สังคม อาหาร และปรสิตภายนอกของค้างคาวในสถานีวิจัยสิ่งแวดล้อมสะแกราช จังหวัดนครราชสีมา

นายศราวี อรุณ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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ปีการศึกษา 2557

COMMUNITY, DIET, AND ECTOPARASITES OF BATS IN SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA PROVINCE

Sarawee Aroon

A Thesis Submitted in Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy in Environmental Biology

Suranaree University of Technology

Academic Year 2014

COMMUNITY, DIET, AND ECTOPARASITES OF BATS IN SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA PROVINCE

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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ศราวี อรุณ : สังคม อาหาร และปรสิตภายนอกของค้างคาวในสถานีวิจัยสิ่งแวดล้อมสะแกราช จังหวัดนครราชสีมา (COMMUNITY, DIET, AND ECTOPARASITES OF BATS IN SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA PROVINCE) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ณัฐวุฒิ ธานี, 191 หน้า.

ค้างคาวเป็นกลุ่มสัตว์เลี้ยงลูกด้วยน้ำนมที่มีความหลากหลายมากที่สุดในประเทศไทย อย่างไรก็ตามข้อมูลเกี่ยวกับนิเวศวิทยาของค้างคาวที่อาศัยในป่าของประเทศไทยยังมีน้อยมาก การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาโครงสร้างทางสังคม อาหาร และปรสิตภายนอกของค้างคาว ที่สถานีวิจัยสิ่งแวดล้อมสะแกราช จังหวัดนครราชสีมา ทำการเก็บข้อมูลของค้างคาวตั้งแต่เดือนมิถุนายน 2556 ถึงเดือนพฤษภาคม 2557 โดยใช้ตาข่ายดักจับจำนวน 16 ผืน ทำการดักจับเป็นเวลา 6 ชั่วโมงหลังจากดวงอาทิตย์ตก ในป่าเต็งรัง เขตรอยต่อป่า ป่าดิบแล้ง และป่าปลูก โดยแบ่งการดักจับออกเป็น 12 คืนต่อหนึ่งฤดูกาล รวมเป็นเวลาดักจับทั้งสิ้น 36 คืน ค้างคาวที่ถูกจับได้ถูกนำไปจำแนกชนิด เพศ อายุ ชั่งน้ำหนัก วัดขนาด และทำเครื่องหมาย จากนั้นทำการเก็บมูลค้างคาวและปรสิตภายนอกเพื่อนำไปวิเคราะห์ ผลการศึกษาพบว่าจับค้างคาวได้ทั้งหมด 66 ตัว จาก 6 วงศ์ 7 สกุล และ 9 ชนิด แบ่งออกเป็นกลุ่มค้างคาวกินผลไม้ร้อยละ 32.82 และกลุ่มค้างคาวกินแมลงร้อยละ 68.18 ค้างคาวที่พบชุกชุมที่สุดคือค้างคาวหน้ายักษ์สามหลืบ (ร้อยละ 34.85) ดัชนีความหลากหลายของแชนนอน-ไวเนอร์ของค้างคาวมีค่าเท่ากับ 1.925 ในขณะที่ดัชนีการกระจายตัวของแชนนอน-ไวเนอร์ของค้างคาวมีค่าเท่ากับ 0.876 จำนวนของค้างคาวที่ถูกจับแตกต่างกันระหว่างป่าดิบแล้งและเขตรอยต่อป่า ($X^2 = 26.52$, df = 8, $p = 0.001$) แต่ไม่พบค้างคาวในป่าเต็งรังและป่าปลูก ความชุกชุมของค้างคาวมีความแตกต่างระหว่างแต่ละฤดูกาลด้วยเช่นกัน ($H = 8.91$, df = 2, $p = 0.011$)

การวิเคราะห์อาหารพบว่าค้างคาวกินแมลงในสังคมนี้ กินแมลงจำนวน 7 อันดับ ประกอบด้วยอันดับโคลีออพเทอรา อันดับเลบปิดออพเทอรา อันดับดิพเทอรา อันดับไฮเมนนอฟเทอรา อันดับเฮมิพเทอรา อันดับไอซอพเทอรา และอันดับออร์ทอพเทอรา โดยอันดับแมลงที่พบบ่อยในมูลของค้างคาวคือ อันดับโคลีออพเทอรา (f = 70.22) และอันดับเลบปิดออพเทอรา (f = 59.56) ความกว้างของวิถีชีวิตเฉพาะมีค่าระหว่าง 0.133 ถึง 0.359 โดยค้างคาวแวมไพร์แปลงเล็กมีความกว้างของวิถีชีวิตเฉพาะมากที่สุด ($B_A = 0.359$) ความคาบเกี่ยวของวิถีชีวิตเฉพาะมีค่าระหว่าง 0.013 ถึง 0.31 โดยค้างคาวหน้ายักษ์สามหลืบกับค้างคาวหูหนูตีนเล็กเขี้ยวยาวมีความคาบเกี่ยวของวิถีชีวิตเฉพาะสูงที่สุด (ดัชนีความคาบเกี่ยวของโมริซิตะ-ฮอร์น = 0.31)

การศึกษาปรสิตภายนอกของค้างคาว พบว่ามีค้างคาวจำนวน 21 ตัว ใน 4 ชนิด มีปรสิตภายนอก (ร้อยละ 31.82) โดยพบปรสิตภายนอกทั้งหมด 64 ตัว จาก 4 วงศ์ 7 สกุล และ 7 ชนิด ปรสิตภายนอกที่พบบ่อยที่สุดคือแมลงวันค้างคาวสกุลบราชีทาซีนา (ดัชนีความเด่นของแบร์เกอร์-ปาร์คเกอร์ = 0.438) ซึ่งพบได้จากค้างคาวหน้ายักษ์สามหลืบ และค้างคาวมงกุฎเทาแดง จำนวนของปรสิตภายนอกของค้างคาวแต่ละชนิดไม่มีความแตกต่างกัน ($H = 1.45$, df = 3, $p = 0.694$) ความชุกชุมเฉลี่ยปรสิตภายนอกของค้างคาวมีค่า 0.139 ในขณะที่ความรุนแรงของการติดปรสิตภายนอกมีค่า 0.435 ดัชนีความหลากหลายของบริลลูอินของปรสิตภายนอกมีค่าเท่ากับ 1.262 ในขณะที่ดัชนีการกระจายตัวของบริลลูอินของปรสิตภายนอกมีค่าเท่ากับ 0.889

สาขาวิชาชีววิทยา
ปีการศึกษา 2557

ลายมือชื่อนักศึกษา__________
ลายมือชื่ออาจารย์ที่ปรึกษา__________
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม__________
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม__________

SARAWEE AROON : COMMUNITY, DIET, AND ECTOPARASITES OF BATS IN SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA PROVINCE. THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 191 PP.

BAT/DIVERSITY/FOOD/PARASITE/SAKAERAT ENVIRONMENTAL RESEARCH STATION

Bats are the most diverse terrestrial mammals in Thailand. However, there is a lack of data on ecology of forest bats in Thailand. The objectives of this study were to investigate community structure, diet, and ectoparasites of bats in Sakaerat Environmental Research Station, Nakhon Ratchasima province. During June 2013 to May 2014, bats were captured by 16 mist nets, set up 6 hours after sunset in dry dipterocarp forest, ecotone, dry evergreen forest, and plantation forest. Surveys were carried out for 12 nights per season, overall 36 sampling nights. Captured bats were identified, sexed, aged, weighed, measured, and marked. Then, faecal pellets and ectoparasies were collected for later analyses. A total of 66 individual bats were captured, representing in 6 families, 7 genera, and 9 species. Of these, megabats comprised 32.82% while microbats constituted 68.18%. The most abundance species was *Hipposideros larvatus* (34.85%). The Shannon-Wiener diversity index of bats was 1.925 while the Shannon-Wiener evenness index of bats was 0.876. The number of bat captured was significantly different between dry evergreen forest and ecotone ($\chi^2 = 26.52$, df = 8, $p = 0.001$). No bat was captured in dry dipterocarp forest and plantation forest. Bat abundance was also significantly different among seasons ($H = 8.91$, df = 2, $p = 0.011$).

Dietary analysis showed that insectivorous bats in this community consumed 7 orders of insects, including Coleoptera, Lepidoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, and Orthoptera. The two most frequent insect orders in the faecal pellets were Coleoptera (%f = 70.22%) and Lepidoptera (%f = 59.56%). The trophic niche breadths of insectivorous bats varied from 0.133 to 0.359. The widest trophic niche breath was found in *Megaderma spasma* (B_A = 0.359). The trophic niche overlap of insectivorous bats ranged from 0.013 to 0.31. The trophic niche overlap was highest between *Hipposideros diadema* and *Myotis muricola* (Morishita-Horn index = 0.31).

The ectoparasites study showed that 21 individuals of 4 bat species were infested with ectoparasites (31.82%). A total of 64 ectoparasites were collected from bats belonging to 4 families, 7 genera, and 7 species. Of these, *Brachytarsina* sp. was the most common ectoparasite of bats (Berger-Parker index = 0.438) which infested on *Hipposideros larvatus* and *Rhinolophus affinis*. Number of parasite loads among bat species was not different (H = 1.45, df = 3, p = 0.694). Mean abundance of ectoparasite infestation of captured bats was 0.139 while mean intensity of infestation was 0.435. The Brillouin diversity index of ectoparasites was 1.262 while the Brillouin evenness index of ectoparasites was 0.889.

School of Biology
Academic Year 2014

Student's Signature____________________
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Sarawee Aroon

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CHAPTER I

INTRODUCTION

1.1 General introduction

The community is the primary unit of ecosystem management. Therefore, an understanding of community ecology is important for effective management. The two main questions of community ecology are (1) how many species are in a community? and (2) what are environmental factors affecting the species in that community (Begon, Townsend, and Harper, 2006)? Generally, assessment of species coexistence in a community focuses on interspecific competitive interactions. However, coexisting species usually avoid competition with each other by niche partitioning (Tschapka, 2004). Bats are very good models for community ecology study because they often have high species richness, their local assemblages are usually rich, and they can consume a variety of food items (Mello, 2009). Hence, they always exhibit niche partitioning in food resources and habitat use (Ashrafi, Beck, Rutishauser, Arlettaz, and Bontadina, 2011; Razgour, Korine, and Saltz, 2011; Fukui, Okazaki, and Maeda, 2009; Bumrungsri, Leelapaibul, and Racey, 2007; Siemers and Swift 2006; Aguirre, Herrel, van Damme, and Matthysen, 2002; Arlettaz, Godat, and Meyer, 2000; Arlettaz, Perrin, and Hausser, 1997).

Bats are the second most speciose order of mammals after rodents. Over 1,200 species of living bats make up one-fifth of all mammalian species (Fenton, 2012). They are distributed throughout the world, with the exception of the Antarctic and a few oceanic islands (Mickleburgh, Hutson, and Racey, 2002). Bats are good indicators of ecosystem quality because they interact with various organisms and exhibit important roles in ecosystem processes such as predation, pollination, and seed dispersion (Kalka, Smith, and Kalko, 2008; Martin, Pine, and DeBlase, 2001; Kalko, 1998; Fujita and Tuttle, 1991). Bats also play important roles in agricultural areas such as controlling insect pests and producing excellent fertilizer from their excrement (Cleveland et al., 2006; Leelapaibul, Bumrungsri, and Pattanawiboon, 2005).

Southeast Asia is a “hotspot” for bat diversity, contributing about 30% of bat species in the world (320 species) (Kingston, 2010). In Thailand, bats comprise about 40% of mammalian fauna (119 species) (Bumrungsri et al., 2006). However, Southeast Asia also has one of the highest deforestation rates in the world (Laurance, 2007). This situation may lead to the extinction of about 20% of bat species in Southeast Asia by 2100 (Lane, Kingston, and Lee, 2006). Thus, bat conservation is a significant topic for biodiversity conservation.

Despite their important roles in ecosystems, agricultural areas, and biodiversity conservation, knowledge of the community ecology, distribution, and resources requirements of bats lags behind that of other groups of mammals (Hutson, Mickleburgh, and Racey, 2001; Francis, 1994; Francis, 1990). There is also a lack of data on the parasites of bats in tropical regions (Krichbaum, Perkins, and Gannon, 2009). This study will help to determine bat community and provide data on the diet and ectoparasites of bats, which will have important implications for the conservation of biodiversity and forest management in Thailand.

1.2 Research objectives

1.2.1 To survey bat community in dry evergreen forest, dry dipterocarp forest, ecotone area, and plantation forest in Sakaerat Environmental Research Station (SERS), Nakhon Ratchasima.

1.2.2 To investigate variation in diet, food niche breath, and food niche overlap among bats in SERS.

1.2.3 To identify ectoparasites associated with bats species, sexes, and age classes.

1.3 Scope and limitations of the study

1.3.1 The study on bat community was conducted in dry evergreen forest, dry dipterocarp forest, ecotone area, and plantation forest in SERS.

1.3.2 Collection of bats were performed from June 2013 to May 2014 by mist netting.

1.3.3 Food items were identified to order level while ectoparasites of bats were identified to genus level.

1.4 Benefits of the study

This study would provide important data on (1) community of bats, (2) variation in diet and food niche of bats, and (3) ectoparasites associated with bats in dry evergreen forest, dry dipterocarp forest, and ecotone area, and plantation forest in Sakaerat Environmental Research Station, which could have been applied for conservation, management, and further study on bats in Thailand.

1.5 References

Aguirre, L. F., Herrel, A., van Damme, R., and Matthysen, E. (2002). Ecomorphological analysis of trophic niche partitioning in a tropical savannah bat community. **Proceedings of the Royal Society of London, Series B: Biological Sciences**. 269: 1271-1278.

Arlettaz, R., Godat, S., and Meyer, H. (2000). Competition for food by expanding pipistrelle bat populations (*Pipistrellus pipistrellus*) might contribute to the decline of lesser horseshoe bats (*Rhinolophus hipposideros*). **Biological Conservation**. 93: 55-60.

Arlettaz, R., Perrin, N., and Hausser, J. (1997). Trophic resource partitioning and competition between the two sibling bat species *Myotis myotis* and *Myotis blythii*. **Journal of Animal Ecology**. 66: 897-911.

Ashrafi, S., Beck, A., Rutishauser, M., Arlettaz, R., and Bontadina, F. (2011). Trophic niche partitioning of cryptic species of long-eared bats in Switzerland: implications for conservation. **European Journal of Wildlife Research**. 57: 843-849.

Begon, M., Townsend, C. R., and Harper, J. L. (2006). **Ecology: From individuals to ecosystems** (4th ed.). London: Wiley-Blackwell. 752p.

Bumrungsri, S., Harrison, D. L., Satasook, C., Prajukjitr, A., Thong-Aree, S., and Bates, P. J. J. (2006). A review of bat research in Thailand with eight new species records for the country. **Acta Chiropterologica**. 8: 325-359.

Bumrungsri, S., Leelapaibul, W., and Racey, P. A. (2007). Resource partitioning in sympatric *Cynopterus* bats in lowland tropical rain forest, Thailand. **Biotropica**. 39: 241-248.

Cleveland, C. J., Betke, M., Federico, P., Frank, J. D., Hallam, T. G., Horn, J., López, J. D., Jr., McCracken, G. F., Medellín, R. A., Moreno-Valdez, A., Sansone, C. G., Westbrook, J. K., and Kunz, T. H. (2006). Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. **Frontiers in Ecology and the Environment**. 4(5): 238-243.

Fenton, M. B. (2012). Bats and white-nose syndrome. **Proceedings of the National Academy of Sciences of the United States of America**. 109: 6794-6795.

Francis, C. M. (1990). Tropic structure of bat communities in the understory of lowland dipterocarp rainforest in Malaysia. **Journal of Tropical Ecology**. 6: 421-431.

Francis, C. M. (1994). Vertical stratification of fruit bats (Pteropodidae) in lowland dipterocarp rainforest in Malaysia. **Journal of Tropical Ecology**. 10: 523-530.

Fujita, M. S. and Tuttle, M. D. (1991). Flying foxes (Chiroptera: Pteropodidae): threatened animals of key ecological and economic importance. **Conservation Biology**. 5: 455-464.

Fukui, D., Okazaki, K., and Maeda, K. (2009). Diet of three sympatric insectivorous bat species on Ishigaki Island, Japan. **Endangered Species Research**. 8: 117-128.

Hutson, A. M., Mickleburgh, S. P., and Racey, P. A. (2001). **Microchiropteran bats: Global status survey and conservation action plan**. Cambridge: International Union for the Conservation of Nature and Natural Resources. 268p.

Kalka, M. B., Smith, A. R., and Kalko, E. K. V. (2008). Bats limit arthropods and herbivory in a tropical forest. **Science**. 320: 71.

Kalko, E. K. V. (1998). Organization and diversity of tropical bat communities through space and time. **Zoology**. 101: 281-297.

Kingston, T. (2010). Research priorities for bat conservation in Southeast Asia: a consensus approach. **Biodiversity and Conservation**. 19: 471-484.

Krichbaum, K., Perkins, S., and Gannon, M. R. (2009). Host-parasite interactions of tropical bats in Puerto Rico. **Acta Chiropterologica**. 11(1): 157-162.

Lane, D. J. W., Kingston, T., and Lee, B. P. Y-H. (2006). Dramatic decline in bat species richness in Singapore, with implications for Southeast Asia. **Biological Conservation**. 131: 584-593.

Laurance, W. F. (2007). Forest destruction in tropical Asia. **Current Science**. 93: 1544-1550.

Leelapaibul, W., Bumrungsri, S., and Pattanawiboon, A. (2005). Diet of wrinkle-lipped free-tailed bat (*Tadarida plicata* Buchannan, 1800) in central Thailand: insectivorous bats potentially act as biological pest control agents. **Acta Chiropterologica**. 7: 111-119.

Martin, R. E., Pine, R. H., and DeBlase, A. F. (2001). **A manual of mammalogy: With keys to families of the world** (3rd ed.). New York: McGraw-Hill. 352p.

Mello, M. A. R. (2009). Temporal variation in the organization of a Neotropical assemblage of leaf-nosed bats (Chiroptera: Phyllostomidae). **Acta Oecologica**. 35: 280-286.

Mickleburgh, S. P., Hutson, A. M., and Racey, P. A. (2002). A review of the global conservation status of bats. **Oryx**. 36(1): 18-34.

Razgour, O., Korine, C., and Saltz, D. (2011). Does interspecific competition drive patterns of habitat use in desert bat communities?. **Oecologia**. 167: 493-502.

Siemers, B. M. and Swift, S. M. (2006). Differences in sensory ecology contribute to resource partitioning in the bats *Myotis bechsteinii* and *Myotis nattereri* (Chiroptera: Vespertilionidae). **Behavioral Ecology and Sociobiology**. 59: 373-380.

Tschapka, M. (2004). Energy density patterns of nectar resources permit coexistence within a guild of Neotropical flower-visiting bats. **Journal of Zoology**. 263: 7-21

CHAPTER II

LITERATURE REVIEWS

2.1 Order Chiroptera

The word “Chiroptera” comes from the Geek word, meaning “hand-wing” which refers to bats. Bats are the only mammals capable of true flight. Their forearms are modified into wings which are formed by a skin membrane call a patagium. Many bats also have a tail membrane called uropatagium. The skeleton and muscles of bats are modified for flight, with a strong pectoral girdle, sternum, and chest muscles. Most bats have tendons in their claw toes for hanging upside down while resting (Vaughan, Ryan, and Czaplewski, 2000). Bats exhibit a great variety of shapes and sizes. The largest bat has a wingspan of up to 2 m and weight up to 1.5 kg (Giant Golden-Crowned Flying Fox, *Acerodon jubatus*) (Stier and Mildenstein, 2005), while the smallest bat has a wingspan of 12-13 cm and weight of 2 g (Kitti's Hog-nosed Bat or Bumblebee Bat, *Craseonycteris thonglongyai*) (Hill and Smith, 1981).

Bats are the second most speciose order of mammals; only the rodents have more species than bats. There are more than 1,200 species of bats comprising about one-fifth of all mammalian species (Fenton, 2012). Bats are the most diverse of living mammals. They exhibit wide ranges of feeding and roosting habits, reproductive strategies, and social behavior (Nowak, 1994).

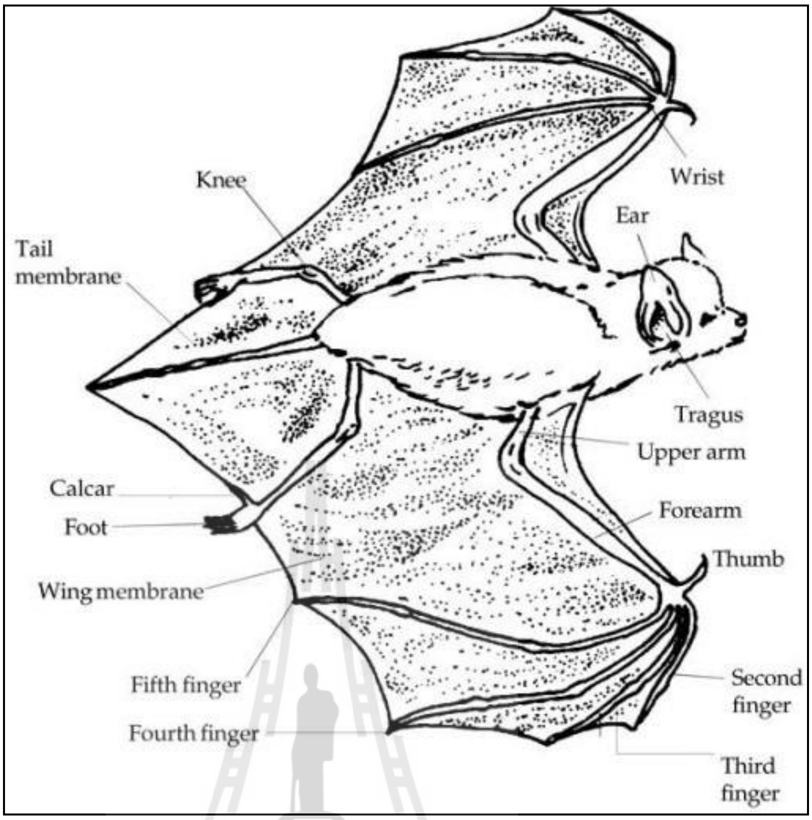

Figure 2.1 Characteristics of bat (Harvey, 1986).

Bats are keystone species in many communities. Frugivorous bats are important seed dispersers of many fruit trees. Nectivorous bats pollinate certain blooming plants. Carnivorous bats can play an important role in limiting the populations of their prey (Kalka, Smith, and Kalko, 2008; Martin, Pine, and DeBlase, 2001; Kalko, 1998; Fujita and Tuttle, 1991). In addition, bats also have numerous benefits to humans. Insectivorous bats control many insect pests. Bat guano is used to fertilize crops worldwide (Cleveland et al., 2006; Leelapaibul, Bumrungsri, and Pattanawiboon, 2005). Large bats are sometimes eaten by humans (Mickleburgh, Hutson, and Racey, 1992; Fujita and Tuttle, 1991). Bats also play an important role in ecotourism activities such as bat tourism and bat watching recreation (Pennisi, Holland, and Stein, 2004).

Although bats provide many benefits to humans, they also have many negative impacts. Some bats adapt to roost in human houses, producing enormous amounts of guano and an unpleasant odor (Giffen, 2007). Moreover, bats can transmit various parasites and diseases to humans and domestic animals (Calisher, Childs, Field, Holmes, and Schountz, 2006).

2.2 Evolution and classification

The oldest specimen of fossil bats is *Icaronycteris index* (Figure 2.2). It was found in the Green River Formation, Wyoming, United States. It appeared about 52.5 million years ago in the early Eocene. The *I. index* is related to the modern Microchiroptera. Scientists believe that flight evolved in bats before echolocation. Furthermore, the early bats were omnivores and lived in a tropical environment (Simmons, Seymour, Habersetzer, and Gunnell, 2008; Eick, Jacobs, and Matthee, 2005).

The traditional classification divides Chiroptera into two suborders: Megachiroptera (Old World fruit bats) and Microchiroptera (echolocating bats). Additionally, chiroptera includes four extinct groups, i.e., *Icaronycteris*, *Archaeonycteris*, *Hassianycteris*, and *Palaeochiropteryx*. Most of them are related to Microchiroptera (Simmons and Geisler, 1998) (Figure 2.3).

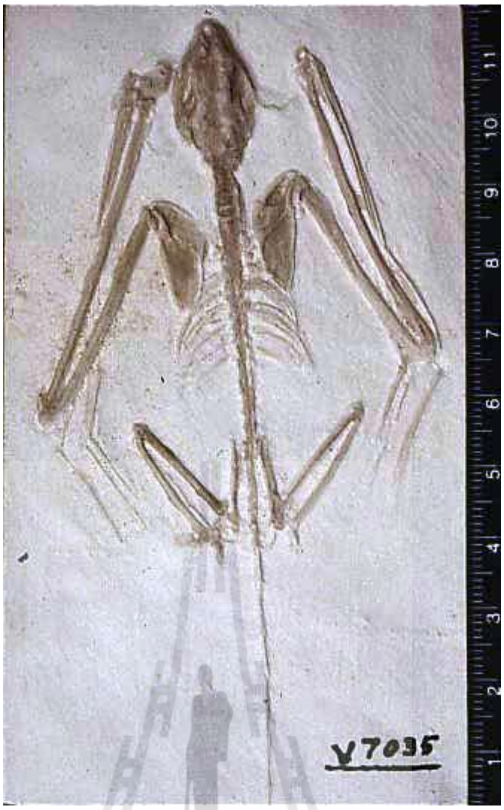

Figure 2.2 The oldest fossil bat (*Icaronycteris index*) from the Green River Formation (http://www.ucmp.berkeley.edu/tertiary/eoc/greenriver.html).

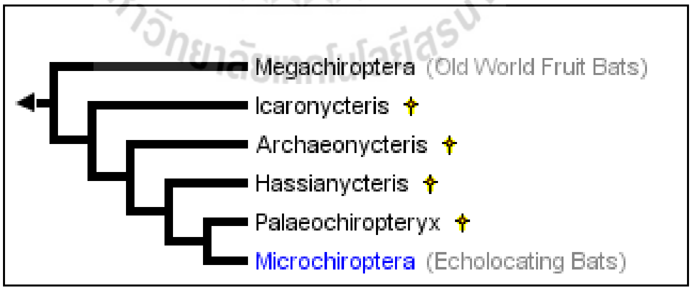

Figure 2.3 The Clade Chiroptera: † = extinct (Simmons and Geisler, 1998).

Suborder Megachiroptera includes a single family of Pteropodidae. The Pteropodidae includes about 190 species of frugivorous and nectivorous bats in the Old World. They have an elongated face and large eyes, which make them look like a fox. Most of them cannot use echolocation, except members of genus *Rousettus* and

Eonycteris. *Rousettus* generates sounds by clicking its tongue while *Eonycteris* generates sound by wing-clapping (Gould, 1988).

Bats of suborder Microchiroptera are generally smaller than megachiropterans. However, some large microchiropterans are bigger than the small megachiropterans. Microchiropterans have large ears and small eyes. They can generate echolocation for navigation and foraging (Vaughan, Ryan, and Czaplewski, 2000).

The traditional classification of bats comes from the diphyly hypothesis, which states that megachiropterans and microchiropterans evolved independently from each other for a long time. In addition, bats are classified in the superorder Archonta, which is related to Scandentia (treeshrews), Dermoptera (colugos), and Primates (lemurs, monkeys, gibbons, and others) (Pettigrew, 1991; Pettigrew et al., 1989; Pettigrew, 1986). However, recent molecular studies revealed that they belong to superorder Laurasiatheria, related to Erinaceomorpha (hedgehogs and gymnures), Soricomorpha (moles, shrews, and solenodons), Perissodactyla (odd-toed ungulates), Artiodactyla (even-toed ungulates), Cetacea (whales, dolphins, and porpoises), Pholidota (pangolins), and Carnivora (cats, dogs, bears, and others) (Eick, Jacobs, and Matthee, 2005; Pumo et al., 1998). The data from molecular studies also support the bat monophyly hypothesis, which states that bats evolved from a monophyletic group (Simmons, Seymour, Habersetzer, and Gunnell, 2008). Consequently, two new suborders have been proposed; Yinpterochiroptera and Yangochiroptera (Figure 2.4) (Hutcheon and Kirsch, 2006; Teeling et al., 2005).

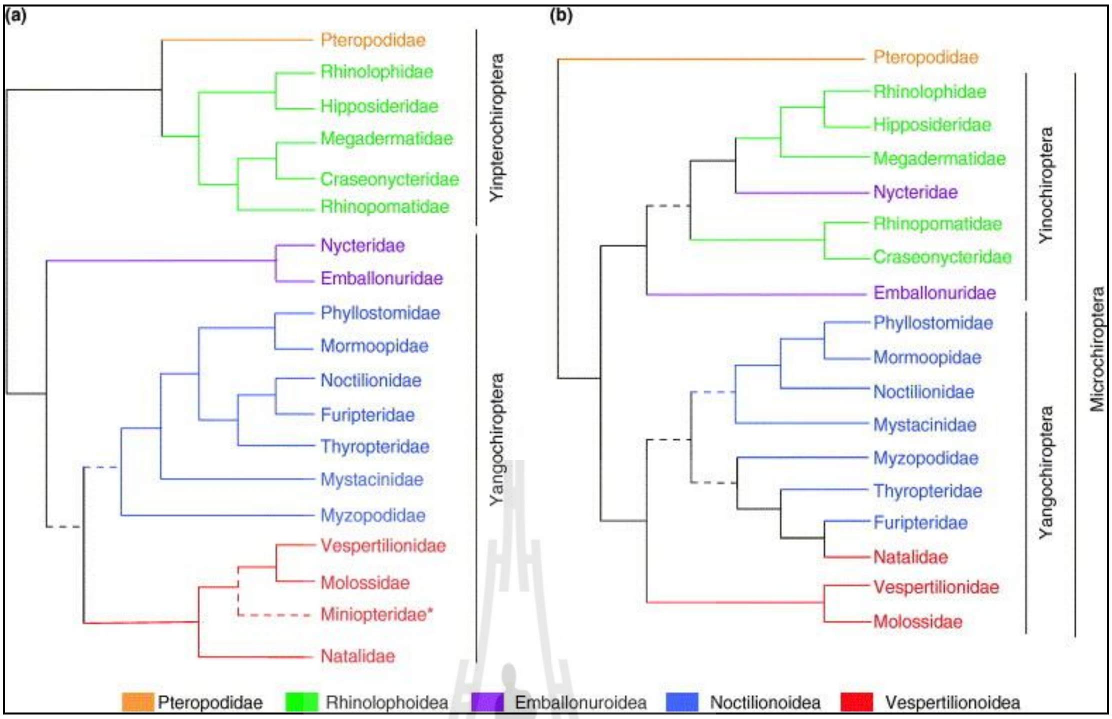

Figure 2.4 Bat phylogenetic trees: present (a) and past (b) (Jones and Teeling, 2006).

2.3 Behaviour

Bats are nocturnal. They start feeding around dusk and are active during the night. However, some bats also fly and hunt for food during the day (Russo, Maglio, Rainho, Meyer, and Palmeirim, 2011; Hirakawa, 2006). Bats rest at their roosts such as caves, trees, and bridges. They generally hang upside down at their roosts to easily start flying. Some bats are solitary, while many species live in a large group. Living together can serve many functions, such as reducing heat loss and providing defense of roosting site (Vaughan, Ryan, and Czaplewski, 2000).

Several group-living bats show the fission-fusion social structure. Fission behavior occurs when bats split their group into subgroups and fusion behavior occurs when bats reform their colonies (Kerth, Perony, and Schweitzer, 2011; Kerth, 2008). Benefits associated with fission behavior of bats include avoidance of predators and parasites and reducion of distance to feeding sites (Willis and Brigham, 2004; Kerth and König, 1999; Lewis, 1995).

Many bats use daily torpor and hibernation in the winter to conserve energy. During hibernation, the body temperature of bats can drop to 1°C (Arlettaz et al., 2001). Other bats avoid cold conditions in the winter by seasonal migration to warmer areas (Popa-Lisseanu and Voigt, 2009).

Bats generally are social animals. They use various ways to communicate with other bats such as sounds, echolocation calls, scent marks, pheromones, and visual displays (Dechmann and Safi, 2005). Same as other nocturnal mammals, olfaction is the major communication of bats. Many bats have well developed olfactory and scent organs which can be useful for individual recognition, mate choice and mate attraction (Bloss, 1999; Voigt and von Helvelversen, 1999; De Fanis and Jones, 1996; Gustin and McCracken, 1987).

Echolocation is another communication of bats. It varies among species, individuals, and tasks (Obrist, 1995; Brigham, Cebek, and Hickey, 1989). Bats heavily use echolocation for navigation and foraging. However, they rarely use echolocation for direct communication. They only use echolocation for passive communication, so called “eavesdropping” (Fenton, 2003; Balcombe and Fenton, 1988; Barclay, 1982). Conversely, bats often use another type of sound for communication. This type of sound is called “social call”, with lower frequency than in echolocation and audible to the human ear. Social calls are used for individual recognition, coordinate foraging, and many currently unknown functions in social behaviors (Andrews and Andrews, 2003; Pfalzer and Kusch, 2003; Wilkinson and Boughman, 1998; Barlow and Jones, 1997).

Bats also use visual displays for communication, especially during courtship. Some species have gorgeous colors on their wing, body, or pelage for attracting mates. However, bats not only use visual displays during courtship but also often use visual displays combined with sound and olfaction (Voigt and von Helversen, 1999).

Flight behaviors of bats are related with wing morphology and wing load. Bats with short and broad wings, low-wing loading are slow flyers but have high agility and maneuverability. This leads them to fly only few minutes per night and forage in cluttered areas. In contrast, species with long and narrow wings, high-wing loading are fast flyers but with low agility and maneuverability. This leads them to fly long distances and forage in open areas (Norberg and Rayner, 1987).

2.4 Reproduction and life history

Bats exhibit a diversity of mating systems, including monogamy, polygyny, polyandry, and promiscuity. Males may protect their roosts and their offspring, while females provide all parental care to their offspring. Females of many species set up maternity colonies to communally nurse their young (Pitnick, Jones, and Wilkinson, 2006).

Most bats have a breeding season. Temperate bats breed before winters, while tropical bats breed in the cycle of wet-dry seasons (Cumming and Bernard, 1997). However, female bats can control the timing of pregnancy and the birth of young to occur when favorable environments for their young are offered (Bernard and Cumming, 1997).

Bats have extremely low reproductive rates. They have one to three offspring per year, depending on species and environments. Newborn bats weigh between 12-

43% of their mother's weight. The wings of newborn bats are too small for flight. Then, newborn bats either cling to their mothers or remain in the roost when their mothers forage (Kurta and Kunz, 1987).

Juvenile bats grow quickly and can fly within two to four weeks. Young microbats become independent at six to eight weeks, while young megabats become independent at about four months old. Bats are sexually mature from nine months to two years old, depending on species (Findley, 1993). They have very long lives, generally about 20 to 30 years in the wild (Wilkinson and South, 2002). The oldest bat on current record is a male Brandt's bat (*Myotis brandtii*), which is at least 41 years old. It is also the oldest small mammal ever recorded (Podlutsky, Khritankov, Ovodov, and Austad, 2005).

