narrow and more rounded than that of *T. aegyptica*; distinct supraorbital processes are present. The braincase is more rounded, not flattened above, as compared to *T. aegyptica*. The sagittal crest is variably developed and extends from the postorbital constriction to the lambda. The dorsal profile has convexities over both the postorbital region and the posterior part of the skull.

1.1 Distribution, population and status

T. plicata ranges from India and Srilanka to Myanmar, southern China and Vietnam, southeast to the Philippines and Indonesia. In Thailand, The population was estimated 2.6 millions by Hillman in 1998. Thus, it is not endangered. In worldwide that is a geographically widespread species that is not endangered. In Indian subcontinent, very little is known of the population status, it is probably restricted to a limited number of colonies located in suitable roosting sites. There is provisionally one endemic subspecies (insularis) from Sri Lunka.

1.2 Food

Watanakul (1976) found that they consumed Lepidoptera and Coleoptera, which showed that they had quite a wide diet. Nabhitabhata (1986) reported one individual of this species in Thailand as having eaten Homoptera, Hymenoptera and Odonata. He suggested that this implies foraging low to the ground or over water, which was supported in Khao Yai, and perhaps indicated that the height reached over Khao Chong Phran may be a commuting height. However, it is quite possible that *T. plicata* feed both high and low, presumably as long as they remain within open air rather than enter more clutterd habitat. Leelapaibul (2005) indicated that *T. plicata* fed on at least nine insects order such as Homoptera, Lepidoptera, Hemiptera, Coleoptera, Diptera, Hymenoptera, Odonata, Orthoptera and Psocoptera. Miller *et al.* (1988) estimated that the population of 500,000 *T. plicata* at Khao Luk Chang cave near the northern end of Khao Yai National Park consumed about 3,500 kg of insects each night. It can be estimated that 2.6 millions bats population at KCP could consume around 17,500 kg of insects each night (Hillman, 1998).

1.3 Foraging

Bats are highly variable in their foraging and echolocation behavior (Fenton, 1990) and some bats used more than one feeding habitat (Schnitzler and Kalko, 2001). Hillman (1998) reported that the main foraging areas for *T. plicata* around the KCP cave seem to be the north and west. The direction that they invariably end up flying in and of those returning around dawn when it is light enough to observe them, the vast majority also come back from this direction and carrier ones from another because on some occasions the lateness of their return meant that the flight direction could be seen for virtually all bats. On most days there are at least a few bats returning from other direction but this is estimated to usually be less than one percent of the total. Such a large colony must disperse over a wide area and travel considerable distance to forage each night, but exactly how far they go is very difficult to judge. The foraging areas appeared to east of north between June and August 1997, whereas in June and July 1998 most bats returned from west of north as they as they did for the rest of the year. It may be that the particularly dry year in 1997 forced the bats to alter their foraging area, feeding more the central plains to the north-east which may have remain wetter for longer and hence may have retained higher insect populations. At this time the bats were coming out earlier and returning later which could be either due to an increased traveling time to suitable foraging areas or to an increased foraging time due to lower insect abundance, or maybe both. The number of bats returning from other directions than the main one seemed to be highest in July 1998 suggesting that foraging areas are perhaps less restricted during wet periods (Hillman, 1998).

After emerging the bats always fly very high estimate of actual height was made but even in daylight some individuals could only be seen with binoculars. The actual foraging areas are unknown and it is possible that this height is used for commuting rather than foraging. However, flight behavior did sometimes suggest active hunting at this height rather than just direct flight, and feeding at 3 km has been recorded for other species in this genus (McCracken, 1996; Hillman, 1998). In Khao Yai National Park, *T. plicata* were seen much lower down flying from their roosting cave just above canopy level, and some foraging activities were observed at almost ground-level. As the results, they did not reach the same height above ground as they did at KCP, although, in terms of height above sea-level it could be similar. At KCP there is some large rivers and other water-bodies nearby but no bats were seen close enough to ground-level to suggest that they may be drinking nearby. At Khao Yai National Park, *T. plicata* were seen drinking from a lake (it seem unlikely that they were surface-foraging in the way that some other species do as this is generally fairly specialist technique). It is likely therefore that the bats from KCP drink well away from the roosting site, but where exactly and how often is unknown (Hillman, 1998).

1.4 Breeding

According to Hillman (1998) breeding activity was found in the following ways, pregnant females present, newly aborted young found on the ground, and juvenile bats being present and the only young ever seen inside the cave before they were able to fly were those stranded on the cave floor. He found that *T. plicata* breeds twice a year, births occurring in March, April and October. The time interval between these two breeding seasons and the frequency of observations are not enough to be certain. It has been shown that rainfall is the most important factor influencing the breeding of tropical insectivorous bats due to the link with abundance of prey (Racey, 1982; Hillman, 1998). There was probably less food available and the young's development may have been delayed because of reduced foraging success of the females. Therefore it is likely that the usual period between breeding seasons is six months.

The young bats roosted in the open area, a few actually in sunlight. At this stage they were flightless but very mobile. Only juvenile bats were ever seen roosting here suggesting that the females left their young in a creche only returning to feed them, as were known for other species of this genus (McCracken, 1984; Hillman, 1998), however no feeding behavior between mother and young. There does not appear to be any relationship between the overall activity pattern through a night and the breeding season. However, to some extent each of the 3 breeding seasons observed by Hillman (1998) were different, with two at the beginning of rainy seasons and at the end, and of the two at the beginning one was in dry year and one in a wet year. A basically bimodal activity pattern, seeming to be the usual case here, is common for insectivorous bats, and other studies have shown a varying degree of importance on the second activity period in the morning, which is influenced by a combination of season and the foraging conditions (Erkert, 1982; Hillman, 1998).

The time of first emergence is clearly related to the breeding season. When the females are in the late stages of pregnancy the first emergence is early, becoming later as the young develop and begin flying. When the young start foraging with the adults the emergence time becomes earlier again, thereafter becoming later until the next breeding season starts and the females are again pregnant. This cyclical pattern is repeated every six month. As already mentioned this suggested that late pregnancy is energetically the most costly time for *T. plicata*. The number of females actively rearing young will drop off because of the apparently high rate of mortality of young around the late pregnancy stage. This will lead to fewer females emerging early and therefore the time that the first bats begin leaving the cave is likely to be later. The numbers of emerging bats also seems to explain the earlier emergence when the young start foraging, as there will be a grate number of bat coming out of the cave once the young join the adults (Hillman, 1998).

2. Echolocation and Vocalization

The echolocation calls produced by a wide range of species reveal that aerial feeding bats and the role of echolocation in the foraging behavior of aerial feeding bats appears clear and unequivocal but it remain unclear just how echolocation is used in foraging by gleaners, blood feeders and plant visiting species (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. Various types of vocalization were noted being made by *T. plicata.* The high end of this range was only from bats flying within about 2m of the detector during emergence or return. The frequencies dominating the echolocation calls of these bats, they are detectable by most bat detectors at distance 5 to >10m. An even more audible ‘buzz’ from bats flying above which is possibly associated with the capture phase of hunting insects.

A loud ‘trill’ which was heard when bats were caught by birds-of-prey sometimes when handle by people and also during emergence for no immediately obvious reasons but could be associated with near or actual collisions. The column of emerging bats clearly reacted to this ‘distress’ call by suddenly twitching as if taking evasive action. Inside the cave there is usually a lot of bats generated noise that dose not appear related to flight activity, but its exact social relevance is known. Vocalizations are more audible as the bats fly out of the cave than when return.

2.1 The ‘feeding buzzes’

An important feature of all echolocation signals, which demonstrates most of these characteristics, is the feeding buzz. This occurs when a bat catches an insect. Consider a bat foraging in an edge environment producing FM/CM calls similar to the pipistrelle calls. When it detects insect prey from a returning echo, it moves towards that area. The echoes take a relatively long time to return to the bat. As the bat closes in, the distance between the bat and its prey is less and therefore it takes less time for the echo to return. So the bat needs to produce echolocation pulses at the faster rate to receive information at a useful rate. The CF signals produced by bats are no longer necessary the bat does not need long distance detection to locate prey because the insects have already been found.

2.2 The ‘Search phase calls’

In describing the echolocation behavior of insectivorous bats, we will show that bats belonging to the same guild share many similarities in echolocation behavior, especially in the structure of search signals, which are intimately linked to habitat type and foraging mode. Search signals are emitted when bats are searching for prey, or when they commute from one place to another and do not approach a specific target (Schnitzler and Kalko, 2001).

2.3 Bat Detector

In bat identification, we are not only concerned with sound emitted by the bat and not the returning echoes. The echo is too quiet to be detected with confidence and would tell us about the insect obstacle but not the bat. 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.

2.3.1 Heterodyning

This is the most common method, and is usually the cheapest. The method converts ultrasound to audible sound by subtracting the frequency to which the detector is turned to the frequency of the incoming ultrasound. For example if a sound is coming in at 50 kHz and the detector is turned to 49 kHz, the resultant sound will be 50+49=99 kHz and 50-49=1 kHz. We can hear the 1 kHz but the 99 kHz is in the ultrasound range so we can ignore this. Paradoxically, this means that when the turned frequency is the same as the incoming frequency the resultant sound should be at its quietest as the subtraction equals zero. The main advantage of this method is that the resultant sound can have tonal qualities such as ‘ticks’ and ‘smacks’ which are related to the type of ultrasound the bat is producing and that the ‘approximate’ frequency of the sound can be determine in the filed. The bat sound can be predicted from the sonogram. It is also possible to predict the whole sound if we are only listen to small sections of the call as with heterodyne detectors.

2.3.2 Frequency Division

This method monitors all ultrasound simultaneously, and uses a ‘zero-crossing’ circuit which produces a square wave output with the same frequency as the fundamental of the incoming signal. This square wave is then usually divided by either 10 or 20. This method preserves all the frequencies of the signal and can be used for limited sonogram analysis. However, some information such as harmonic structure is lost, and often some spurious signals are included in the result, as

2.3.3 Time Expansion

This method gives the most accurate reproduction of the bat call. Basically it stores digitally the ultrasound signal and replays it at a slower speed. The signal retains all the characteristics of the original signal. So we hear the entire call as it should sound except that it is 10 times lower in frequency and ten times slower. We can then record these calls as we would with any audible sound and display them as sonogram which allows us to further identify species and also carry out analysis using a computer software program.

METERIALS AND METHODS

1. Materials

1.1 Topographic maps of Khao Chong Phran Non-hunting Area, Ratchaburi Province 1 : 50,000 sheet 4936 I series L7017 edition 2-RTSD, AMPHOE BAN-PONG, sheet 4936 II series L7017 edition 2-RTSD, CHANGWAT RATCHABURI, sheet 4936 III series L7017 edition 2-RTSD AMPHOE CHOM BUNG and sheet 4936 IV series L7017 edition 2-RTSD AMPHOE THA MUANG

1.2 Pettersson D240x Ultrasound Bat Detector

1.3 Sony recorder

1.4 GPS

1.5 Hoop net, cloth bags

1.6 Thermometer, headlamps, flashlights, batteries, camera and other accessories

1.7 Computer loaded with BatSound (Pettersson D240x, Petterson Elektronik AB, Uppsala Sweden)

2. Methods

2.1 Study site

2.1.1 Location

Field work was carried out during July 2006-October 2007. The main study site is the area around the Khao Chong Pharn cave, KCP (13°43’ N, 99°47’ S) in Ratchaburi Province, Central Thailand. The KCP cave is the limestone outcrop which is 23 km from north of Ratchaburi city and 100 km west of Bangkok. To the north of the site the habitat is predominantly rice fields with some orchards or plantations, to the east and south the landscape is dominated by rice fields and some open areas of open forest and to the west the habitat is primary orchard or plantation with the land becoming increasing hilly westwards (Figure 7).

This site covers about 11.5 hectare (72 rai) which has been designated as a non-hunting area to protect the bats by the Royal Forest Department. This cave is surrounded by rice fields, plantations and sparse local settlements (Figure 2b) with average elevation 70-180 m a.s.l. The cave contains one of the largest colonies of *T. plicata* in Thailand and the population estimated up to 2.6 million individuals by Hillman in 1998. In Thailand, there are at least 18 caves known to support populations of these bats (Figure 3), most of them located in central Thailand.

Generally, habitats in the study area at Ratchaburi Province can be classified into 5 categories consisting of 15% rice fields, 25% crops and 16% plantations. Others were forest patches (35%) and non-classified area (=others, 9%) (Figure 1).

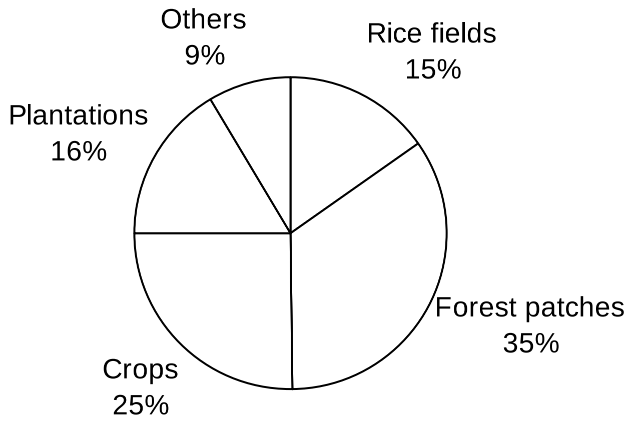

Figure 1 Classification of land use types at study sites, Ratchaburi Province

Source: Land Development Department (LDD), 2002

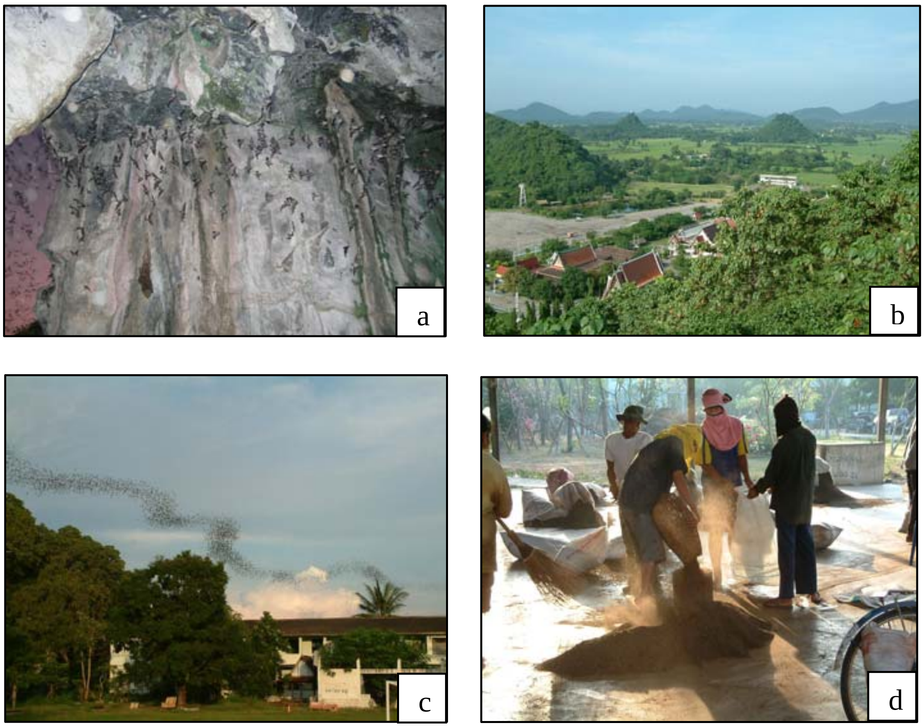

Figure 2 (a) Khao Chong Phran cave inside view

(b) Khao Chong Phran cave outside view

(c) Emerging of *Tadarida plicata* at Khao Chong Phran cave

(d) Bat Guano Collecting at Khao Chong Phran cave

Figure 3 Distribution of *Tadarida plicata* sites in Thailand

Source: Wanghongsa and Boonkird (2000)

2.1.2 Climate

The seasonal climate condition at Ratchaburi Province including three seasons: the rainy season during June-October; the cool season during November-February and the hot season during March-May. Mean annual rainfall is 959.2 mm in 2006 and it is 1,284.5 mm in 2007. The monthly rain fall is highest in October, 2006 and also in May, 2007 and lowest in January and November, 2006 and January to March, 2007 (Figure 4). The average air temperature ranged between 25-31°C (Figure 5).

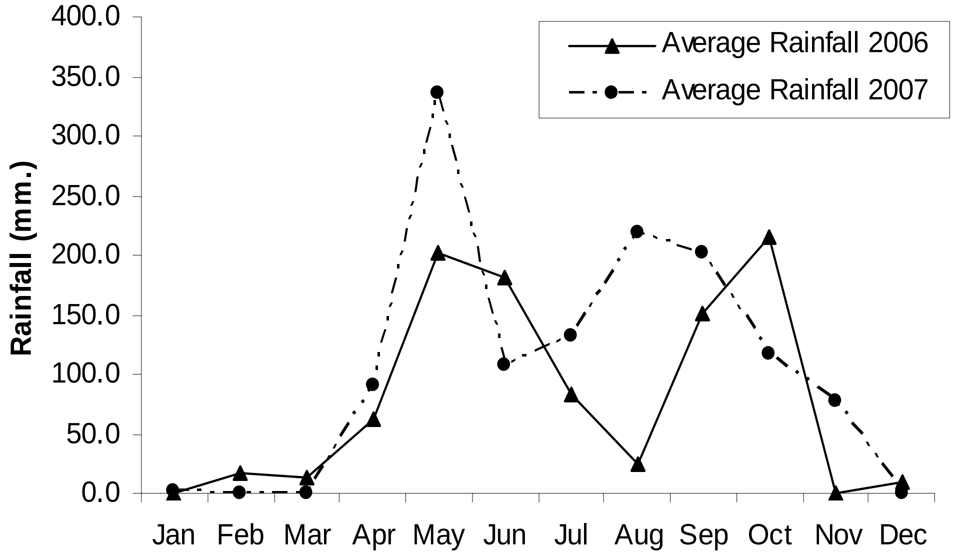

Figure 4 Monthly rainfall at Ratchaburi Province (2006-2007)

Source: Ratchaburi Meteorological Station

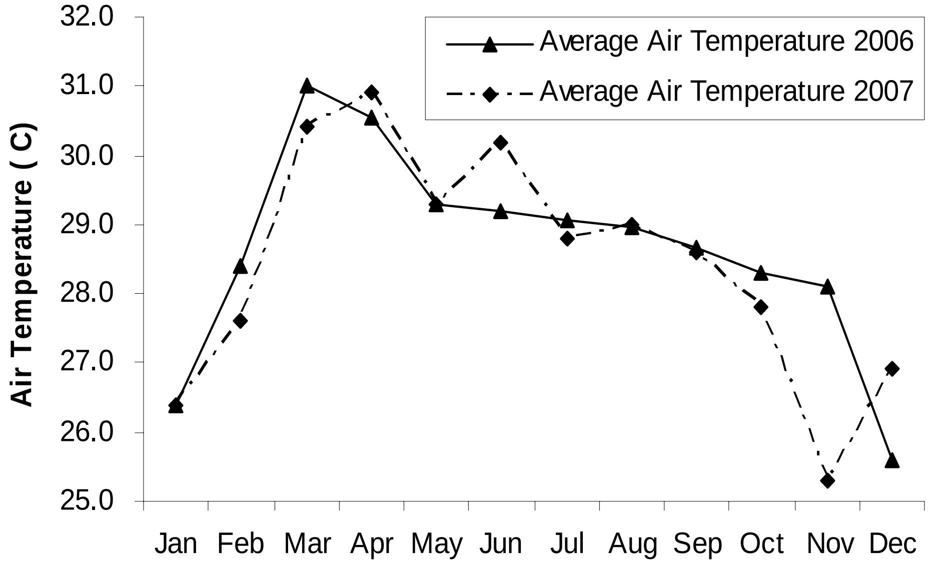

Figure 5 Average air temperature at Ratchaburi Province (2006-2007)

Source: Ratchaburi Meteorological Station

2.2 Data collection

2.2.1 Bat identification

Identification of bat species by their echolocation is often used in field studies (Ahlen, 1981, 1990; Jones, 1993; Kalko and Schnizler, 1993; Rydell *et al.*, 1994; Carmel and Safriel, 1998). An ultrasound bat detector which transforms bat echolocation calls to sound within the audible range. The detector was used in heterodyne (tuned) and time expansion modes.