2.5 Distribution and habitat use

Bats occur throughout all continents, with the exception of the Antarctic and a few Oceanic Islands (Mickleburgh, Hutson, and Racey, 2002). They are especially diverse in tropical regions. Around 88% of bat species are exclusively tropical (Findley, 1993). Megachiropterans are found only in the Old World tropics, while microchiropterans are broadly distributed in both the Old World and the New World tropics (Table 2.1) (Hutson, Mickleburgh, and Racey, 2001; Mickleburgh, Hutson, and Racey, 1992).

Bats are found in almost all terrestrial habitats, ranging from seasides, forests, mountains, and deserts. Moreover, they are also found in human modified areas such as agricultural areas, suburban, and urban areas. However, bats require only two important factors for survival that are roosts and foraging grounds (Bihari, 2004; Lacki and Baker, 2003).

Bats spend over half their lives in their roosts (Winchell and Kunz, 1993; Vaughan and O'Shea, 1976). Roosts provide bats with shelter from predators and bad weather conditions as well as sites for social interaction, mating, and rearing young (Lewis, 1996; Lewis, 1995). Bats use a variety of roosts, including caves, rock crevices, tree hollows, flowers, foliage, animal dens, and anthropogenic structures. Some bats can build their own roosts from foliage and other plant parts, which are known as "tents" (Dechmann, Kalko, König, and Kerth, 2005; Kunz and McCracken, 1996). Although bats can use a variety of roost types, tree hollows are most commonly roosted by bats worldwide (Boonman, 2000).

Riparian forests and water bodies are the most important habitats for many bat species (Akasaka, Nakano, and Nakamura, 2009; Russ and Montgomery, 2002; Warren, Waters, Altringham, and Bullock, 2000; Brigham, Aldridge, and Mackey, 1992). They provide bats with commuting, roosting, drinking, and foraging areas, particularly for insectivorous bats (Lloyd, Law, and Goldingay, 2006; Whitaker, 2004; Russo and Jones, 2003; Ciechanowski, 2002; Seidman and Zabel, 2001; Holloway and Barclay, 2000). Water surfaces attract many insectivorous bats because the air above them is rich in insects (Hagen and Sabo, 2012; Hagen and Sabo, 2011; Fukui, Murakami, Nakano, and Aoi, 2006; Rydell, Miller, and Jenson, 1999; Racey, Swift, Rydell, and Brodie, 1998). Bats are also facilitated in detecting insect preys above water because of the absence of disturbing echoes from water surfaces (Svensson, Danielsson, and Rydell, 2002).

Table 2.1 Living families and distribution of bats (Martin, Pine, and DeBlase, 2001).

Family	Common name	Distribution
Pteropodidae	Old world fruit bats	Australian, Oriental, Ethiopian, south Palearctic, some Oceanic Islands
Rhinopomatidae	Mouse-tailed bats	North Ethiopian, south Palearctic, west Oriental
Craseonycteridae	Bumblebee bat	Thailand
Emballonuridae	Sheath-tailed bats	North Neotropical, Ethiopian, south Palearctic, Oriental, Australian
Nycteridae	Hollow-faced bats	Ethiopian, Oriental, south Palearctic
Megadermatidae	Old world false vampire bats	Ethiopian, Oriental, Australian
Rhinolophidae	Horseshoe bats	Most of Eastern Hemisphere
Noctilionidae	Bulldog bats	North Neotropical
Mormoopidae	Leaf-chinned bats	Neotropical, south Nearctic
Phyllostomidae	Leaf-nosed bats	Neotropical, south Nearctic
Natalidae	Funnel-eared bats	North Neotropical
Furipteridae	Smoky bats	North Neotropical
Myzopodidae	Sucker-footed bats	Madagascar
Vespertilionidae	Vespertilionid bats	Worldwide
Mystacinidae	New Zealand short-tailed bats	New Zealand
Molossidae	Free-tailed bats	All regions except northern Holarctic

Caves are another important roosting site for several bat species. They provide bats with permanency and stable microclimates, which are important for living and nursing young (Kingston, 2010). Other bat species roost and forage in various habitats, depending on species, ambient temperature, forest structure, food availability, moon phase, time of year, and time of day (Kusch, Weber, Idelberger, and Koob, 2004; Cosson, Pons, and Masson, 1999; Hayes, 1997; Vaughan, Jones, and Harris, 1997; de Jong, 1995; Kunz, 1973). Moreover, some bat species can use multiple habitats for roosting and foraging (Findley, 1993; Crome and Richards, 1988).

2.6 Feeding habits

Bats forage in nighttime to avoid competition with birds (Speakman et al., 2000). Some bats can travel up to 800 km to search for food (Hunter, 2007). Bats rarely forage in rain because rain increases bats' metabolic rate and interferes with the echolocation system (Voigt, Schneeberger, Voigt-Heucke, and Lewanzik, 2011). Bats also avoid foraging during moonlit nights because moonlight increases risk of predation on bats and decreases availability of insect preys of bats (Lang, Kalko, Römer, Bockholdt, and Dechmann, 2006).

Bats feed on a variety of food preferences. Like other mammals, all newborn bats feed on the milk from their mothers. In the next few weeks, they can fly and forage by themselves. Megabats have well-developed olfactory organs and visual cues for foraging (Raghuram, Thangadurai, Gopukumar, Nathar, and Sripathai, 2009; Acharya, Roy, and Krishna, 1998). Most megabats are herbivores, which feed on fruits, nectar, foliage or pollen (Bumrungsri, Leelapaibul, and Racey, 2007; Stier and Mildestein, 2005). However, megabats also feed on insects to obtain sufficient protein (Barclay, Barclay, and Jacobs, 2006; Courts, 1998).

Microbats rely on echolocation to find their preys. They feed mainly on both aerial and ground-dwelling insects. Insectivorous bats make up about 70% of bat species worldwide (Schnitzler and Kalko, 2001). Bats usually feed on insects about one-third of their body weight per night but nursing bats can eat up to their body weight per night (Kurta, Bell, Nagy, and Kunz, 1989). Other microbats adapt to feed on fruits, nectars, foliage, fish, frogs, lizards, rodents, birds, and other bats (Kunz and Diaz, 1995; Findley, 1993; Willig, Camilo, and Noble, 1993; Zortea and Mendes, 1993), and three species in subfamily Desmodontinae (vampire bat) feed on blood of other vertebrates (Wetterer, Rockman, and Simmons, 2000).

Bats generally feed only on the parts of their foods that they want to ingest. Frugivorous bats chew fruits, swallow the juices, and spit out the pulps and seeds (Barclay and Jacobs, 2011; Kalko, Herre, and Handley, 1996). Insectivorous bats bite off wings and legs of insect preys before feeding (Dechmann, Safi, and Vonhof, 2006).

2.7 Parasites and pathogens

Bats are high mobile animals, have broad distribution and carry a large number of endoparasites, ectoparasites, and pathogens. These make them natural reservoirs of many infectious diseases (Breed, Field, Smith, Edmonston, and Meers, 2010; Wong, Lau, Woo, and Yuen, 2007; Calisher, Childs, Field, Holmes, and Schountz, 2006). Many bat species have high tolerance for diseases and often do not develop diseases while infected (Swanepoel et al., 1996).

Bats are hosts of several ectoparasites. There are 687 bat ectoparasites that have been documented. They belong to the orders Demaptera, Hemiptera, Diptera, Siphonaptera, and Acarina. However, only six families are restricted ectoparasites on bats, namely, Nycteribiidae, Streblidae (bat flies), Spinturnicidae, and Macronyssidae (mites), Ischnopsyllidae (bat fleas), and Cimicidae (bat bugs) (Dick, Gannon, Little, and Patrick, 2003). Of these, the Nycteribiidae and the Streblidae have evolved from non-blood sucking insects and have co-evolved with bats, which lived in caves (Waage, 1979).

Bats are also harborers of endoparasites such as plasmodium, trypanosomes, and worms. Bats are associated with four genera of malaria protozoans, *Plasmodium*, *Hepatocystis*, *Haemoproteus*, and *Leucocytozoon*. These parasites also infect birds, reptiles, and other mammals but none of the malarial parasites of bats can cause malaria in humans (Perkins and Schall, 2002).

Trypanosome protozoans have co-evolved with bats (Stevens, Noyes, Dover, and Gibson, 1999). They are common endoparasites of bats. They cause a variety of human diseases, such as sleeping sickness and Chagas disease (Hamilton, Cruickshank, Stevens, Teixeira, and Mathwes, 2012). In addition, many trematodes, cestodes, and nematodes are also found in digestive tracts and body cavities of bats (Krichbaum, Perkins, and Gannon, 2009; McAllister and Bursey, 2009; Nogueira, de Fabio, and Peracchi, 2004; Esteban, Amengual, and Cobo, 2001).

Bats are well known natural reservoirs of many viruses. Recently, more than 100 viruses have been detected in bats (Baker, Schountz, and Wang, 2013). These include viruses that cause many fatal diseases in humans, for example, rabies virus and other lyssaviruses (Fooks et al., 2003; Messenger, Smith, and Repprecht, 2002; McColl, Tordo, and Setién, 2000), severe acute respiratory syndrome coronavirus (Cheng, Lau, Woo, and Yuen, 2007; Wang et al., 2006; Li et al., 2005), Ebola virus (Leroy et al., 2005; Swanepoel et al., 1996), and henipaviruses (Mackenzie and Field, 2004; Johara et al., 2001; Halpin, Young, Field, and Mackenzie, 2000).

2.8 Threats and conservation

Although bats have few natural predators, their populations are declining throughout the world. Human activities are the major cause of declining bat populations. The greatest threat to bat populations is loss of roosting sites, such as by deforestation and habitat fragmentation (Lane, Kingston, and Lee, 2006; Hutson, Mickleburgh, and Racey, 2001). Introduced predators and competitors for roosting sites are other serious threats on bat populations (O'Donnell, 2000). People kill numerous bats using dynamites, guns, smoke, fire, and poisons because of concern about disease transmission from bats to humans and livestock (Mickleburgh, Hutson, and Racey, 2002). In addition, some local people hunt bats for food and traditional medicine (Mohd-Azlan, Zubaid, and Kunz, 2001).

People also have indirect impacts on bat populations in many ways such as by decreasing food supply for bats or using toxins. People decrease insect preys of many insectivorous bats by using pesticides in agricultural areas, drying water, reducing water quality or changing water flow rate (Hagen and Sabo, 2012; Wickramasinghe, Harris, Jones, and Vaughan, 2004; Vaughan, Jones, and Harris, 1996). Drying water also reduces water supply for all bat species. Intensified pesticide use is another indirect harm to bats, especially insectivorous bats (Stahlschmidt and Bruhl, 2012; Kunz, Anthony, and Rumage III, 1977).

Wind turbines also have negative impacts on bat populations (Kunz et al., 2007). Large numbers of dead bats are found beneath wind turbines. It is clear that bats are killed by blades of wind turbines (Rydell et al., 2010; Horn, Arnett, and Kunz, 2008). Moreover, wind turbines create air pressure fluctuation around them, causing barotrauma in bats (Baerwald, D'amours, Klug, and Barclay, 2008).

Bats are victims of several diseases. Currently, white nose syndrome is the most serious disease of bats. It has been associated with the deaths of more than a million bats in North America since 2006 (Frick et al., 2010). White nose syndrome is also widespread in Europe, but mass mortality does not occur (Puechmaille et al., 2011). The name of the disease is from a white fungus, *Pseudogymnoascus destructans*, which grows on the muzzles, ears, and wings of bats (Minnis and Lindner, 2013). The fungus disturbs the cycle of hibernal bats, causing damage to wing membranes, loss of stored body, and death (Reichard and Kunz, 2009). There is no treatment or prevention of transmission at the present time. Mortality rate is up to 98% in some species (Turner, Reeder, and Coleman, 2011).

Bats are one of the most threatened mammals. Therefore, they are protected by many international and national laws (Mickleburgh, Hutson, and Racey, 2002; Hutson, Mickleburgh, and Racey, 2001). Approximately 15% (172 species) of bat species are considered threatened and 7% (83 species) are listed as near threatened species (IUCN, 2013). At present, conservation efforts to protect bats focus on threatened species, particularly island bats (Mickleburgh, Hutson, and Racey, 2002). Roosting and foraging habitats are also important for maintaining bat populations. Moreover, educational campaigns on bats and more study on cryptic species are recommended for bat conservation (Fenton, 1997).

2.9 Studies on community, diet, and ectoparasites of bats in Thailand

Thailand is very rich in bat species, with 2 suborders, 10 families, 33 genera, and 119 species (Bumrungsri et al., 2006; Lekagul and McNeely, 1988). Of these, 100 species are considered as protected animals of Thailand (Wildlife Conservation Office, 2006). The bat families in Thailand are as follows;

Suborder Megachiroptera
        Family Pteropodidae (9 genera)
Suborder Microchiroptera
    Superfamily Emballonuroidea
        Family Rhinopomatidae (1 genus)
        Family Emballonuridae (2 genera)
        Family Craseonycteridae (1 genus)
    Superfamily Rhinolophoidea
        Family Nycteridae (1 genus)
        Family Megadermatidae (1 genus)
        Family Rhinolophidae (1 genus)
        Family Hipposideridae (3 genera)
    Superfamily Vespertilionoidea
        Family Vespertilionidae (12 genera)
        Family Molossidae (2 genera)

There have been numerous specimen collections and taxonomic classifications of bats in Thailand. The first bat collection was started in 1821. At those times, the most bat collections were performed by foreign researchers (Bumrungsri et al., 2006). Until in 1963, Kitti Thonglongya, the first Thai researcher started the bat collection in Thailand. He also discovered a new bat species in the world, bumblebee bat

(*Craseonycteris thonglongyai*). It also was a new bat family, the Craseonycteridae (Lekagul and McNeely, 1988; Hill and Smith, 1981).

There are only four studies that focus on bat communities in Thailand. Boonkird and Sirikarin (1993) surveyed bats in Phu Kieo Wildlife Sanctuary, Chaiyaphum province. They found 6 families and 21 species of bats. Robinson, Bumrungsri, and Hill (1996) found 58 bat species in Thung Yai Naresuan and Huai Kha Khaeng Wildlife Sanctuaries. Robinson and Smith (1997) found 24 bat species from Loei province. Prachakchitra and Thong-Aree (2004) recorded 47 bat species from Hala-Bala Wildlife Sanctuary. Furthermore, there are two studies on bat community in habitat modifications such as gas pipelines (Boonkird, 1998) and rubber plantations (Phommexay, Satasook, Bates, Pearch, and Bumrungsri, 2011). However, bat surveys often were a part of many biodiversity, small mammals or wildlife surveys in Thailand.

The previous survey on bat communities in SERS was done in 2003. A total of 11 bat species were documented in that survey. There were greater short-nosed fruit bat (*Cynopterus sphinx*), tailless fruit bat (*Megaerops ecaudatus*), pouched tomb bat (*Taphozous saccolaimus*), lesser false vampire bat (*Megaderma spasma*), acuminate horseshoe bat (*Rhinolophus acuminatus*), least horseshoe bat (*Rhinolophus pusillus*), intermediate horseshoe bat (*Rhinolophus affinis*), woolly horseshoe bat (*Rhinolophus luctus*), intermediate roundleaf bat (*Hipposideros larvatus*), lesser large-footed bat (*Myotis hasseltii*), and round-eared tube-nosed bat (*Murina cyclotis*) (Pakarnseree et al., 2003).

Most studies on diet of bats in Thailand focus on one bat species per study, such as dawn bat (Bumrungsri et al., 2013), wrinkle-lipped free-tailed bat (Boonkird et al., 2009; Leelapaibul, Bumrungsri, and Pattanawiboon, 2005; Leeraphaibool, Bumrungsri, Pattanavibool, and Wiwatwitaya, 2003), Kitti's hog-nosed bat (Boonkird, Amornputinan, and Wanghongsa, 2005), and long-winged tomb bat (Boonkird, Amornputinan, Poonprasert, and Wanghongsa, 2005). Few studies focused on diet of a bat community (Bumrungsri, Leelapaibul, and Racey, 2007; Boonkird and Wanghongsa; 2001).

The study on ectoparasites of bats was started in 1965 by Nadchatram and Mitchell (1965). They collected bat chiggers from horseshoe bats (*Rhinolophus luctus*) at Doi Suthep. Next, Hill and McNeely (1975) found 116 species of ectoparasites of Thai bats. Uchikawa and Kobayashi (1978, 1979) also surveyed ectoparasites of bats in Thailand at the same time as Hill and McNeely. Changbunjong et al. (2010) surveyed ectoparasites of birds, small mammals, and bats at Srinakarin Dam, Kanchanaburi.

2.10 References

Acharya, K. K., Roy, A., and Krishna, A. (1998). Relative role of olfactory cues and certain non-olfactory factors in foraging of fruit-eating bats. **Behavioural Processes**. 44: 59-64.

Akasaka, T., Nakano, D., and Nakamura, F. (2009). Influence of prey variables, food supply, and river restoration on the foraging activity of Daubenton's bat (*Myotis daubentonii*) in the Shibetsu River, a large lowland river in Japan. **Biological Conservation**. 142: 1302-1310.

Andrews, M. M. and Andrews, P. T. (2003). Ultrasound social calls made by greater horseshoe bats (*Rhinolophus ferrumequinum*) in a nursery roost. **Acta Chiropterologica**. 5: 221-234.

Arlettaz, R., Ruchet, C., Aeschimann, J., Brun, E., Genoud, M., and Vogel, P. (2001). Physiological traits affecting the distribution and wintering strategy of the bat *Tadarida teniotis*. **Ecology**. 81: 1004-1014.

Baerwald, E. F., D'amours, G. H., Klug, B. J., and Barclay, R. M. R. (2008). Barotrauma is a significant cause of bat fatalities at wind turbines. **Current Biology**. 18: R695-R696.

Baker, M. L., Schountz, T., and Wang, L-F. (2013). Antiviral immune responses of bats: a review. **Zoonoses and Public Health**. 60: 104-116.

Balcombe, J. P. and Fenton, M. B. (1988). Eavesdropping by bats: the influence of echolocation call design and foraging strategy. **Ethology**. 79(2): 158-166.

Barclay, R. M. R. (1982). Interindividual use of echolocation calls: eavesdropping by bats. **Behavioral Ecology and Sociobiology**. 10: 271-275.

Barclay, R. M. R., Barclay, L. E., and Jacobs, D. S. (2006). Deliberate insectivory by the fruit bat *Rousettus aegyptiacus*. **Acta Chiropterologica**. 8: 549-553.

Barclay, R. M. R. and Jacobs, D. S. (2011). Differences in the foraging behaviour of male and female Egyptian fruit bats (*Rousettus aegyptiacus*). **Canadian Journal of Zoology**. 89: 466-473.

Barlow, K. E. and Jones, G. (1997). Function of pipistrelle social calls: field data and a playback experiment. **Animal Behaviour**. 53(5): 991-999.

Bernard, R. T. F. and Cumming, G. S. (1997). African bats: evolution and reproductive patterns and delays. **The Quarterly Review of Biology**. 72(3): 253-274.

Bihari, Z. (2004). The roost preference of *Nyctalus noctula* (Chiroptera, Vespertilionidae) in summer and the ecological background of their urbanisation. **Mammalia**. 68: 329-336.

Bloss, J. (1999). Olfaction and the use of chemical signals in bats. **Acta Chiropterologica**. 1: 31-45.

Boonkird, K. (1998). Environmental impact assessment of the Yadana gas pipeline on bats in Kanchanaburi province. (in Thai). **Journal of Wildlife in Thailand**. 7(1): 121-126.

Boonkird, K., Amornputinan, S., Poonprasert, P., and Wanghongsa, S. (2005). Food habits of long-winged tomb bats (*Taphozous longimanus*) roosting in the 84th Year Anniversary Building of the Royal Forest Department. (in Thai). **Wildlife Yearbook**. 6: 36-47.

Boonkird, K., Amornputinan, S., and Wanghongsa, S. (2005). Food habits of Kitti's hog-nosed bat (*Craseonycteris thonglongyai*). (in Thai). **Wildlife Yearbook**. 6: 23-35.

Boonkird, K., Boonyai, N., Siripattaranukul, K., Khotchompoo, P., Phomma, C., and Wanghongsa, S. (2009). Food habit of wrinkled-lipped bat (*Tadarida plicata*) at Praram Cave in Tham Chaoram Wildlife Sanctuary, Sukothai province. (in Thai). **Wildlife Yearbook**. 11: 137-147.

Boonkird, K. and Sirikarin, K. (1993). Bat species diversity in Phu Kieo Wildlife Sanctuary. (in Thai). **Journal of Wildlife in Thailand**. 3(1): 117-122.

Boonkird, K. and Wanghongsa, S. (2001). Food habits of some insectivorous bats. (in Thai). **Wildlife Yearbook**. 2: 1-22.

Boonman, M. (2000). Roost selection by noctules (*Nyctalus noctula*) and Daubenton's bats (*Myotis daubentonii*). **Journal of Zoology**. 251: 385-389.

Breed, A. C., Field, H. E., Smith, C. S., Edmonston, J., and Meers, J. (2010). Bats without borders: long distance movements and implications for disease management. **EcoHealth**. 7: 204-121.

Brigham, R. M., Aldridge, H. D. J. N., and Mackey, R. L. (1992). Variation in habitat use and prey selection by Yuma bats, *Myotis yumanensis*. **Journal of Mammalogy**. 73: 640-645.

Brigham, R. M., Cebek, J. E., and Hickey, M. B. C. (1989). Intraspecific variation in the echolocation calls of two species of insectivorous bats. **Journal of Mammalogy**. 70: 426-428.

Bumrungsri, S., Harrison, D. L., Satasook, C., Prajukjitr, A., Thong-Aree, S., and Bates, P. J. J. (2006). A review of bat research in Thailand with eight new species records for the country. **Acta Chiropterologica**. 8: 325-359.

Bumrungsri, S., Lang, D., Harrower, C., Sripaoraya, E., Kitpipit, K., and Racey, P. A. (2013). The dawn bat, *Eonycteris spelaea* Dobson (Chiroptera: Pteropodidae) feeds mainly on pollen of economically important food plants in Thailand. **Acta Chiropterologica**. 15: 95-104.

Bumrungsri, S., Leelapaibul, W., and Racey, P. A. (2007). Resource partitioning in sympatric *Cynopterus* bats in lowland tropical rain forest, Thailand. **Biotropica**. 39: 241-248.

Calisher, C. H., Childs, J. E., Field, H. E., Holmes, K. V., and Schountz, T. (2006). Bats: important reservoir hosts of emerging viruses. **Clinical Microbiology Reviews**. 19(3): 531-545.

Changbunjong, T., Jirapattharasate, C., Buddhirongawatr, R., Chewajon, K., Charoenyongyoo, P., Suwanapakdee, S., Waengsothorn, S., Triwitayakorn, K., Chaichoun, K., and Ratanakorn, P. (2010). Ectoparasitic fauna of birds, and volant and non-volant small mammals captured at Srinakarin Dam, Kanchanaburi, Thailand. **The Southeast Asian Journal of Tropical Medicine and Public Health**. 41(3): 526-535.

Cheng, V. C., Lau, S. K., Woo, P. C., and Yuen, K. Y. (2007). Severe acute respiratory syndrome coronavirus as an agent of emerging and reemerging infection. **Clinical Microbiology Reviews**. 20: 660-694.

Ciechanowski, M. (2002). Community structure and activity of bats (Chiroptera) over different water bodies. **Mammalian Biology**. 67: 276-285.

Cleveland, C. J., Betke, M., Federico, P., Frank, J. D., Hallam, T. G., Horn, J., López, J. D., Jr., McCracken, G. F., Medellín, R. A., Moreno-Valdez, A., Sansone, C. G., Westbrook, J. K., and Kunz, T. H. (2006). Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. **Frontiers in Ecology and the Environment**. 4(5): 238-243.

Cosson, J. F., Pons, J. M., and Masson, D. (1999). Effects of forest fragmentation on frugivorous and nectarivorous bats in French Guiana. **Journal of Tropical Ecology**. 15: 515-534.

Courts, S. E. (1998). Dietary strategies of Old World fruit bats (Megachiroptera: Pteropodidae). How do they obtain sufficient protein?. **Mammal Review**. 28: 185-194.

Crome, F. H. J. and Richards, G. C. (1988). Bats and gaps: microchiropteran community structure in a Queensland rain forest. **Ecology**. 69: 1960-1969.

Cumming, G. S. and Bernard, R. T. F. (1997). Rainfall, food abundance and timing of parturition in African bats. **Oecologia**. 111: 309-317.

Dechmann, D. K. N., Kalko, E. K. V., König, B., and Kerth, G. (2005). Mating system of a Neotropical roost-making bat: the white-throated, round-eared bat, *Lophostoma silvicolum* (Chiroptera: Phyllostomidae). **Behavioural Ecology and Sociobiology**. 58: 316-325.

Dechmann, D. K. N. and Safi, K. (2005). Studying communication in bats. **Cognition, Brain, Behavior**. 9: 479-496.

Dechmann, D. K. N., Safi, K., and Vonhof, M. J. (2006). Matching morphology and diet in the disc-winged bat *Thyroptera tricolor* (Chiroptera). **Journal of Mammalogy**. 87: 1013-1019.

De Fanis, E. and Jones, G. (1996). Allomaternal care and recognition between mothers and young in pipistrelle bats (*Pipistrellus pipistrellus*). **Journal of Zoology**. 240: 781-787.

de Jong, J. (1995). Habitat use and species richness of bats in a patchy landscape. **Acta Theriologica**. 40: 237-248.

Dick, C. W., Gannon, M. R., Little, W. E., and Patrick, M. J. (2003). Ectoparasite associations of bats from Central Pennsylvania. **Journal of Medical Entomology**. 40: 813-819.

Eick, G. N., Jacobs, D. S., and Matthee, C. A. (2005). A nuclear DNA phylogenetic perspective on the evolution of echolocation and historical biogeography of extant bats (Chiroptera). **Molecular Biology and Evolution**. 22(9): 1869-1886.

Esteban, J. G., Amengual, B., and Cobo, J. S. (2001). Composition and structure of helminth communities in two populations of *Pipistrellus pipistrellus* (Chiroptera: Vespertilionidae) from Spain. **Folia Parasitologica**. 48: 143-148.

Fenton, M. B. (1997). Science and the conservation of bats. **Journal of Mammalogy**. 78: 1-14.

Fenton, M. B. (2003). Eavesdropping on the echolocation and social calls of bats.

Mammal Review. 33: 193-204.

Fenton, M. B. (2012). Bats and white-nose syndrome. **Proceedings of the National Academy of Sciences of the United States of America**. 109: 6794-6795.

Findley, J. S. (1993). **Bats: A community perspective**. Cambridge: Cambridge University Press. 167p.

Fooks, A. R., McElhinney, L. M., Pounder, D. J., Finnegan, C. J., Mansfield, K., Johnson, N., Brookes, S. M., Parsons, G., White, K., McIntyre, P. G., and Nathwani, D. (2003). Case report: isolation of a European bat lyssavirus type 2a from a fatal human case of rabies encephalitis. **Journal of Medical Virology**. 71: 281-289.

Frick, W. F., Pollock, J. F., Hicks, A. C., Langwig, K. E., Reynolds, D. S., Turner, G. R., Butchkoski, C. M., and Kunz, T. H. (2010). An emerging disease causes regional population collapse of a common North American bat species. **Science**. 329: 679-682.

Fujita, M. S. and Tuttle, M. D. (1991). Flying foxes (Chiroptera: Pteropodidae): threatened animals of key ecological and economic importance. **Conservation Biology**. 5: 455-464.

Fukui, D., Murakami, M., Nakano, S., and Aoi, T. (2006). Effect of emergent aquatic insects on bat foraging in a riparian forest. **Journal of Animal Ecology**. 75: 1252-1258.

Giffen, N. R. (2007). **Nuisance wildlife education and prevention plan for the Oak Ridge National Laboratory**. Tennessee: The U.S. Department of Energy. 42p.

Gould, E. (1988). Wing-clapping sounds of *Eonycteris spelaea* (Pteropodidae) in Malaysia. **Journal of Mammalogy**. 69: 378-379.

Gustin, M. K. and McCracken, G. F. (1987). Scent recognition between females and pups in the bat *Tadarida brasiliensis mexicana*. **Animal Behaviour**. 35: 13-19.

Hagen, E. M. and Sabo, J. L. (2011). A landscape perspective on bat foraging ecology along rivers: does channel confinement and insect availability influence the response of bats to aquatic resources in riverine landscapes?. **Oecologia**. 166: 751-760.

Hagen, E. M. and Sabo, J. L. (2012). Influence of river drying and insect availability on bat activity along the San Pedro River, Arizona (USA). **Journal of Arid Environments**. 84: 1-8.

Halpin, K., Young, P. L., Field, H. E., and Mackenzie, J. S. (2000). Isolation of Hendra virus from pteropid bats: a natural reservoir of Hendra virus. **Journal of General Virology**. 81: 1927-1932.

Hamilton, P. B., Cruickshank, C., Stevens, J. R., Teixeira, M. M., and Mathews, F. (2012). Parasites reveal movement of bats between the New and Old Worlds. **Molecular Phylogenetics and Evolution**. 63: 521-526.

Harvey, M. J. (1986). **Arkansas bats: A valuable resource**. Little Rock: Arkansas Game Fish Commission. 48p.

Hayes, J. P. (1997). Temporal variation in activity of bats and the design of echolocation-monitoring studies. **Journal of Mammalogy**. 78: 514-524.

Hill, J. E. and McNeely, J. A. (1975). **The bats and bat's parasites of Thailand**. U.S. Army Research and Development Group (Far East). 87p.

Hill, J. E. and Smith, S. E. (1981). *Craseonycteris thonglongyai*. **Mammalian Species**. 160: 1-4.

Hirakawa, H. (2006). Daytime feeding in an insectivorous bat. **Bulletin of the Asian**

Bat Research Institute. 5: 19-22.

Holloway, G. and Barclay, R. M. R. (2000). Importance of riparian zones to bats in southeastern Alberta. **Ecoscience**. 7: 115-122.

Horn, J. W., Arnett, E. B., and Kunz, T. H. (2008). Behavioral responses of bats to operating wind turbines. **The Journal of Wildlife Management**. 72: 123-132.

Hunter, P. (2007). The nature of flight. The molecules and mechanics of flight in animals. **EMBO Reports**. 8(9): 811-813.

Hutcheon, M. and Kirsch, J. A. W. (2006). A moveable face: deconstructing the Microchiroptera and a new classification of extant bats. **Acta Chiropterologica**. 8: 1-10.

Hutson, A. M., Mickleburgh, S. P., and Racey, P. A. (2001). **Microchiropteran bats: Global status survey and conservation action plan**. Cambridge: International Union for the Conservation of Nature and Natural Resources. 268p.

IUCN. (2013). **The IUCN red list of threatened species** [On-line]. Version 2013.1. Available: http://www.iucnredlist.org. Accessed on 12 August 2013.

Johara, M., Field, H., Rashdi, A., Morrissy, C., van der Heide, B., Rota, P., bin Adzhar, A., White, J., Daniels, P., Jamaluddin, A., and Ksiazek, T. (2001). Serological evidence of infection with Nipah virus in bats (order Chiroptera) in Peninsular Malaysia. **Emerging Infectious Diseases**. 7: 439-441.

Jones, G. and Teeling, E. C. (2006). The evolution of echolocation in bats. **Trends in Ecology and Evolution**. 21: 149-156.

Kalka, M. B., Smith, A. R., and Kalko, E. K. V. (2008). Bats limit arthropods and herbivory in a tropical forest. **Science**. 320: 71.

Kalko, E. K. V. (1998). Organization and diversity of tropical bat communities through space and time. **Zoology**. 101: 281-297.

Kalko, E. K. V., Herre, E. A., and Handley, C. O. (1996). Relation of fig fruit characteristics to fruit-eating bats in the New and Old World tropics. **Journal of Biogeography**. 23: 565-576.

Kerth, G. (2008). Causes and consequences of sociality in bats. **BioScience**. 58(8): 737-746.

Kerth, G. and König, B. (1999). Fission, fusion and nonrandom associations in female Bechstein’s bats (*Myotis bechsteinii*). **Behaviour**. 136: 1187-1202.

Kerth, G., Perony, N., and Schweitzer, F. (2011). Bats are able to maintain long-term social relationships despite the high fission–fusion dynamics of their groups. **Proceedings of the Royal Society of London, Series B: Biological Sciences**. 278: 2761-2767.

Kingston, T. (2010). Research priorities for bat conservation in Southeast Asia: a consensus approach. **Biodiversity and Conservation**. 19: 471-484.

Krichbaum, K., Perkins, S., and Gannon, M. R. (2009). Host-parasite interactions of tropical bats in Puerto Rico. **Acta Chiropterologica**. 11(1): 157-162.

Kunz, T. H. (1973). Resource utilization: temporal and spatial components of bats activity in central Iowa. **Journal of Mammalogy**. 54: 14-32.

Kunz, T. H., Anthony, E. L. P., and Rumage III, W. T. (1977). Mortality of little brown bats following multiple pesticide applications. **Journal of Wildlife Management**. 41(3): 476-483.

Kunz, T. H., Arnett, E. B., Erickson, W. P., Hoar, A. R., Johnson, G. D., Larkin, R. P., Strickland, M. D., Thresher, R. W., and Tuttle, M. D. (2007). Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. **Frontiers in Ecology and the Environment**. 5: 315-324.

Kunz, T. H. and Diaz, C. A. (1995). Folivory in fruit-eating bats, with new evidence from *Artibeus jamaicensis* (Chiroptera: Phyllostomidae). **Biotropica**. 27: 106-120.

Kunz, T. H. and McCracken, G. F. (1996). Tents and harems: apparent defense of foliage roosts by tent-making bats. **Journal of Tropical Ecology**. 12: 121-137.

Kurta, A., Bell, G. P., Nagy, K. A., and Kunz, T. H. (1989). Energetics of pregnancy and lactation in freeranging little brown bats *Myotis lucifugus*. **Physiological Zoology**. 62: 804-818.

Kurta, A. and Kunz, T. H. (1987). Size of bats at birth and maternal investment during pregnancy. **Symposia of the Zoological Society of London**. 57: 79-106.

Kusch, J., Weber, C., Idelberger, S., and Koob, T. (2004). Foraging habitat preferences of bats in relation to food supply and spatial vegetation structures in a western European low moutain range forest. **Folia Zoologica**. 53: 113-128.

Lacki, M. J. and Baker, M. D. (2003). A prospective power analysis and review of habitat characteristics used in studies of tree-roosting bats. **Acta Chiropterologica**. 5: 199-208.

Lane, D. J. W., Kingston, T., and Lee, B. P. Y-H. (2006). Dramatic decline in bat species richness in Singapore, with implications for Southeast Asia. **Biological Conservation**. 131: 584-593.

Lang, A. B., Kalko, E. K. V., Römer, H., Bockholdt, C., and Dechmann, D. K. N. (2006). Activity levels of bats and katydids in relation to the lunar cycle. **Oecologia**. 146: 659-666.

Leelapaibul, W., Bumrungsri, S., and Pattanawiboon, A. (2005). Diet of wrinkle-lipped free-tailed bat (*Tadarida plicata* Buchannan, 1800) in central Thailand: insectivorous bats potentially act as biological pest control agents. **Acta Chiropterologica**. 7(1): 111-119.

Leeraphaibool, W., Bumrungsri, S., Pattanavibool, A., and Wiwatwitaya, D. (2003). Diet and feeding factors of the wrinkled-lipped free-tailed bat (*Tadarida plicata*) at Khao-chong-Pran, Ratchaburi province. (in Thai). **Journal of Wildlife in Thailand**. 11(1): 108-118.

Lekagul, B., and McNeely, J. A. (1988). **Mammals of Thailand** (2nd ed.). Bangkok: Sahakarn Bhaet. 758p.

Leroy, E. M., Kumulungui, B., Pourrut, X., Rouquet, P., Hassanin, A., Yaba, P., Délicat, A., Paweska, J. T., Gonzalez, J-P., and Swanepoel, R. (2005). Fruit bats as reservoirs of Ebola virus. **Nature**. 438: 575-576.

Lewis, S. E. (1995). Roost fidelity in bats: a review. **Journal of Mammalogy**. 76: 481-496.

Lewis, S. E. (1996). Low roost-site fidelity in pallid bats: associated factors and effect on group stability. **Behavioral Ecology and Sociobiology**. 39: 335-344.

Li, W., Shi, Z., Yu, M., Ren, W., Smith, C., Epstein, J. H., Wang, H., Crameri, G., Hu., Z., Zhang, H., Zhang, J., McEachern, J., Field, H., Daszak, P., Eaton, B. T., Zhang, S., and Wang, L. F. (2005). Bats are natural reservoirs of SARS-like coronaviruses. **Science**. 310: 676-679.

Lloyd, A., Law, B., and Goldingay, R. (2006). Bat activity on riparian zones and upper slopes in Australian timber production forests and the effectiveness of riparian buffers. **Biological Conservation**. 129: 207-220.

Mackenzie, J. S. and Field, H. E. (2004). Emerging encephalitogenic viruses: lyssaviruses and henipaviruses transmitted by frugivorous bats. **Archives of Virology, Supplement**. 18: 97-111.

Martin, R. E., Pine, R. H., and DeBlase, A. F. (2001). **A manual of mammalogy: With keys to families of the world** (3rd ed.). New York: McGraw-Hill. 352p.

McAllister, C. T. and Bursey, C. R. (2009). New host and geographic distribution records for helminths (Trematoda, Nematoda) in three species of vespertilionid bats (Chiroptera) from the Pine Ridge of Dawes County, Nebraska, U.S.A. **Comparative Parasitology**. 76(1): 117-121.

McColl, K. A., Tordo, N., and Setién, A. A. (2000). Bat lyssavirus infections. **Revue Scientifique et Technique (International Office of Epizootics)**. 19(1): 177-196.

Messenger, S. L., Smith, J. S., and Repprecht, C. E. (2002). Emerging epidemiology of bat-associated cryptic cases of rabies in humans in the United States. **Clinical Infectious Diseases**. 35(6): 738-747.

Mickleburgh, S. P., Hutson, A. M., and Racey, P. A. (1992). **Old World fruit bats: An action plan for their conservation**. Switzerland: International Union for the Conservation of Nature and Natural Resources. 252p.

Mickleburgh, S. P., Hutson, A. M., and Racey, P. A. (2002). A review of the global conservation status of bats. **Oryx**. 36(1): 18-34.

Minnis, A. M. and Lindner, A. L. (2013). Phylogenetic evaluation of *Geomyces* and allies reveals no close relatives of *Pseudogymnoascus destructans*, comb. nov., in bat hibernacula of eastern North America. **Fungal Biology**. 117: 638-649.

Mohd-Azlan, J., Zubaid, A., and Kunz, T. H. (2001). The distribution, relative abundance, and conservation status of the large flying fox, *Pteropus vampyrus*, in Peninsular Malaysia: a preliminary assessment. **Acta Chiropterologica**. 3(2): 149-162.

Nadchatram, M. and Mitchell, C. J. (1965). New bat chiggers from Thailand and the Solomon Islands with notes on the subgenus *Vercammen-Grandjean* (Acarina: Trombiculidae). **Journal of Medical Entomology**. 2(1): 70-74.

Nogueira, M. R., de Fabio, S. P., and Peracchi, A. L. (2004). Gastrointestinal helminth parasitism in fruit-eating bats (Chiroptera: Stenodermatinae) from western Amazonian Brazil. **Revista de Biología Tropical**. 52(2): 387-392.

Norberg, U. M. and Rayner, J. M. V. (1987). Ecological morphology and flight in bats (Mamalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. **Proceedings of the Royal Society of London, Series B: Biological Sciences**. 316: 335-427.

Nowak, R. (1994). **Walker's bats of the world**. Introduction by Kunz, T. H. and Pierson, E. D. Baltimore: Johns Hopkins University Press. 288p.

Obrist, M. K. (1995). Flexible bat echolocation: the influence of individual, habitat and conspecifics on sonar signal design. **Behavioral Ecology and Sociobiology**. 36: 207-219.

O'Donnell, C. F. J. (2000). Conservation status and causes of decline of the threatened New Zealand long-tailed bat *Chalinolobus tuberculatus* (Chiroptera: Vespertilionidae). **Mammal Review**. 30(2): 89-106.

Pakarnseree, L., Nadee, N., Nabhitabhata, J., Chanard, T., Sewakhonburi, S., and Sribunchuai, P. (2003). **Study and survey on wildlife for setting up biodiversity database of the Sakaerat conservation forest area**. Bangkok:

Thailand Institute of Scientific and Technological Research. 690p.

Pennisi, L. A., Holland, S. M., and Stein, T. V. (2004). Achieving bat conservation through tourism. **Journal of Ecotourism**. 3(3): 195-207.

Perkins, S. L. and Schall, J. J. (2002). A molecular phylogeny of malarial parasites recovered from cytochrome b gene sequences. **Journal of Parasitology**. 88(5): 972-978.

Pettigrew, J. D. (1986). Flying primate? Megabats have the advanced pathway from eye to mid-brain. **Science**. 231: 1304-1306.

Pettigrew, J. D. (1991). Wing or brain? Convergent evolution in the origin of bats. **Systematic Zoology**. 40: 199-216.

Pettigrew, J. D., Jamieson, B. G. M., Robson, S. K., Hall, L. S., McAnally, K. I., and Cooper, H. M. (1989). Phylogenetic relations between microbats, megabats and primates. (Mamalia: Chiroptera and Primates). **Proceedings of the Royal Society of London, Series B: Biological Sciences**. 325: 489-559.

Pfalzer, G. and Kusch, J. (2003). Structure and variability of bat social calls: implications for specificity and individual recognition. **Journal of Zoology**. 261: 21-33.

Phommexay, P., Satasook, C., Bates, P., Pearch, M., and Bumrungsri, S. (2011). The impact of rubber plantations on the diversity and activity of understorey insectivorous bats in southern Thailand. **Biodiversity and Conservation**. 20: 1441-1456.

Pitnick, S., Jones, K. E., and Wilkinson, G. S. (2006). Mating system and brain size in bats. **Proceedings of the Royal Society of London, Series B: Biological Sciences**. 273: 719-724.

Podlutsky, A. J., Khritankov, A. M., Ovodov, N. D., and Austad, S. N. (2005). A new field record for bat longevity. **Journal of Gerontology Series A: Biological Sciences and Medical Sciences**. 60: 1366-1368.

Popa-Lisseanu, A. G. and Voigt, C. C. (2009). Bats on the move. **Journal of Mammalogy**. 90: 1283-1289.

Prachakchitra, A. and Thong-Aree, S. (2004). Initial report on the new-recorded bats for Thailand. (in Thai). **Journal of Wildlife in Thailand**. 12(1): 217.

Puechmaille, S. J., Frick, W. F., Kunz, T. H., Racey, P. A., Voigt, C. C., Wibbelt, G., and Teeling, E. C. (2011). White-nose syndrome: is this emerging disease a threat to European bats?. **Trends in Ecology and Evolution**. 26(11): 570-576.

Pumo, D. E., Finamore, P. S., Franek, W. R., Phillips, C. J., Tarzami, S., and Balzarano, D. (1998). Complete mitochondrial genome of a Neotropical fruit bat, *Artibeus jamaicensis*, and a new hypothesis of the relationships of bats to other Eutherian mammals. **Journal of Molecular Evolution**. 47(6): 709-717.

Racey, P. A., Swift, S. M., Rydell, J., and Brodie, L. (1998). Bats and insects over two Scottish rivers with contrasting nitrate status. **Animal Conservation**. 1: 195-202.

Raghuram, H., Thangadurai, C., Gopukumar, N., Nathar, K., and Sripathai, K. (2009). The role of olfaction and vision in the foraging behavior of an echolocating megachiropteran fruitbat, *Rousettus leschenaulti* (Pteropodidae). **Mammalian Biology**. 74: 9-14.

Reichard, J. D. and Kunz, T. H. (2009). White-nose syndrome inflicts lasting injuries to the wings of little brown myotis (*Myotis lucifugus*). **Acta Chiropterologica**. 11: 457-464.

Robinson, M. F., Bumrungsri, S., and Hill, J. E. (1996). Chiroptera from Thung Yai

Naresuan and Huai Kha Khaeng Wildlife Sanctuaries. *Natural History* **Bulletin of the** *Siam Society*. 44: 243-247.

Robinson, M. F. and Smith, A. L. (1997). Chiroptera from Loei province, North East Thailand. **Natural History Bulletin of the Siam Society**. 45: 1-16.

Russ, J. M. and Montgomery, W. I. (2002). Habitat associations of bats in Northern Ireland: implications for conservation. **Biological Conservation**. 108: 49-58.

Russo, D. and Jones, G. (2003). Use of foraging habitats by bats in a Mediterranean area determined by acoustic surveys: conservation implications. **Ecography**. 26: 197-209.

Russo, D., Maglio, G., Rainho, A., Meyer, C. F. J., and Palmeirim, J. M. (2011). Out of the dark: diurnal activity in the bat *Hipposideros ruber* on São Tomé island (West Africa). **Mammalian Biology**. 76: 701-708.

Rydell, J., Bach, L., Dubourg-Savage, M-J., Green, M., Rodrigues, L., and Hedenström, A. (2010). Bat mortality at wind turbines in northwestern Europe. **Acta Chiropterologica**. 12: 261-274.

Rydell, J., Miller, L. A., and Jensen, M. E. (1999). Echolocation constraints of Daubenton’s bat foraging over water. **Functional Ecology**. 13: 247-255.

Schnitzler, H. U. and Kalko, E. K. V. (2001). Echolocation by insect- eating bats. **BioScience**. 51: 557-569.

Seidman, V. M. and Zabel, C. J. (2001). Bat activity along intermittent streams in Northwestern California. **Journal of Mammalogy**. 82: 738-747.

Simmons, N. B. and Geisler, J. H. (1998). Phylogenetic relationships of *Icaronycteris, Archeonycteris*, *Hassianycteris*, and *Palaeochiropteryx* to extant bat lineages, with comments on the evolution of echolocation and foraging strategies in

Microchiroptera. **Bulletin of the American Museum of Natural History**. 235: 1-182.

Simmons, N. B., Seymour, K. L., Habersetzer, J., and Gunnell, G. F. (2008). Primitive early Eocene bat from Wyoming and the evolution of flight and echolocation. **Nature**. 451: 818-821.

Speakman, J. R., Rydell, J., Webb, P. I., Hayes, J. P., Hays, G. C., Hulbert, I. A. R., and Mcdevitt, R. M. (2000). Activity patterns of insectivorous bats and birds in northern Scandinavia (69° N), during continuous midsummer daylight. **Oikos**. 88: 75-86.

Stahlschmidt, P. and Bruhl, C. A. (2012). Bats at risk? bat activity and insecticide residue analysis of food items in an apple orchard. **Environmental Toxicology and Chemistry**. 31(7): 1556-1563.

Stevens, J. R., Noyes, H. A., Dover, G. A., and Gibson, W. C. (1999). The ancient and divergent origins of the human pathogenic trypanosomes, *Trypanosoma brucei* and *T. cruzi*. **Parasitology**. 118: 107-116.

Stier, S. and Mildenstein, T. L. (2005). Dietary habitat of the world's largest bats: the Philippine flying foxes, *Acerodon jubatus* and *Pteropus vampyrus lanensis*. **Journal of Mammalogy**. 86(4): 719-728.

Svensson, A. M., Danielsson, I., and Rydell, J. (2002). Avoidance of bats by water striders (*Aquarius najas,* Hemiptera). **Hydrobiologia**. 489: 83-90.

Swanepoel, R., Leman., P. A., Burt, F. J., Zachariades, N. A., Braack, L. E., Ksiazek, T. G., Rollin, P. E., Zaki, S. R., and Peters, C. J. (1996). Experimental inoculation of plants and animals with Ebola virus. **Emerging Infectious Diseases**. 2(4): 321-325.

Teeling, E. C., Springer, M. S., Madsen, O., Bates, P., O'Brien S. J., and Murphy, W. J. (2005). A molecular phylogeny for bats illuminates biogeography and the fossil record. **Science**. 307: 580-584.

Turner, G. G., Reeder, D. M., and Coleman, J. T. H. (2011). A five-year assessment of mortality and geographic spread of white-nose syndrome in North American bats and a look to the future. **Bat Research News**. 52: 13-27.

Uchikawa, K. and Kobayashi, T. (1978). A contribution to the ectoparasite fauna of bats in Thaland II. blood-sucking acari (Argasidae, Spinturnicidae and Macronyssidae). **Contributions from the Biological Laboratory Kyoto University**. 25(3): 249-254.

Uchikawa, K. and Kobayashi, T. (1979). A contribution to the ectoparasite fauna of bats in Thaland I. fur mites of the family Myobiidae (Acarina; Trombidiformes). **Acarologia**. 20(3): 368-384.

Vaughan, N., Jones, G., and Harris, S. (1996). Effects of sewage effluent on the activity of bats (Chiroptera: Vespertilionidae) foraging along rivers. **Biological Conservation**. 78: 337-343.

Vaughan, N., Jones, G., and Harris, S. (1997). Habitat use by bats (Chiroptera) assessed by means of a broad-band acoustic method. **Journal of Applied Ecology**. 34: 716-730.

Vaughan, T. A. and O'shea, T. J. (1976). Roosting ecology of the pallid bat, *Antrozous pallidus*. **Journal of Mammalogy**. 57: 19-42.

Vaughan, T. A., Ryan, J. P., and Czaplewski, N. J. (2000). **Mammalogy** (4th ed.). Fort Worth: Saunders College. 672p.

Voigt, C. C., Schneeberger, K., Voigt-Heucke, S. L., and Lewanzik, D. (2011). Rain increases the energy cost of bat flight. **Biology Letters**. 7: 793-795.

Voigt, C. C. and von Helversen, O. (1999). Storage and display of odour by male *Saccopteryx bilineata* (Chiroptera, Emballonuridae). **Behavioral Ecology and Sociobiology**. 47: 29-40.

Waage, J. K. (1979). The evolution of insect/vertebrate associations. **Biological Journal of the Linnean Society**. 12: 187-224.

Wang, L. F., Shi, Z., Zhang, S., Field, H., Daszak, P., and Eaton, B. T. (2006). Review of bats and SARS. **Emerging Infectious Diseases**. 12: 1834-1840.

Warren, R. D., Waters, D. A., Altringham, J. D., and Bullock, D. J. (2000). The distribution of Daubenton’s bats (*Myotis daubentonii*) and pipistrelle bats (*Pipistrellus pipistrellus*) (Vespertilionidae) in relation to small-scale variation in riverine habitat. **Biological Conservation**. 92: 85-91.

Wetterer, A. L., Rockman, M. V., and Simmons, N. B. (2000). Phylogeny of phyllostomid bats (Mammalia: Chiroptera): data from diverse morphological systems, sex chromosomes, and restriction sites. **Bulletin of the American Museum of Natural History**. 248: 1-200.

Whitaker, J. O., Jr., (2004). Prey selection in a temperate zone insectivorous bat community. **Journal of Mammalogy**. 85: 460-469.

Wickramasinghe, L. P., Harris, S., Jones, G., and Jennings, N. V. (2004). Abundance and species richness of nocturnal insects on organic and conventional farms: effects of agricultural intensification on bat foraging. **Conservation Biology**. 18(5): 1283-1292.

Wildlife Conservation Office. (2006) **Protected animals of Thailand** [online]. Available: http://web3.dnp.go.th/wildlifenew/wlProtect.aspx. Accessed on 20

August 2013.

Wilkinson, G. S. and Boughman, J. W. (1998). Social calls coordinate foraging in greater spear-nosed bats. **Animal Behaviour**. 55: 337-350.

Wilkinson, G. S. and South, J. M. (2002). Life history, ecology and longevity in bats. **Aging Cell**. 1: 124-131.

Willig, M. R., Camilo, G. R., and Noble, S. J. (1993). Dietary overlap in frugivorous and insectivorous bats from Edaphic Cerrado habitats of Brazil. **Journal of Mammalogy**. 74: 117-128.

Willis, C. K. R. and Brigham, R. M. (2004). Roost switching, roost sharing and social cohesion: forest-dwelling big brown bats, *Eptesicus fuscus*, conform to the fission-fusion model. **Animal Behaviour**. 68: 495-505.

Winchell, J. M. and Kunz, T. H. (1993). Sampling protocols for estimating time budgets of roosting bats. **Canadian Journal of Zoology**. 71: 2244-2249.

Wong, S., Lau, S., Woo, P., and Yuen, K-Y. (2007). Bats as a continuing source of emerging infections in humans. **Reviews in Medical Virology**. 17: 67-91.

Zortea, M. and Mendes, S. L. (1993). Folivory in the big fruit-eating bat, *Artibeus lituratus* (Chiroptera: Phyllostomidae) in eastern Brazil. **Journal of Tropical Ecology**. 9: 117-120.

CHAPTER III

COMMUNITY STRUCTURE OF BATS IN SEKAERAT ENVIRONMENTAL RESEARCH STATION

3.1 Abstract

A study of bats in Sakaerat Environmental Research Station was undertaken to determine the influence of habitat types and seasons on community structure of forest bats. During June 2013 to May 2014, bats were surveyed using 16 mist nets, set up 6 hours after sunset in dry dipterocarp forest, ecotone, dry evergreen forest, and plantation forest. Surveys were carried out for 12 nights per season, overall 36 sampling nights. A total of 81,216 net meter hours resulted in the capture of 66 individuals, representing 6 families, 7 genera, and 9 species. The proportion of captured megabats was 32.82% while the proportion of captured microbats was 68.18%. The most abundance species in the study was *Hipposideros larvatus* (34.85%). Shannon-Wiener diversity index was 1.925 while the equitability was 0.876. Number of bat captured was different between dry evergreen forest and ecotone (χ^2 = 26.52, df = 8, p = 0.001). No bat was captured in dry dipterocarp forest and plantation forest. Bat abundance was also different among seasons (H = 8.91, df = 2, p = 0.011). The results demonstrated that dry evergreen forest in SERS is important habitat that supports abundant and diverse forest-dwelling bats.

3.2 Introduction

Bats are classified in the order Chiroptera, the second largest of mammalian order, comprising 20% of mammalian diversity worldwide (Patterson, 1994). In addition, their local assemblages in many tropical ecosystems are usually rich. (Findley, 1993; Fleming, 1973). Tropical bats coexist in diverse communities and developed to avoid overlap in their habitats and resources (Jones, Jacobs, Kunz, Willig, and Racey, 2009). Then, their richness, diversity, and composition vary spatially and temporally (Aguirre, lens, van Damme, and Matthysen, 2003; Moreno and Halffter, 2001).

Bats are a major portion of mammalian diversity throughout the Asian tropics (Kingston, 2010). They comprise one-third of all mammal species in mainland Southeast Asia (Francis, 2008). In Thailand, bats comprise about 40% of mammalian fauna (119 species) (Bumrungsri et al., 2006). However, tropical forests in Southeast Asia are among the most threatened in the world (Laurance, 2007). This situation can reduce biodiversity and modify community structures which may lead to the extinction about 20% of bat species in Southeast Asia by 2100 (Lane, Kingston, and Lee, 2006).

Bats are considered as keystone species for maintenance of ecosystems, especially in tropical forests (Kunz, de Torrez, Bauer, Lobova, and Fleming, 2011; Bernard, 2002). Frugivorous bats act as pollinators and seed dispersers of a broad spectrum of plant species (Medellín and Gaona, 1999; Charles-Dominique, 1991), while carnivorous bats are predators of insects as well as small vertebrates (Kalka, Smith, and Kalko, 2008; Martin, Pine, and DeBlase, 2001; Findley, 1993). Additionally, many bat species support agricultural areas as pest controllers and fertilizer producers. (Cleveland et al., 2006; Leelapaibul, Bumrungsri, and Pattanawiboon, 2005).

Although, tropical bats are extremely rich mammal community and play various important ecological and economic roles. Data on their diversity, distribution, and ecological requirements are still scanty (Hutson, Mickleburgh, and Racey, 2001). Moreover, data on forest bats in Thailand are needed (Bumrungsri et al., 2006). To redress this, the bat survey was conducted in Sakaerat Environmental Research Station. The objectives of this study were to determine the influence of forest types and seasons on community structure of tropical bats. Determination of bat community composition is important implications for the forest management plans and bat conservation (Carroll, Carter, and Fledhamer, 2002).

3.3 Materials and methods

3.3.1 Study area

Sakaerat Environmental Research Station (SERS) is situated on the edge of Thailand’s Korat Plateau about 300 km north-east of Bangkok (14° 30′ N, 101° 55′ E) (Figure 3.1). The approximate area is 78.08 km^2. The elevation ranges from 250 to 762 m above sea level. Average maximum temperature was 34.2°C, average minimum temperature was 20°C, the annual precipitation was 1082.4 mm, and the mean annual relative humidity was 81% in 2012. SERS has a tropical climate and three distinct seasons; the summer (March-May), the rainy season (June-October), and the winter (November-February) (Sakaerat Environmental Research Station, 2013a).

The main vegetation types in SERS are dry evergreen and dry dipterocarp forests. Dry evergreen forest covers 60% of the area, including tree species such as

Hopea ferrea, *Hopea odorata*, and *Hydnocarpus ilicifolia*. Dry dipterocarp forest covers 18% of the station area. The common trees are *Shorea obtusa*, *Dipterocarpus intricatus*, *Shorea siamensis*, and *Gardenia sootepensis*. Other vegetation types in the station include bamboo forest, plantation forest, and grassland (Sakaerat Environmental Research Station, 2013b).

SERS supports highly diverse fauna. Approximately 430 vertebrate species are found in SERS. Of these, 80 species are mammals. These include serow (*Naemorhedus sumatraensis*), one of the 15 species protected under Thai law due to their rarity and risk of extinction. Other common mammals are barking deer (*Muntiacus mantjak*), Indochinese ground squirrel (*Menetes berdmorei*), pig-tailed macaque (*Macaca nemestrina*), slow loris (*Nycticebus coucang*) as well as rodents and various bats (Sakaerat Environmental Research Station, 2013b).

3.3.2 Data collection

Bats were surveyed from June 2013 to May 2014. Surveys were divided into three sessions: the rainy season (June-October), the winter (November-February), and the summer (March-May). Each survey session was carried out for 12 nights, overall 36 sampling nights.

Eight sampling sites were selected covering four habitat types in SERS: two sites in dry evergreen forest, two sites in dry dipterocarp forest, two sites in ecotone area, and two sites in plantation forest (Figure 3.1). At each sampling site, two mist nets (9.4 m long x 2.5 m high, 25 mm mesh size, 4 shelves) were set up at ground level (2.5 m high) and two mist nets were set up at higher level (5 m high). Nets were placed at flyways of bats such as ponds, open trails, and gaps, operated for six hours from 18.00 to 24.00 and checked every 30 minutes. To avoid the effect of lunar phobia, mist nettings were not performed around full moon nights (Lang, Kalko, Römer, Bockholdt, and Dechmann, 2006; Morrison, 1978). Moreover, netting was suspended when there was heavy rain or strong wind.

Captured bats were kept in individual cloth bags and sent to field laboratory. Subsequently, bats were identified, sexed, aged, weighed, measured, and photographed. Bats were identified to species level, following Francis (2008). Age class was categorized as juvenile or adult by examining level of ossification of metacarpal-phalangeal joints (Brunet-Rossinni and Wilkinson, 2009). Sex was categorized as male (presence of testes) or female (presence of nipples). Reproductive condition of adult females was categorized as non-breeding (absence of a fetus and hairy nipples), pregnant (presence of abdominal distension), lactating (hairless nipples and producing milk), or post-lactating (hairless nipples and no milk) (Fleming, Hooper, and Wilson, 1972). After processing, bats were marked on the wings using a pen marker and fur was clipped on the dorsal side of body. Then, bats were released at the capture sites. This study was performed under of the SUT Animal Care and Use Committee.

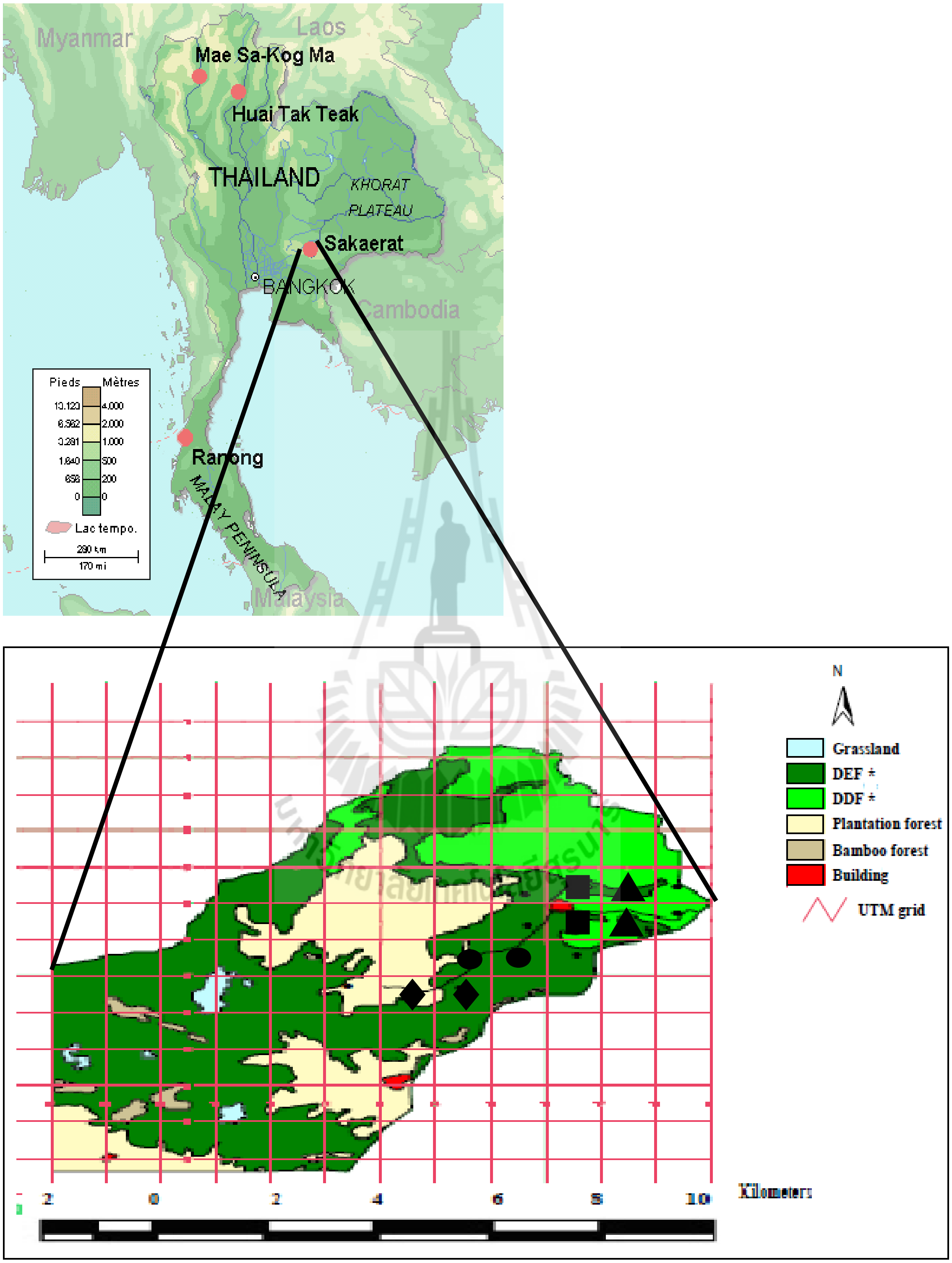

Figure 3.1 Location, land use type, and study plots of Sakaerat Environmental Research Station (SERS). (●) Dry evergreen forest plots, (◆) Plantation forest plots, (▲) Dry dipterocarp forest plots, (■) Ecotone plots (UNESCO, 2009).

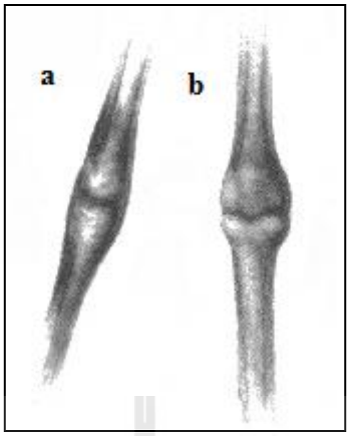

Figure 3.2 Wing joint of bat: (a) juvenile (present of cartilage) and (b) adult (no cartilage) (Nagorsen and Brigham, 1993).

3.3.3 Data analysis

3.3.3.1 Completeness of bat sampling

- Species accumulation curve

Species accumulation curves were plotted to assess completeness of sampling effort among habitat types and seasons.

- Non-parametric estimators

Various non-parametric estimators were also used to assess completeness of bat surveys. Satisfactory level of completeness was considered at 90% (Moreno and Halffter, 2000). It was calculated based on the following the formula:

$$\text{Completeness} = (S_{obs} / S_{max}) \times 100 \tag{3.1}$$

where S_{obs} = the number of species observed in the sample

S_{max} = total species richness

Total species richness was examined using various non-parametric estimators (Colwell and Coddington, 1994):

Chao 1 estimator

$$\check{S}_{Chao1} = S_{\mathrm{obs}} + (f_1^2 / 2f_2) \qquad (3.2)$$

where $\check{S}_{Chao1} = S_{max}$

S_{obs} = the number of species observed in the sample

f_1 = the number of species observed just once

f_2 = the number of species observed just twice

Chao 2 estimator

$$\check{S}_{Chao2} = S_{obs} + (q_1^2 / 2q^2) \qquad (3.3)$$

where $\check{S}_{Chao2} = S_{max}$

S_{obs} = the number of species observed in the sample

q_1 = the number of species found in just one sample

q_2 = the number of species found in just two samples

Abundance-based coverage estimator (ACE)

$$\check{S}_{ACE} = S_{abun} + (S_{rare} / C_{ACE}) + [(f_1 / C_{ACE})\, y^2_{ACE}] \qquad (3.4)$$

where $\check{S}_{ACE} = S_{max}$

S_{abun} = the species that occur more than 10 times

S_{rare} = the species that occur 10 times or less

f_1 = the number of all individuals

C_{ACE} = the sample coverage estimate

y^2_{ACE} = the coefficient of variation

Then calculating the sample coverage estimate and the coefficient of variation from the following fomulas:

$$C_{ACE} = 1 - (f_1 / n_{rare}) \tag{3.5}$$

where C_{ACE} = the sample coverage estimate

f_1 = the number of all individuals

n_{rare} = the number of individuals in the rare species

$$y^2_{ACE} = \max\ [(S_{rare} / C_{ACE})\ \{\Sigma^{10}_{k=1}\ k\ (k - 1)\ f_k / (n_{rare})\ (n_{rare} - 1)\} - 1, 0] \tag{3.6}$$

where y^2_{ACE} = the coefficient of variation

S_{rare} = the species that occur in 10 times or less

C_{ACE} = the sample coverage estimate

n_{rare} = the number of individuals in the rare species

Incidence-based coverage estimator (ICE)

$$\check{S}_{ICE} = S_{freq} + (S_{infr} / C_{ICE}) + [(q_1 / C_{ICE})\, y^2_{ICE}] \qquad (3.7)$$

where $\check{S}_{ICE} = S_{max}$

S_{freq} = the species that occur in more than 10 samples

S_{infr} = the species that occur in 10 samples or less

q_1 = the number of all individuals

C_{ICE} = the sample coverage estimate

y^2_{ICE} = the coefficient of variation

Then the sample coverage estimate and the coefficient of variation was calculated from the following fomulas:

$$C_{ICE} = 1 - (q_1 / n_{infr}) \qquad (3.8)$$

where C_{ICE} = the sample coverage estimate

q_1 = the number of all individuals

n_{infr} = the number of incidences in the infrequent species

$$y^2_{ICE} = \max [(S_{infr} / C_{ICE})\, (m_{infr} / m_{infr} - 1)\, \{\Sigma^{10}_{k=1}\, k\, (k - 1)\, q_k / (n_{infr})^2\} - 1, 0] \qquad (3.9)$$

where y^2_{ICE} = the coefficient of variation

S_{infr} = the species that occur in 10 times or less

C_{ICE} = the sample coverage estimate

m_{infr} = the number of samples that have at least one infrequent species

n_{infr} = the number of individuals in the rare species

The first-order Jackknife estimator

$$\check{S}_{jackknife1} = S_{obs} + k\,(n - 1 / n) \qquad (3.10)$$

where $\check{S}_{jackknife1} = S_{max}$

S_{obs} = the number of species observed in the sample

n = the sample size

k = the number of unique species

The second-order Jackknife estimator

$$\check{S}_{jackknife2} = S_{obs} + [k\,(2n - 3) / n - m\,(m - 2)^2 / n\,(n - 1)] \qquad (3.11)$$

where $\check{S}_{jackknife2} = S_{max}$

S_{obs} = the number of species observed in the sample

n = the sample size

k = the number of unique species

m = the number of species that occur in exactly two samples

Bootstrap estimator

$$\check{S}_{Bootstrap} = S_{obs} + \Sigma\, (1 - p_j)^n \qquad (3.12)$$

where $\check{S}_{Bootstrap} = S_{max}$

S_{obs} = the number of species observed in the sample

n = the sample size

p = the proportion of plots containing the species j

3.3.3.2 Relative abundance

Relative abundance of bats in each habitat and season was calculated as number of individuals caught per 100 net-meter hours (nmh) (Aguirre, 2002).

$$\text{Net meter-hours} = \text{length of all nets in meters} \times \text{total sampling hours} \qquad (3.13)$$

3.3.3.3 Similarity

Sorensen's coefficient was used to compare similarity in bat species assemblages among habitats (Krebs, 1998).

$$CC = 2C / A + B \qquad (3.14)$$

where CC = Sorenson's coefficient

C = the number of species shared by the two communities

A = the number of species in community A

B = the number of species in community B

3.3.3.4 Species diversity

Shannon-Wiener diversity index was used to quantify diversity of bats among habitats (Krebs, 1998).

$$H' = -\Sigma^{s}_{i=1} P_i \text{ In } P_i \qquad (3.15)$$

where H' = Shannon-Wiener diversity index

P_i = the proportion of individuals in the i species

s = total number of species

3.3.3.5 Species evenness

Shannon-Wiener evenness index was used to quantify equitability of bats among habitats (Krebs, 1998).

$$E_{\mathrm{H}} = H / H_{\mathrm{max}} \qquad (3.16)$$

where E = Shannon-Wiener evenness index

H' = Shannon-Wiener diversity index

H'_{max} = ln S

3.3.3.6 Statistical analysis

Chi-square was used to test for differences in abundance and species richness of bats between ecotone and dry evergreen forest. *T*-test was used to compare the diversity index among habitats and seasons. Kruskal-Wallis test was used to test for differences in abundance and species richness of bats among seasons. Kruskal-Wallis test was also used to compare the times and heights of captured bats (Zar, 1999). Statistical analyses were performed using PASW Statistics 18 (IBM) with 95% confidence interval.