T. plicata call has the frequency ranging between 23-30 kHz. Around KCP cave, there are many species of bats (Hillman, 1998). There were three species that produce call frequency ranging between 15-35 kHz which is close to *T. plicata* e.g., *Taphozous melanopogon*, *Taphozous* sp. and *Scotophillus* sp. The bat detector and tape recorder were used to record of these species in the study areas. Some bats were captured by a hoop net, and then the calls were recorded. In this way, the identification from calls of these species was confirmed, except *Scotophillus* sp. which was not found and captured.

Discrimination between species of these bats was not made by the calls structure only because both of them have the same frequency range and the same shape. Distinction between *T. plicata* and *Taphozous* sp. can be identified by observation that *T. plicata* fly very high but *Taphozous* sp. was lower and was seen and heard at the same time.

2.2.2 Activity sampling

The habitats around the cave are identified within a radius of 30 km from the KCP cave. Habitat types were classified into eight groups (Table 1 and Figure 6) (1) dry rice field (2) wet rice field (3) village (4) sugarcane field (5) forest patche (6) forest plantation and (7) urban area. Almost all sample sites are located in Ratchaburi Province and some are in Kanchanaburi Province within the foraging range of these bats. The spot sample sites were chosen by carrying out monthly road transects covering 7 roads using the cave as the center. In each transect contained 8-10 spot samples (Figure 8). An average 56 spot samples per month. The closest transects to the cave were 0-5 km away and the farthest transects were about 27-30 km away. The start and the end point were alternated to reduce bias from spatial distribution of bats over time.

Table 1 Description of habitat types

Abbrevation	Habitat	Description
DRF	Dry rice field	The area of rice field patches cover with rice /empty land in hot-dry season
WRF	Wet rice field	The area of rice field patches cover with water and some rice growing in rainy season
V	Village	Area of lands and houses cover with little tree not in town
SCF	Sugarcane field	Areas consisting of sugarcane
FPa	Forest patche	Land of forest and hill cover with trees and some plants
FPl	Forest plantation	Lowland areas that have *Eucalyptus* sp. and *Azadirachta excelsa* plantations and also have vegetables plants and some fruit gardens such as Yard long bean , *Asparagus* sp., chillies, corns etc.
UA	Urban area	Area in a city have building

An ultrasonic bat detector (Pettersson D240x) was used to identify the species, to determine the relative activity of bats and the insect capture rate. A pilot project demonstrated that *T. plicata* could be identified by its echolocation calls. On each night, five-minute spot samples were applied to sampling bat activity for a total of 120 minutes beginning after 8-10 pm. I assumed bat activity would be homogenous during the 1-2 hour after sunset followed Swift (1980) and Russ *et al.* (2002).

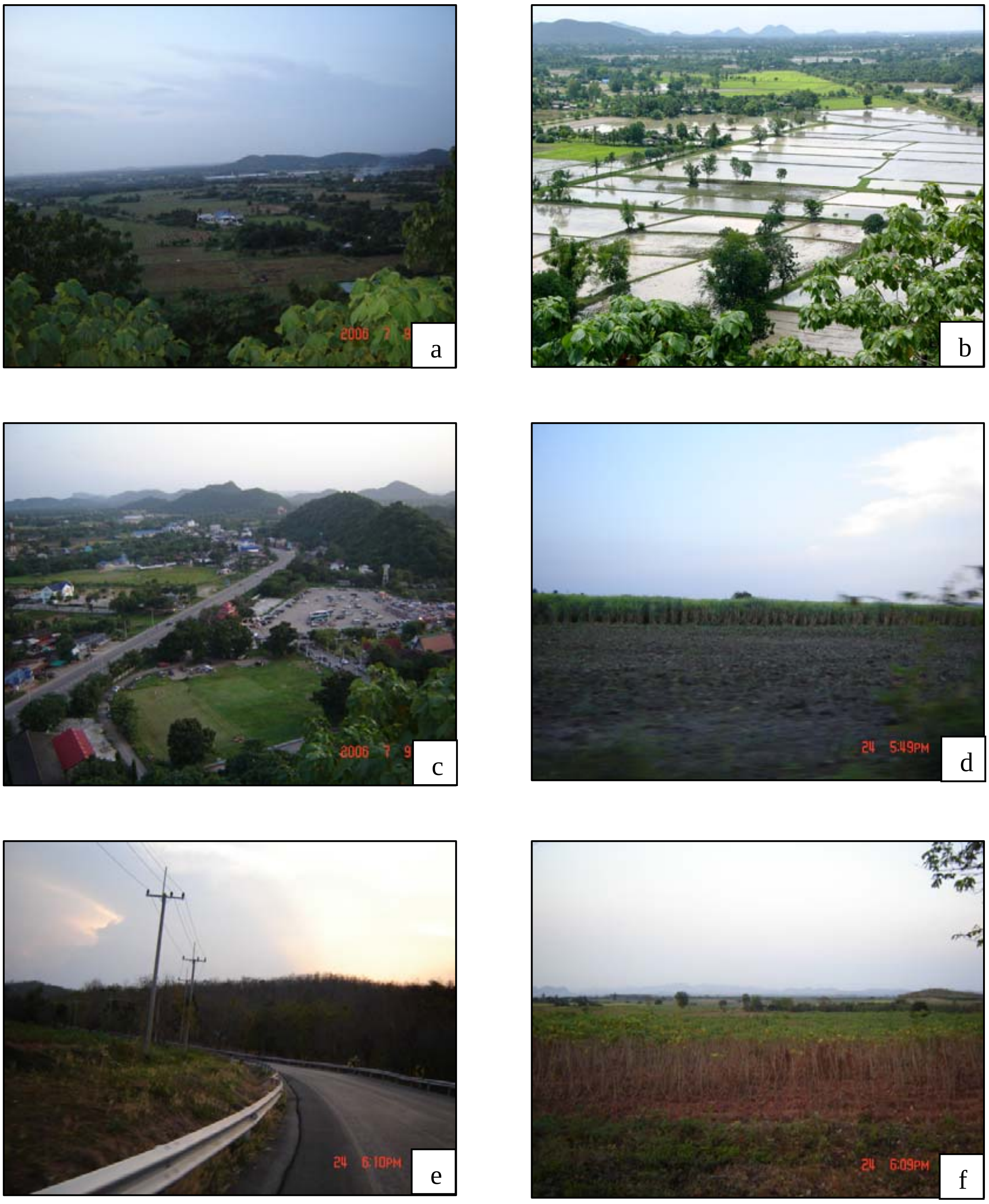

Figure 6 The habitat types (a) Dry rice field

(b) Wet rice field

(c) Village

(d) Sugarcane field

(e) Forest patches

(f) Forest plantation

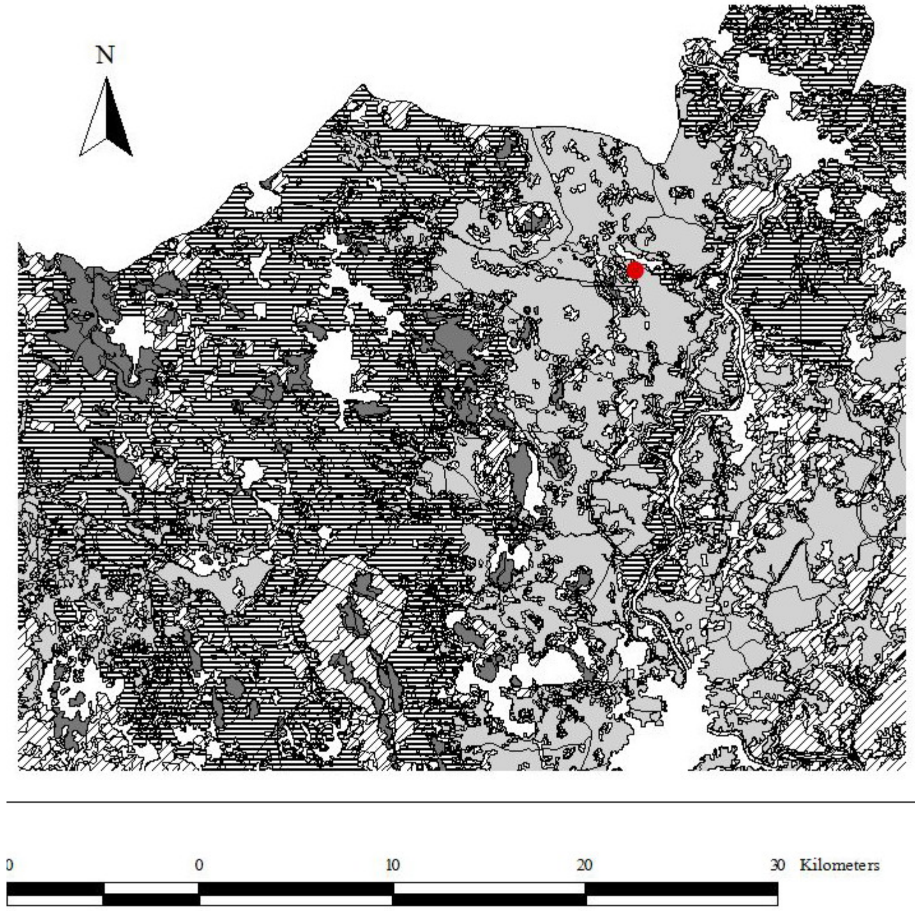

Figure 7 Habitats at study sites, Ratchaburi Province (within 30 km).