3.4 Results

3.4.1 Bat community structure in SERS

Overall, bat sampling in SERS from June 2013 to May 2014 resulted in the capture of 66 individuals, representing six families, seven genera, and nine species. Of these, three species were megachiropteran i.e. *Cynopterus sphinx* (n = 10), *Megaerops niphanae* (n = 9), and *Cynopterus brachyotis* (n = 2) while six species were microchiroptera i.e. *Hipposideros larvatus* (n = 23), *Megaderma spasma* (n = 6), *Rhinolophus affinis* (n = 5), *Hipposideros diadema* (n = 4), *Myotis muricola* (n = 4), and *Chaerephon plicata* (n = 3). There were no recaptured bats in any study sites (Table 3.1). The proportion of captured megabats was 32.82% while proportion of captured microbats was 68.18%. Shannon-Wiener diversity index of bats in SERS was 1.925 whereas the equitability was 0.876.

Total trapping effort was 81,216 net meter hours (nmh). Overall trapping success was 0.08 bats/100 nmh. Megachiropteran bats were captured 0.026 bats/100 nmh while microchiropteran bats were captured 0.055 bats/100 nmh. The most abundance species in the study was *Hipposideros larvatus* that made up 34.85% of total bats (0.028 bats/100 nmh). The other common species in the study were *Cynopterus sphinx* (15.15% of total bats; 0.012 bats/100 nmh), and *Megaerops niphanae* (13.63% of total bats; 0.011 bats/100 nmh). The remaining six species were locally rare (n ≤ 6; ≤ 0.007 bats/100 nmh) (Table 3.1).

A total of 30 males (45%) and 36 females (54%) were captured. The sex ratio of total capture was 1 male per 1.2 females. A majority of captured bats were adults (60 individuals) and only four individuals were sub-adults (Table 3.2). The ratio of adults to non-adults was 1:0.07. The body mass and body measurements of captured bats are shown in Table 3.3 (immature bats were excluded).

Table 3.1 Number of individuals and relative abundance (bats/100 nmh) of captured bats in SERS from June 2013 to May 2014.

Taxon	**Number of individuals (Relative abundance)**								
	Jun-13	**Jul-13**	**Aug-13**	**Sep-13**	**Dec-13**	**Jan-14**	**Feb-14**	**Mar-14**	**total**
Megachiroptera									
Cynopterus sphinx	1 (0.001)	-	1 (0.001)	2 (0.002)	6 (0.007)	-	-	-	10 (0.012)
Cynopterus brachyotis	-	-	-	2 (0.002)	-	-	-	-	2 (0.002)
Megaerops niphanae	-	-	1 (0.001)	1 (0.001)	-	2 (0.002)	4 (0.005)	1 (0.001)	9 (0.011)
Microchiroptera									
Hipposideros larvatus	3 (0.004)	14 (0.017)	2 (0.002)	4 (0.005)	-	-	-	-	23 (0.028)
Hipposideros diadema	-	1 (0.001)	-	-	-	-	-	3 (0.004)	4 (0.005)
Megaderma spasma	-	1 (0.001)	-	2 (0.002)	-	3 (0.003)	-	-	6 (0.007)
Chaerephon plicata	-	2 (0.002)	-	-	1 (0.001)	-	-	-	3 (0.004)
Rhinolophus affinis	-	-	1 (0.001)	4 (0.005)	-	-	-	-	5 (0.006)
Myotis muricola	-	-	-	1 (0.001)	1 (0.001)	-	2 (0.002)	-	4 (0.005)

Table 3.2 Sex, age, and reproductive stage of captured bats in SERS from June 2013 to May 2014.

Species	**Adult**				**Young**	
	Male	**Female**			**Male**	**Female**
		Pregnant	**Lactating**	**Post-lactating**		
Cynopterus sphinx	2	-	2	6	-	-
Cynopterus brachyotis	-	-	-	-	-	2
Megaerops niphanae	4	-	3	1	-	1
Hipposideros larvatus	8	-	-	15	-	-
Hipposideros diadema	3	-	-	1	-	-
Megaderma spasma	6	-	-	-	-	-
Chaerephon plicata	1	-	-	2	-	-
Rhinolophus affinis	3	-	-	2	-	-
Myotis muricola	2	-	-	1	1	-

Table 3.3 Body mass (g) and body measurements (mm) (mean ± SD) of adult bats in SERS from June 2013 to May 2014; HB = head- body length, TL = tail length, FA = forearm length, HF = hindfoot length, E = ear length, WT = weight.

Species	sex	n	HB	TL	FA	HF	E	WT
Cynopterus sphinx	M	2	85.15 ± 5.00	10.50 ± 4.38	68.88 ± 4.63	14.04 ± 1.00	18.28 ± 0.39	44.30 ± 4.95
	F	8	83.84 ± 4.35	12.11 ± 5.63	71.35 ± 3.48	14.98 ± 2.46	19.09 ± 1.34	44.43 ± 4.15
Megaerops niphanae	M	4	70.06 ± 1.57	-	55.09 ± 3.85	12.09 ± 0.90	14.99 ± 0.77	25.23 ± 1.50
	F	4	72.50 ± 3.25	-	57.44 ± 0.96	12.78 ± 0.64	14.84 ± 1.55	30.95 ± 2.95
Hipposideros larvatus	M	8	67.94 ± 5.06	32.44 ± 1.82	63.23 ± 1.79	10.80 ± 0.79	22.05 ± 2.42	21.14 ± 1.78
	F	15	63.93 ± 3.57	34.11 ± 7.97	61.94 ± 1.56	10.48 ± 0.51	20.85 ± 1.07	19.72 ± 1.01
Hipposideros diadema	M	3	89.32 ± 0.85	55.03 ± 3.79	90.10 ± 9.97	15.23 ± 2.11	29.03 ± 4.93	48.33 ± 4.82
	F	1	91.10	59.40	80.75	17.20	26.30	55.40
Megaderma spasma	M	6	62.30 ± 9.02	-	59.21 ± 0.73	16.33 ± 0.75	34.37 ± 2.26	18.60 ± 1.65
Chaerephon plicata	M	1	60.40	38.00	47.55	8.10	21.60	15.00
	F	2	65.85 ± 2.90	30.58 ± 0.67	43.68 ± 2.37	8.23 ± 0.32	21.75 ± 0.21	14.35 ± 0.35
Rhinolophus affinis	M	3	52.70 ± 4.81	20.62 ± 1.00	48.25 ± 0.26	10.47 ± 0.64	17.50 ± 1.47	6.63 ± 0.59
	F	2	47.70 ± 1.20	21.25 ± 1.63	48.35 ± 0.14	11.23 ± 0.6	17.25 ± 0.35	11.55 ± 0.07
Myotis muricola	M	2	43.83 ± 1.38	32.28 ± 7.95	37.68 ± 0.46	5.45 ± 0.49	11.43 ± 0.81	4.70 ± 0.42
	F	1	42.40	29.30	35.50	5.90	11.80	4.90

3.4.2 Times and heights of bat captures

Bats were captured between 19.00 and 24.00. Time of bat capture was peaked at 19.00 (one hours after sunset), accounted for 25.76% of the overall captures (Figure 3.2). Most bats were captured within four hours after sunset (91.67%). The heights of bat captures were from 0 m to 5 m above ground. The most bats were captured at 2 m-height (18.18%), followed by at 3 m-height (16.67%). The average height of bat captures was 2.32 m (Figure 3.3). Active times of bats were significantly different among species (H = 48.5, df = 8, p = 0.000). Moreover, heights of bat captures were also significantly different among species (H = 32.2, df = 8, p = 0.000).

Mean active time of *Hipposideros larvatus* was 73.04 ± 25.30 minutes after sunset, *Myotis muricola* was 105 ± 17.32 minutes after sunset, *Rhinolophus affinis* was 138 ± 58.48 minutes after sunset, *Megaerops niphanae* was 153.33 ± 69.46 minutes after sunset, *Megaderma spasma* was 185 ± 22.58 minutes after sunset, *Cynopterus brachyotis* was 210 ± 42.43 minutes after sunset, *Cynopterus sphinx* was 216 ± 74.57 minutes after sunset, *Hipposideros diadema* was 277.5 ± 15 minutes after sunset, and *Chaerephon plicata* was 330 ± 51.96 minutes after sunset (Figure 3.3).

Mean height of *Hipposideros larvatus* capture was 1.65 ± 0.83 m above ground, *Megaderma spasma* was 1.58 ± 1.13 m above ground, *Rhinolophus affinis* was 1.8 ± 1.2 m above ground, *Myotis muricola* was 2.13 ± 0.38 m above ground, *Megaerops niphanae* was 2.44 ± 1.42 m above ground, *Cynopterus sphinx* was 3.1 ± 0.62 m above ground, *Hipposideros diadema* was 3.5 ± 0.41 m above ground, *Cynopterus brachyotis* was 3.5 ± 0.71, and *Chaerephon plicata* was 4.67 ± 0.58 m above ground (Figure 3.4).

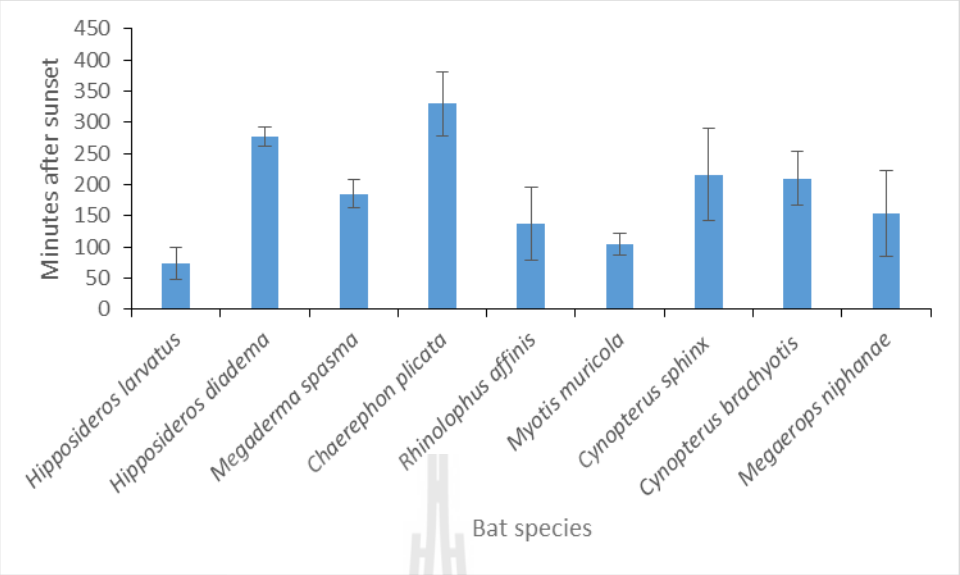

Figure 3.3 Mean temporal distributions (minutes after sunset ± SD) of bat captures in SERS from June 2013 to May 2014.

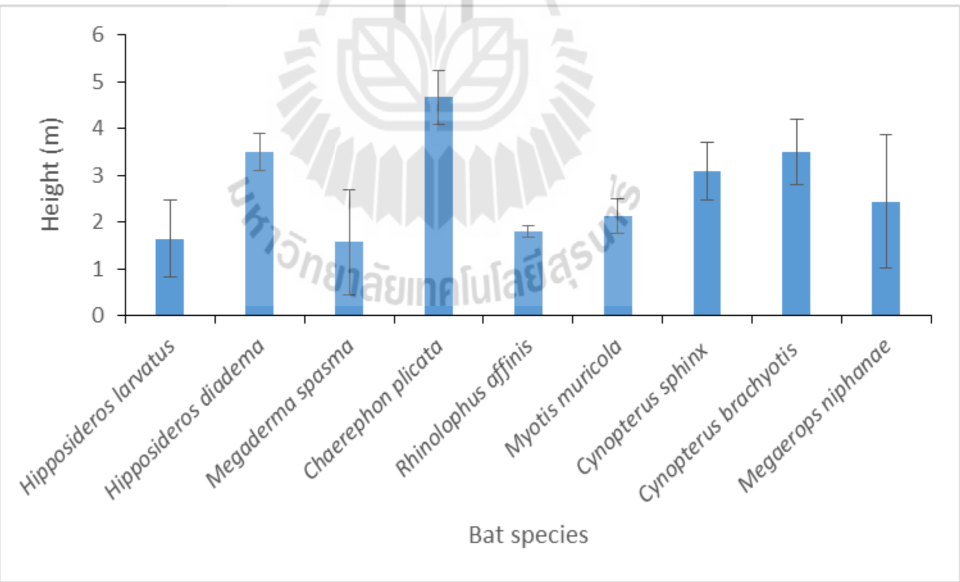

Figure 3.4 Mean height distributions (m ± SD) of bat captures in SERS from June 2013 to May 2014.

3.4.3 Species richness, abundance, and diversity of bats among habitats

All bat taxa in this study were found in dry evergreen forest, comprising 60 individuals in six families, seven genera, and nine species, including *Cynopterus sphinx* (n =10), *Megaerops niphanae* (n = 9), *Cynopterus brachyotis* (n = 2), *Hipposideros larvatus* (n = 22), *Megaderma spasma* (n = 6), *Rhinolophus affinis* (n = 5), *Hipposideros diadema* (n = 4), *Myotis muricola* (n = 4), and *Chaerephon plicata* (n = 3) (Table 3.4).

Bat abundance in dry evergreen forest was 0.296 bats/100 nmh. *Hipposideros larvatus* was the dominant species in this area (n = 22; 0.108 bats/100 nmh) followed by *Cynopterus sphinx* (n = 10; 0.049 bats/100 nmh), respectively. The remaining seven species were captured ≤ 7 individuals (≤ 0.034 bats/100 nmh).

In ecotone, there were 6 individuals belonging to two families, two genera, and three species i.e. *Hipposideros larvatus* (n = 1), *Hipposideros diadema* (n = 3), and *Megaerops niphanae* (n = 2). Relative abundance of bats in this area was 0.03 bats/100 nmh. There was no captured bat in dry dipterocarp forest and plantation forest (Table 3.4).

Captures in dry evergreen forest accounted for 90.91% of the total bats and ecotone for 9.09% of the total bats. Total number of individuals was significantly different between dry evergreen forest and ecotone ($\chi^2 = 26.52$, df = 8, $p = 0.001$). The Shannon-Wiener diversity index of bats in dry evergreen forest was 1.866 while the diversity index of bats in ecotone was 1.011. The equitability of bats in dry evergreen forest was 0.849 while the equitability of bats in ecotone was 0.921. The Shannon-Wiener diversity index was different between the dry evergreen forest and ecotone ($t = 3.36$, df = 8.74, $p = 0.009$). Sorenson’s coefficient was 0.545 for bat species between dry evergreen forest and ecotone.

Table 3.4 Number of individuals and relative abundance (bats/100 nmh) of captured bats in four habitat types in SERS; DDF = dry dipterocarp forest, ECO = ecotone, DEF = dry evergreen forest, PTF = plantation forest.

Taxon	**Number of individuals (Relative abundance)**			
	DDF	**ECO**	**DEF**	**PTF**
Megachiroptera				
Cynopterus sphinx	-	-	10 (0.049)	-
Cynopterus brachyotis	-	-	2 (0.01)	-
Megaerops niphanae	-	2 (0.01)	7 (0.034)	-
Microchiroptera				
Hipposideros larvatus	-	1 (0.005)	22 (0.108)	-
Hipposideros diadema	-	3 (0.015)	1 (0.005)	-
Megaderma spasma	-	-	6 (0.03)	-
Chaerephon plicata	-	-	3 (0.015)	-
Rhinolophus affinis	-	-	5 (0.025)	-
Myotis muricola	-	-	4 (0.02)	-
Total	-	6 (0.03)	60 (0.296)	-

3.4.4 Species richness, abundance, and diversity of bats among seasons

All bat species in this study were captured in the rainy season, including 43 individuals in six families, seven genera, and nine species i.e. *Cynopterus sphinx* (n = 4), *Megaerops niphanae* (n = 2), *Cynopterus brachyotis* (n = 2), *Hipposideros larvatus* (n = 23), *Megaderma spasma* (n = 3), *Rhinolophus affinis* (n = 5), *Hipposideros diadema* (n = 1), *Chaerephon plicata* (n = 2), and *Myotis muricola* (n = 1). Relative abundance of bats in the rainy season was 0.159 bats/ 100 mnh (Table 3.5).

A total of 19 individuals were captured during the winter belonging to four families, five genera, and five species i.e. *Megaderma spasma* (n = 3), *Chaerephon plicata* (n = 1), *Myotis muricola* (n = 3), *Cynopterus sphinx* (n = 6), and *Megaerops* *niphanae* (n = 6). Relative abundance of bats in the winter was 0.07 bat/ 100 mnh. In the summer, only four bats were captured comprising three individuals of *Hipposideros diadema* and one individual of *Megaerops niphanae*. Bat abundance in this season was 0.015 bats/ 100 mnh (Table 3.5).

Captures in the rainy season accounted for 65.15% of the total bats, the winter for 28.79% of the total bats and the summer for 6.06% of the total bats. Total number of individuals were significantly different among seasons (H = 8.91, df = 2, p = 0.011). Shannon-Wiener diversity index was highest in the rainy season (1.595), followed by the winter (1.466), and the summer (0.562), respectively. The diversity index was not statistically different between the rainy season and the winter (t = 0.592, df = 61, p = 0.555). However, the diversity index was significantly different between the summer and the rainy season (t = 3.007, df = 7.119. p = 0.019) and between the summer and the winter (t = 2.787, df = 5.68, p = 0.0336). Evenness of bats was highest in the winter (0.911), followed by the summer (0.811), and the rainy season (0.726), respectively. The highest Sorenson's coefficient was found between the rainy season and the winter (0.714) but Sorenson's coefficient between the rainy season and the summer (0.364) and between the winter and the summer was low (0.286). Sorenson's coefficient is used to compare similarity in bat species assemblages among habitats and seasons. This result implies that bat species are rather similar between the rainy season and the winter.

Table 3.5 Number of individuals and relative abundance (bats/100 nmh) of captured bats among seasons in SERS.

Taxon	Number of individuals (Relative abundance)		
	Rainy season	**Winter**	**Summer**
Megachiroptera			
Cynopterus sphinx	4 (0.015)	6 (0.022)	-
Cynopterus brachyotis	2 (0.007)	-	-
Megaerops niphanae	2 (0.007)	6 (0.022)	1 (0.004)
Hipposideros larvatus	23 (0.085)	-	-
Hipposideros diadema	1 (0.004)	-	3 (0.011)
Megaderma spasma	3 (0.011)	3 (0.011)	-
Chaerephon plicata	2 (0.007)	1 (0.004)	-
Rhinolophus affinis	5 (0.018)	-	-
Myotis muricola	1 (0.004)	3 (0.011)	-
Total	43 (0.159)	19 (0.07)	4 (0.015)

3.4.5 Completeness of bat sampling

3.4.5.1 Total bat samplings

Overall captured bats in this study were nine species. Species accumulation curve of the total bat samplings reached an asymptote, suggested that bat samplings in this study were complete. The accumulation curve showed that eight bat species (88% of the total species) were captured in the first 21 nights whereas all bat species were captured at 36 nights (Figure 3.5).

Non-parametric estimators predicted that the numbers of bat species in this study were 9 (Chao 1), 9.54 (Chao 2), 10.66 (Jack 1), 11.12 (Jack 2), 9.06 (ACE), 12.49 (ICE), and 9.8 (Bootstrap). Consequently, completeness of total bat samplings in SERS ranged from 74.75% to 100% (Table 3.6).

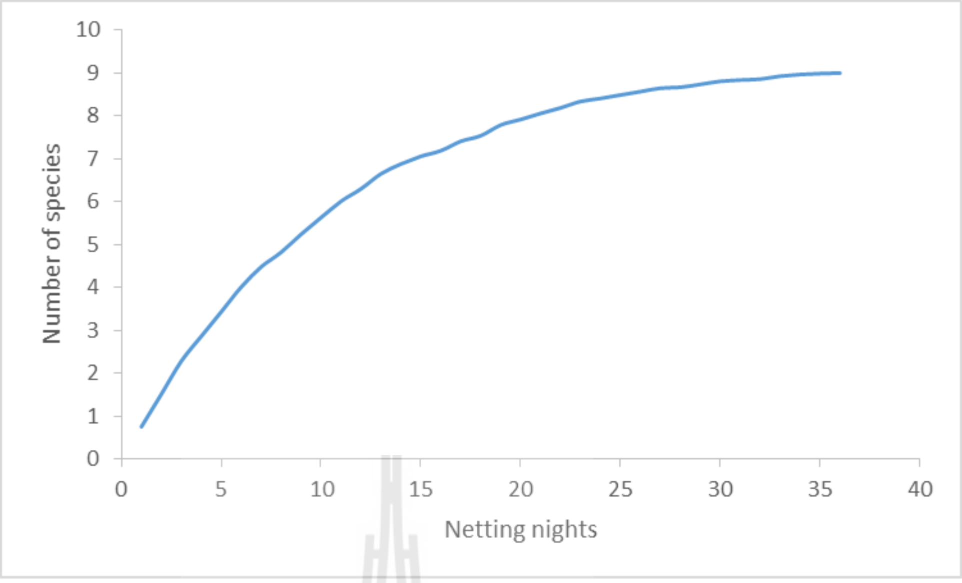

Figure 3.5 Species accumulation curve for total bat samplings in SERS from June 2013 to May 2014.

Table 3.6 Completeness of bat samplings and expected number of bat species in SERS from June 2013 to May 2014 with non-parametric estimators.

Estimators	**No. of species**	**Expected species**	**% Complete**
Chao 1	9	9	100
Chao 2	9	9.54	94.34
Jackknife 1	9	10.66	84.43
Jackknife 2	9	11.12	80.94
ACE	9	9.06	99.34
ICE	9	12.49	74.75
Bootstrap	9	9.8	84.43

3.4.5.2 Bat samplings among habitats

A total of nine bat species were captured in dry evergreen forest and three bat species were captured in ecotone. Species accumulation curve for bat samplings in dry evergreen forest reached an asymptote and revealed that eight bat species (88% of the total species) were captured in the first 12 nights whereas all bat species were captured at 18 nights. However, species accumulation curve for ecotone was sloped and did not reach an asymptote in ecotone (Figure 3.6). According to species richness estimators, the expected numbers of bat species in dry evergreen forest were 9 (Chao 1), 9.4 (Chao 2), 10.89 (Jack 1), 11.22 (Jack 2), 9.48 (ACE), 14.36 (ICE), and 10.03 (Bootstrap). Consequently, completeness of bat samplings in dry evergreen forest ranged from 62.67% to 100%. The expected numbers of bat species in ecotone were 3 (Chao 1), 5.83 (Chao 2), 5.83 (Jack 1), 8.5 (Jack 2), 3.6 (ACE), 5.83 (ICE), and 4.07 (Bootstrap). Then, completeness of bat samplings in ecotone ranged from 35.29% to 100% (Table 3.7).

Table 3.7 Completeness of bat samplings and expected number of bat species in dry evergreen forest and ecotone in SERS from June 2013 to May 2014 with non-parametric estimators.

Estimators	**Dry evergreen forest**		**Ecotone**	
	Species/expected	**% Complete**	**Species/expected**	**% Complete**
Chao 1	9/9	100	3/3	100
Chao 2	9/9.4	95.85	3/5.83	51.46
Jackknife 1	9/10.89	82.64	3/5.83	51.46
Jackknife 2	9/11.22	80.21	3/8.5	35.29
ACE	9/9.48	95.14	3/3.6	83.33
ICE	9/14.36	62.67	3/5.83	51.46
Bootstrap	9/10.03	89.73	3/4.07	73.71

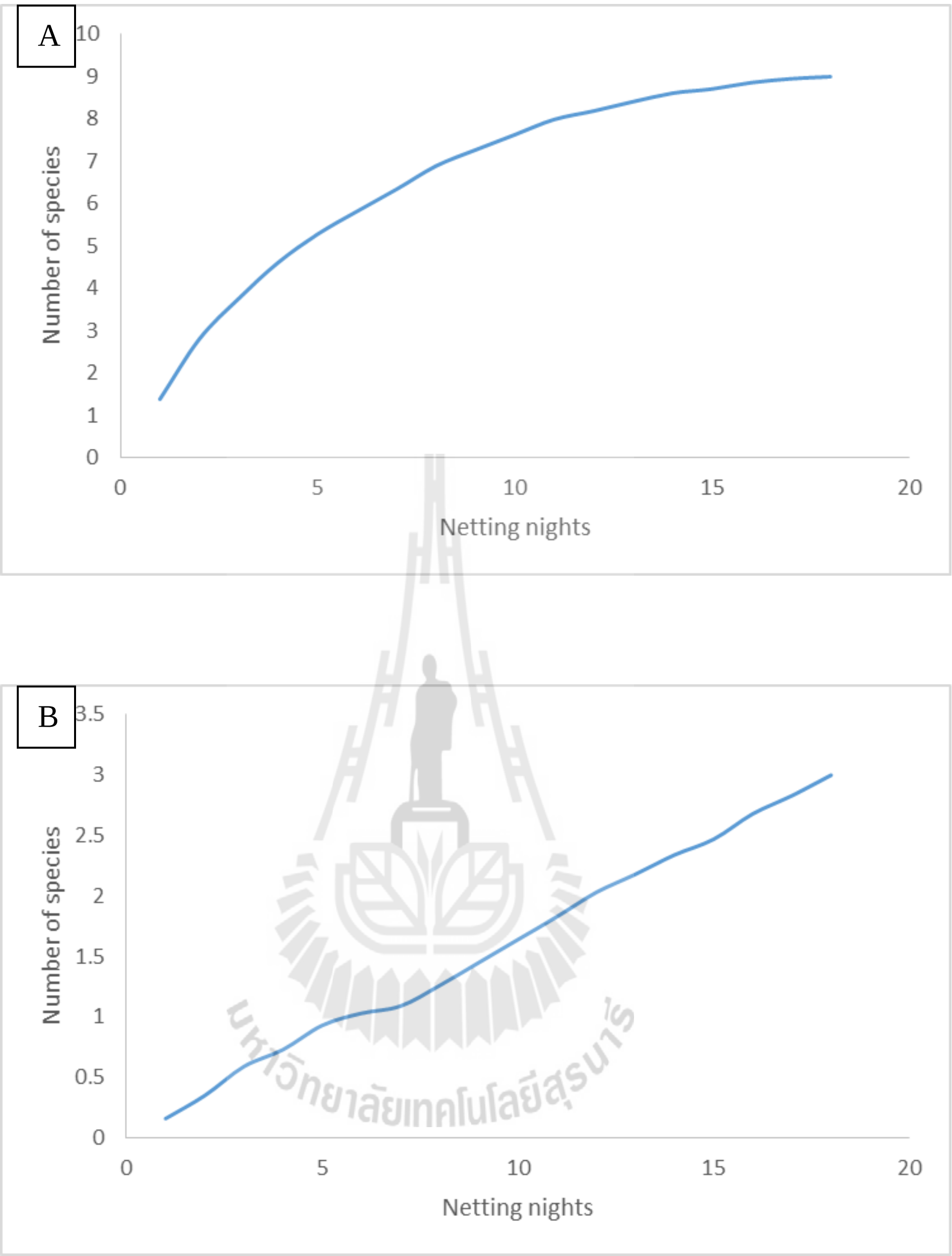

Figure 3.6 Species accumulation curve for bat samplings in dry evergreen forest (A) and ecotone (B) in SERS from June 2013 to May 2014.

3.4.5.3 Bat samplings among seasons

A total of nine bat species were captured in the rainy season, five bat species were captured in the winter, and two bat species were captured in the summer. Species accumulation curve for bat samplings in the rainy season reached an asymptote. In the rainy season, eight bat species (88% of the total species) were captured in the first 20 nights. Nevertheless, the accumulation curves for bat samplings in the winter and the summer did not reach asymptotes (Figure 3.7).

On the base of species richness estimators, the expected numbers of bat species in the rainy season were 9.67 (Chao 1), 13 (Chao 2), 12.83 (Jack 1), 14.75 (Jack 2), 9.95 (ACE), 18.05 (ICE), and 10.77 (Bootstrap). Percentage of completeness of bat samplings in the rainy season ranged from 49.86% to 93.07%. The expected numbers of bat species in the winter were 5 (Chao 1), 6.48 (Chao 2), 7.88 (Jack 1), 9.75 (Jack 2), 5.4 (ACE), 10.32 (ICE), and 6.24 (Bootstrap). Percentage of completeness of bat samplings in the winter ranged from 60.24% to 100%. The expected numbers of bat species in the summer were 2 (Chao 1), 2.96 (Chao 2), 3.92 (Jack 1), 5.75 (Jack 2), 3.11 (ACE), 2.96 (ICE), and 2.72 (Bootstrap). Percentage of completeness of bat samplings in the summer ranged from 34.78% to 100% (Table 3.8).

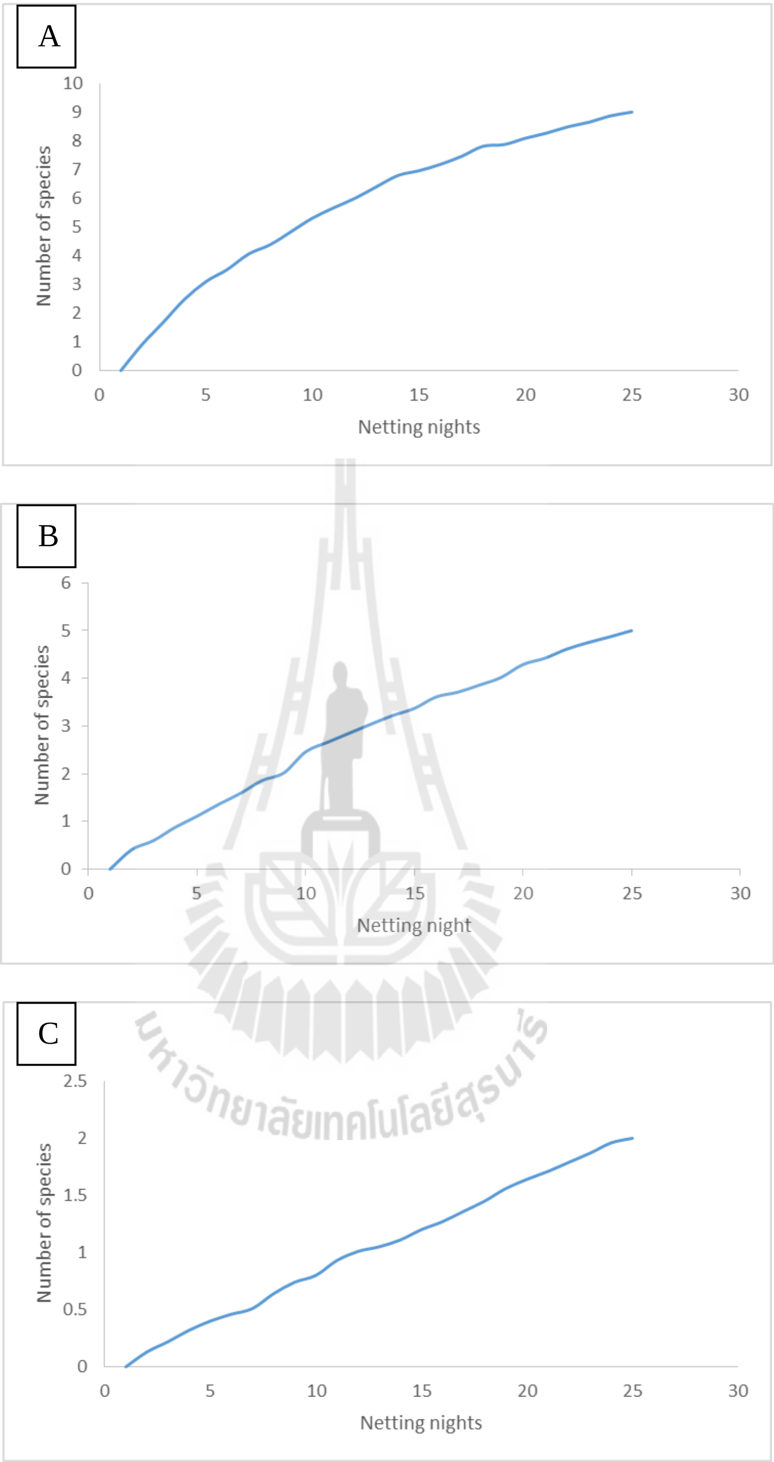

Figure 3.7 Species accumulation curve for bat samplings in the rainy season (A), the winter (B), and the summer (C) in SERS from June 2013 to May 2014.

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Table 3.8 Completeness of bat samplings and expected number of bat species among seasons in SERS from June 2013 to May 2014 with non-parametric estimators.

Estimators	**Rainy season**		**Winter**		**Summer**	
	Species/ expected	**% Complete**	**Species/ expected**	**% Complete**	**Species/ expected**	**% Complete**
Chao 1	9/9.67	93.07	5/5	100	2/2	100
Chao 2	9/13	70.59	5/6.48	96.62	2/2.96	67.57
Jackknife 1	9/12.87	70.15	5/7.88	76.92	2/3.92	51.02
Jackknife 2	9/14.75	61.02	5/9.75	70.92	2/5.75	34.78
ACE	9/9.95	90.45	5/5.4	92.59	2/3.11	64.31
ICE	9/18.05	49.86	5/10.32	60.24	2/2.96	67.57
Bootstrap	9/10.77	83.57	5/6.24	73.53	2/2.72	73.53

3.5 Discussion

3.5.1 Bat community and capture methods

A total of 9 bat species were recorded in this study, including *Cynopterus sphinx*, *Megaerops niphanae*, *Hipposideros larvatus*, *Hipposideros diadema*, *Megaderma spasma*, *Chaerephon plicata*, *Rhinolophus affinis*, and *Myotis muricola*. Nevertheless, the previous bat surveys in SERS were documented 11 species i.e. *Cynopterus sphinx*, *Megaerops ecaudatus*, *Taphozous saccolaimus*, *Megaderma spasma*, *Rhinolophus acuminatus*, *Rhinolophus pusillus*, *Rhinolophus affinis*, *Rhinolophus luctus*, *Hipposideros larvatus*, *Myotis hasseltii*, and *Murina cyclotis* (Pakarnseree et al., 2003). Thus, 4 bat species are the new records in this area (*Megaerops niphanae*, *Hipposideros diadema*, *Chaerephon plicata*, and *Myotis muricola*) and leading the total species of bat recorded in SERS to 15 species. Consequently, bat community in SERS represents 12.61% of total bat species in Thailand (119 species) (Bumrungsri et al., 2006).

The number of bat species in this study is low when compared to the other studies in Thailand. For instance, a total of 21 bat species were found in Phu Kieo Wildlife Sanctuary, Chaiyaphum province (Boonkird and Sirikarin, 1993), 58 bat species were recorded in Thung Yai Naresuan and Huai Kha Khaeng Wildlife Sanctuaries (Robinson, Bumrungsri, and Hill, 1996), 24 bat species were reported from Loei province (Robinson and Smith, 1997), and 47 bat species were recorded in Hala-Bala Wildlife Sanctuary (Prachakchitra and Thong-Aree, 2004). Moreover, the number of bat species in this study are lower than the other studies in Indochina. For example, 51 species of insectivorous bats were documented in Kuala Lompat Research Station, Malaysia (Kingston, Francis, Akbar, and Kunz, 2003), 50 bat species were recorded at Ulu Gombak, Malaysia (Heller and Volleth, 1995), and 36 bat species were reported in Kim Hy Nature Reserve, Vietnam (Furey, Mackie, and Racey, 2010). However, comparisons of bat diversity between this study area and other bat communities are difficult. The diversity of bats is influenced by many factors such as sampling effort, sampling technique, regional biogeographic, as well as meteorological differences (Bredt, Uieda, and Magalhães, 1999; Voss and Emmons, 1996). Additionally, Findley (1993) suggested that the diversity of bats depended on a complex partitioning of resources such as food and habitats.

The individuals of captured bats in this study (66 individuals) are also lower than the other studies in Indochina. In comparison, 355 individual bats were captured in southern Thailand (Phommexay, Satasook, Bates, Pearch, and Bumrungsri, 2011), 2,560 individual bats were caught in Kuala Lompat Research Station, Malaysia (Kingston, Francis, Akbar, and Kunz, 2003), and 694 individual bats were recorded in Kim Hy Nature Reserve, Vietnam (Furey, Mackie, and Racey, 2010). This probably because the lack of large caves in the study area, some bats which require caves as roost site are rarely captured.

Moreno and Halffter (2000) demonstrated that bias of sampling equipment caused the underrepresentation of some species in bat community. In this study, mist netting is only one method to sampling the bats. Mist netting can yield biased in bat sampling because many species of insectivorous bats can detect and avoid mist nets e.g. Nycteridae, Megadermatidae, Rhinolophidae, and Hipposideridae (Larsen et al., 2007; MacCarthy, Carter, Steffen, and Feldhamer, 2006; Fahr and Ebigbo, 2004; Francis, 1989; Aldridge and Rautenbach, 1987) and some bats forage at great heights e.g. Molossidae, Vespertilionidae, and Mormoopidae (Simon and Voss, 1998). In addition, mist netting should not perform on consecutive nights because bats can remember the net locations and learn to avoid them on the second sampling night. (Winhold and Kurta, 2008). These biases could be reasons for low number of captured bats in this study.

Although there are several biases associated with mist netting, it is the traditional method for bat sampling (Robbins, Murray, and McKenzie, 2008). Most fruit bats are easily sampled with ground mist nets (Kalko, Herre, and Handley, 1996; Voss and Emmons, 1996). Furthermore, mist netting was the main method for various bat studies such as foraging ecology (Ingle, 2003), reproductive biology (Heideman, Cummings, and Heaney, 1993), and ectoparasites (ter Hofstede and Fenton, 2005).

Harp traps are more efficient for surveying bats than mist nets. Many species of insectivorous bats cannot detect harp traps by their echolocation calls. Then, insectivorous bats appear more susceptible to capture by harp traps (Berry, O'Connor, Holderied, and Jones, 2004; Francis, 1989). Nevertheless, disadvantages of harp traps include the small sampling area (about 2 m^2), too heavy, and limit to the understorey (Dai, Tadashi, Naoki, and Toshiki, 2001). Similar to mist nets, high-flying bats can avoid harp traps and bat species in community are also underrepresented.

Alternatively, ultrasonic detectors are useful for surveying high-flying bats that produce echolocation calls (Murray, Britzke, Hadley, and Robbins, 1999; O’Farrell and Gannon, 1999). However, the accurate identification of echolocation calls to species of some bats can be in troubles because unavailable of call libraries (Barclay, 1999), difficult to detect low intensity calls (Kingston, Jones, Akbar, and Kunz, 1999), and echolocation characteristics are very similar among some species (Jung, Thomson, Titman, and Applejohn, 1999; Kalcounis, Hobson, Brigham, and Hecker, 1999). Moreover, the number of recorded calls can be overestimated because some bats continuously emit their echolocation calls (Lee et al., 2006).

Obviously, no single method is effective for studying bat community (Kunz, 1988). O’Farrell and Gannon (1999) showed that 63.5% of total bat species were captured by mist nets and harp traps and 86.9% of total bat species were recorded by ultrasonic detectors, but using both capture and acoustic methods reached more complete inventory. Then, a combination of both captures and acoustic surveys as well as searching for roosts should be carried out to complete the bat inventory in SERS.

3.5.2 Bat activities, heights of bat captures, and recapture

There was no recapture of bats in this study. Bats are notoriously difficult to capture and recapture rates are often low (Heideman and Heaney, 1989). The recapture rates of bats are low due to the fact that the bats can remember trapping sites and avoid them (Fadhullah and Ho, 2013). Recapture rates of bats via nets in forests in temperate North America ranged from 1% to 3% (Winhold and Kurta, 2008; Wilhide, Harvey, McDaniel, and Hoffman, 1998). However, Gaisler and Chytil (2002) showed 22.8% recapture rate of hibernating bats in Czech Republic. That recapture rate was high because some bat species frequent used of their roosts.

In this study, most bats were captured within four hours after sunset. Hayes (1997) showed that activities of bats were peak shortly after sunset when they emerged from their roosts. However, active times of bats in this study were significantly different among species. This data suggested that temporal segregation is an important factor of community structure of bats in SERS. This pattern was also observed in other bat communities (Lee and McCracken, 2004; Rydell, Entwistle, and Racey, 1996; Ramírez-Pulido and Armella, 1987). Variation in nocturnal activity patterns is a strategy to minimize ecological overlap of bats in a community (Mancina, García-Rivera, and Capote, 2007).

Bats in this study also exhibited variation in heights of captures. Bernard (2001) reported that insectivorous bats tended to be found above the canopy and Hodgkison, Blading, Zubaid, and Kunz (2004) showed that Old World fruit bats were greater diversity in the canopy. The differences in wing morphology is a significant factor in the vertical partitioning of bats (Bumrungsri, Leelapaibul, and Racey, 2007). Although bats predominantly use the canopy or upper the canopy, many bats were captured at ground level in this study. This data suggested that these bats can use various level of the vegetation.

3.5.3 Bat community among habitats in SERS

Bat community structure in this study differed among four habitat types, suggested that habitat types can influence community structure of bats. The highest species richness, species diversity, and abundance were found in dry evergreen forest, followed by ecotone. There was no captured bat in dry dipterocarp forest and plantation forest. The non-collection of frugivorous bat in dry dipterocarp forest in this study probably associate with fruit availability. Marinho-Filho (1991) revealed that the distribution and abundance of frugivorous and nectarivorous bats was related with the temporal and spatial availability of fruits and flowers. No captured of insectivorous bats in dry dipterocarp forest and plantation forest may be because these bats can avoid mist nets, especially netting in open areas or lack of canopy cover areas. Furthermore, wing morphology and echolocation call of insectivorous bats may not allow them to forage in the more open habitats (Phommexay, Satasook, Bates, Pearch, and Bumrungsri, 2011).

On the other hand, some bat species appear to utilize open habitats, agriculture areas or degraded forests. These bats are very common and have wide distribution such as *Cynopterus sphinx*, *Cynopterus brachyotis*, and *Hipposideros larvatus* (Lekagul and McNeely, 1988). However, these bats were not recorded in dry dipterocarp forest and plantation forest in this study.

Data from several studies showed that most bats preferred old-growth forests (Avila-Cabadilla, Stoner, Henry, and Añorve, 2009; Medellín, Equihua, and Amin, 2000; dos Reis and Muller, 1995). Similarly, dry evergreen forest in SERS is extremely important for bats. The vegetation in old-growth forests are highest diversity and structural complexity which provide increased opportunities for foraging by bats (Hayes and Gruver, 2000; Humes, Hayes, and Collopy, 1999). In addition, the old-growth forests provide more roost and food availability for bats than other forest habitats (Perry, Thill, and Leslie, 2007; Crampton and Barclay, 1998).

Water bodies may be another important habitats for bats in SERS. There are one large pond in dry evergreen forest and one small pond in ecotone but no aquatic habitats in dry dipterocarp forest and plantation forest. This data is another reason to explain why bats disappeared from dry dipterocarp forest and plantation forest in SERS. In general, bats demand more energy and water than other mammals of the same size (Voigt, Sörgel, and Dechmann, 2010). Subsequently, bats must visit water bodies more than other mammals. Water bodies not only provide drinking water but also provide food for bats. These riparian habitats provide greatly density of both terrestrial and aquatic prey insects for insectivorous bats (Hagen and Sabo, 2011; Fukui, Murakami, Nakano, and Aoi, 2006) as well as provide pollen and fruits for frugivorous bats (MacSwiney, Bolivar, Clarke, and Racey, 2009).

3.5.4 Bat community among seasons in SERS

As expected, bat capture rates in this study varied seasonally. The highest species richness, species diversity, and abundance were found in the rainy season, followed by the winter, and the summer, respectively. Similar to the study of Mello (2009) who demonstrated that Phyllostomid bats in Neotropical were highest abundance in the rainy season. He also showed that the variation of bat abundance depended on the seasons. The variation in species richness, diversity, and abundance of bats are associated with climate conditions. Rainy season provides higher food resources for bats both fruits and insects (Pech-Canche, Moreno, and Halffter, 2011). In addition, precipitation in the rainy season may increase reproductive activity of bats (Mello, Schittini, Selig, and Bergallo, 2004). It can be concluded that rainy season was found to support bat community in this study more than other seasons.

Many bats migrate seasonally or fly long distances to reach their resources when resources are insufficient (Montiel, Estrada, and León, 2006). In this study, food availability of bats may be low in the winter and the summer. Moreover, the water bodies in the study area were in shortage during the winter and the summer. Bat diversity and abundance deceased when water supply is scarce (Salsamendi, Arostegui, and Aihartza, 2012; Francl, 2008; Russo and Jones, 2003). Hence, the lower capture rates of bats in the winter and the summer in this study are probably due to the scarcity of food and water supply for bats.

3.5.5 Completeness of bat sampling

3.5.5.1 Species accumulation curves

Although species accumulation curve is introduced to bat studies recently, many researchers consided it as an essential tool to assess the bat community (Moreno and Halffter, 2000). The cumulative number of species is plotted against sampling efforts or number of individuals. The shape of curves reach an asymptote when the samplings are complete. Species accumulation curves provide a predictive tool for designing sampling protocols to save money, time, and effort. Moreover, it can be used to compare species diversity in different communities or locations (Soberón, J. and Llorente, 1993).

In this study, species accumulation curves of total bat samplings in SERS and dry evergreen forest reached asymptotes. These data indicate that all bat species in SERS and dry evergreen forest are recorded. If bat samplings are continued, no new bat species will be added. Nevertheless, species accumulation curve of samplings in ecotone was still steep. It illustrated that bat samplings in ecotone are far from being complete. More bat species can be found if more samplings are carryed out in ecotone. In addition, species accumulation curve in the rainy season also reached an asymptote. But the accumulation curves for bat samplings in the winter and the summer did not reach asymptotes.

It is clear that bat samplings in dry evergreen forest and in rainy season were complete whereas samplings in ecotone, the winter, and the summer were incomplete. It can be concluded that mist nettings are suitable methods for capturing bats in SERS. However, Ugland, Gray, and Ellingsen (2003) suggested that species accumulation curve gave a large underestimate of total species richness. Thus, bat species in SERS in this survey are more than nine species.

3.5.5.2 Species richness estimators

Species richness estimators are statistical models which uses approximate true species richness of organisms. Several models are recommended for estimating species richness such as Chao 1 estimator, Chao 2 estimator, Jackknife 1 estimator, Jackknife 2 estimator, Bootstrap estimator, etc. (Colwell and Coddington, 1994). Although there are many estimator models, no single model is appropriate for all field protocols or all taxonomic groups (Bunge and Fitzpatrick, 1993). An estimator will yield reliable results if true species richness is known and used as a reference (Baltanás, 1992). However, it is impractical to use in field study. Hence, this study uses various estimators to estimate the ranges of true species richness of bat species in SERS.

The completeness of total bat samplings in SERS ranged from 74.75% to 100%. This data demonstrated that there were well bat samplings in this study. All bat species were captured or only few rare species were missed during sampling efforts.

The completeness of bat samplings in dry evergreen forest ranged from 62.67% to 100%. The ICE estimator seems not suitable for this area because the value quite differs from other estimators. When the ICE estimator was excluded, the completeness of samplings in dry evergreen forest range from 80.21% to 100%. Then, the data showed that there were also satisfactory bat samplings in dry evergreen forest.

In ecotone, the completeness of samplings ranged from 35.39% to 100%. In this case, Chao 1 and Jackknife 2 estimators may be not suitable for estimation. Both Chao 1 and Jackknife 2 estimators were then discarded resulting in the completeness of samplings in ecotone ranging from 51.46% to 83.33%. Consequently, bat samplings in ecotone were incomplete. Because ecotone was less canopy cover than dry evergreen forest, acoustic detector method is recommended to more complete the bat inventory in this area.

The completeness of bat samplings in the rainy season ranged from 49.86% to 93.07%. The ICE and Jackknife estimators differ from other estimators. If exclude both of them, the completeness in the rainy season range from 70.15% to 93.07%. Hence, the data suggested that bat samplings in the rainy season are quite well.

In the winter, the completeness of bat samplings ranged from 60.24% to 100%. Again, the ICE estimator seems difference from other estimators. If exclude the ICE estimator, the completeness in the winter range from 70.92% to 100%. Then, bat samplings in the winter are also quite well.

The completeness of bat samplings in the summer ranged from 34.78% to 100%. In this case, Chao 1 and Jackknife 2 seem difference from other estimators.

If exclude both of them, the completeness in the summer range from 51.02% to 73.53%. Thus, bat samplings in the summer are incomplete. More sampling efforts are recommended to complete the bat inventory in this season.

The data from this study revealed that some values of Jackknife 2 and ICE estimators are lower than other estimators. Similar to the study of Baltanás (1992) who suggested that Jackknife 2 estimator generally underestimated true species richness by 10%. Moreover, Rex, Kelm, Wiesner, Kunz, and Voigt, (2008) reported that Jackknife 2 estimator underestimated true species richness about 20% of phyllostomid bat community in Ecuador.

The values of Chao 1 estimator in this study seem higher than other estimators. However, Colwell and Coddington (1994) suggested that Chao’s statistic provided a better estimation for relatively species poor communities. In this study, the values of Chao 2, Jackknife 1, ACE, and, Bootstrap estimators are aggregation. Then, these estimators are recommended to approximate true species richness of bats in SERS.

3.6 Conclusion

In summary, diversity of bat species in SERS was low with only nine species captured. It is possibly because no large cave in the study area as well as efficiency of capture method. The only one method to capture bats is mist netting which is specific to understorey bat species. High-flying and insectivorous bats may be missed from this study. Then, acoustic method is needed to complete the bat inventory in SERS.

Bat community structure varied among habitats in SERS. Most bats were found in dry evergreen forest while few bats were found in ecotone. There was no bat in dry dipterocarp forest and plantation forest. It is clear that dry evergreen forest is the important habitat for bat community in SERS. In addition, aquatic habitats in this area are probably essential habitats for bats. Further study should be done on these habitats.

Bat community also varied among seasons. Therefore, bat species in the rainy season were higher than in the winter and the summer. The variation of bat species among seasons associates with food availability. Food is high abundance in rainy season but low abundance in winter and summer. Consequently, some bats may migrate from the study area in winter and summer.

The bat samplings in this study was nearly completed, except in ecotone and in summer. The combination method between mist netting and acoustic method is recommended to complete the bat inventory in SERS.

3.7 References

Aguirre, L. F. (2002). Structure of a Neotropical savanna bat community. **Journal of Mammalogy**. 83: 775-784.

Aguirre, L. F., Lens, L., van Damme, R., and Matthysen, E. (2003). Consistency and variation in the bat assemblages inhabiting two forest islands within a Neotropical savanna in Bolivia. **Journal of Tropical Ecology**. 19: 367-374.

Aldridge, H. D. J. N. and Rautenbach, I. L. (1987). Morphology, echolocation and resource partitioning in insectivorous bats. **Journal of Animal Ecology**. 56: 763-778.

Avila-Cabadilla, L. D., Stoner, K. E., Henry, M., and Añorve, M. Y. A. (2009). Composition, structure and diversity of phyllostomid bat assemblages in different successional stages of a tropical dry forest. **Forest Ecology and Management**. 258: 986-996.

Baltanás, A. (1992). On the use of some methods for the estimation of species richness. **Oikos**. 65: 484-492.

Barclay, R. M. R. (1999). Bats are not birds: a cautionary note on using echolocation calls to identify bats: a comment. **Journal of Mammalogy**. 80: 290-296.

Bernard, E. (2001). Vertical stratification of bat communities in primary forests of Central Amazon, Brazil. **Journal of Tropical Ecology**. 17: 115-126.

Bernard, E. (2002). Diet, activity and reproduction of bat species (Mammalia, Chiroptera) in Central Amazonia, Brazil. **Revista Brasileira de Zoologia**. 19(1): 173-188.

Berry, N., O'Connor, W., Holderied, M. W., and Jones, G. (2004). Detection and avoidance of harp traps by echolocating bats. **Acta Chiropterologica**. 6: 335-346.

Boonkird, K. and Sirikarin, K. (1993). Bat species diversity in Phu Kieo Wildlife Sanctuary. (in Thai). **Journal of Wildlife in Thailand**. 3(1): 117-122.

Bredt, A., Uieda, W., and Magalhães, E. D. (1999). Cave bats from the Distrito Federal area in mid-western Brazil (Mammalia, Chiroptera). **Revista Brasileira de Zoologia**. 16: 731-770.

Brunet-Rossinni, A. K. and Wilkinson, G. S. (2009). **Methods for age estimation and the study of senescence in bats**. In: Kunz, T. H. and Parsons, S. (Eds.). Ecological and behavioral methods for the study of bats. Baltimore: Johns Hopkins University Press. pp. 315-325.

Bumrungsri, S., Harrison, D. L., Satasook, C., Prajukjitr, A., Thong-Aree, S., and Bates, P. J. J. (2006). A review of bat research in Thailand with eight new species records for the country. **Acta Chiropterologica**. 8: 325-359.

Bumrungsri, S., Leelapaibul, W., and Racey, P. A. (2007). Resource partitioning in sympatric *Cynopterus* bats in lowland tropical rain forest, Thailand. **Biotropica**. 39: 241-248.

Bunge, J. and Fitzpatrick, M. (1993). Estimating the number of species: a review. **Journal of the American Statistical Association**. 88: 364-373.

Carroll, S. K., Carter, T. C., and Fledhamer, G. A. (2002). Placement of nets for bats: effects on perceived fauna. **Southeastern Naturalist**. 1(2): 193-198.

Charles-Dominique, P. (1991). Feeding strategy and activity budget of the frugivorous bat *Carollia perspicillata* (Chiroptera: Phyllostomidae) in French Guiana. **Journal of Tropical Ecology**. 7: 243-256.

Cleveland, C. J., Betke, M., Federico, P., Frank, J. D., Hallam, T. G., Horn, J., López, J. D., Jr., McCracken, G. F., Medellín, R. A., Moreno-Valdez, A., Sansone, C. G., Westbrook, J. K., and Kunz, T. H. (2006). Economic value of the pest control service provided by Brazilian free-tailed bats in south-central Texas. **Frontiers in Ecology and the Environment**. 4(5): 238-243.

Colwell, R. K. and Coddington, J. A. (1994). Estimating terrestrial biodiversity through extrapolation. **Proceedings of the Royal Society of London, Series B: Biological Sciences**. 345: 101-118.

Crampton, L. H. and Barclay, R. M. R. (1998). Selection of roosting and foraging habitat by bats in different-aged aspen mixedwood stands. **Conservation Biology**. 12: 1347-1358.

Dai, F., Tadashi, I., Naoki, A., and Toshiki, A. (2001). Efficiency of harp trap for capturing bats in boreal broad-leaved forest in Japan. **Eurasian Journal of Forest Research**. 3: 23-26.

dos Reis, N. R. and Muller, M. F. (1995). Bat diversity of forests and open areas in a subtropical region of south Brazil. **Ecología Austral**. 5: 31-36.

Fadhullah, W. and Ho, W. C. (2013). Bats diversity in Kolej Universiti Sains dan Teknologi Malaysia (KUSTEM). **International Journal for Innovation Education and Research**. 1(3): 1-6.

Fahr, J. and Ebigbo, N. (2004). **Rapid survey of bats (Chiroptera) in the Forêt Classée du Pic de Fon, Guinea**. In: McCullough, J. (Ed.). A rapid biological assessment of the Forêt Classée du Pic de Fon, Simandou Range, South-eastern Republic of Guinea. Washington, D.C.: Conservation International. pp. 69-77.

Findley, J. S. (1993). **Bats: A community perspective**. Cambridge: Cambridge University Press. 167p.

Fleming, T. H. (1973). Numbers of mammal species in North and Central American forest communities. **Ecology**. 54: 555-563.

Fleming, T. H., Hooper, E. T., and Wilson, D. E. (1972). Three Central American bats communities: structure, reproductive cycles and movement patterns. **Ecology**. 53: 555-569.

Francis, C. M. (1989). A comparison of mist nets and two designs of harp traps for capturing bats. **Journal of Mammalogy**. 70: 865-870.

Francis, C. M. (2008). **A field guide to the mammals of Thailand and South-East Asia**. Bangkok: Asia Books. 392p.

Francl, K. E. (2008). Summer bat activity at woodland seasonal pools in the northern Great Lakes region. **Wetlands**. 28: 117-124.

Fukui, D., Murakami, M., Nakano, S., and Aoi, T. (2006). Effect of emergent aquatic insects on bat foraging in a riparian forest. **Journal of Animal Ecology**. 75: 1252-1258.

Furey, N. M., Mackie, I. J., and Racey, P. A. (2010). Bat diversity in Vietnamese limestone karst areas and the implications of forest degradation. **Biodiversity and Conservation**. 19: 1821-1838.

Gaisler, J. and Chytil, J. (2002). Mark-recapture results and changes in bat abundance at the cave of Na Turoldu, Czech Republic. **Folia Zoologica**. 51(1): 1-10.

Hagen, E. M. and Sabo, J. L. (2011). A landscape perspective on bat foraging ecology along rivers: does channel confinement and insect availability influence the response of bats to aquatic resources in riverine landscapes?. **Oecologia**. 166: 751-760.

Hayes, J. P. (1997). Temporal variation in activity of bats and the design of echolocation-monitoring studies. **Journal of Mammalogy**. 78(2): 514-524.

Hayes, J. P. and Gruver, J. C. (2000). Vertical stratification of bat activity in an old-growth forest in western Washington. **Northwest Science**. 74: 102-108.

Heideman, P. D., Cummings, J. A., and Heaney, L. R. (1993). Observations on reproductive timing and early embryonic development in an Old World fruit bat, *Otopteropus cartilagonodus*. **Journal of Mammalogy**. 74: 621-630.

Heideman, P. D. and Heaney, L. R. (1989). Population biology and estimates of abundance of fruit bats (Pteropodidae) in Philippine submontane rainforest. **Journal of Zoology**. 218: 565-586.

Heller, K. G. and Volleth, M. (1995). Community structure and evolution of insectivorous bats in the Palaeotropics and Neotropics. **Journal of Tropical Ecology**. 11: 429-442.

Hodgkison, R., Blading, S. T., Zubaid, A., and Kunz, T. (2004). Habitat structure, wing morphology, and the vertical stratification of Malaysian fruit bats (Megachiroptera: Pteropodidae). **Journal of Tropical Ecology**. 20: 667-673.

Humes, M. L., Hayes, J. P., and Collopy, M. W. (1999). Bat activity in thinned, unthinned, and old-growth forests in western Oregon. **Journal of Wildlife Management**. 63: 553-561.

Hutson, A. M., Mickleburgh, S. P., and Racey, P. A. (2001). **Microchiropteran bats: Global status survey and conservation action plan**. Cambridge: International Union for the Conservation of Nature and Natural Resources. 268p.

Ingle, N. R. (2003). Seed dispersal by wind, birds, and bats between Philippine montane rainforest and successional vegetation. **Oecologia**. 134: 251-261.

Jones, G., Jacobs, D. S., Kunz, T. H., Willig, M. R., and Racey, P. A. (2009). Carpe noctem: the importance of bats as bioindicators. **Endangered Species Research**. 8: 93-115.

Jung, T. S., Thomson, I. D., Titman, R. D., and Applejohn, A. P. (1999). Habitat selection by forest bats in relation to mixed-wood stand types and structure in central Ontario. **Journal of Wildlife Management**. 63: 1306-1319.

Kalcounis, M. C., Hobson, K. A., Brigham, R. M., and Hecker, K. R. (1999). Bat activity in the boreal forest: importance of stand type and vertical strata. **Journal of Mammalogy**. 80: 673-682.

Kalka, M. B., Smith, A. R., and Kalko, E. K. V. (2008). Bats limit arthropods and herbivory in a tropical forest. **Science**. 320: 71.

Kalko, E. K. V., Herre, E. A., and Handley, C. O. (1996). Relation of fig fruit characteristics to fruit-eating bats in the New and Old World tropics. **Journal of Biogeography**. 23: 565-576.

Kingston, T. (2010). Research priorities for bat conservation in Southeast Asia: a consensus approach. **Biodiversity and Conservation**. 19: 471-484.

Kingston, T., Francis, C. M., Akbar, Z., and Kunz, T. H. (2003). Species richness in an insectivorous bat assemblage from Malaysia. **Journal of Tropical Ecology**. 19: 11-12.

Kingston, T., Jones, G., Akbar, Z., and Kunz, T. H. (1999). Echolocation signal design in Kerivoulinae and Murininae (Chiroptera: Vespertilionidae) from Malaysia. **Journal of Zoology**. 249: 359-374.

Krebs, C. J. (1998). **Ecology Methodology** (2nd ed.). California: Benjamin/Cummings. 624p.

Kunz, T. H. (1988). **Ecological and behavioral methods for the study of bats**. Washington, D.C.: Smithsonian Institution Press. 533p.

Kunz, T. H., de Torrez, E. B., Bauer, D., Lobova, T., and Fleming, T. H. (2011). Ecosystem services provided by bats. **Annals of the New York Academy of Sciences**. 1223: 1-38.

Lane, D. J. W., Kingston, T., and Lee, B. P. Y-H. (2006). Dramatic decline in bat species richness in Singapore, with implications for Southeast Asia. **Biological Conservation**. 131: 584-593.

Lang, A. B., Kalko, E. K. V., Römer, H., Bockholdt, C., and Dechmann, D. K. N. (2006). Activity levels of bats and katydids in relation to the lunar cycle. **Oecologia**. 146: 659-666.

Larsen, R. J., Boegler, K. A., Genoways, H. H., Masefield, W. P., Kirsch, R. A., and Pedersen, S. C. (2007). Mist netting bias, species accumulation curves, and the rediscovery of two bats on Montserrat (Lesser Antilles). **Acta Chiropterologica**. 9(2): 423-435.

Laurance, W. F. (2007). Forest destruction in tropical Asia. **Current Science**. 93: 1544-1550.

Lee, Y.-F., Kuo, Y.-M., Lin, Y.-H., Chu, W.-C., Wang, H.-H., and Wu, S.-H. (2006). Composition, diversity, and spatial relationships in anurans following wetland restoration in a managed tropical forest. **Zoological Science**. 23: 883-891.

Lee, Y.-F. and McCracken, G. F. (2004). Flight activity and food habits of three species of *Myotis* bats (Chiroptera: Vespertilionidae) in sympatry. **Zoological Studies**. 43: 589-597.

Leelapaibul, W., Bumrungsri, S., and Pattanawiboon, A. (2005). Diet of wrinkle-lipped free-tailed bat (*Tadarida plicata* Buchannan, 1800) in central Thailand: insectivorous bats potentially act as biological pest control agents. **Acta Chiropterologica**. 7(1): 111-119.

Lekagul, B. and McNeely, J. A. (1988). **Mammals of Thailand** (2nd ed.). Bangkok: Sahakarn Bhaet. 758p.

MacCarthy, K. A., Carter, T. C., Steffen, B. J., and Feldhamer, G. A. (2006). Efficacy of mist-net protocol for the Indiana bats: a video analysis. **Northeastern Naturalist**. 13(1): 25-28.

MacSwiney, M. C., Bolivar, B., Clarke, F. M., and Racey, P. A. (2009). Insectivorous bat activity at cenotes in the Yucatán Peninsula, Mexico. **Acta Chiropterologica**. 11: 139-147.

Mancina, C. A., García-Rivera, L., and Capote, R. T. (2007). Habitat use by phyllostomid bat assemblages in secondary forests of the ‘Sierra del Rosario’ Biosphere Reserve, Cuba. **Acta Chiropterologica**. 9: 203-218.

Marinho-Filho, J. S. (1991). The coexistence of two frugivorous bats and the phenology of their food plants in Brazil. **Journal of Tropical Ecology**. 7(1): 59-67.

Martin, R. E., Pine, R. H., and DeBlase, A. F. (2001). **A manual of mammalogy: With keys to families of the world** (3rd ed.). New York: McGraw-Hill. 352p.

Medellín, R. A., Equihua, M., and Amin, M. A. (2000). Bat diversity and abundance as indicators of disturbance in neotropical rainforests. **Conservation Biology**. 14: 1666-1675.

Medellín, R. and Gaona, O. (1999). Seed dispersal by bats and birds in forest and disturbed habitats in Chiapas, Mexico. **Biotropica**. 31: 478-485.

Mello, M. A. R. (2009). Temporal variation in the organization of a Neotropical assemblage of leaf-nosed bats (Chiroptera: Phyllostomidae). **Acta Oecologica**. 35: 280-286.

Mello, M. A. R., Schittini, G. M., Selig, P., and Bergallo, H. G. (2004). A test of the effects of climate and fruiting of *Piper* species (Piperaceae) on reproductive patterns of the bat *Carollia perspicillata* (Phyllostomidae). **Acta Chiropterologica**. 6(2): 309-318.

Montiel, S., Estrada, A., and León, P. (2006). Bat assemblages in a naturally fragmented ecosystem in the Yucatan Peninsula, Mexico: species richness, diversity and spatio-temporal dynamics. **Journal of Tropical Ecology**. 22: 267-276.

Moreno, C. E. and Halffter, G. (2000). Assessing the completeness of bat biodiversity inventories using species accumulation curves. **Journal of Applied Ecology**. 37: 149-158.

Moreno, C. E. and Halffter, G. (2001). Spatial and temporal analysis of α, β and γ diversities of bats in a fragmented landscape. **Biodiversity and Conservation**. 10: 367-382.

Morrison, D. W. (1978). Lunar phobia in a Neotropical fruit bat, *Artibeus jamaicensis* (Chiroptera: Phyllostomidae). **Animal Behaviour**. 26: 852-855.

Murray, K. L., Britzke, E. R., Hadley, B. M., and Robbins, L. W. (1999). Surveying bat communities: a comparison between mist nets and AnaBat II bat detector system. **Acta Chiropterologica**. 1: 105-112.

Nagorsen, D. W. and Brigham, R. M. (1993). **The mammals of British Columbia 1: Bats**. British Columbia: University of British Columbia press. 166p.

O’Farrell, M. J. and Gannon, W. L. (1999). A comparison of acoustics versus capture techniques for the inventory of bats. **Journal of Mammalogy**. 80: 24-30.

Pakarnseree, L., Nadee, N., Nabhitabhata, J., Chanard, T., Sewakhonburi, S., and Sribunchuai, P. (2003). **Study and survey on wildlife for setting up biodiversity database of the Sakaerat conservation forest area**. Bangkok: Thailand Institute of Scientific and Technological Research. 690p.

Patterson, B. D. (1994). Accumulating knowledge on the dimensions of biodiversity: systematic perspectives on Neotropical mammals. **Biodiversity Letters**. 2: 79-86.

Pech-Canche, J. M., Moreno, C. E., and Halffter, G. (2011). Additive partitioning of phyllostomid bat richness at fine and coarse spatial and temporal scales in Yucatan, Mexico. **Ecoscience**. 18(1): 42-51.

Perry, R. W., Thill, R. E., and Leslie, D. M. (2007). Selection of roosting habitat by forest bats in a diverse forest landscape. **Forest Ecology and Management**. 238: 156-166.

Phommexay, P., Satasook, C., Bates, P., Pearch, M., and Bumrungsri, S. (2011). The impact of rubber plantations on the diversity and activity of understorey insectivorous bats in southern Thailand. **Biodiversity and Conservation**. 20: 1441-1456.

Prachakchitra, A. and Thong-Aree, S. (2004). Initial report on the new-recorded bats for Thailand. (in Thai). **Journal of Wildlife in Thailand**. 12(1): 217.

Ramírez-Pulido, J. and Armella, M. A. (1987). Activity patterns of Neotropical bats (Chiroptera: Phyllostomidae) in Guerrero, Mexico. **Southwestern Naturalist**. 32: 363-370.

Rex, K., Kelm, D. H., Wiesner, K., Kunz, T. H., and Voigt, C. C. (2008). Species richness and structure of three Neotropical bat assemblages. **Biological Journal of the Linnean Society**. 94: 617-629.

Robbins, L. W., Murray, K. L., and McKenzie, P. M. (2008). Evaluating the effectiveness of the standard mist-netting protocol for the endangered Indiana bat (*Myotis sodalis*). **Northeastern Naturalist**. 15: 275-282.

Robinson, M. F., Bumrungsri, S., and Hill, J. E. (1996). Chiroptera from Thung Yai Naresuan and Huai Kha Khaeng Wildlife Sanctuaries. **Natural History Bulletin of the Siam Society**. 44: 243-247.

Robinson, M. F. and Smith, A. L. (1997). Chiroptera from Loei province, North East Thailand. **Natural History Bulletin of the Siam Society**. 45: 1-16.

Russo, D. and Jones, G. (2003). Use of foraging habitats by bats in a Mediterranean area determined by acoustic surveys: conservation implications. **Ecography**. 2: 197-209.

Rydell, J., Entwistle, A., and Racey, P. A. (1996). Timing of foraging flights of three species of bats in relation to insect activity and predation risk. **Oikos**. 76: 243-252.

Sakaerat Environmental Research Station. (2013a). **Monthly values of meteorological obsevation 2012** [On-line]. Available: http://www.tistr.or.th/ sakaerat/ Meteorlogical/Mont/2012-mont.htm. Accessed on 1 July 2013.

Sakaerat Environmental Research Station. (2013b). **Sakaerat Environmental Research Station environment** [On-line]. Available: http://www.tistr.or.th/ sakaerat/SakaeratE/Environment/environment.htm. Accessed on 1 July 2013.

Salsamendi, E., Arostegui, I., and Aihartza, J. (2012). Foraging ecology in mehely's horseshoe bats: influence of habitat structure and water availability. **Acta Chiropterologica**. 14: 121-132.

Simmons, N. B. and Voss, R. S. (1998). The mammals of Paracou, French Guiana: a Neotropical lowland rainforest fauna part 1, bats. **Bulletin of the American Museum of Natural History**. 237: 1-219.

Soberón, J. and Llorente, J. (1993). The use of species accumulation functions for the prediction of species richness. **Conservation Biology**. 7: 480-488.

ter Hofstede, H. M. and Fenton, M. B. (2005). Relationships between roost preferences, ectoparasite density, and grooming behaviour of neotropical bats.

Journal of Zoology. 266: 333-340.