Red spot is KCP cave as the center.

= Rice fields

= Sugarcane fields

= Plantations

= Forest patches

= Human communities

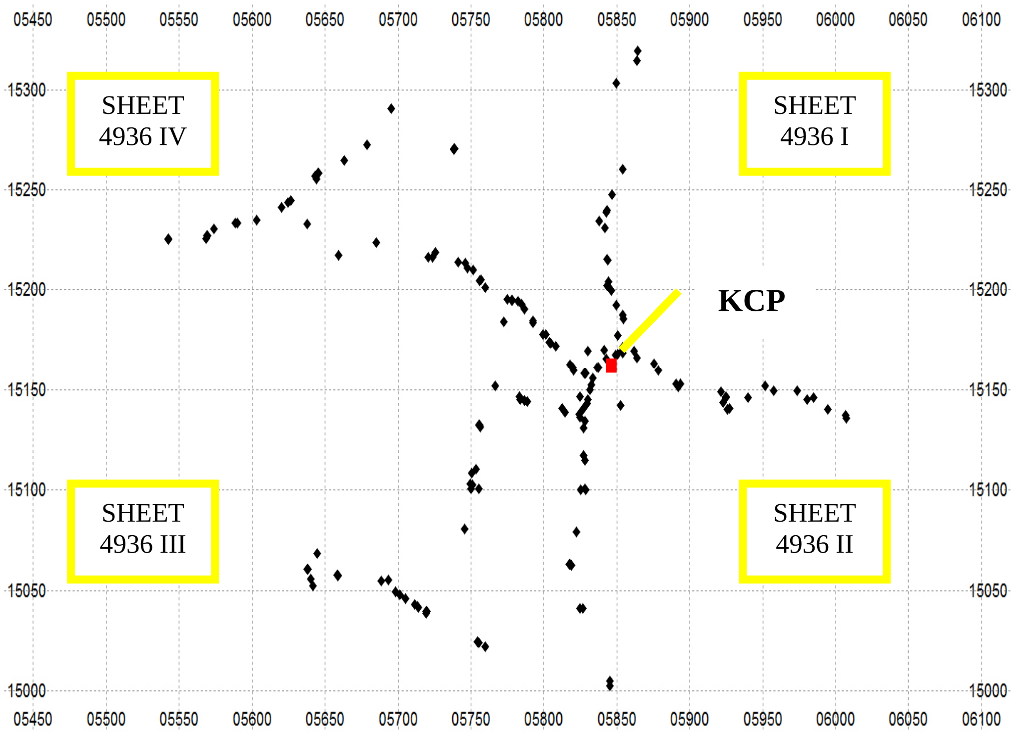

Figure 8 Distribution of survey points and routes. (Khao Chong Phran is marked with a red square)

A vehicle was used to travel between sampling sites to ensure that distance between adjacent sample sites was long enough and thus samples were independent. Seven different routes leading away from and within a 30 km radius of KCP cave were identified. It was estimated that 8-10 randomly selected spot sample sites per transect were collected in sequence along a single route (one transect per night). The direction of travel along routes each night was random. Sampling along each route commenced approximately thirty minutes after sunset as it was considered that a large proportion of the bats had left the roost at the roost at this time (Hillman, 1998). For 7 nights per month, there were five minutes spot samples per habitat type. Two types of bat activities: searching (*i.e.*, traveling or searching for prey) and feeding (*i.e.*, feeding attempt) were differentiated based on the structure of sequential echolocation calls. Bat activities were simultaneously assessed by two methods in the following.

Time Expansion: For each five-minute spot sample, the bat detector was set under automatically triggered time expansion (TE) mode (x10) which records ‘snapshots’ of ultrasound and then stretches it out to the audible levels so that they could be recorded by the recording device. The detector was set to record in time expansion mode and record 1.7 seconds of ultrasound every 18.7 seconds and approximately 27 seconds of ultrasound were recorded within five minute period. The time expanded sound was stored by a recorder. Sound recorded was transferred to a PC and converted to WAV format and analyzed by BatSound (Pettersson D240x, Petterson Elektronik AB, Uppsala Sweden) to identify species, number of calls, and foraging activities.

Heterodyne: The investigator listened to the sound in heterodyne mode (HD). The bat sounds were tuned within the range 23 - 30 kHz by bat detector. The investigator counted the number of feeding buzzes and bat passes heard in order to obtain a measure of insect capture rate. A bat pass is defined as a sequence of 1 or more echolocation pulses with < 1s between sequential pulses (Fenton, 1970; Korine and Pinshow, 2004). Feeding buzzes were easily identified on a heterodyne detector as they consisted of a series of calls with an increasing repetition rate as a bat approaches and attacks an insect. The feeding buzzes were distinguished from search-phase calls and the number of bat passes and feeding buzzes heard were counted. The grid reference and altitude was recorded at each spot sample using a GPS system. The locations were maps using GIS and identify important areas of bat activity.

Full time fieldwork and analysis was carried out from July 2006 to October 2007. It was allowed to make comparisons of the bat activities between bat reproductive periods (e.g., lactation, non reproductive period) and also harvesting crop cycles changes (e.g., before and after harvesting) which was assessed on a monthly basis.

2.3 Data analyses

2.3.1 Activity sampling

Bat activities were estimated at each site (7 habitats). The proportion of signal-receiving time was measured over the total recording time to obtain an estimate of the relative activity of bats within each habitat. Search-phase calls of *T. plicata* was recorded in high numbers, almost making them difficult to count but following Russ (personally contact) the search-phase calls were counted by tallied one pulse as one bat and feeding intensity was estimated by the number of feeding buzzes per unit of activity time and calculate an index attack rate by bats similar to Lee and McCracken (2002).

2.3.2 Index of attack rate

$$\text{Index of attack rate} = \frac{\text{Number of feeding buzzes}}{\text{Unit of activity time}}$$

In time expansion mode, the sonograms were analyzed, bats were identified from calls and feeding buzzes were counted. Feeding buzzes was then compared with the data in heterodyne. The data was presented as means ($\pm$SE).

ANOVA was further used to examine differences in mean attack attempt (numbers of feeding buzzes per unit of activity time) between recording sessions, among habitats and among seasons (Lee and McCracken, 2002). The comparison of habitat use was compared directly between nights and between the different reproductive periods by using analysis of variance (Brigham *et al*., 1992).

2.2.3 Statistical Analysis

All statistical tests were conducted using alpha 0.05, Sample sizes (N) refer to the number of night observation. When the seasonal effect was significant, the Fisher's PLSD multiple ranges test to locate differences for paired comparisons (Sokal and Rohlf, 1994). The seasonal effect was determined among 1) bats reproductive periods *i.e.*, female pregnant, lactating and young foraging and 2) crop cycles *i.e.*, harvesting and non-harvesting.

RESULTS AND DISCUSSION

1. Sampling efforts

In total, 1,160 hours were acoustically sampled covering all habitats within 30 km of KCP cave. Overall, the signal-receiving time was 69,600 minutes in time expansion and also 674 feeding buzzes in heterodyne (Table 2, 3). There was a significant positive correlation between feeding buzzes recorded using a heterodyne mode and feeding buzzes obtained using a time expansion mode (Pearson Correlation coefficient, $r = 0.588$, $N = 580$, $P < 0.001$) (Table 3). Due to methodological difference (*i.e.*, time expansion and heterodyne), it is difficult to compare directly total bat activity in habitat in this study which time expansion method is suitable to estimate the number of bat calls and the number of feeding buzzes. Therefore, data obtained using the time expansion method was used for all analysis.

Table 2 The proportion of sampling effort in each habitat undertaken with time expansion bat detector

Habitat types	No. of Sites	Total sample time (min)	% of sampling Effort
DRF	97	11,640	16.7
WRF	92	11,040	15.9
V	122	14,640	21.0
SCF	66	7,920	11.4
FPa	101	12,120	17.4
FPl	48	5,760	8.3
UA	54	6,480	9.3
Total	**580**	**69,600 (1,160 hr)**	**100**

Table 3 Comparison of the number of bats estimated between heterodyne and time expansion methods

Habitat	Feeding Buzzes	
	Heterodyne	Time expansion
DRF (n=97)	172	169
WRF (n=92)	73	72
V (n=122)	201	255
SCF (n=66)	70	64
FPa (n=101)	85	49
FPl (n=48)	48	19
UA (n=54)	43	40

2. Species identification

T. plicata often emit intense, narrowband calls of long duration, low frequency, and with long call interval for long range detection of prey. *T. plicata* produce highly variable echolocation pulses consisting of frequency modulated sweeps with peak frequency of 27$\pm$ 5.7 kHz (Table 4). In less cluttered environments the echolocation pulses become lower in frequency, led broadband and of longer duration (personal observation). Its echolocation calls and feeding buzz is shown in figure 9(a-b).

To determine species habitat use, objective and quantitative identification methods are recommended, otherwise surveys may lead to serious misinterpretation (Vaughan *et al.*, 1997b). Such a few numbers of species makes acoustic identification of bats in study sites were possible. Therefore, it was important to rely on a discrimination method that makes it possible to quantify the degree of correct identification (Zingg, 1990; Vaughan *et al.*, 1997b; Parsons and Jones, 2000, Russo and Jones, 2003). *Taphozous melanopogon* and *Taphozous longimanus* mostly found in sattlements near streetlights. These two species were found in different height from the ground. *T. plicata* foraged very high from above ground while *T. melanopogon* fly lower than *T. plicata*, and always found near ground level. *Scotophillus heathii* was not observed in the study areas at the time of this study.

Table 4 Measured values for three frequencies and one parameter of echolocation calls recorded from three species of microchiropteran bats from KCP cave, Ratchaburi Province. Values are presented as means ± standard deviation, number of bats is the sample size (N) as one call is measured per bat

Species	Bats	Duration (ms)	Minimum Frequency (kHz)	Maximum Frequency (kHz)	Peak Frequency (kHz)
Tadarida plicata	9	7.2±2.1	26.0±6.8	36.8±8.1	27.4±5.7
Taphozous melanopogon	4	5.8±1.3	22.8±2.4	42.3±3.3	22.2±4.6
Taphozous sp.	7	15.6±2.6	22.4±4.7	27.0±4.7	25.0±4.8
Scotophillus sp.	3	9.2±5.0	24.0±1.4	32.2±0.7	26.0±1.7

Echolocation calls are also shaped by ecology. Schnitzler and Kalko (2001) reviewed the effects of habitat structure on call design. Bats that fly in open spaces such as *T. plicata* often emit intense, narrowband calls of long duration, low frequency, and with long call intervals for long range detection of prey. *T. plicata* produce highly variable echolocation pulses consisting of frequency modulated sweeps with a start frequency of 29.46±4.78 kHz, an end frequency of 21.91±1.72 kHz, a duration of 3.27±2.12 ms and peak frequency of 25.03+2.20 kHz (Mackie, In press). In less cluttered environments the echolocation pulses become lower in frequency, led broadband and of longer duration (personal observation).

Bat activity was determined by counting the number of *T. plicata* echolocation pulses within each five minutes spot sample. Thus, an increase in the number of echolocation pulses could indicate that there were more bats in the vicinity of the bat detector, a bat was approaching the bat detector and therefore increasing its repetition rate and/or an individual had orientated itself towards the loudspeaker (Russ, personally contact).

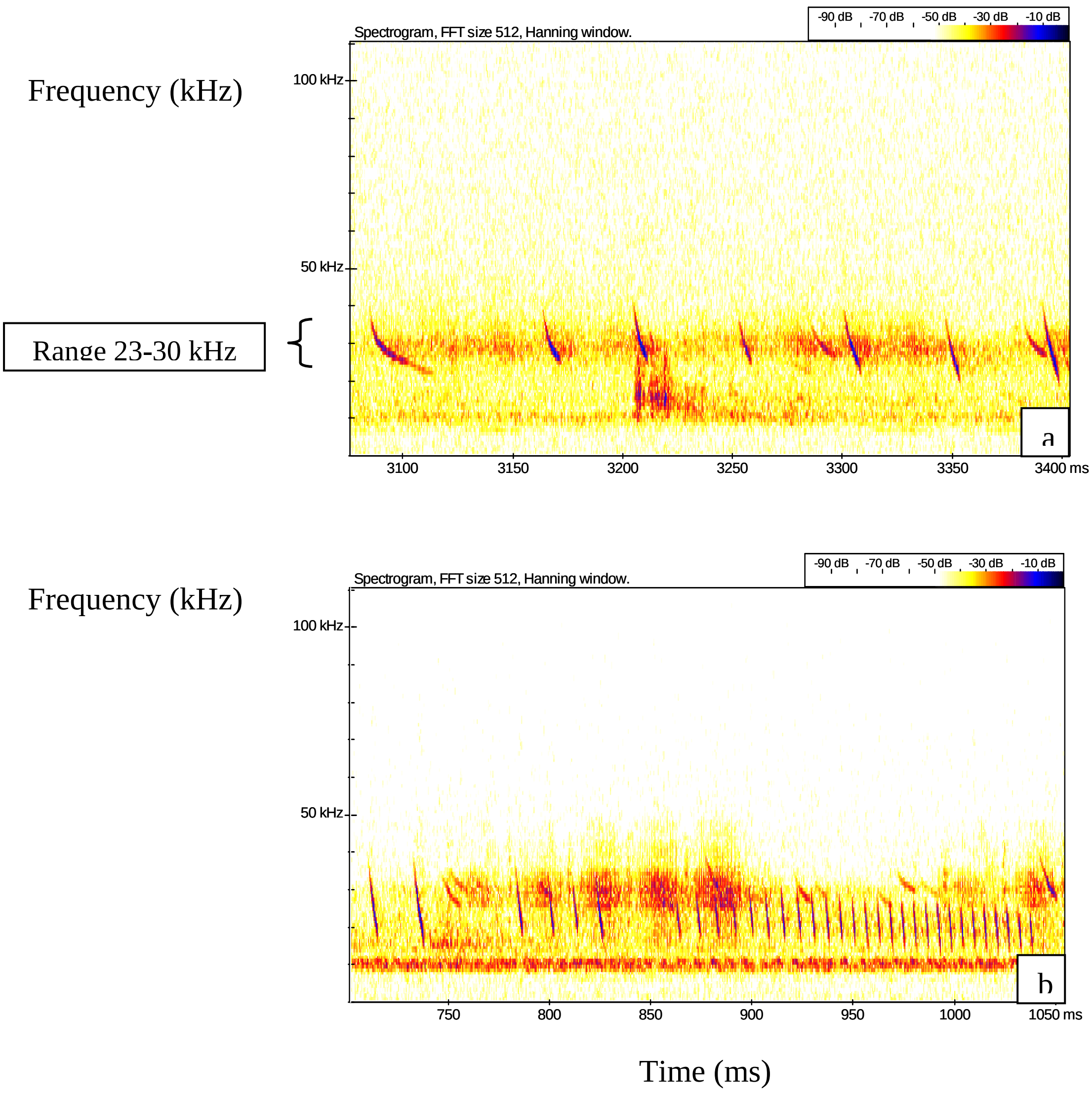

Figure 9 The spectrogram of *Tadarida plicata* calls (a) individual calls and (b) feeding buzzes

The echolocation calls were analyzed by examining *.wav files in BatSound Pro. After transferring this information, the output of the analysis provided duration of calls (ms), peak frequencies (kHz), and minimum and maximum frequencies (kHz). Peak frequency was taken directly from power spectra (Table 4).

BatSound (Pettersson Elektronik AB, Uppsala, Sweden) is the software used to analyze bat calls *i.e.*, the total number of individual *T. plicata* calls per spot sample (Figure 9(a)) and total number of feeding buzzes per spot sample (Figure 9(b)). Figure 9 showed the spectrogram of *T. plicata* calls and feeding buzzes indicating the frequency within the range of 25-30 kHz. One echolocation call from each bat pass was analyzed.

3. Bat activity and habitat use

3.1 Bat Activity

Both signal-receiving time and feeding buzz were highest in villages (mean number of activity time 16.0$\pm$1.4 sec/min, mean number of feeding buzzes 2.1$\pm$0.3 time/min) and dry rice fields was in the second rank (13.8$\pm$1.1, 1.7$\pm$0.4). Forest plantations were respectively the least used habitats by *T. plicata* (5.7$\pm$1.2, 0.4$\pm$0.3) (Figure 10). Building in urban area might affect to bats feeding because this species are in large colonies, fast flyers, and forage in opening habitats (Gaisler and Kolibac, 1992; Rachwald, 1992).

The results of this analysis indicated that there was a significant difference in signal-receiving time between habitat categories (ANOVA: $F_{7, 572} = 8.17$, $P < 0.001$) (Figure 10). The highest numbers of bat calls were recorded in villages, but it was not significantly different from dry rice fields and wet rice fields. There were relatively few calls recorded in forest plantations.

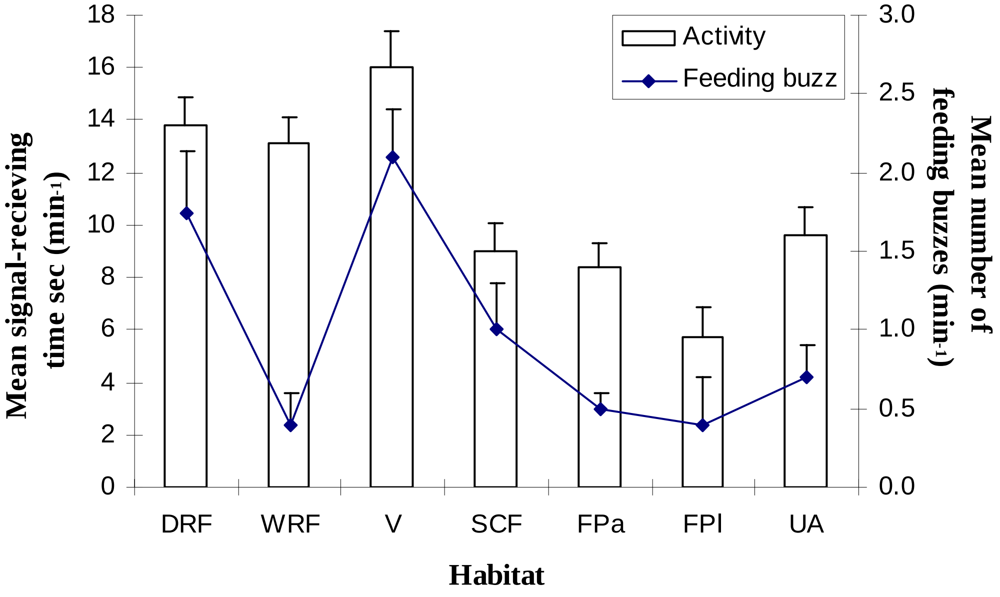

Figure 10 Mean of bat activity time and the number of feeding buzzes on habitats

In Fisher's PLSD on log transformed, bat activity in village was highest on mean significant differences compared with forest plantation (Fisher's PLSD: Mean Diff. = 0.719, P < 0.001), the second rank was on mean significant differences in dry rice fields compared with forest plantation (Fisher's PLSD: Mean Diff. = 0.602, P < 0.001) and the lowest was no mean significant difference in urban areas compared with dry rice fields (Fisher's PLSD: Mean Diff. = 0.015, P > 0.05) (Table 5). Bats primarily selected areas in village and dry rice fields. This is probably because such habitats support higher insect densities. The results were similar to the previous studies on difference species and supported the suggestion that streetlights are also important foraging habitats for free-tailed bats (Lee and McCracken, 2002).