Ugland, K. I., Gray, J. S., and Ellingsen, K. E. (2003). The species–accumulation curve and estimation of species richness. **Journal of Animal Ecology**. 72: 888-897.

UNESCO (2009). **Biosphere Reserves Directory** [On-line]. Available: http://www2.unesco.org/mab/br/brdir/asia/Thailandmap.htm. Accessed on 1 July 2013.

Voigt, C. C., Sörgel, K., and Dechmann, D. K. N. (2010). Refueling while flying: foraging bats combust food rapidly and directly to power flight. **Ecology**. 91: 2908-2917.

Voss, R. S. and Emmons, L. H. (1996). Mammalian diversity in Neotropical lowland rainforests: a preliminary assessment. **Bulletin of the American Museum of Natural History**. 230: 1-115.

Wilhide, J. D., Harvey, M. J., McDaniel, V. R., and Hoffman, V. E. (1998). Highland pond utilization by bats in the Ozark National Forest, Arkansas. **Journal of the Arkansas Academy of Sciences**. 52: 110-112.

Winhold, L. and Kurta, A. (2008). Netting surveys for bats in the northeast: difference associated with habitat, duration of netting, and use of consecutive nights. **Northeastern Naturalist**. 15: 263-274.

Zar, J. H. (1999). **Biostatistical analysis** (4th ed.). New Jersey: Prentice Hall. 662p.

CHAPTER IV

DIET OF BATS IN SEKAERAT ENVIRONMENTAL RESEARCH STATION

4.1 Abstract

The trophic ecology of bat community in Sakaerat Environmental Research Station was studied during June 2013 to May 2014. Bats were captured using mist nets and their faecal pellets were collected for dietary analysis. Simultaneously, fruit availability was surveyed using transect survey and nocturnal flying insects were collected using light traps. Fruit availability for frugivorous bats was 21 plant species and insect availability for insectivorous bats was 15 insect orders. The orders Coleoptera, Hymenoptera, Lepidoptera, and Hemiptera were the common insect diet. Coleoptera was the highest biomass of insect order, followed by Hemiptera, and Lepidoptera, respectively. Dietary analysis of 225 faecal pellets from 45 insectivorous bats showed that bats consumed 7 orders of insects, including Coleoptera (beetles), Lepidoptera (butterflies), Diptera (flies), Hymenoptera (bees, wasps), Hemiptera (bugs), Isoptera (termites), and Orthoptera (locusts, grasshoppers). The two most frequent insect orders in the faecal pellets were Coleoptera (%f = 70.22%) and Lepidoptera (%f = 59.56%). There was no relationship between food availability and bat abundance. The trophic niche breadths of insectivorous bats varied from 0.133 to 0.359. The widest trophic niche breath was found in *Megaderma spasma* (B_A = 0.359). The trophic niche overlap of insectivorous bats ranged from 0.013 to 0.31. The trophic

niche overlap was highest between *Hipposideros diadema* and *Myotis muricola* (Morishita-Horn index = 0.31).

4.2 Introduction

A major question of community ecology is "what are functions of species coexistence in a community?" (Begon, Townsend, and Harper, 2006). Resource partitioning is an important function in community ecology (Findley, 1993). Naturally, coexisting species within a community often partition their resources to separate their ecological niches (Leibold and McPeek, 2006). One of the most important components of an ecological niche is the trophic niche, which is examination for diet and foraging behavior of species in a community (Smirnov and Vekhnik, 2014).

Bats are a good model for examining the trophic niche because their local assemblages are usually rich and can consume a wild variety of plants and animals (Mello, 2009). Subsequently, they have impacts on immobilization and mineralization of nutrients and energy in ecosystems (Medellín and Gaona, 1999; Rainey, Pierson, Colbene, and Barclay, 1992). A bat community usually comprise of coexistence of sympatric species which is promoted by niche differentiation in food resources (Siemers, Greif, Borissov, Voigt-Heucke, and Voigt, 2011; Fukui, Okazaki, and Maeda, 2009; Aguiar and Antonini, 2008; Bumrungsri, Leelapaibul, and Racey, 2007; Arlettaz, Perrin, and Hausser, 1997). Thus, investigating diet among coexisting bats is a key to understand the function of species coexistence.

Several dietary studies of bats have emphasized on interactions between single species of bat and their diets, resulting in an incomplete picture of bat community. There are few studies on food resource partitioning among coexisting bat species.

Study on food items consumed by coexisting species is important to determine functions of resource partitioning among bats (*Munin*, Fisher, and Gonçalvez, 2012).

The purposes of this study were to describe the food preferences and trophic niches among bats in Sakaerat Environmental Research Station, Nakhon Ratchasima, Thailand which help us to better understand the function of species coexistence of bat community.

4.3 Materials and methods

4.3.1 Data collection

Fecal pellets were collected from the cloth bags, air-dried and kept in vials for later analyses. In the laboratory, five fecal pellets were randomly selected from each bat for the analysis. Pellets were softened in 70% ethyl alcohol and teased apart using a dissection needle under a stereo microscope (Whitaker, 2004). Fecal contents were grouped into six categories (seeds, fruit pulp, arthropods, pollen and flower parts, leaves, and undetermined) and identified by comparison with a reference collection which is collected in the study area.

4.3.2 Fruit availability

The available food of bats was sampled at the bat sampling plots and coincide with the periods of bat samplings. Fruit trees were surveyed using two of 1 km-long transects per habitat type (Marques, Pereira, and Palmeirim, 2012). Fruiting season was obtained from the website of SERS (Sakaerat Environmental Research Station, 2013).

4.3.3 Insect availability

Insect preys were trapped using light traps (8-W white florescent, Lampton) and buckets filled with ethyl acetate. The light traps were set up at 1 m above the ground, about 100 m from mist nets. Traps were open from 18.00 to 24.00. Trapped insects were stored in 70% ethyl alcohol and identified to order level (Matthews, Neiswenter, and Ammerman, 2010). Then, insects were dried at 50°C for up to 40 hours and weighed to estimate biomass (Gullan and Cranston, 2014).

4.3.4 Data analysis

4.3.4.1 Percentage frequency (%f)

The percentage frequency of occurrence provides a measure of the commonness of each food item in the diet (Whitaker, 1988). It was calculated by the following formula:

$$\%f = (\text{Number of pellet containing a particular item / Total samples}) \times 100 \tag{4.1}$$

4.3.4.2 Percentage volume (%v)

The percentage volume of food items provides a measure of the proportion of each food item in the diet (Whitaker, 1988). It was calculated by the following formula:

$$\%v = (\text{Sum of individual volume of food / Total volume}) \times 100 \tag{4.2}$$

4.3.4.3 Food niche breadth

The food niche breadth was calculated using the Levins's standardized niche breadth (Krebs, 1998).

$$B_A = (B - 1) / (n - 1) \qquad (4.3)$$

where B_A = Levins's standardized niche breadth

B = Levins's measure of niche breadth

n = the number of food items available

Then Levins's measure of niche breadth was calculated by the following formula:

$$B = 1/\sum_{i=1}^{n} p_i^2 \qquad (4.4)$$

where B = Levins's measure of niche breadth

p_i = the frequency of food items i in the total sample

4.3.4.4 Food niche overlap

The food niche overlap among bat species was determined using Morisita-Horn index (Krebs, 1998).

$$C_H = 2\sum_{i=1}^{n} p_{ij}p_{ik} / \sum_{i=1}^{n} p^2{}_{ij} + \sum_{i=1}^{n} p^2{}_{ik} \qquad (4.5)$$

Where C_H = the Morisita's index of niche overlap between species j and k

p_{ij} = the proportion of a resource i in the total resources used by species j

p_{ik} = the proportion of a resource i in the total resources used by species k

4.3.4.5 Parameters of food availability

Relative abundance of available fruit was calculated as number of fruit trees per kilometer (Marques, Pereira, and Palmeirim, 2012). The presence of insects in each trap was calculated as percentage frequency and the number of insects captured per habitat per night was used as relative abundance of insect preys.

4.3.4.6 Diversity of food availability and diet of bats

Shannon-Wiener diversity index was used to quantify diversity of bats among habitats (Krebs, 1998).

$$H' = -\sum_{i=1}^{s} P_i \ln P_i \qquad (4.6)$$

where H'= Shannon-Wiener diversity index

P_i = the proportion of individuals in the i species

s = total number of species

4.3.4.7 Equitability of fruit trees

Shannon-Wiener evenness index was used to quantify equitability of bats among habitats (Krebs, 1998).

$$E_{\mathrm{H}} = H / H_{\mathrm{max}} \qquad (4.7)$$

where E = Shannon-Wiener evenness index

H' = Shannon-Wiener diversity index

H'_{max} = ln S

4.3.4.8 Similarity of fruit trees

Sorensen's coefficient was used to compare similarity in bat species assemblages among habitats (Krebs, 1998).

$$CC = 2C / A + B \tag{4.8}$$

where CC = Sorenson's coefficient

C = the number of species shared by the two communities

A = the number of species in community A

B = the number of species in community B

4.3.4.9 Similarity of insect communities

Species-based similarity

The species-based similarity of trapped insects was calculated using Jaccard's similarity coefficient (Krebs, 1998).

$$Sj = a / (a + b + c) \tag{4.9}$$

Where Sj = Jaccard's similarity coefficient

a = number of insect orders in sample a and sample b

b = number of insect orders in sample b but not in sample a

c = number of insect orders in sample a but not in sample b

Dominance-based similarity

The dominance-based similarity of trapped insects was calculated using Renkonen similarity index (Krebs, 1998).

$$P = \sum_i minimun\ (p_{1i} p_{2i}) \tag{4.10}$$

Where P = percentage similarity between sample 1 and 2

P_{1i} = percentage of orders i in community sample 1

P_{2i} = percentage of orders i in community sample 2

Combined species and dominance-based

The combined species and dominance-based similarity of trapped insects was calculated using Wainstein index (Kusch and Schotte, 2007).

$$K_w = Sj \times P \tag{4.11}$$

Where K_w = Wainstein index

Sj = Jaccard’s similarity coefficient

P = Renkonen similarity index

4.3.4.10 Statistical analysis

Chi-square was used to compare frequency of occurrence data of food items among bat species. Difference in mean percentage volume of diets among bat species was examined using Kruskal-Wallis *H*-test. Spearman’s rank correlation coefficient was used to test correlation between bat abundance in each habitat and in each season and parameters of food availability (Zar, 1999). Statistical analyses were performed using PASW Statistics 18 (IBM) with 95% confidence interval.

4.4 Results

4.4.1 Fruit tree availability

A total of 21 species of fruit trees were recorded along eight transect samplings in SERS. Of these, 7 species were found in dry dipterocarp forest, 13 species were found in ecotone, 7 species were found in dry evergreen forest, and three species were found in plantation forest (Table 4.1). There were 17 species fruiting in the rainy season, 7 species fruiting in the winter, and 15 species fruiting in the summer (Table 4.2). Total number of fruit trees was 136 trees and relative abundance of fruit trees was 17 trees/km. The most common fruit tree was *Memecylon ovatum* representing 17.65% of total fruit tree (n = 24).

The highest abundance of fruit trees was found in dry evergreen forest (24.5 trees/km) followed by dry dipterocarp forest (20.5 trees/km), ecotone (17.5 trees/km), and plantation forest (5.5 trees/km), respectively (Table 4.1). However, there was no significant difference in the number of fruit trees among different habitats (F = 1.036, df = 3, p = 0.381).

Total diversity of fruit trees was 2.626 while total evenness of fruit trees was 0.863. The highest diversity of fruit trees was recorded in ecotone (2.2), followed by dry dipterocarp forest (1.695), dry evergreen forest (1.493), and plantation forest (1.036), respectively. Significant differences in diversity of fruit trees were found between ecotone and dry evergreen forest (t = -2.1443, df = 76.706, p = 0.035) and between ecotone and plantation forest (t = -2.2837, df = 16.212, p = 0.036) while diversity of fruit trees in other habitats was not different. The Shannon-Wiener evenness index was highest in plantation forest (0.9432), followed by dry dipterocarp forest (0.8711), ecotone (0.8579), and dry evergreen forest (0.7674), respectively. The similarity index of tree species ranged from 0 to 0.3, indicated that tree species among habitats in SERS were different.

The data on statistical analysis indicated that no relationship between total bat abundance and total number of fruit trees in SERS (r_s = - 0.494, p = 0.177). There was also no relationship between frugivorous bat abundance and total number of fruit trees (r_s = - 0.5, p = 0.667).

Table 4.1 Number and relative abundance (trees/km) of fruit trees among habitats in SERS.

Plant species	Dry dipterocarp forest		Ecotone		Dry evergreen forest		Plantation forest	
	n	Relative abundance	n	Relative abundance	n	Relative abundance	n	Relative abundance
Canarium subulatum	7	3.5	-	-	1	0.5	-	-
Phyllanthus emblica	10	5	-	-	-	-	-	-
Mangifera caloneura	6	3	-	-	-	-	-	-
Buchanania lanzan	4	2	-	-	-	-	-	-
Antidesma ghaesembilla	1	0.5	-	-	-	-	-	-
Morinda coreia	12	6	1	0.5	-	-	-	-
Spondias pinnata	1	0.5	1	0.5	-	-	-	-
Walsura trichostemon	-	-	4	2	15	7.5	-	-
Grewia hirsute	-	-	2	1	-	-	-	-
Dialium cochinchinense	-	-	5	2.5	-	-	2	1
Morinda coreia	-	-	3	1.5	1	0.5	-	-
Nephelium hypoleucum	-	-	11	5.5	-	-	4	2
Microcos tomentosa	-	-	1	0.5	-	-	-	-
Streblus asper	-	-	1	0.5	7	3.5	-	-
Ficus annulata	-	-	2	1	-	-	-	-
Ailanthus triphysa	-	-	1	0.5	-	-	-	-
Garcinia cowa	-	-	1	0.5	-	-	-	-
Diospyros malabarica	-	-	2	1	-	-	-	-
Flacourtia indica	-	-	-	-	6	3	-	-
Aglaia edulis	-	-	-	-	19	5	5	2.5
Memecylon ovatum	-	3.5	-	-	1	0.5	-	-
Total	41	20.5	35	17.5	49	24.5	11	5.5

Table 4.2 Fruiting seasons of fruit trees in SERS (rainy season: June-October, winter: November-February, summer: March-May).

Plant species	**Rainy season**					**Winter**				**Summer**		
	Jun	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Canarium subulatum		✓	✓	✓								
Phyllanthus emblica	✓	✓	✓									
Mangifera caloneura									✓	✓	✓	✓
Buchanania lanzan	✓										✓	✓
Antidesma ghaesembilla	✓	✓										✓
Morinda coreia	✓	✓										✓
Spondias pinnata	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Walsura trichostemon	✓											✓
Grewia hirsute				✓	✓	✓						
Dialium cochinchinense				✓	✓	✓	✓					
Morinda coreia	✓	✓										✓
Nephelium hypoleucum										✓	✓	✓
Microcos tomentosa					✓	✓						
Streblus asper										✓	✓	
Ficus annulata	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ailanthus triphysa											✓	✓
Garcinia cowa	✓									✓	✓	✓
Diospyros malabarica	✓	✓	✓	✓	✓	✓	✓					✓
Flacourtia indica	✓										✓	✓
Aglaia edulis	✓										✓	✓
Memecylon ovatum	✓	✓										

4.4.2 Insect availability

4.4.2.1 Nocturnal insect community in SERS

A total of 36 nights of light trapping yielded 23,155 insects of 15 orders (non-insects and wingless insects were excluded), including Trichoptera, Hymenoptera, Phasmida, Isoptera, Mantodea, Blattaria, Diptera, Orthoptera, Hemiptera, Coleoptera, Lepidoptera, Ephemeroptera, Odonata, Psocoptera, and Mecoptera. Of these, Coleoptera was the most common insect order (41.5% of total capture), followed by Hymenoptera (21.15% of total capture). Other common insect orders included Lepidoptera (15.75% of total capture) and Hemiptera (14.18% of total capture) (Table 4.3).

Relative abundance of insects was 321.6 insects/trap. Total biomass of insects was 4,770.37 g. The highest biomass of insects was order Coleoptera (56.38% of total biomass), followed by order Hemiptera (17.6% of total biomass), and order Lepidoptera (15.56% of total biomass), respectively. The Shannon-Wiener diversity index and the Shannon-Wiener evenness index for all insects in the area were 1.588 and 0.586, respectively. There was no relationship between insectivorous bat abundance and total number of insect (r_s = - 0.486, p = 0.329) and between insectivorous bat abundance and total biomass of insects in SERS (r_s = - 0.314, p = 0.544).

Table 4.3 Number and biomass (g) of insect communities in SERS from June 2013 to May 2014.

Insect orders	Number	% of total capture	Biomass	% Biomass	Insects/trap
Trichoptera	353	1.53	20.761	0.435	4.9

Table 4.3 (Continued) Number and biomass (g) of insect communities in SERS from June 2013 to May 2014.

Insect orders	Number	% of total capture	Biomass	% Biomass	Insects/trap
Hymenoptera	4897	21.15	119.594	2.507	68.01
Phasmida	89	0.38	1.14	0.024	1.24
Isoptera	110	0.48	2.848	0.06	1.53
Mantodea	52	0.23	13.847	0.29	0.72
Blattaria	493	2.13	171.585	3.597	6.85
Diptera	157	0.68	1.633	0.034	2.18
Orthoptera	419	1.81	167.328	3.508	5.82
Hemiptera	3285	14.19	839.444	17.598	45.63
Coleoptera	9609	41.5	2689.382	56.379	133.46
Lepidoptera	3649	15.75	742.182	15.56	50.68
Ephemeroptera	15	0.07	0.294	0.006	0.21
Odonata	21	0.09	0.147	0.003	0.29
Psocoptera	2	0.01	0.002	0	0.03
Mecoptera	4	0.02	0.182	0.004	0.06
Total	**23155**	**100**	**4770.369**	**100**	**321.6**

4.4.2.2 Insect diversity, abundance, and biomass among habitats

A total of 3,055 insects of 12 insect orders were captured in dry dipterocarp forest, including Trichoptera, Hymenoptera, Phasmida, Isoptera, Mantodea, Blattaria, Diptera, Orthoptera, Hemiptera, Coleoptera, Lepidoptera, and Ephemeroptera. The order Odonata, Psocoptera, and Mecoptera were not found in dry dipteracarp forest (Table 4.4). The most common insect order in this area was Coleoptera (42.2% of total capture). The other common insect orders were Hymenoptera (32.21% of total capture) and Lepidoptera (18% of total capture). Relative abundance of insects was 169.72 insects/trap. Insect biomass was 412.98 g and average insect biomass was 22.94 g/trap. The highest biomass in dry dipterocarp forest was Coleoptera (62.99% of total biomass) and the second highest biomass was Lepidoptera (20.99% of total biomass). The Shannon-Wiener diversity index and the Shannon-Wiener evenness index for insects in dry dipterocarp forest were 1.588 and 0.543, respectively.

In total, 4,759 insects of 13 orders were captured in ecotone including, Trichoptera, Hymenoptera, Phasmida, Mantodea, Blattaria, Diptera, Orthoptera, Hemiptera, Coleoptera, Lepidoptera, Ephemeroptera, Odonata, and Psocoptera. The order Isoptera and Mecoptera were not found in ecotone (Table 4.4). The common insects in this area were coleopterans (48.2% of total capture) and hymenopterans (22.23% of total capture). Relative abundance of insects was 246.38 insects/trap. Insect biomass was 1,215.4 g and average biomass was 67.52 g/trap. The highest biomass was order Coleoptera (77.95% of total biomass). Diversity of insects in ecotone was 1.495 while equitability of insects was 0.583.

There were 6,752 individuals of 13 orders in dry evergreen forest, consisting Trichoptera, Hymenoptera, Phasmida, Isoptera, Mantodea, Blattaria, Diptera, Orthoptera, Hemiptera, Coleoptera, Lepidoptera, Odonata, and Mecoptera. The order Ephemeroptera and Psocoptera were not captured in dry evergreen forest (Table 4.4). Relative abundance of insects was 375.11 insects/trap. The highest abundance of insects were coleopterans (33.23% of total capture), followed by hymenopterans (27.24% of total capture) and lepidopterans (18.81% of total capture), respectively. Insect biomass was 1,318.55 g and average insect biomass was 73.25 g/trap. The highest biomass of insect orders was Coleoptera (48.31% of total biomass), followed by Hemiptera (26.05% of total biomass) and Lepidaoptera (14.34% of total biomass), respectively (Table 4.4). Diversity of insects in ecotone was 1.627 while equitability of insects was 0.634.

In plantation forest 8,589 insects of 11 insect orders were captured (Table 4.4). Relative abundance of insects was 477.17 insects/trap, consisting Trichoptera, Hymenoptera, Phasmida, Isoptera, Mantodea, Blattaria, Diptera, Orthoptera, Hemiptera, Coleoptera, and Lepidoptera. The orders Ephemeroptera, Odonata, Psocoptera, and Mecoptera were not captured in plantation forest (Table 4.4). The most common insect order was Coleoptera (43.97% of total capture), followed by Hemiptera (17.95% of total capture) and Lepidoptera (17.86% of total capture), respectively. Insect biomass was 1,823.45 g and average insect biomass was 102.3 g/trap. The highest biomass of insects was Coleoptera (46.35% of total biomass), followed by Hemiptera (21.81% of total biomass) and Lepidoptera (19.83% of total biomass), respectively. The diversity index of insects was 1.568 while the evenness index of insects was 0.654.

The number of captured insects in this study was not different among habitats (F = 1.638, df = 3, p = 0.17). Moreover, the biomass of insects also was not different among habitats (F = 0.962, df = 3, p = 0.41). However, most insect diversities were different among habitats i.e. dry dipterocarp forest and dry evergreen forest (t = 15.783, df = 4774.4, p = 0.000), dry dipterocarp forest and plantation forest (t = 7.987, df = 6710.2, p = 0.000), ecotone and dry evergreen forest (t = 12.482, df = 6690, p = 0.000), ecotone and plantation forest (t = 5.822, df = 8755.9, p = 0.000), and dry evergreen forest and plantation forest (t = 8.539, df = 14554, p = 0.000). Only insect diversity between dry dipterocarp forest and ecotone was not different (t = 1.28, df =

7766.7, *p* = 0.201). The values of similarity index among habitats ranged from 0.73 to 0.87 (Jaccard index), from 65.03 to 97.95 (Renkonen index), and from 51.11 to 78.58 (Wainstein index) (Table 4.5).

Table 4.4 Number and biomass (g) of insect communities among habitats in SERS from June 2013 to May 2014.

Insect orders	**Dry dipterocarp forest**		**Ecotone**		**Dry evergreen forest**		**Plantation forest**	
	Number	**Biomass**	**Number**	**Biomass**	**Number**	**Biomass**	**Number**	**Biomass**
Trichoptera	70	4.13	80	4.68	118	6.96	85	4.99
Hymenoptera	983	18.08	1058	24.89	1839	50.69	1017	25.94
Phasmida	7	0.04	33	0.2	19	0.11	30	0.79
Isoptera	3	0.09	-	-	55	0.95	52	1.81
Mantodea	8	1.59	28	8.36	7	1.62	9	2.28
Blattaria	6	1.89	128	41.39	123	43.03	236	85.27
Diptera	24	0.72	42	0.42	38	0.31	53	0.18
Orthoptera	8	4.6	39	19.83	118	45.02	254	97.88
Hemiptera	90	34.76	383	63.63	1270	343.44	1542	397.6
Coleoptera	1294	260.01	2294	947.35	2244	636.93	3777	845.1
Lepidoptera	552	86.63	660	104.57	903	189.19	1534	361.62
Ephemeroptera	10	0.26	5	0.03	-	-	-	-
Odonata	-	-	7	0.05	14	0.1	-	-
Psocoptera	-	-	2	0	-	-	-	-
Mecoptera	-	-	-	-	4	0.18	-	-
Total	3055	412.98	4759	1215.4	6752	1318.55	8589	1823.45
Insects/trap	169.72	22.94	264.38	67.52	375.11	73.25	477.17	101.30

Table 4.5 Similarity of insect communities among habitats in SERS from June 2013 to May 2014; DDF = dry dipterocarp forest, ECO = ecotone, DEF = dry ever green forest, PTF = plantation forest.

Habitats	Jaccard index	Renkonen index	Wainstein index
DDF x ECO	0.78	65.03	51.11
DDF x DEF	0.78	79.99	62.87
DDF x PTF	0.8	82.06	65.65
ECO x DEF	0.73	82.29	60.32
ECO x PTF	0.87	97.95	76.25
DEF x PTF	0.87	90.63	78.58

4.4.2.3 Insect diversity, abundance, and biomass among seasons

A total of 3,632 insects of 12 orders were recorded in the rainy season, including Trichoptera, Hymenoptera, Phasmida, Isoptera, Mantodea, Blattaria, Diptera, Orthoptera, Hemiptera, Coleoptera, Lepidoptera, and Ephemeroptera. The orders Odonata, Psocoptera, and Mecoptera were not captured in the rainy season (Table 4.6). The highest abundance insect order in this season was Hymenoptera (52.91% of total capture), followed by Coleoptera (18.79% of total capture), and Lepidoptera (18.77% of total capture), respectively. Relative abundance of insects was 151.33 insects/trap. Total insect biomass was 326.4 g and average insect biomass was 13.6 g/trap. The highest biomass was order Coleoptera (51.11% of total biomass), followed by Lepidoptera (26.45% of total biomass). Diversity of insects in the rainy season was 1.367 while equitability of insects was 0.55.

There were 1,627 individuals of 8 insect orders in the winter, including Trichoptera, Hymenoptera, Diptera, Hemiptera, Coleoptera, Lepidoptera, Odonata, and Psocoptera. Other 7 insect orders were not found i.e. Phasmida, Isoptera, Mantodea, Blattaria, Orthoptera, Odonata, and Mecoptera (Table 4.6). The common insects were Hymenopterans (46.59% of total capture) and Coleopterans (37.8% of total capture). Relative abundance of insects was 67.79 insects/trap. Insect biomass in the winter was 148.73 g and average insect biomass was 6.19 g/trap. The highest biomass was Lepidoptera (53.46% of total biomass), followed by Coleoptera (26.04% of total biomass). The Shannon-Wiener diversity index was 1.24 while the Shannon-Wiener evenness index was of insects was 0.6.

In the summer, 17,896 insects of 13 orders were captured, including Trichoptera, Hymenoptera, Phasmida, Isoptera, Mantodea, Blattaria, Diptera, Orthoptera, Hemiptera, Coleoptera, Lepidoptera, Odonata, and Mecoptera. The order Psocoptera and Ephemeroptera were not captured in the rainy season (Table 4.6). Coleopterans were the most captured insects (49.3% of total capture), followed by hemipterans (17.9% of total capture) and lepidopterans (13.1% of total capture), respectively. Relative abundance of captured insects was 745.67 insects/trap. Total biomass of insect in this season was 4295.25 g and average biomass was 178.97 g/trap. Coleopteran was the highest biomass of insects in this season (57.83% of total biomass). The diversity of insects in the summer was 1.482 while the evenness index of insects was 0.578.

The individuals of insects differed among seasons (*F* = 5.356, df = 2, *p* = 0.005). The total insect biomass also differed among seasons (*F* = 5.135, df = 2, *p* = 0.006). Moreover, insect diversities differed between the summer and the rainy season (*t* = 6.146, df = 5064.8, *p* = 0.000) and between the summer and the winter (*t* = - 8.044, df = 2028.7, *p* = 0.000). However, insect diversity was not different between the rainy season and the winter (*t* = -1.498, df = 4080.1, *p* = 0.134). The values of similarity index among seasons ranged from 0.43 to 0.79 (Jaccard index), from 30.75 to 77.03 (Renkonen index), and from 15.36 to 34.84 (Wainstein index) (Table 4.7).

Table 4.6 Number and biomass (g) of insect communities among seasons in SERS from June 2013 to May 2014.

Insect orders	Rainy season		Winter		Summer	
	Number	**Biomass**	**Number**	**Biomass**	**Number**	**Biomass**
Trichoptera	67	3.93	59	3.48	227	13.35
Hymenoptera	1920	39.12	758	16.42	2219	64.06
Phasmida	88	0.53	-	-	1	0.61
Isoptera	22	1.42	-	-	88	1.43
Mantodea	7	1.29	-	-	45	12.56
Blattaria	10	2.54	-	-	483	169.05
Diptera	69	0.76	50	0.26	38	0.61
Orthoptera	8	3.54	-	-	411	163.79
Hemiptera	60	19.78	28	10.25	3197	809.42
Coleoptera	684	166.73	103	38.72	8824	2483.93
Lepidoptera	681	86.47	615	79.52	2350	576.2
Ephemeroptera	15	0.29	-	-	-	-
Odonata	-	-	12	0.08	9	0.06
Psocoptera	-	-	2	0	-	-
Mecoptera	-	-	-	-	4	0.18
Total	3632	326.4	1627	148.73	17896	4295.25
Insects/trap	151.33	13.6	67.79	6.19	745.67	178.97

Table 4.7 Similarity of insect communities among seasons in SERS from June 2013 to May 2014.

Seasons	Jaccard index	Renkonen index	Wainstein index
rainy season x winter	0.43	77.03	33.05
rainy season x summer	0.79	44.32	34.84
winter x summer	0.5	30.75	15.38

4.4.3 Diet of bat community in SERS

A total of 257 faecal pellets were collected from 45 individuals of 6 insectivorous bats species (5.71 pellets/bat). However, 5 pellets per bat were used to examine the diet of bats in this study. Then, 225 from 45 individual bats pellets were analyzed representing 115 pellets of 23 *Hipposideros larvatus*, 20 pellets of 4 *Hipposideros diadema*, *30 pellets of 6 Megaderma spasma*, 15 pellets of 3 *Chaerephon plicata*, *25 pellets of 5 Rhinolophus affinis*, and 20 pellets of 4 *Myotis muricola*. The faecal pellets of frugivorous bats were excluded from diet analysis because they were semi-solid matters which could not collected from the sampling bags in this study.

All faecal pellets of insectivorous bats contained entire insect remains. There were no plant materials or other animal parts in the pellets. The number of preys in each sample varied from 1 to 4 items. The insect remains in the pellets were classified into 8 groups i.e. Coleoptera, Lepidoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, Orthoptera, and unidentified group. The most frequent insect orders presented in the pellets was Coleoptera (%f = 70.22%), followed by Lepidoptera (%f = 59.56%). The other remain taxa were uncommon diet of bat community in SERS (%f < 15%) (Figure 4.1).

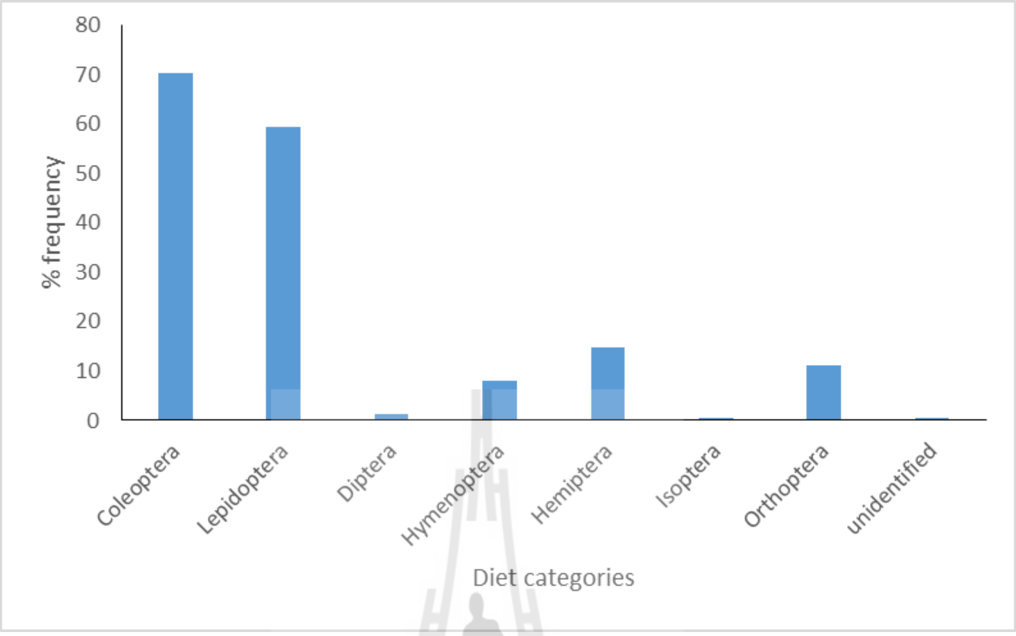

Figure 4.1 Percentage frequency of occurrence (%f) of diet categories of insectivorous bats in SERS from June 2013 to May 2014.

4.4.4 Diet composition among bat species

Hipposideros larvatus

The faecal analysis of 115 pellets from 23 bats revealed that *Hipposideros larvatus* consumed six orders of insects i.e. Coleoptera, Lepidoptera, Diptera, Hymenoptera, Hemiptera, and Isoptera. Of these, Coleoptera were the most frequently consumed by *Hipposideros larvatus* (%f = 84.35%), followed by the orders Lepidoptera (%f = 58.25%), and Hymenoptera (%f = 11.3%), respectively. The coleopterans were also the highest volume in the diet of bats (%v = 84.26% ± 6.36 SE). The other high volume of insects in the diet were lepidopterans (%v = 34.29% ± 11.2 SE) and hymenopterans (%v = 23.2% ± 16.86 SE). The other remain taxa were occasionally consumed by bats (%f < 5%; %v $\leq$ 10%) (Table 4.8). The diversity of insects in the diet of *Hipposideros larvatus* was 1.085 whereas the evenness of insects in the diet was 0.606.

Hipposideros diadema

A total of 20 pellets from 4 individuals of *Hipposideros diadema were analyzed for diet composition. There were only 2 insect orders in their diet i.e. Coleoptera and Lepidoptera. Both* percentage frequency of occurrence and percentage volume of Coleoptera (%f = 100%; %v = 97.5% ± 1.04 SE) in the diet were higher than Lepidoptera (%f = 70%; %v = 3.33% ± 0.88 SE) (Table 4.8). The Shannon-Wiener diversity index of diets was 0.678 while the Shannon-Wiener evenness index was 0.977.

Megaderma spasma

In total, *30 pellets from 6 individuals of Megaderma spasma* were examined the *diet composition. The diet of Megaderma spasma* contained 4 insect orders, comprising Coleoptera, Lepidoptera, Hymenoptera, and Orthoptera. Orthopterans were the most frequent diet for *Megaderma spasma* (%f = 83%). They also were the highest volume in the diet of *Megaderma spasma* (%v = 96.4% ± 1.81 SE). Furthermore, *Megaderma spasma* sometimes consumed coleopterans (%f = 30%; %v = 55% ± 45 SE) and lepidopterans (%f = 30%; %v = 51.5% ± 46.5 SE). Hymenopterans were rarely consumed by *Megaderma spasma* (%f = 6.7%; %v = 2%) (Table 4.8). The diversity index of diet was 1.109 while the evenness index of diet was 0.8.

Chaerephon plicata

The diet analysis of 15 pellets from 3 bats indicated that *Chaerephon plicata* consumed 3 orders of insects, including Coleoptera, Hymenoptera, and Hemiptera. Of these, Hemiptera was the most important diet of *Chaerephon plicata (*%f = 100%; %v

= 58.33% ± 23.1 SE*), followed by Coleoptera (*%f = 66.67%; %v = 60% ± 20 SE*) and Hymenoptera (*%f = 20%; %v = 15%*), respectively (Table 4.8).* The diversity index of diet was 0.941 whereas the evenness index was 0.857.