Previous studies indicated that villages were used by bat due to the abundance of insects attracted by streetlights. Illuminated streets and roads are frequently used as feeding sites by several species of insectivorous bats (Griffin,1958 ,Shields and Bildstein, 1979, Fenton *et al.*,1983, Belwood and Fullard, 1984, Geggie and Fenton, 1985, Haffner and Stutz,1985, 1986, Baagoe, 1986, Schnitzler *et al.*, 1987, Furlonger *et al.*, 1987, Kronwitter, 1988, Barak and Yom-Tov, 1989, Hickey and Fenton, 1990 and Rydell, 1991.

However, Blake *et al*. (1994) observed that illuminated by white streetlights on the road in Southern England attracted three times more foraging bats (mostly *Pipistrellus pipistrellus*) than did roads lit by orange streetlights or unlit roads. More insects flew around white lamps than around orange lamps. The mean number of bat passes recorded in any 1 km section of road was correlated positively to the number of white streetlights along the section. Rydell (1992) reported similar differences between types of streetlight.

Table 5 Statistical significant differences in bat activity compared on habitats (Fisher's PLSD for Log10Passes (TE), Significant Level: 0.05)

Habitats	Mean Diff.	P-Value	Significant level
DRF vs WRF	-0.070	0.483	NS
DRF vs V	-0.117	0.211	NS
DRF vs SCF	0.283	0.010	S
DRF vs FPa	0.394	<0.001	S
DRF vs FPl	0.602	<0.001	S
DRF vs UA	-0.015	0.898	NS
WRF vs V	-0.047	0.620	NS
WRF vs SCF	0.352	0.002	S
WRF vs FPa	0.463	<0.001	S
WRF vs FPl	0.535	0.019	S
WRF vs UA	0.055	0.640	NS
V vs UA	0.102	0.363	NS
V vs FPa	0.510	<0.001	S
V vs FPl	0.719	<0.001	S
V vs SCF	0.399	0.001	S
SCF vs FPa	0.111	0.306	NS
SCF vs FPl	0.183	0.432	NS
SCF vs UA	-0.297	0.018	S
FPa vs FPl	0.209	0.110	NS
FPa vs UA	-0.408	0.004	S
FPl vs UA	-0.480	0.042	S

Noted: S = Significant difference, Ns = Non-significant difference

Changing foraging habitats may seriously affect insectivorous bat populations (de Jong, 1995; Vaughan *et al*., 1996; Stebbing, 1998; Law *et al.*, 1999; Mitchell, 1999; Russo and Jones, 2003). It is therefore essential to identify the habitat types to define appropriate conservation and management. Bat activity may be successfully surveyed using an ultrasonic detector (Rydell *et al*., 1994; Walsh *et al*., 1995; Walsh and Harris, 1996a, b; Vaughan *et al*., 1997a; Russo and Jones, 2003).

3.2 Feeding activity

Significant differences among habitat categories were found in number of feeding buzzes (ANOVA: $F_{7, 572} = 7.41$, $P < 0.001$) (Figure 11). Feeding activity was highest in villages followed by dry rice fields. In contrast, feeding activity was rarely found in plantations and forest patches (Figure 12). My result supported the previous conclusions of Lee and McCracken (2002) and Leelapaibul (2005). The latter found that *T. plicata* spent most of the time feeding in rice fields.

In the present study bat foraging activity (number of feeding buzzes) was high in rice fields. The spatial distribution of bat activity is mainly determined by the distribution of their prey (Rydell, 1992). White-backed planthoppers (*Sogatella* sp.) are a major pest of rice fields and are particularly dominant in central Thailand (Vangsilabutr, 2001). A recent study by Leelapaibul *et al.* (2005) revealed that planthoppers were found most in the diet of *T. plicata* and concluded that the species potentially plays an importance role in controlling this major crop pest. Thus, this finding supported the results of Leelapaibul *et al.* (2005).

Hillman (1998) observed that the main foraging areas of *T. plicata* around KCP cave were to the north and west, based primarily on the direction that bats flew after emergence. However, I found that bat activities were highest in the north and east of the cave. These directions include primarily of rice fields and forest patches, orchards or plantation. In west, the habitat is primarily orchards or plantations which *T. plicata* was found infrequently and the elevation of landscape gradually becomes higher.

Hillman (1998) observed that in a dry year, bats would tend to travel more to the north and north-east of the cave as these areas remain wetter for longer and hence may retain higher insect populations. However, during my study the precipitation was higher than average. Therefore, the emergence directions do not reflect the areas in which they ultimately forage. Indeed, Hillman (1998) hypothesized that after emerging bats always flew very high and it seemed that this height was used for commuting rather than foraging.

One of the problems was the detection at the high level from the ground. *T. plicata* produces a relatively loud echolocation pulse which may be heard at distances of up to approximately 200 m (Russ, personally communication). However, bats of the same genus were recorded at heights of 3000 m (McCracken, 1996) where they may be converging with, and feeding on, populations of migratory moths. Leelapaibul *et al.* (2005) agreed that the incidence of macropterous (longwinged morph) planthoppers (Homoptera) in its diet was the only planthoppers that are able to migrate. They found large percentage of moths in its diet compared to trapped insects suggesting high altitude foraging. These insects were found to migrate at elevation 0.1–2.5 km. Thus, my finding may apply to individuals foraging within the vicinity of the ground, foraging activity at high altitudes require further study.

Feeding activity was highest during the rainy (June-October) and cool (November-February) seasons and lowest during the hot (March-May) season. Leelapaibul *et al.* (2005) showed that Homoptera was the most important diet in February, March, June, October, November and December. Although to a certain extent the decrease in Homoptera in *T. plicata* diet coincides with the seasonal decrease in foraging activity. It is not possible to determine whether there is seasonal variation in the use of rice fields by bats. *T. plicata* was described as an opportunist-forager on different insect species as they become available (Leelapaibul *et al.*, 2005).

In Fisher’s PLSD on log transformed between habitats had significant difference on feeding activity. The adjusted means of feeding buzzes between habitats are shown in Table 5. Feeding activity in village was highest on mean significant differences compared with forest plantation (Fisher's PLSD: Mean Diff. = 0.288, $P < 0.001$), the second rank was on mean significant differences in village compared with forest patches (Fisher's PLSD: Mean Diff. = 0.221, $P < 0.001$) and the lowest was no mean significant difference in wet rice fields compared with sugarcane fields (Fisher's PLSD: Mean Diff. = -0.003, $P > 0.05$).

3.3 Breeding status and seasonal effect

The habitat use by bats was assessed in correspondence to crop cycles (*i.e.*, harvesting and non-harvesting) and breeding status (*i.e.*, female pregnant, lactating and young foraging) on 580 nights. Sampling of bat activity in this study was purposely carried out as short period as possible to investigate the impact of seasonal effect in bat activity.

During the breeding status based on monthly data, *T. plicata* give birth twice a year: March, April and October (Hillman, 1998). In the present study, breeding status of *T. plicata* followed Hillman (1998) who found that female bats are pregnant in February and March and again in September and October. Lactation occurs in April to May and again in November. Young foraging status was found in July and again in December to January.

Bat activity was highest during the period of young foraging (ANOVA: $F_{2,577} = 5.58$, $P < 0.01$) (Figure 11). Because of bats population increase when adult and young forage at the same time. With respect to feeding activity, feeding activity was highest during lactating and lowest when the female pregnant (ANOVA: $F_{2,577} = 7.52$, $P < 0.01$) (Figure 12). During pregnancy, the body mass of female increase, thus, the decreased maneuverability of pregnant females may be responsible for its lower diet diversity compared to lactating females (Leelapaibul, 2003). This result that female pregnant fed on their food lower than lactating females may be also depend on the variation of insect availability at that time. Thus, bat activity and feeding activity varied significantly with breeding status.

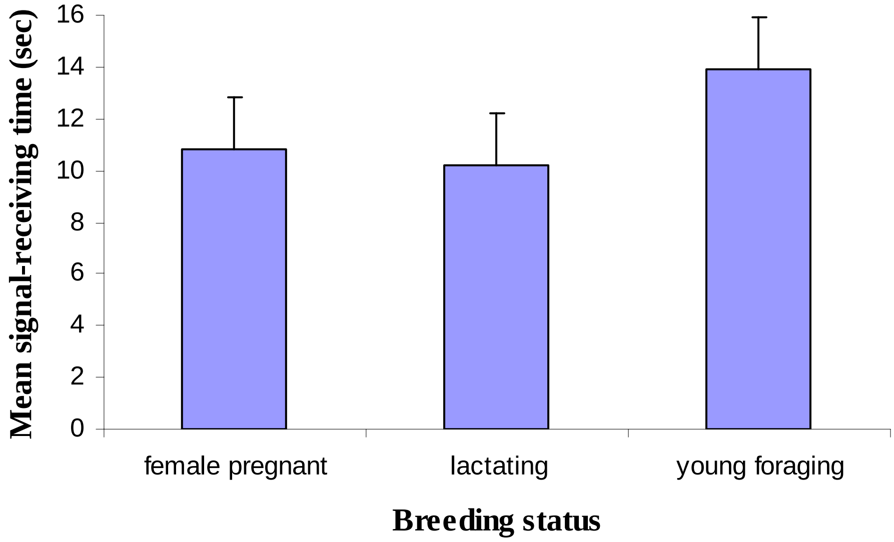

Figure 11 Signal-receiving time and breeding status presented as mean $\pm$ SE

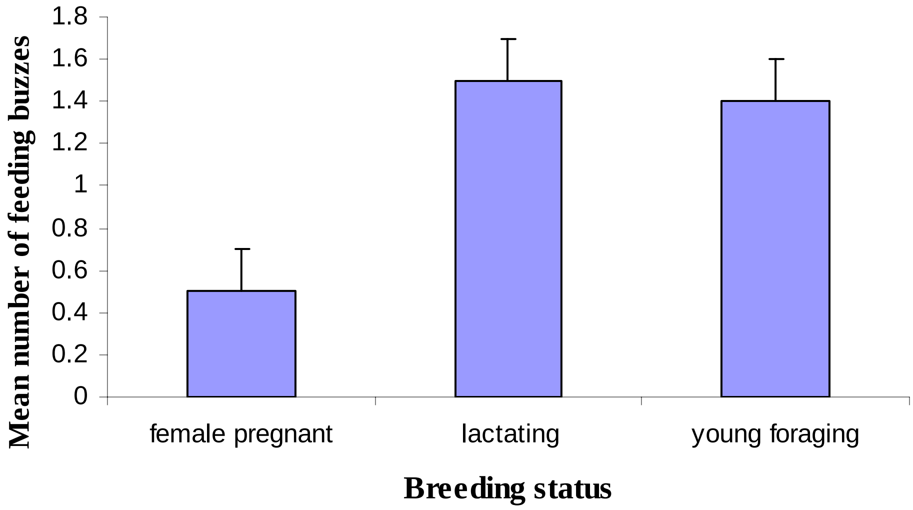

Figure 12 Feeding activity and breeding status presented as mean $\pm$ SE

There was a significant difference in the mean signal-receiving time recorded between seasons (ANOVA: $F_{2, 532} = 7.09$, $P < 0.01$). The highest bat activity was in the cool and rainy seasons (mean number of signal-receiving time in the cool season 12.5$\pm$0.8, in the rainy season 12.2$\pm$0.8) with the lowest in the hot season (8.3$\pm$0.8) (Figure 13).

Table 6 Statistical significant differences in bat activity between season (Fisher's PLSD for Log10Passes(TE), Significant Level: 0.05)

Season	Mean diff.	P-Value	Significant level
Cool, Hot	0.048	0.170	NS
Cool, Rainy	-0.043	0.133	NS
Hot, Rainy	-0.091	0.004	S

Noted: S = Significant difference, Ns = Non-significant difference

In the number of feeding activity recorded between seasons, there was no significant difference (ANOVA: $F_{2, 532} = 2.99$, $P > 0.05$). The highest feeding activity was in the cool and rainy seasons (mean number of feeding activity in the season 1.3 ± 0.3, in the rainy season 1.3 ± 0.2) with the lowest in the hot season (0.6 ± 0.1) (Figure 13).

In Fisher’s PLSD on log transformed between seasons, the adjusted means of feeding buzzes between seasons are shown in Table 7. Feeding activity in the rainy season was highest on mean significant differences compared with the hot season (Fisher’s PLSD: Mean Diff. = 0.091, $P < 0.01$) and the lowest was no mean significant differences in the rainy season compared with the cool season (Fisher’s PLSD: Mean Diff. = 0.043, $P > 0.05$).

Table 7 Statistical significant differences in feeding activity between season (Fisher's PLSD for Log10Buzzes (TE), Significant Level: 0.05)

Season	Mean diff.	P-Value	Significant level
Cool vs Hot	3.304	0.879	NS
Cool vs Rainy	-45.060	0.012	S
Hot vs Rainy	-48.364	0.015	S

Noted: S = Significant difference, Ns = Non-significant difference

Seemingly, the result did not agree with the fact that *T. plicata* should discover less in the rainy season, because of rainfall is probably an important factor in bat activity as in others bats (Racey, 1982; Bernard and Cumming, 1997; Happold and Happold, 1990; Racey and Entwistle, 2000; Bumrungsri, 2002). Thus, the effect from weather as rainfall appeared to be wetness for bats. The difference in bat activity patterns, time of emergence and return, and foraging direction between the cool and rainy seasons were much greater than any observed differences due to local weather patterns. This might be because wetness affected the abundance of insects available (Hillman, 1998).

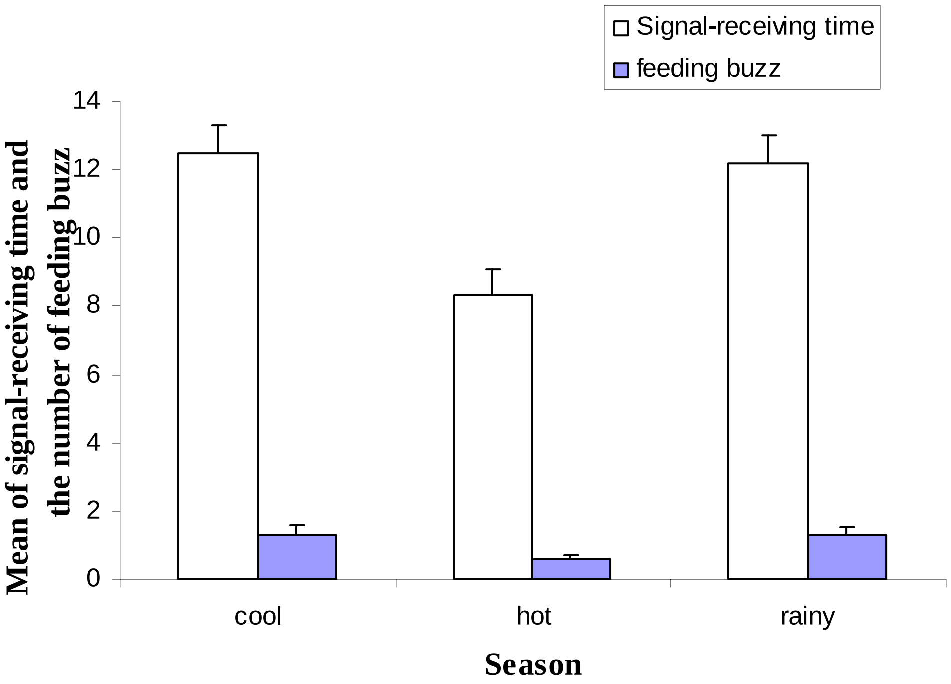

Figure 13 The Mean $\pm$ SE of signal-receiving time and the number of feeding buzz of *Tadarida plicata* in different seasons

Climate conditions were not much different between all recorded nights. Other influential extrinsic factors may include temperature (Catto *et al*., 1995), cloud cover and heavy rain (McAney and Fairley, 1988). Temperature appeared to have some effect on bat activity, under rainy and windy weather (Gaisler *et al*., 1998). The direction and strength of wind seemed to affect the degree of movement of the column of bats during fly out. Cloudiness might influence the moving of column of emerging bats (personal observation).

3.4 Distance from cave

T. plicata has a larger home ranges. Six categories (*i.e.*, 0-5 km, 5-10 km, 10-15 km, 15-20 km, 20-25 km and 25-30 km) were identified based on mean distance from the KCP cave. From the analysis, there was a significant differences in bat activity among distance categories (ANOVA: $F_{5, 575} = 7.45$, $P < 0.001$) (Figure 14). The number of signal-receiving time was highest at 0-5 km from the KCP cave. Thus, it could be expected that distance near the cave also has a lot of bat activities and still has some bats continually flied out and returned to the cave throughout the night.

However, there were significant differences in feeding activity among distance categories (ANOVA: $F_{5, 575} = 3.59$, $P < 0.01$) (Figure 14). Feeding activity was highest within a 0-5 km radius of the KCP Cave. One explanation for the localization of feeding activity with any distance may be these bats simultaneously fly and feed on, thus, no matter how distance near or far from cave they were captured and eaten their foods.

Focused on lactating status of *T. plicata*, bat activity seemed to be highest within a 0-5 km radius of the KCP cave. In addition, there was a significant difference in signal-receiving time (ANOVA: $F_{5, 244} = 2.75$, $P < 0.05$) (Figure 15) but was not significant difference in feeding activity of bats in this period (ANOVA: $F_{5, 244} = 1.23$, $P > 0.05$) (Figure 15).

In the first lactation, it was occurred in the ending of April until June and the second was occurred in November. Female bats of *Tadarida brasiliensis mexicana* are not take their baby off when they fly to forage and young bats are not necessarily nursed by their own mother. Thus, female bats have to early come back early to the cave after feeding for feeding their young (Clyde, 2003). From this reason, only few recorded calls were found in the distances far from cave e.g., 25-30 km or 30> km.