Rhinolophus affinis

A total of 25 pellets of 5 individuals of *Rhinolophus affinis* were analyzed for diet composition. Diet of *Rhinolophus affinis* contained 3 insect orders i.e. Coleoptera, Lepidoptera, and Hemiptera. Of these, the order Lepidoptera was the most frequently found in the diet of *Rhinolophus affinis* (%f = 100%). The second order frequency of prey in the diet was Hemiptera (%f = 52%) and the third order frequency of prey was Coleoptera (%f = 16%). Based on percentage volume, Lepidopterans were the highest volume in the diet of *Rhinolophus affinis* (%v = 78% ± 18.34 SE), followed by coleopterans (%v = 60%) and hemipterans (%v = 16.67 ± 9.2 SE), respectively (Table 4.8). The diversity of diet was 0.896 while the equitability of diet was 0.815.

Myotis muricola

The diet analysis of 20 pellets from 4 bats revealed that *Myotis muricola consumed 2 orders of insects i.e. Coleoptera and Lepidoptera, with one unidentified insect. Myotis muricola frequently consumed both the order Lepidoptera (%f = 95%) and Coleoptera (%f = 90%). However, the volume of Coleoptera (%v = 95% ± 2.04 SE) in the diet was higher than Lepidoptera (%v = 5% ± 0 SE) (Table 4.8).* The diversity of diet of *Myotis muricola* was 0.796 whereas the equitability of diet was 0.725.

A statistical analysis of frequency of food items indicated that among six bat species consumed prey items differed significantly ($\chi^2 = 69.257$, df = 30, *p* = 0.00).

However, the percentage volume of diets did not differ among 6 bat species (H = 3.152, df = 5, p = 0.677).

Table 4.8 Percentage frequency of occurrence (%f) and percentage volume (%v ± SE) of food items of insectivorous bats in SERS from June 2013 to May 2014 (number of pellets analyzed for each bat species = 5 x bat individual).

Food items	***H. larvatus* (23)**		***H. diadema* (4)**		***M. spasma* (6)**		***C. plicata* (3)**		***R. affinis* (5)**		***M. muricola* (4)**	
	%f	**%v**	**%f**	**%v**	**%f**	**%v**	**%f**	**%v**	**%f**	**%v**	**%f**	**%v**
Coleoptera	84.35	84.26 ± 6.35	100	97.5 ± 1.04	30	55 ± 45	66.67	60 ± 20	16	60	90	95 ± 2.04
Lepidoptera	58.26	34.29 ± 11.2	70	3.33 ± 0.88	30	51.5 ± 46.5	-	-	100	78 ± 18.34	95	5 ± 0
Diptera	2.61	6	-	-	-	-	-	-	-	-	-	-
Hymenoptera	11.3	23.2 ± 16.86	-	-	6.7	2	20	15	-	-	-	-
Hemiptera	4.35	10	-	-	-	-	100	58.33 ± 23.1	52	16.67 ± 9.2	-	-
Isoptera	0.87	1	-	-	-	-	-	-	-	-	-	-
Orthoptera	-	-	-	-	83	96.4 ± 1.81	-	-	-	-	-	-
Unidentified	-	-	-	-	-	-	-	-	-	-	0.14	10

4.4.5 Trophic niche breadth and niche overlap

The Levins's standardized niche breadth indicated that trophic niche breadths of insectivorous bats varied from 0.133 to 0.359. *Megaderma spasma* exhibited the widest niche breath (B_A = 0.359), followed by *Hipposideros larvatus* (B_A = 0.319) and *Chaerephon plicata* (B_A = 0.262), respectively. The fourth widest niche breath was *Rhinolophus affinis* (B_A = 0.219) and the fifth widest niche breath was *Hipposideros diadema* (B_A = 0.16). Finally, *Myotis muricola* displayed the narrowest niche breaths in this bat community (B_A = 0.133) (Figure 4.2).

The Morisita-Horn index revealed that trophic niche overlap among 6 species of insectivorous bats ranged from 0.013 to 0.31. The trophic niche overlaps were highest between *Hipposideros diadema* and *Myotis muricola* (Morishita-Horn index = 0.31), followed by between *Hipposideros larvatus* and *Myotis muricola* (Morishita-Horn index = 0.234) and between *Hipposideros larvatus* and *Hipposideros diadema* (Morishita-Horn index = 0.208), respectively. The other species displayed very low trophic niche overlap (Morishita-Horn index < 0.129) (Table 4.9).

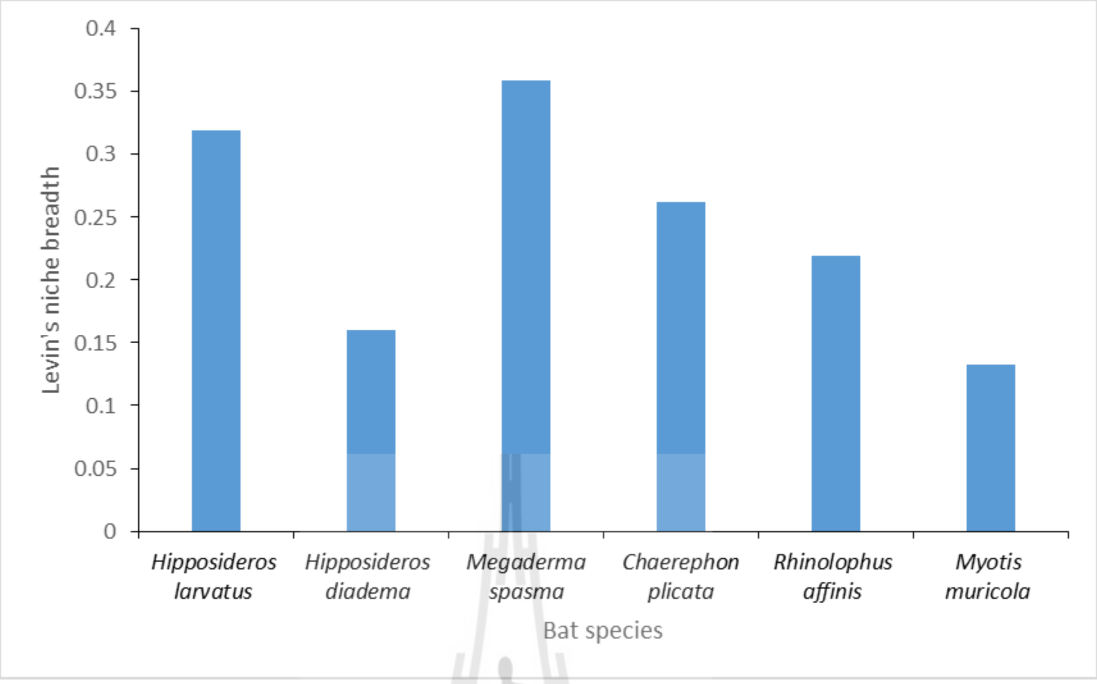

Figure 4.2 Trophic niche breadth calculated using Levins's standardized niche breadth of insectivorous bats in SERS from June 2013 to May 2014.

Table 4.9 Trophic niche overlap calculated using Morisita-Horn index of insectivorous bats in SERS from June 2013 to May 2014.

Bat species	*H. larvatus*	*H. diadema*	*M. spasma*	*C. plicata*	*R. affinis*	*M. muricola*
H. larvatus	-	0.208	0.035	0.064	0.099	0.234
H. diadema	0.208	-	0.044	0.08	0.129	0.31
M. spasma	0.035	0.044	-	0.013	0.024	0.048
C. plicata	0.064	0.08	0.013	-	0.071	0.104
R. affinis	0.099	0.129	0.024	0.071	-	0.08
M. muricola	0.234	0.31	0.048	0.104	0.08	-

4.5 Discussion

4.5.1 Food availability

4.5.1.1 Fruit availability

Fruit availability for frugivorous bats in SERS was 21 plant species. Evaluation of species richness of plant community in this study is difficult. This study focused on only fruit trees whereas other studies surveyed on whole fruit species (mix of tree, shrub, and vine). For instant, Kitamura et al. (2002) surveyed fleshy fruits in Khao Yai National Park, Thailand. In addition, this study surveyed fruit trees using transect survey method but the traditional method for studying plant community is plot sampling method. For example, the study on diversity of plants in Khao Yai National Park (Kitamura et al., 2005) and the study on diversity and dynamics of tree populations and plant-animal interactions at Mo Singto in Khao Yai National Park (Brockelman, Nathalang, and Gale, 2011). However, transect survey method is commonly used for surveying fruit availability for frugivorous bats (Marques, Pereira, and Palmeirim, 2012; Richter and Cumming, 2006).

The highest species richness of fruit trees was found in ecotone whereas the highest abundance of fruit tress was found in dry evergreen forest. Ecotones are well-known biodiversity hotspots that support numerous plant and animal communities (Kark and van Rensburg, 2006; Boone and Krohn, 2000). Moreover, Marques, Pereira, and Palmeirim (2012) showed that number of several fruit trees were high in river bank vegetation. Then, the large pond in dry evergreen forest may be a reason to support the highest abundance of fruit trees in this area.

The peak season of fruiting in SERS occurred in the rainy season. Several studies also showed that fruiting of forest trees peaked in the wet season. For example, in dry tropical forest in Northern Thailand (Elliott, Promkutkaew, and Maxwell, 1994) and in West Java, Indonesia (Sulistyawati, Mashita, Setiawan, Choesin, and Suryana, 2012). Thus, the rainy season in SERS possibly supports more frugivorous bats than the winter and the summer.

4.5.1.2 Insect availability

Although there is a bias on light attractiveness of some insects, light trapping is still a useful method for collecting nocturnal insects. It is the most effective method for estimating abundance, diversity, and activity patterns of insects (Black, 1974). Furthermore, collections of nocturnal insects provide data on insect availability for insectivorous bats as well as reference materials for the identification of prey remains in bat pellets (Zhang et al., 2005; Whitaker, 2004).

Many studies reported the influence of habitats on insect assemblages i.e. Haddad, Tilman, Haarstad, Ritchie, and Knops (2001) revealed that abundance and diversity of insects associated with plant richness and abundance in the field experiment. Taki et al. (2010) showed that insect assemblages responded to community structure, diversity, and abundance of understory plants in plantations. Wickramasinghe, Harris, Jones, and Jennings (2004) showed that abundance and species richness of nocturnal insects varied among agricultural systems. Surprisingly, abundance and biomass of nocturnal insects were not different among habitats in this study. It probably because this study perform in the small area. Consequently, some insects can move across these habitats. However, the diversity of nocturnal insects in this study differed among habitats, excepting between dry dipterocarp forest and ecotone. This data supports the hypothesis that habitats have influence on insect assemblages.

In this study, abundance and biomass of nocturnal insects were highest in the summer. Most studies also showed that insect assemblages varied among seasons and had highest activity during summer (Andreas, Reiter, and Benda, 2012; Threlfall, Law, and Banks, 2012; Scanlon and Petit, 2008; Taylor, (1963). Moreover, Speakman et al. (2000) found that integration between light intensity and temperature was the best predictor of insect activity. Thus, it can be assumed that insect activity increase when increasing temperature (Korine and Pinshow, 2004).

4.5.2 Relationship between bat abundance and food availability

4.5.2.1 Relationship between frugivorous bat abundance and fruit availability

There were no relationship between frugivorous bat abundance and total number of fruit trees in SERS. Similarly, Heithaus, Fleming, and Opler (1975) suggested that captured phyllostomatid bats in Costa Rican forest did not necessarily coincide with their feeding habitat. In addition, Mello, Kalko, and Silva (2008) found that although *Sturnira lilium* mainly fed on Solanaceae fruit, there was no association between capture success of *Sturnira lilium* and average individual of Solanaceae fruit. They also concluded that fruit availability appeared to be less important than air temperature in determining population of *Sturnira lilium*.

Although several studies confirmed that no association between frugivorous bat abundance and fruit availability, some studies showed relation between them. For instance, Aguiar and Marinhi-Filho (2004) demonstrated that phyllostomid bats had high abundance in the rainy season when Cecropia and Piper trees were fruiting. Stoner (2005) showed that number of Phyllostomid bats was greatest in the wet season when peak in fruit availability in Costa Rica. Furthermore, Fleming (2005) reported that the number of bat species responded to number of their favorite plant taxa with a bat-to-plant species ratio close to 1:3. The association between frugivorous bats and food availability may be because species-specific behavior. Some bats are more specialist species, depending on their favorite fruits than other generalist species. Consequently, those bats perhaps associate with fruit availability than other species (Mello et al., 2011).

4.5.2.2 Relationship between insectivorous bat abundance and insect availability

There was also no relationship between insectivorous bat abundance and insect availability in this study. On the contrary, numerous studies showed that insectivorous bat activity associated with abundance and biomass of insects (Threlfall, Law, and Banks, 2012; Kusch and Idelberger, 2005; Kusch, Weber, Idelberger, and Koob, 2004; Agosta, Morton, and Kuhn, 2003; Taylor and O’Neill, 1998; de Jong and Ahlén, 1991). However, Morris, Miller, and Kalcounis-Rueppell (2010) suggested that insectivorous bat activity associated with habitat structure more than prey occurrence in pine forest. Additionally, Dodd et al. (2012) also suggested that habitat structure was more important than insect availability in determining activity patterns of insectivorous in silvicultural area.

Assessment the relationship between bats and food availability still is a main problem for animal ecologists. Firstly, it is impossible to assess the insect availability in a given habitat. Secondly, many bat species may be forage outside the insect sampling areas (Kunz, 1988). In addition, activity patterns of insectivorous bats relate not only insect availability but also other factors. For instance, habitat structure (Dodd et al., 2012; Morris, Miller, and Kalcounis-Rueppell, 2010), prey accessibility (Adams, Law, and French, 2009), preferred prey (Rainho, Augusto, and Palmeirim, 2010), and nightly temperature and length of night (Hayes, 1997). However, resource availability and distribution are the most important factors to determine bat activity (Heithaus, Fleming, and Opler, 1975).

4.5.3 Faecal sampling and analysis

Pellets of fruigivorous bats were not analyzed in this study. They were semi-solid matters which could not collected from the sampling bags. However, directly collecting pellets from bats usually underrepresent of fruit species, especially large and fleshy fruits or *large*-seeded *fruits (*Dumont, Herrel, Medellín, Vargas-Contreras, and Santana, 2009; Mello, 2009*). Frugivorous bats often carry fruit to nearby trees or roosts before consumption (*Bonaccorso, 1975*). Next,* bats chew fruits, swallow the juices, and spit out the pulps and seeds (Kalko, Herre, and Handley, 1996). Thus, those bat pellets normally compose of pulps or plant materials without any seeds (Castro-Luna and Galindo-González, 2012). Additionally, some frugivorous bats usually consume leave (Kunz and Díaz, 1995). Those leave also low in bat pellets because bats consume only juices and discard dry matter (Munin, Costa, and Fischer, 2011).

Spreading a plastic sheet beneath the nets or roosts are recommended method for sampling pellets of frugivorous bats. This method also increase seed collection efficiency and allow greater plant richness to be collected in a short period of time (Galindo-González, Vázquez-Domínguez, Sal-Daña-Vázquez, and Hernández-Montero, 2009). However, this method is difficulty to separating pellet of each individual bat.

Faecal analysis is the traditional method for studying bat diet, especially insectivorous bats (Kunz and Whitaker, 1983). However, there are many limitations and may be give biased results. For example, bats almost completely digested soft bodied insects and difficult to identify them from bat faeces (Rabinowitz and Tuttle, 1982). In addition, some bat species bite off wings and legs of insect preys before feeding (Dechmann, Safi, and Vonhof, 2006). These reasons may be lead to underestimating food items in bat diet.

Moreover, most prey fragments in bat faeces are only identified to order level. Thus, faecal analysis is not reflect truly trophic niche of bats (Feldhamer, Carter, and Whitaker, 2009; Jiang, Feng, Sun, and Wang, 2008). However, this method still gives the reliable results and commonly uses for studying bat diet (Kunz and Whitaker, 1983).

4.5.4 Diet of bats in SERS

4.5.4.1 Diet of bat community

Overall, bats in SERS mainly fed on insects in the orders Coleoptera and Lepidoptera. It is demonstrated that bat community in SERS plays important role in controlling population of coleopterans and lepidopterans. Coleopterans and lepidopterans are also important diet of many insectivorous bat species such as *Myotis volans*, *Myotis evotis*, *Myotis thysanodes*, *Corynorhinus townsendii*, *Eptesicus fuscus*, and *Lasiurus cinereus* (Ober and Hayes, 2008; Lacki, Johnson, Dodd, and Baker, 2007). They are often consumed by bats because their sizes are rather large. Consequently, they produce more noise which are easily detected by bats (Siemers and Güttinger, 2006). Nevertheless, diet of insectivorous bats can vary among bat species, seasons, and food availability (Lee and McCracken, 2005; Arlettaz, 1996; Whitaker, neefus, and kunz, 1996).

The highest abundance of insects in this study were coleopterans, followed by hymenopterans, and lepidopterans, respectively. The major diet of bats seem to coincide with insect availability. However, bats did not mainly consume hymenopterans in this area. Similarly to the study of Leelapaibul, Bumrungsri, and Pattanawiboon (2005) who reported that *Tadarida plicata* mainly fed on homopterans and lepidopterans while coleopterans and homopterans were highest abundance in central Thailand. In addition, Johnston and Fenton (2001) studied diet of *Antrozous pallidus* in Tocalma and showed that bats did not consume some prey that was common in pit-trap samples. These data reflect that status of ecosystems are good because bats can choose their preferred food from a variety of food availability in the area (Whitaker, 2004).

The other insect fragments in the diet werethe orders Diptera, Hymenoptera, Hemiptera, Isoptera, and Orthoptera. Therefore, bats did not consume insects in the orders Trichoptera, Phasmida, Mantodea, Blattaria, Ephemeroptera, Odonata, Psocoptera, and Mecoptera in the study area. These insects are not consumed by bats probably because they are low abundance. Additionally, some small insects are not consumed by bats even if they are high abundance because they have lower biomass and energy content (Graclik and Wasielewski, 2012; Pereira, Rebelo, Rainho, and Palmeirim, 2002).

4.5.4.2 Diet composition among bat species

The major diet of *Hipposideros larvatus* were Coleopterans. They also consumed insects in the orders Lepidoptera, Diptera, Hymenoptera, Hemiptera, and Isoptera in the study area. There is no available data on diet of this bat species. However, several studies reported that coleopterans were the major diet of genus *Hipposideros* such as *Hipposideros commersoni (***Rakotoarivelo et al., 2009***),* *Hipposideros speoris* (Pavey, Burwell, Grunwald, Marshall, and Neuweiler, 2001), *Hipposideros turpis* (Fukui, Okazaki, and Maeda, 2009), and *Hipposideros diadema* (Pavey and Burwell, 1997). Those studies also showed that bats of genus *Hipposideros* consumed various food groups i.e. Lepidoptera, Hymenoptera, Diptera, and Acarina. These data indicate that *Hipposideros larvatus* possibly are opportunistic and generalist feeders.

Hipposideros diadema consumed only coleopterans and lepidopterans in this study. The previous study on diet of Hipposideros diadema also showed that coleopterans and lepidopterans were the major diet of Hipposideros diadema. However, they also consumed other insect groups, spiders, and birds (Pavey and Burwell, 1997). *Hipposideros diadema consumed only coleopterans and lepidopterans in this study probably because insects in SERS are plentiful. Then, bats can choose only their favorite food.*

In this study, Megaderma spasma predominantly consumed orthopterans. They also consumed coleopterans, lepidopterans, and hymenopterans. Several studies showed that *Megaderma spasma* consumed a variety of food items. For instance, Balete (2010) showed that *Megaderma spasma* in the Philippines consumed coleopterans, hemipterans, orthopterans, and lepidopterans. In addition, they also fed on vertebrates, including lizards, frogs, fish, birds, small rodents, and smaller bats (French, 1997; Davison and Zubaid, 1997). These data insist that *Megaderma spasma* are generalist species that can feed on both invertebrates and vertebrates.

Chaerephon plicata consumed three insect orders in this study i.e. Coleoptera, Lepidoptera, and Hymenoptera. However, Boonkird et al. (2009) reported that *Chaerephon plicata in* Tham Chaoram Wildlife Sanctuary, Sukothai province consumed six insect orders, including Lepidoptera, Homoptera, Diptera, Coleoptera, Hymenoptera, and Hemiptera. Moreover, Leelapaibul, Bumrungsri, and Pattanawiboon (2005) showed that *Chaerephon plicata* in central Thailand ate nine insect orders i.e. Homoptera, Lepidoptera, Hemiptera, Coleoptera, Diptera, Hymenoptera, Odonata, Orthoptera, and Psocoptera. These data indicate that *Chaerephon plicata* can consume various insect orders. Only three insect orders were found in the diet of *Chaerephon plicata* in this study may be because of low sample size. If there are higher sample size, the data on number of insect orders in the diet of this bat species possibly increase.

In this study, diet of *Rhinolophus affinis* contained three insect orders i.e. Coleoptera, Lepidoptera, and Hemiptera. This data correspond with the study of Muhammad (2013), who found that *Rhinolophus affinis* in Malaysia consumed only two insect orders i.e. Coleoptera and Hemiptera. However, Jiang, Lu, Sun, Luo, and Feng (2013) showed that *Rhinolophus affinis* in China fed on 10 insect orders, including Coleoptera, Lepidoptera, Hemiptera, Hymenoptera, Orthoptera, Homoptera, Megaloptera, Diptera, Neuroptera, and Trichoptera. They also noted that despite bats consumed 10 insects orders, they mainly consumed only Coleoptera and Lepidoptera. These data imply that *Rhinolophus affinis* can consume a variety of insects but they concentrate on the orders Coleoptera, Lepidoptera, and Hemiptera.

The diet of *Myotis muricola* in this study mostly prefered of Coleoptera and Lepidoptera. There is no previous data on diet of *Myotis muricola.* However, many studies showed bats in genus *Myotis fed* on various food items. For example, Arlettaz (1996) reported that *Myotis myotis* maily consumed carabid beetles and *Myotis blythii* mainly consumed bush crickets in the Alps of Valais, Switzerland. Johnson, Dodd, Kiser, Peterson, and Watrous (2012) showed that *Myotis leibii* in West Virginia fed on eight orders of arthropod i.e. Lepidoptera, Coleoptera, Diptera, Neuroptera, Hemiptera, Hymenoptera, Trichoptera, and Araneae. Moreover, Ma et al. (2006) found that *Myotis ricketti* in China consumed seven insect orders (Coleoptera, Lepidoptera, Homoptera, Ephemeroptera, Hemiptera, Diptera, and Hymenoptera) as well as 3 kinds of fish (*Zacco platypus*, *Carassius auratus*, and *Phoxinus lagowskii*). It can be concluded that bats in genus *Myotis* can consumed various food items. However, the data from this study suggest that *Myotis myotis* prefer only Coleoptera and Lepidoptera.

4.5.5 Trophic niche breadth and niche overlap

All bats in this study exhibited narrow trophic niche breadth ($B_A < 0.359$). They consumed insects from two to six orders. These data suggest that all bats are relatively specialist species. However, the optimal foraging theory advise that food niche breadth decrease with increasing food abundance (Lacher, Willig, and Mares, 1982; Pyke, Pulliam, and Charnov, 1977). It can be concluded that SERS has high abundance of insect preys which lead to foraging specialization of bats.

Insectivorous bats displayed low trophic niche overlap in this study. This data presume that each bat species feed on different food items. The trophic niche overlap of bats possibly lower if food items can be identified at finer taxonomic levels (Matthews, Niswenter, and Ammerman, 2010). In addition, the plentiful of food availability can cause increasing of trophic niche overlap (González-Solís, Oro, Jover, Ruiz, and Pedrocchi, 1997). For example, coleopterans and lepidopterans are high abundance in this area. They are easily accessed by most bats. These superabundance preys lead to higher trophic niche overlap among these generalist species.

The niche theory states that sympatric species should partition at least one niche dimension to avoid their competition (Pianka, 1973). In this study, bats also showed differences in active time. The different temporal patterns of bats possibly because they separate their prey (Matthews, Niswenter, and Ammerman, 2010). These data indicate that insectivorous bats in this community exhibit few competition in food resources and use various strategies for their coexistence.

4.6 Conclusion

Fruit availability in this study differ among habitats and seasons. The highest species richness of fruit trees was found in ecotone whereas the highest abundance of fruit trees was found in dry evergreen forest. The peak season of fruiting occurred in the rainy season. Insect availability also differ among seasons. Abundance and biomass of nocturnal insects were highest in the summer. Nevertheless, abundance and biomass of insects were not different among habitats.

Food availability seem no influence on bat abundance because no relationship between bat abundance and food availability in this study. Other factors may have more influence on bat abundance such as habitat structure and temperature. However, assessment the relationship between bats and food availability still is a major problem for animal ecologists.

The insectivorous bats in SERS consumed seven insect orders i.e. Coleoptera, Lepidoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, and Orthoptera. However, the diet of bats slightly differ among bat species. Consequently, these bats displayed narrow trophic niche breadth and low trophic niche overlap. It can be concluded that insectivorous bats in this community avoid their competition in food resources. The data from this study support the niche theory which states that sympatric species should partition their niches for their coexistence.

4.7 References

Adams, M. D., Law, B. S., and French, K. O. (2009). Vegetation structure influences the vertical stratification of open- and edge-space aerial-foraging bats in harvested forests. Forest Ecology and Management. 258: 2090-2100.

Agosta, S. J., Morton, D., and Kuhn, K. M. (2003). Feeding ecology of bat *Eptesicus fuscus*: ‘preferred’ prey abundance as one factor influencing prey selection and diet breadth. **Journal of Zoology**. 260: 169-177.

Aguiar, L. M. S. and Antonini, Y. (2008). Diet of two sympatric insectivores bats (Chiroptera: Vespertilionidae) in the Cerrado of Central Brazil. **Revista Brasileira de Zoologia**. 25(1): 28-31.

Aguiar, L. M. S. and Marinhi-Filho, J. (2004). Activity patterns of nine phyllostomid bat species in a fragment of the Atlantic forest in southeastern Brazil. **Revista Brasileira de Zoologia**. 21(2): 385-390.

Andreas, M., Reiter, A., and Benda, P. (2012). Prey selection and seasonal diet changes in the western barbastelle bat (*Barbastella barbastellus*). **Acta Chiropterologica**. 14: 81-92.

Arlettaz, R. (1996). Feeding behaviour and foraging strategy of free-living mouse-eared bats, *Myotis myotis* and *Myotis blythii*. **Animal Behaviour**. 51: 1-11.

Arlettaz, R., Perrin, N., and Hausser, J. (1997). Trophic resource partitioning and competition between the two sibling bat species *Myotis myotis* and *Myotis blythii*. **Journal of Animal Ecology**. 66: 897-911.

Balete, D. S. (2010). Food and roosting habits of the lesser false vampire bat, *Megaderma spasma* (Chiroptera: Mergadermatidae), in a Philippine lowland forest. **Asia Life Science**. Supplement 4: 111-129.

Begon, M., Townsend, C. R., and Harper, J. L. (2006). **Ecology: From individuals to ecosystems** (4th ed.). London: Blackwell. 752p.

Black, H. L. (1974). A north temperate bat community: structure and prey populations. **Journal of Mammalogy**. 55: 138-157.

Bonaccorso, F. J. (1979). Foraging and reproductive ecology in a Panamian bat community. **Bulletin of the Florida State Museum, Biological Sciences**. 24: 359-408.

Boone, R. B. and Krohn, W. B. (2000). Relationship between avian range limits and plant transition zones in Maine. **Journal of Biogeography**. 27: 471-482.

Boonkird, K., Boonyai, N., Siripattaranukul, K., Khotchompoo, P., Phomma, C., and Wanghongsa, S. (2009). Food habit of wrinkled-lipped bat (*Tadarida plicata*) at Praram Cave in Tham Chaoram Wildlife Sanctuary, Sukothai province. (in Thai). **Wildlife Yearbook**. 11: 137-147.

Brockelman, W. Y., Nathalang, A., and Gale, G. A. (2011). The Mo Singto forest dynamics plot, Khao Yai National Park, Thailand. ***Natural History* Bulletin of the *Siam Society***. 57: 35-55.

Bumrungsri, S., Leelapaibul, W., and Racey, P. A. (2007). Resource partitioning in sympatric *Cynopterus* bats in lowland tropical rain forest, Thailand.

Biotropica. 39: 241-248.

Castro-Luna, A. A. and Galindo-González, J. (2012). *Seed dispersal by phyllostomid bats in two contrasting vegetation types in a Mesoamerican reserve.* **Acta Chiropterologica**. 14(1): 133-142.

Davison, G. W. H. and Zubaid, A. (1992). Food habits of the lesser false vampire, *Megaderma spasma*, from Kuala Lompat, Peninsular Malaysia. ***Zeitschrift für Säugetierkunde***. 57(5): 310-312.

Dechmann, D. K. N., Safi, K., and Vonhof, M. J. (2006). Matching morphology and diet in the disc-winged bat *Thyroptera tricolor* (Chiroptera). **Journal of Mammalogy**. 87: 1013-1019.

de Jong, J. and Ahlén, I. (1991). Factors affecting the distribution pattern of bats in Uppland, central Sweden. **Holarctic Ecology**. 14: 92-96.

Dodd, L. E., Lacki, M. J., Britzke, E. R., Buehler, D. A., Keyser, P. D., Larkin, J. L., Rodewald, A. D., Wigley, T. B., Wood, P. B., and Rieske, L. K. (2012). Forest structure affects trophic linkages: how silvicultural disturbance impacts bats and their insect prey. **Forest Ecology and Management**. 267: 262-270.

Dumont, E. R., Herrel, A., Medellín, R. A., Vargas-Contreras, J. A., and Santana, S. E. (2009). Built to bite: cranial design and function in the wrinkle-faced bat. **Journal of Zoology**. 279: 329-337.

Elliott, S., Promkutkaew, S., and Maxwell, J. F. (1994). Flowering and seed production phenology of dry tropical forest trees in Northern Thailand. In **Proceeding of International Symposium on Genetic Conservation and Production of Tropical Forest Tree Seed** (pp. 52-62). Thailand: ASEAN-

Canada Forest Tree Seed Centre.

Feldhamer, G. A., Carter, T. C., and Whitaker, J. O., Jr. (2009). Prey consumed by eight species of insectivorous bats from southern Illinois. **American Midland Naturalist**. 162: 43-51.

Findley, J. S. (1993). **Bats: A community perspective**. Cambridge: Cambridge University Press. 167p.

Fleming, T. H. (2005). The relationship between species richness of vertebrate mutualists and their food plants in tropical and subtropical communities differs among hemispheres. **Oikos**. 111: 556-562.

French, B. (1997). *False vampires and other carnivorous*. **Bats**. 15(2): 11-14.

Fukui, D., Okazaki, K., and Maeda, K. (2009). Diet of three sympatric insectivorous bat species on Ishigaki Island, Japan. **Endangered Species Research**. 8: 117-128.

Galindo-González, J., Vázquez-Domínguez, G., Sal-Daña-Vázquez, R. A., and Hernández-Montero, J. R. (2009). A more efficient technique to collect seeds dispersed by bats. **Journal of Tropical Ecology**. 25: 205-209.

González-Solís, J., Oro, D., Jover, L., Ruiz, X., and Pedrocchi, V. (1997). Trophic niche width and overlap of two sympatric gulls in the southwestern Mediterranean. **Oecologia**. 112: 75-80.

Graclik, A. and Wasielewski, O. (2012). Diet composition of *Myotis myotis* (Chiroptera, Vespertilionidae) in western Poland: results of fecal analyses. **Turkish Journal of Zoology**. 36: 209-213.

Gullan P. J. and Cranston, P. S. (2014). **The insects: An outline of entomology** (5th ed.). Chichester: Wiley-Blackwell. 624p.

Haddad, N. M., Tilman, D., Haarstad, J., Ritchie, M., and Knops, J. M. H. (2001). Contrasting effects of plant richness and composition on insect communities: a field experiment. **American Naturalist**. 158: 17-35.

Hayes, J. P. (1997). Temporal variation in activity of bats and the design of echolocation-monitoring studies. **Journal of Mammalogy**. 87: 514-524.

Heithaus, E. R., Fleming, T. H., and Opler, P. A. (1975). Foraging patterns and resources utilization in seven species of bats in a seasonal tropical forest. **Ecology**. 56: 841-854.

Jiang, T., Feng, J., Sun, K., and Wang, J. (2008). Coexistence of two sympatric and morphologically similar bat species *Rhinolophus affinis* and *Rhinolophus pearsoni*. **Progress in Natural Science**. 18: 523-532.

Jiang, T., Lu, G., Sun, K., Luo, J., and Feng, J. (2013). Coexistence of *Rhinolophus affinis* and *Rhinolophus pearsoni* revisited. ***Acta Theriologica***. *58: 47-53.*

Johnson, J. S., Dodd, L. E., Kiser, J. D., Peterson, T. S., and Watrous, K. S. (2012). Food habits of *Myotis leibii* along a forested ridgetop in West Virginia. **Northeastern Naturalist**. 19(4): 665-672.

Johnston, D. S. and Fenton, M. B. (2001). Individual and population-level variability in diets of Pallid bats (*Antrozous pallidus*). **Journal of Mammalogy**. 82(2): 362-373.

Kalko, E. K. V., Herre, E. A., and Handley, C. O. (1996). Relation of fig fruit characteristics to fruit-eating bats in the New and Old World tropics. **Journal of Biogeography**. 23: 565-576.

Kark, S. and van Rensburg, B. J. (2006). Ecotones: marginal or central areas of transition. Israel Journal of Ecology and Evolution. 52: 29-53.

Kitamura, S., Suzuki, S., Yumoto, T., Chuailua, P., Plongmai, K., **Poonswad, P.**, Noma, N., Maruhashi, T., and Suckasam, C. (**2005)**. A botanical inventory of a tropical seasonal forest in Khao Yai National Park, Thailand: implications for fruit-frugivore interactions. **Biodiversity Conservation**. 14: 1241-1262.

Kitamura, S., Yumoto, T., **Poonswad, P**., Chuailua, P., Plongmai, K., Maruhashi, T., and Noma, N. (**2002)**. Interactions between fleshy fruits and frugivores in a tropical seasonal forest in Thailand. **Oecologia**. 133: 559-572.

Korine, C. and Pinshow, B. (2004). Guild structure, foraging space use, and distribution in a community of insectivorous bats in the Negev Desert. **Journal of Zoolog**y. 262: 187-196.

Krebs, C. J. (1998). **Ecology methodology** (2nd ed.). California: Benjamin/ Cummings. 624p.

Kunz, T. H. (1988). Methods of assessing the availability of prey to insectivorous bats. In: Kunz, T. H. (Ed.). Ecological and behavioral methods for the study of bats. Washington D. C.: Smithsonian Institution Press. pp. 191-210.

Kunz, T. H. and Díaz, C. A. (1995). Folivory in fruit-eating bats, with new evidence from *Artibeus jamaicensis* (Chiroptera: Phyllostomidae). **Biotropica**. 27: 106-120.

Kunz, T. H. and Whitaker, J. O., Jr. (1983). An evaluation of fecal analysis for determining food habits of insectivorous bats. Canadian Journal of Zoology. 61: 1317-1321.