This results related to figure 15 that the mean signal-receiving time and the mean number of feeding buzzes were higher after 0-5 km and it was highest in 15-20 km from the KCP cave. William *et al.* (1973) studied on the home range of *T. brasiliensis* by using radar, he found that bats had an average foraging areas 20-400 km^2 and it was 5-25 km distance from cave (average 17 km) and Davis *et al.* (1962) indicated that bat in genus *Tadarida* has average 17 km. It could be expect that *T. plicata* has as the same average distance. For this reason, the distance category of 15-20 km from cave also has bats much more than other distance categories.

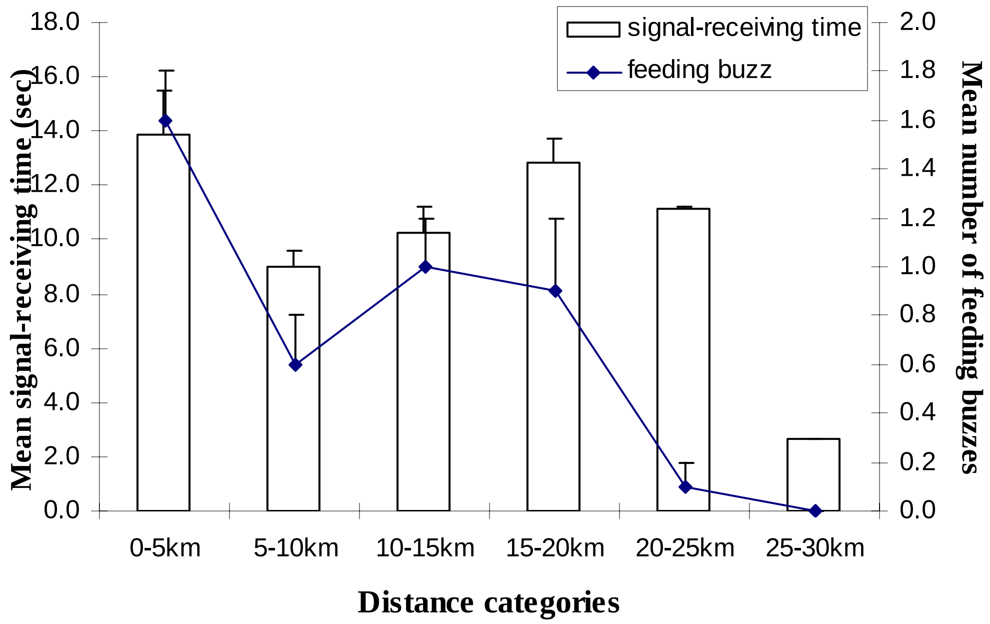

Figure 14 Bat activity and feeding activity (mean±SE) of *Tadarida plicata* in distance from cave

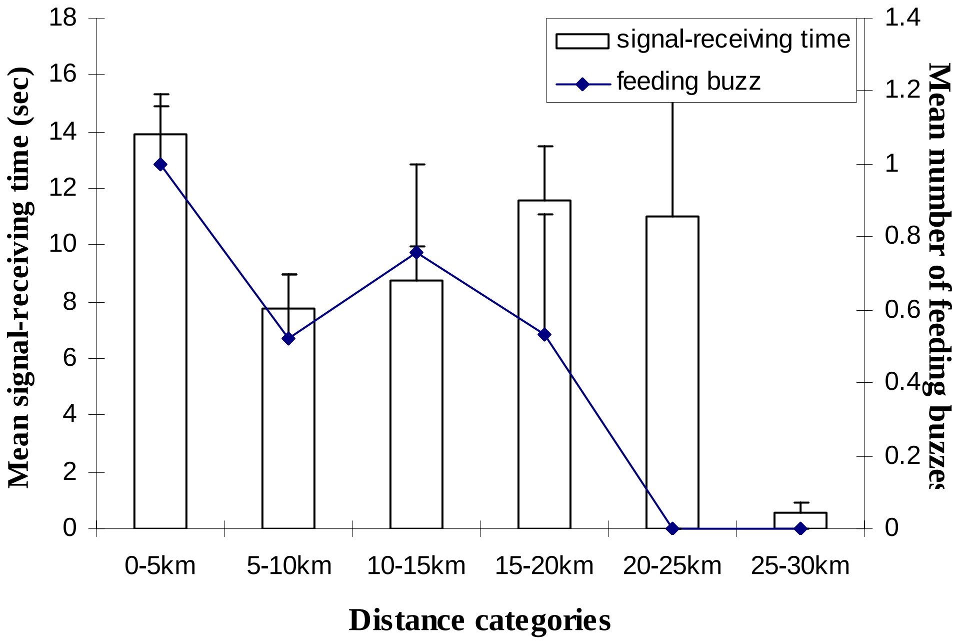

Figure 15 Bat activity and feeding activity (mean±SE) of *Tadarida plicata* in distance from cave during lactating period.

4. Conservation Application

Rice fields are the most important targets for *T. plicata* conservation at Ratchaburi Province in Thailand and elsewhere, because they were found to have a considerable number of bat passes and feeding buzzes. The habitat of rice fields should be maintained and also the village areas might be preferred. Where streetlights are often present sustained a significant number of bat activities. This complication form of management, should be encouraged where possible.

The most important and cause of habitat disturbance of bats is the expansion and intensification of urban use. Conventional agricultural systems fragment a large area into small patches compared with the surrounding intensively agricultural landscape, and may therefore attractive to a number of prey density. Fragmenting a large area of habitat into a mosaic may be beneficial to certain bat species by increasing edge habitat, although it will be detrimental to others by decreasing linear features connecting foraging areas (Russ and Montgomery, 2002; Wickramasinghe *et al*., 2003).

In Ratchaburi Province, the number of *T. plicata* activity seems to be decreasing although there is particular concern about this specie was threatened. The observations of this cause suggest that it is in severe decline from farmers by pesticide which is use for rice growing stock. Thus, the use of agrochemicals may explain the differences in bat activity over agricultural habitats and implies that localized changes in pollutions may discount abundance of some insect species, directly decrease the diets of bats. The agricultural landscapes are also tending to disappear as towns or urban areas develop and spread. The negative effect of urbanization on bats (Kurta and Teramino, 1992, Geisler *et al*., 1998; Russo and Jones, 2003) might be mitigated by maintaining rice fields, small patches of cultivated land.

Finally, this result has implication directly for farmers because bats feed mainly over rice field and crop systems. In the text of Leelapaibul's work on diet of *T. plicata* proof that bats spend much time over rice and crops. This may indicate that they are feeding on planthoppers and this species of *T. plicata*'s diet was found in rice fields. A restricted use of pesticides in rice fields should be initiated. This would encourage the expansion of an organic agricultural at the expense of pesticides dependent in agriculture, and further promote bat conservation (Carmel and Safriel, 1998). The importance of habitat management was demonstrated in an agricultural landscape for bat conservation.

CONCLUSION AND RECOMMENDATION

1. Bat activity was quantified using an acoustic monitoring method on transects in seven habitat types *i.e.*, dry rice fields, wet rice fields, villages, sugarcane fields, forest patches, forest plantations and also urban areas, habitats within 30 km of Khao Chong Phran cave, Ratchaburi Province, central Thailand. From sampling effort of 1,160 hour, the total of signal-receiving time was 93,027 minutes and 674 feeding buzzes were found.

2. Total *T. plicata* signal-receiving time and feeding buzzes indicated that this bat was selected most in villages and dry rice fields. There were a significant differences number of bat calls among habitats ($P < 0.001$). Villages were most selected because streetlights provided many insects.

3. The habitat use was assessed by bats of breeding status (*i.e.*, female pregnant, lactating and young foraging) and seasonal climate (*i.e.*, cool, hot and rainy) on 580 night observations. From this research, bat activity was highest when bats were young foraging ($P < 0.01$). With respect to feeding activity, it was highest during lactating and lowest when the female pregnant ($P < 0.01$). Furthermore, the highest bat activity was in the cool and rainy seasons with the lowest in the hot season ($P < 0.01$). Feeding activity was highest in the cool and rainy seasons ($P > 0.05$).

4. Bat activity was highest within a 0-5 km radius of Khao Chong Phran cave. There was a significant difference in bat activity among distance categories ($P < 0.001$). Thus, it could be expected that distance near the cave also has a lot of bat activities and still has some bats continually flied out and returned to the cave throughout the night. However, feeding activity also seemed to be highest within a 0-5 km. There were significant differences in feeding activity among distance categories ($P < 0.01$).

5. The study such as this can be used directly for habitat use managing, for restoring bat habitat and protecting habitats that require conservation measures.

Previous study indicated that homopterans as white-backed planthoppers which were the most common component of the diet for *T. plicata* in Ratchaburi Province (Leelapaibul, 2005). This species is very common in an agricultural landscape such as rice fields. In the present study, villages and dry rice fields which the most habitats selection of *T. plicata.* This would be useful in the combination with other studies and for monitoring these bats. In the future, should be using some technique to show the result obviously such as radio-tracking etc.

6. For conservation management, it should reduced the use of the insecticide in habitat needs of bats. Most habitats in Ratchaburi Province, rice fields are the primary importance. Management plan should maintain natural fertilizers and decrease pesticides use in that habitats. The suggestion for future research is the guano collecting benefits and activities especially in term of economic values.

7. For data collecting, the recommendation with equipments e.g., bat detector, tape recorder should be changed batteries once during the nights observation to prevent the variation in the reception of the ultrasonic pulses followed Fenton (1970).

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APPENDIX

Appendix Figure 1 The wrinkle-lipped free-tailed bat (*Tadarida plicata)*

CURRICULUM VITAE

NAME	: Miss Kessarin Utthammachai		
BIRTH DATE	: February 10, 1983		
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