Kusch, J. And Idelberger, S. (2005). Spatial and temporal variability of bat foraging in a western European low mountain range. **Mammalia**. 69: 21-33.

Kusch, J. and Schotte, F. (2007). Effects of fine-scale foraging habitat selection on bat community structure and diversity in a temperate low mountain range forest. **Folia Zoologica**. 56: 263-276.

Kusch, J., Weber, C., Idelberger, S. And Koob. T. (2004). Foraging habitat preferences of bats in relation to food supply and spatial vegetation structures in a western European low mountain range forest. **Folia Zoologica**. 53: 113-128.

Lacher, T. E., Willig, M. R., and Mares, M. A. (1982). Food preference as a function of resource abundance with multiple prey types: an experimental analysis of optimal foraging theory. **American Naturalist**. 120: 297-316.

Lacki, M. J., Johnson, J. S., Dodd, L. E., and Baker, M. D. (2007). Prey consumption of insectivorous bats in coniferous forests of North-Central Idaho. Northwest Science. 81: 199-205.

Lee, Y. and McCracken, G. F. (2005). Dietary variation of Brazilian free-tailed bats links to migratory populations of pest insects. **Journal of Mammalogy**. 86: 67-76.

Leelapaibul, W., Bumrungsri, S., and Pattanawiboon, A. (2005). Diet of wrinkle-lipped free-tailed bat (*Tadarida plicata* Buchannan, 1800) in central Thailand: insectivorous bats potentially act as biological pest control agents. **Acta Chiropterologica**. 7: 111-119.

Leibold, M. A. and McPeek, M. A. (2006). Coexistence of the niche and neutral perspectives in community ecology. **Ecology**. 87: 1399-1410.

Ma, J., Zhang, J., Liang, B., Zhang, L., Zhang, S., and Metzner, W. (2006). Dietary characteristics of *Myotis ricketti* in Beijing, North China. Journal of

Mammalogy. 87: 339-344.

Marques, T. J., Pereira, M. J. R., and Palmeirim, J. M. (2012). Availability of food for frugivorous bats in lowland Amazonia: influence of flooding and of river banks. **Acta Chiropterologica**. 14(1): 183-194.

Matthews, A. K., Neiswenter, S. A., and Ammerman, L. K. (2010). Trophic ecology of the free-tailed bats *Nyctinomops femorosaccus* and *Tadarida brasiliensis* (Chiroptera: Molossidae) from Big Bend National Park, Texas. **Southwestern Naturalist**. 55(3): 340-346.

Medellín, R. and Gaona, O. (1999). Seed dispersal by bats and birds in forest and disturbed habitats in Chiapas, Mexico. **Biotropica**. 31: 478-485.

Mello, M. A. R. (2009). Temporal variation in the organization of a Neotropical assemblage of leaf-nosed bats (Chiroptera: Phyllostomidae). **Acta Oecologica**. 35: 280-286.

Mello, M. A. R., Kalko, E. K. V., and Silva, W. R. (2008). Diet and abundance of the bat *Sturnira lilium* (Chiroptera) in a Brazilian montane Atlantic forest. **Journal of Mammalogy**. 89(2): 485-492.

Mello, M. A. R., Marquitti, F. M. D., Guimarães, P. R., Jr., Kalko, E. K. V., Jordano. P., and de Aguiar, M. A. M. (2011). The missing part of the seed dispersal networks: structure and robustness of bat-fruit interactions. **PLoS ONE**: 6(2): e17395.

Morris, A. D., Miller, D. A., and Kalcounis-Rueppell, M. C. (2010). Use of forest edges by bats in a managed pine forest landscape. **Journal of Wildlife Management**. 74: 26-34.

Muhammad, N. A. F. B. (2013). *Insects in diet of microchiropterans from selected localities in Kuching, Sarawak.* **University Malaysia Sarawak**. *Project Report.*

Munin, R. L., Costa, P. C., and Fischer, E. (2011). Differential ingestion of fig seeds by a Neotropical bat, *Platyrrhinus lineatus*. **Mammalian Biology**. 76: 772-774.

Munin, R. L., Fisher, E., and Gonçalvez, F. (2012). Food habits and dietary overlap in a phyllostomid bat assemblage in the Pantanal of Brazil. **Acta Chiropterologica**. 14(1): 195-204.

Ober, H. K. and Hayes, J. P. (2008). Prey selection by bats in forests of western Oregon. Journal of Mammalogy. 89: 1191-1200.

Pavey, C. R. and Burwell, C. J. (1997). The diet of the diadem leaf-nosed bat *Hipposideros diadema*: confirmation of a morphologically-based prediction of carnivory. **Journal of Zoology**. 243: 295-303.

Pavey, C. R., Burwell, C. J., Grunwald, J.-E., Marshall, C. J., and Neuweiler, G. (2001). Dietary benefits of twilight foraging by the insectivorous bat *Hipposideros speoris*. **Biotropica**. 33: 670-681.

Pereira, M. J. R., Rebelo, H., Rainho, A., and Palmeirim, J. M. (2002). Prey selection by *Myotis myotis* (Vespertilionidae) in a Mediterranean region. **Acta Chiropterologica**. 4: 183-193.

Pianka, E. R. (1973). The structure of lizard communities. **Annual Review of Ecology and Systematics**. 4: 53-74.

Pyke, G. H., Pulliam, H. R., and Charnov, E. L. (1977). Optimal foraging: a selective review of theory and tests. **Quarterly Review of Biology**. 52: 137-154.

Rabinowitz, A. R. and Tuttle, M. D. (1982). A test of the validity of two currently used methods of determining bat prey preferences. Acta Theriolgica. 27: 283-293.

Rainey, W. W., Pierson, E. D., Colbene, N., and Barclay, J. H. (1992). Bats in hollow redwoods: seasonal uses and role of nutrient transfer into old growth communities. **Bat Research News**. 33: 71.

Rainho, A., Augusto, A. M., and Palmeirim, J. M. (2010). Influence of vegetation clutter on the capacity of ground foraging bats to capture prey. Journal of Applied Ecology. 47: 850-858.

Rakotoarivelo, A. R., Ralisata, M., Ramilijaona, O., Rakotomalala, M., Racey, P. A., and Jenkins, R. K. B. (2009). The food habits of a Malagasy giant: *Hipposideros commersoni* (E. Georffroy, 1813). ***African Journal of Ecology***. **47**: 283-288.

Richter, H. V. and Cumming, G. S. (2006). Food availability and annual migration of the straw-colored fruit bat (*Eidolon helvum*). **Journal of Zoology**. 268: 35-44.

Sakaerat Environmental Research Station. (2013). **Biodiversity of Plants Database** [On-line]. Available: http://www.tistr.or.th/sakaerat/ Flora_Fauna /Plant%20in %20 Sakaerat/plant.htm. Accessed on 1 July 2013.

Scanlon, A. and Petit, S. (2008). Biomass and biodiversity of nocturnal aerial insects in an Adelaide city park and implications for bats (Microchiroptera). **Urban Ecosystems**. 11: 91-106.

Siemers, B. M., Greif, S., Borissov, I., Voigt-Heucke, S. L., and Voigt, C. C. (2011). Divergent trophic levels in two cryptic sibling bat species. **Oecologia**.

166: 69-78.

Siemers, M. B. and Güttinger, R. (2006). Prey conspicuousness can explain apparent prey selectivity. **Current Biology**. 16: 157-159.

Smirnov, D. G. and Vekhnik, V. P. (2014). Ecology of nutrition and differentiation of the trophic niches of bats (Chiroptera: Vespertilionidae) in floodplain ecosystems of the Samara Bend. **Biology Bulletin**. 41(1): 60-70.

Speakman, J. R., Rydell, J., Webb, P. I., Hayes, J. P., Hays, G. C., Hulbert, I. A. R., and McDevitt, R. M. (2000). Activity patterns of insectivorous bats and birds in northern Scandinavia (69°N), during continuous midsummer daylight. **Oikos**. 88: 75-86.

Stoner, K. E. (2005). Phyllostomid bat community structure and abundance in two contrasting tropical dry forests. **Biotropica**. 37: 591-599.

Sulistyawati, E., Mashita, N., Setiawan, N. N., Choesin, D. N., and Suryana, P. (2012). Flowering and fruiting phenology of tree species in Mount Papandayan Nature Reserve, West Java, Indonesia. **Tropical Life Sciences Research**. 23(2): 81-95.

Taki, H., Inoue, T., Tanaka, H., Makihara, H., Sueyoshi, M., Isono, M., and Okabe, K., (2010). Responses of community structure, diversity, and abundance of understory plants and insect assemblages to thinning in plantations. **Forest Ecology and Management**. 259: 607-613.

Taylor, L. R. (1963). Analysis of the effect of temperature on insects in flight. **Journal of Animal Ecology**. 32: 99-117.

Taylor, R. J. and O’Neill, M. G. (1988). Summer activity patterns of insectivorous bats and their prey in Tasmania. **Wildlife Research**. 15: 533-539.

Threlfall, C. G., Law, B., and Banks, P. B. (2012). Influence of landscape structure and human modifications on insect biomass and bat foraging activity in an urban landscape. **PLoS ONE**. 7(6): e38800.

Whitaker, J. O., Jr. (1988). **Food habits analysis of insectivorous bats**. In: Kunz, T. H. (Ed.). Ecological and behavioral methods for the study of bats. Washington D. C.: Smithsonian Institution Press. pp. 171-190.

Whitaker, J. O., Jr. (2004). Prey selection in a temperate zone insectivorous bat community. **Journal of Mammalogy**. 85: 460-469.

Whitaker, J. O., Jr., Neefus, C., and Kunz, T. H. (1996). Dietary variation in the Mexican free-tailed bat (*Tadarida brasiliensis mexicana*). **Journal of Mammalogy**. 77(3): 716-724.

Wickramasinghe, L. P., Harris, S., Jones, G., and Jennings, N. V. (2004). Abundance and species richness of nocturnal insects on organic and conventional farms: effects of agricultural intensification on bat foraging. **Conservation Biology**. 18(5): 1283-1292.

Zar, J. H. (1999). **Biostatistical analysis** (4th ed.). New Jersey: Prentice Hall. 662p.

Zhang, L., Jones, G., Rossiter, S., Ades, G., Liang, B., and Zhang, S. (2005). Diet of flat-headed bats, *Tylonycteris pachypus* and *T. robustula*, in Guangxi, South China. **Journal of Mammalogy**. 86: 61-66.

CHAPTER V

ECTOPARASITES OF BATS IN SEKAERAT ENVIRONMENTAL RESEARCH STATION

5.1 Abstract

The ectoparsites of bats in Sakaerat Environmental Research Station were studied during June 2013 to May 2014. Altogether, 66 bats were captured using mist nets and investigated for their ectoparasites. Of these, 21 bats of 4 species were infested with ectoparasites (31.82%) i.e. *Hipposideros larvatus*, *Rhinolophus affinis*, *Myotis muricola*, and *Cynopterus sphinx*. A total of 64 ectoparasites were collected from bats belonging to 4 families, 7 genera, and 7 species i.e. *Brachytarsina* sp. (n = 28), *Raymondia* sp. (n = 21), *Nycteribia* sp. (n = 2), *Phthiridium* sp. (n =4), *Cyclopodia* sp. (n = 2), *Spinturnix* sp. (n = 6), and *Ixodes* sp. (n = 1). *Brachytarsina* sp. was the most common ectoparasites of bats (Berger-Parker index = 0.438) which infested on *Hipposideros larvatus* and *Rhinolophus affinis*. *Raymondia* sp. was the second most common ectoparasites of bats (Berger-Parker index = 0.328) which was found on *Rhinolophus affinis*. Number of parasite loads among bat species was not different (H = 1.45, df = 3, p = 0.694). Mean abundance of ectoparasite infestation of captured bats was 0.139 while mean intensity of infestation was 0.435. The Brillouin diversity index of ectoparasites was 1.262 while the Brillouin evenness index was 0.889.

5.2 Introduction

Ectoparasites are organisms which live and feed on external surfaces of other organisms. They feed on various animal hosts both domestic animals and wildlife (Hopla, Durden, and Keirans, 1994). Most mammals are well known harborers of ectoparasites, especially small mammals and bats (Ritzi and Whitaker, 2003; Whitaker, 1982).

Bats are usual hosts of several ectoparasites, including ticks, mites, chiggers, bugs, fleas, and flies (Dick, Gannon, Little, and Patrick, 2003). Some ectoparasites of bats are specificity and have coevolution with their hosts (Christe et al., 2007; Dick, 2007). Moreover, many ectoparasites of bats are vector-borne which transmit numerous diseases to other animals as well as humans. However, there are few studies on ectoparasites of bats, particularly in tropical regions (Krichbaum, Perkins, and Gannon, 2009).

Bats are excellent models for studying host-parasite relationship because their taxonomy and behaviours are extremely diverse (Kurta, Whitaker, Wrenn, and Soto-Centeno, 2007). Many bat species can live together with thousands of individuals in one cave (Findley, 1993), which are favouring parasites that are transmitted both horizontally (among individuals) and vertically (from mother to offspring) (ter Hofstede and Fenton, 2005; Christe, Arlettaz, and Vogel, 2000; Clayton and Tomkins, 1994). Studying host-parasite relationship between bats and their ectoparasites is important information on biology, systematics, and phylogeny of their hosts (Fritz, 1983). To our knowledge, there are few records of ectoparasites associated with bats in Thailand. Moreover, studies on quantitative relationships between ectoparasites and bats are scarce (Sharifi, Taghinezhad, Mozafari, and Vaissi, 2003). Thus, the goals of this study were to identify and quantify rates of infestation of ectoparasites related to bats in Sakaerat Environmental Research Station.

5.3 Materials and methods

5.3.1 Collecting and identifying ectoparasites

Ectoparasites were directly collected from captured bats using forceps and fine toothbrush. In addition, the cloth bags were examined for ectoparasites that moved off the bats. Collected ectoparasites were preserved in vials containing 70% ethyl alcohol. Ectoparasites were mounted on glass slides in polyvinyl alcohol (PVA) for later identification under a binocular microscope (Millar, Uys, and Urban, 1999). Then, ectoparasites were identified following Price and Graham (1997), Wall and Shearer (1997), and Furman and Catts (1982).

5.3.2 Data analysis

5.3.2.1 Ectoparasites community analysis

Dominance of ectoparasites

Berger-Parker dominance index was used to quantify numeric dominance of ectoparasites (May, 1975).

$$d = N_{\max} / N \tag{5.1}$$

where d = Berger-Parker dominance index

$N_{\max}$ = the number of individuals in the most abundant species

N = the total number of individuals in the sample

Similarity

Similarity in ectoparasites assemblages among hosts was compared using Sorenson’s coefficient (Krebs, 1998).

$$CC = 2C / A + B \qquad (5.2)$$

where CC = Sorenson’s coefficient

C = the number of species shared by the two communities

A = the number of species in community A

B = the number of species in community B

Species diversity

Brillouin diversity index was used to quantify diversity of ectoparasites among hosts (Magurran, 1988).

$$HB = \ln N! - \sum_{i=1}^{s} \ln n_i! / N \qquad (5.3)$$

where HB = Brillouin diversity index

N = the total number of individuals in the sample

n_i = the number of individuals in i species

s = the species number

Species evenness

Brillouin evenness index was used to quantify equitability of ectoparasites among hosts (Magurran, 1988).

$$E = HB / HB_{\max} \tag{5.4}$$

where E = Brillouin evenness index

HB = Brillouin diversity index

HB_{max} = the maximum value of the Brillouin diversity index

5.3.2.2 Parasitism parameters

Parasitism parameters was examined following Bush, Lafferty, Lotz, and Shostak (1997):

Prevalence of ectoparasites

$$\text{Prevalence} = (\text{Number of infested hosts} / \text{Number of examined hosts}) \times 100 \tag{5.5}$$

Mean abundance of infestation

$$\text{Mean abundance} = \text{Number of parasites} / \text{Number of examined hosts} \tag{5.6}$$

Mean intensity

$$\text{Mean intensity} = \text{Number of parasites} / \text{Number of infested hosts} \tag{5.7}$$

5.3.2.3 Statistical analysis

Kruskal-Wallis *H*-test was used to examine differences in parasite loads among bat species. Differences in parasite loads between male and female bats were compared using Mann-Whitney *U*-test (Zar, 1999). Spearman’s rank correlation coefficient was used to test correlation between parasite loads with bat weights. Statistical analyses were performed using Quantitative Parasitology 3.0 software (Rózsa, Reiczigel, and Majoros, 2000).

5.4 Results

5.4.1 Ectoparasite community and parasitism parameters of total bats

Altogether 66 individuals of 9 bat species were investigated for ectoparasites. Of these, 21 individuals of 4 bat species were infested with ectoparasites (31.82% of total captured bats) including *Hipposideros larvatus* (n =11), *Rhinolophus affinis* (n = 5), *Myotis muricola* (n = 3), and *Cynopterus sphinx* (n = 2). No ectoparasite was found on *Hipposideros diadema*, *Megaderma spasma*, *Chaerephon plicata*, *Cynopterus brachyotis*, and *Megaerops niphanae* (Table 5.1).

A total of 64 individuals of ectoparasites were collected from bats in SERS, representing 3 orders i.e. orders Diptera, Mesostigmata, and Parasitiformes. The order Diptera comprised of *Brachytarsina* sp. (n = 28) and *Raymondia* sp. (n = 21) of family Streblidae and *Nycteribia* sp. (n = 2), *Phthiridium* sp. (n = 4), and *Cyclopodia* sp. (n = 2) of family Nycteribiidae. The order Mesostigmata contained *Spinturnix* sp. (n = 6) of family Spinturnicidae and the order Parasitiformes contained *Ixodes* sp. (n = 1) of family Ixodidae (Table 5.2).

The presence of ectoparasites sharing the same host was observed in 3 bat species i.e. *Hipposideros larvatus* (*Brachytarsina* sp., *Nycteribia* sp., and *Phthiridium* sp.), *Rhinolophus affinis* (*Brachytarsina* sp. and *Raymondia* sp.), and *Cynopterus sphinx* (*Cyclopodia* sp. and *Ixodes* sp.). In contrast, *Myotis muricola* was associated with only spinturnicid mites.

Numbers of parasite loads among bat species were not different (H = 1.45, df = 3, p = 0.694). The similarity of ectoparasites of *Hipposideros larvatus* and *Rhinolophus affinis* was 0.67. The sample sizes of other bat species did not allow for investigation the similarity index. The Berger-Parker dominance index indicated that dominance of ectoparasites ranged from 0.016 to 0.438. The dominant ectoparasites on bats were *Brachytarsina* sp. (Berger-Parker index = 0.438) and *Raymondia* sp. (Berger-Parker index = 0.328) whereas the other ectoparasites were rare (Berger-Parker index < 0.1) (Table 5.2). Mean abundance of ectoparasite on total captured bats was 0.139 while mean intensity was 0.435. The diversity of ectoparasites was 1.262 and the evenness was 0.889.

Table 5.1 Number of infested hosts and prevalence of ectoparasites of captured bats in SERS from June 2013 to May 2014.

Host species	**No. captured bats**	**No. infested hosts**	**Prevalence (%)**
Hipposideros larvatus	23	11	47.83
Hipposideros diadema	4	-	-
Megaderma spasma	6	-	-
Chaerephon plicata	3	-	-
Rhinolophus affinis	5	5	100
Myotis muricola	4	3	75
Cynopterus sphinx	10	2	20
Cynopterus brachyotis	2	-	-
Megaerops niphanae	9	-	-
Total	66	21	31.82

Table 5.2 Species, number, and Berger-Parker dominance index of ectoparasites of captured bats in SERS from June 2013 to May 2014.

Ectoparasites taxon	**No. of ectoparasites**	**Dominance index**
Streblidae (bat fly)		
Brachytarsina sp.	28	0.438
Raymondia sp.	21	0.328
Nycteribiidae (bat fly)		
Nycteribia sp.	2	0.031
Phthiridium sp.	4	0.063
Cyclopodia sp.	2	0.031
Ixodidae (tick)		
Ixodes sp.	1	0.016
Spinturnicidae (mite)		
Spinturnix sp.	6	0.094
Total	64	-

5.4.2 Ectoparasites of each bat species

Hipposideros larvatus

In total, 23 individual bats were examined for ectoparasite infestation. Of these, 11 bats were infested with ectoparasites (47.83%) dividing into 5 adult male bats and 6 adult female bats. The male bats were infested with 2 species of ectoparasites i.e. *Brachytarsina* sp. (n = 12) and *Phthiridium* sp. (n = 2) while the female bats were infested with 3 species of ectoparasites i.e. *Brachytarsina* sp. (n = 10), *Phthiridium* sp. (n = 2), and *Nycteribia* sp. (n = 2) (Table 5.3). Number of parasite load between male and female bats was not different ($U = 4$, $Z = 0$, $p = 1.00$). The highest dominance index was found in *Brachytarsina* sp. (Berger-Parker index = 0.786), followed by *Phthiridium* sp. (Berger-Parker index = 0.143) and *Nycteribia* sp. (Berger-Parker index = 0.071), respectively. Mean abundance of ectoparasites on *Hipposideros larvatus* was 0.406 while mean intensity of ectoparasites on *Hipposideros larvatus* was 0.846 (Table 5.3). The diversity index of ectoparasites was 0.555 whereas the evenness index of ectoparasites was 0.709. There was no correlation between number of ectoparasites and bat weights (r_s = 0.154, p = 0.53).

Rhinolophus affinis

A total of 5 individual bats were examined for ectoparasites. All bats were infested with ectoparsites (100%), divided into 3 adult male bats and 2 adult female bats. The male bats were infested with *Brachytarsina* sp. (n = 6) and *Raymondia* sp. (n = 10) and the female bats were only infested with *Raymondia* sp. (n = 11) (Table 5.3). Number of parasite loads between male and female bats was not different (U = 2, Z = 0.387, p = 0.699). The dominance index of *Raymondia* sp. on *Rhinolophus affinis* (Berger-Parker index = 0.778) was higher than *Brachytarsina* sp. (Berger-Parker index = 0.222). Mean abundance of ectoparasites on *Rhinolophus affinis* was 2.7 while mean intensity of ectoparasites on *Rhinolophus affinis* also was 2.7 (Table 5.3). The diversity index of ectoparasites was 0.467 while the evenness index of ectoparasites was 0.791. There was no correlation between number of ectoparasites and bat weights (r_s = - 0.105, p = 0.867).

Myotis muricola

Data on examining ectoparasites showed that 3 of 4 *Myotis muricola* were infested with ectoparasites (75%), including 2 adult male bats and 1 young female bat. The male bats were infested with *Spinturnix* sp. (n =3) and the female bat was also infested with *Spinturnix* sp. (n = 3) (Table 5.3). The Berger-Parker dominance index of *Spinturnix* sp. was 1. Mean abundance of infestation of ectoparasites on *Myotis muricola* was 1.5 while mean intensity of infestation of ectoparasites on *Myotis muricola* was 2

(Table 5.3). The Brillouin diversity index of ectoparasites was 0 whereas the Brillouin evenness index of ectoparasites was 1. There was no correlation between ectoparasite load and bat weights (r_s = - 0.04, p = 0.417).

Cynopterus sphinx

A total of 10 individual bats were examined for ectoparasites. Of these, only 2 adult females were infested with ectoparasites (20%). The female bats were associated with 2 species of ectoparasites i.e. *Cyclopodia* sp. (n = 2) and *Ixodes* sp. (n = 1) (Table 5.3). The dominant of *Cyclopodia* sp. (Berger-Parker index = 0.667) was higher than *Ixodes* sp. (Berger-Parker index = 0.333). Mean abundance of ectoparasites on *Cynopterus sphinx* was 0.15 while mean intensity of ectoparasites on *Cynopterus sphinx* was 0.75 (Table 5.3). The Brillouin diversity index of ectoparasites was 0.366 while the Brillouin evenness index of ectoparasites was 1. There was no correlation between ectoparasite load and bat weight (r_s = - 0.087, p = 0.811).

Table 5.3 Number of ectoparasites associated with male and female bats in SERS from June 2013 to May 2014.

Ectoparasite taxon	***Hipposideros larvatus***		***Rhinolophus affinis***		***Myotis muricola***		***Cynopterus sphinx***
	Male (n = 5)	**Female (n = 6)**	**Male (n = 3)**	**Female (n = 2)**	**Male (n = 2)**	**Female (n = 1)**	**Female (n = 2)**
Brachytarsina sp.	12	10	6	-	-	-	-
Raymondia sp.	-	-	10	11	-	-	-
Nycteribia sp.	-	2	-	-	-	-	-
Phthiridium sp.	2	2	-	-	-	-	-
Cyclopodia sp.	-	-	-	-	-	-	2
Ixodes sp.	-	-	-	-	-	-	1
Spinturnix sp.	-	-	-	-	3	3	-
Total	14	14	16	11	3	3	3

Table 5.4 Prevalence, mean abundance, and mean intensity of ectoparasites collected on bats in SERS from June 2013 to May 2014.

Host species	n	Ectoparasite taxon	n	Host infested	Mean abundance	Mean intensity	Prevalence (%)
Hipposideros larvatus	23	*Brachytarsina* sp.	22	11	0.96	2	47.83
		Nycteribia sp.	2	2	0.09	1	8.7
		Phthiridium sp.	4	4	0.17	1	17.39
Rhinolophus affinis	5	*Brachytarsina* sp.	6	2	1.2	3	40
		Raymondia sp.	21	5	4.2	4.2	100
Myotis muricola	4	*Spinturnix* sp.	6	3	1.5	2	75
Cynopterus sphinx	10	*Cyclopodia* sp.	2	2	0.2	1	20
		Ixodes sp.	1	1	0.1	1	10
Total	42		64	30	-	-	-

5.5 Discussion

5.5.1 Ectoparasite community and parasitism parameters of total bats

In total, 64 individuals in 7 species of ectoparasites were found from 66 bats in SERS, comprising bat flies (n = 57), mites (n = 6), and tick (n = 1). Only one ixodid tick recorded in this study can be regarded it as contamination. There were no fleas, chiggers, and bat bugs which were reported previously from bats in Thailand (Uchikawa and Kobayashi, 1979; Hill and McNeely, 1975; Nadchatram and Mitchell, 1965). Some ectoparasites were not found in this study may be because low number of captured hosts. According to Changbunjong et al. (2010) who surveyed ectoparasites of birds, small mammals, and bats in Kanchanaburi, Thailand. They found only 2 individuals of ectoparsites from 23 bats.

Bat flies are the most common ectoparasites of bats in this area, followed by mites. This data corroborate with the study of Autino, Claps, Barquez, and Díaz (2011) who reported that mites and bat flies were common ectoparasites on bats whereas fleas are rare observed on bats. Many studies also showed that bat flies and mites were the rich ectoparasites of bats. For example, Moras, Bernardi, Graciolli, and Gregorin (2013) found 14 bat fly species and 9 mite species from bats in southern Minas Gerais, Brazil. Almeida, Silva, Serra-Freire, and Valim (2011) sampled 10 bat fly species and 11 mite species from bats in southeastern Brazil. Bertola et al. (2005) recorded 19 bat fly species from bats in São Paulo, Brazil. These data confirm that bat flies and mites are primary ectoparasites of several bat species.

Marshall (1981) suggested that host-parasite associations could be classified into monoxenous (utilizing a single host species), oligoxenous (utilizing two or more hosts in the same genus), pleioxenous (utilizing two or more hosts in the same family), and polyxenous (two or more hosts of different families). Then, *Nycteribia* sp., *Phthiridium* sp., *Raymondia* sp., *Cyclopodia* sp., *Ixodes* sp., and *Spinturnix* sp. are classified as monoxenous whereas *Brachytarsina* sp. are classified as polyxenous. This data show that most ectoparasites seem to be host-parasite specificity, excepting *Brachytarsina* sp.. However, determination of host-parasite specificity is very complex because many factors have influence on the specificity such as host isolation, climate, competition, morphological characteristics, physiological adaptation as well as evolutionary relationships (Dick and Patterson, 2007; Esbérard et al., 2005; Marshall 1976).

Although bats are notorious ectoparasite reservoirs, few bats in this study were infested by ectoparasites (31.82% of total captured bats). Similarly, other studies also showed that there were low ectoparasites prevalence on bats. For instance, Ahamad et al. (2013) found that 25.6% of bats in Malaysia were infested with acarines. Mariana et al. (2008) reported that 7.32% of bats infested by ectoparasites in Ulu Muda Forest Reserve, Malaysia. Furthermore, mean intensity of ectoparasites on bats in this study was also low (0.435). There is no data on quantitative parasitism of ectoparasites on bats in Thailand. However, several studies in other areas reported higher mean intensity of parasitism on bats. For example, Aguiar and Antonini (2011) reported that mean intensity of bat flies on vampire bats in Central Brazil was 2.16. Czenze and Broders (2011) documented that average intensity of infection by ectoparasites on bats in Canada was 2.4. Camilotti, Graciolli, Weber, Arruda, and Cáceres (2010) hypothesized that mean intensity increase when less competition of ectoparasites for hosts. However, variations in parasitism rates of ectoparasites on bats can be influenced by many factors such as temperature (Marshall, 1982), host shelter (Patterson, Dick, and Dittmar, 2007; Lewis, 1995) and roosting biology (ter Hofstede, Fenton, and Whitaker, 2004; Whiteman and Parker 2004).

5.5.2 Ectoparasites of each bat species

Hipposideros larvatus

In the present study, *Hipposideros larvatus* were infested by 3 species of ectoparasites i.e. *Brachytarsina* sp. and *Phthiridium* sp., and *Nycteribia* sp.. This bat species was found to associate with many ectoparasite groups. For example, Bush and Robbins (2012) reported that *Hipposideros larvatus* were infested by *Ixodes vespertilionis* in southern China. Mariana et al. (2005) found that *Hipposideros larvatus* were infested by chiggers in Gunung Stong Forest Reserve, Malaysia. Moreover, Gay et al. (2014) showed that *Hipposideros larvatus* were infested by 15 ectoparasite species. These data confirm that *Hipposideros larvatus* were harbours of numerous of ectoparasite groups.

Rhinolophus affinis

Rhinolophus affinis in this study were infested by *Brachytarsina* sp. and *Raymondia* sp.. Several studies also recorded that this bat species associated with various ectoparasites groups. For example, Kolonin (2003) recorded that *Rhinolophus affinis* was infested by *Ixodes simplex* in Vietnam. Mariana et al. (2008) found that *Rhinolophus affinis* was infested by chiggers at Ulu Muda Forest Reserve, Malaysia. Dahal and Thapa (2009) found fleas in family Ischnopsyllidae and bat flies in families Nycteribiidae and Streblidae fed on *Rhinolophus affinis* in Nepal. Gay et al. (2014) showed that 8 ectoparasite species fed on *Rhinolophus affinis*. These data indicate that *Rhinolophus affinis* also harbours of many ectoparasites groups.

Myotis muricola

There were no record of ectoparasites associated with *Myotis muricola* (Gay et al., 2014; Bush and Robbins, 2012). However, *Spinturnix* sp. was found on *Myotis muricola* in this study. Then, this is the first record of ectoparasite associated with *Myotis muricola*.

Cynopterus sphinx

In this study, *Cynopterus sphinx* associated with *Cyclopodia* sp. and *Ixodes* sp.. Theodor (1955) reported bat flies of the genus *Eucampsipoda* fed on *Cynopterus sphinx* in India. Rajasekar, Chattopadhyay, and Sripathi (2006) reported that bat flies of the genus *Basilia* were common ectoparasites of *Cynopterus sphinx*. These data support that many bat flies of family Nycteribiidae prefer Old World fruit bats (Dick and Patterson, 2006; Maa, 1962).

Other remain bat species

There were no recorded of ectoparasites on *Hipposideros diadema*, *Megaderma spasma*, *Chaerephon plicata*, *Cynopterus brachyotis*, and *Megaerops niphanae* in this study. However, Gay et al. (2014) showed that *Hipposideros diadema* associated with 7 ectoparasite species, *Megaderma spasma* associated with 7 ectoparasite species, *Chaerephon plicata* associated with 11 ectoparasite species, and *Cynopterus brachyotis* associated with 11 ectoparasite species. None of ectoparasites found on these bats probably because low sample size of hosts. There are many factors have influence on variation of ectoparasites on each bat species such as size of hosts (Christe, Giorgi, Vogel, and Arlettaz, 2003), life cycle of bats (Whitaker, Deunff, and Belwood, 2000), and grooming behaviour (Hart, 1994).

5.5.3 Differences of ectoparasites between sexes and ages

There were no difference of ectoparasite loads between male and female bats in SERS. However, many studies showed that female bats were more infested by ectoparasites than male bats (Dick and Patterson, 2008; Kurta, Whithaker, Wrenn, and Soto-Centeno, 2007; Chilton, Vonhof, Peterson, and Wilson, 2000; Christe, Arlettaz, Vogel, 2000). Female bats have higher ectoparasite load because they often congregate in large maternity colonies (Zahn and Rupp, 2004; Reisen, Kennedy, and Reisen, 1976). Additionally, Christe, Arlettaz, and Vogel (2000) suggested that immunocompetence in female bats decreased when reproduction. Consequently, ectoparasites may responded to this mechanism in female bats. In contrary, male bats often roost solitary which possibly is a tactic to reduce ectoparasite load (Czenze and Broders, 2011). Male bats also have more energy budget for self-grooming which reduce ectoparasite load, compared to reproductive female bats (Dick, Gannon, Little, and Patrick, 2003).

Although several studies showed that female bats had higher ectoparasite load than male bats, few studies showed that male bats had more ectoparasite load than female bats (Komeno and Linhares, 1999). Moreover, some authors reported that ectoparasite load between male and female bats did not differ (Aguiar and Antonini, 2011; Bertola et al., 2005). These data suggest that ectoparasite load between male and female bats can be varied depending on many factors such as bat species, behaviours of bats, and life cycle of bats and ectoparasites.

In this study, the number of juvenile bats was low (n = 4). Only one juvenile *Myotis muricola* was infested by *Spinturnix* sp. Several authors revealed that juvenile bats carried ectoparasites more than adult bats. They also suggested that juvenile bats might be less skill to removing their ectoparasites and had lower immune defense

(Zhang et al., 2010; Christe et al., 2007; Christe, Arlettaz, and Vogel, 2000; McLean and Speakman, 1997). However, some studies showed that adult bats had more ectoparasite load than juvenile bats (Zahn and Rupp, 2004). Then, the conclusion about parasitism in relation to age of bat hosts is still in controversy (Pearce and O'Shea, 2007).

5.5.4 Ectoparasite load and body condition of bats

There was no effect of ectoparasite load on body condition of bats in this study. Many studies also documented that ectoparasite load had no impact on body condition of bats (Sharifi, Mozafari, Taghinezhad, and Javanbakht, 2008; Lučan, 2006). Moreover, Marshall (1982) suggested that ectoparasites had no effect on bat condition but ectoparasites were attracted by weak bats. However, several studies reported that ectoparasite load had various impacts on bats such as weight loss (Lourenço and Palmeirim, 2007; Pearce and O'Shea, 2007; Christe, Arlettaz, and Vogel, 2000), more grooming (ter Hofstede and Fenton, 2005; Giorgi, Arlettaz, Christe, and Vogel, 2001), and increase roost switching (Bartonicka and Gaisler, 2007; Reckardt and Kerth, 2007; Reckardt, K. and Kerth, 2006; Lewis, 1996). In this study, no correlation between ectoparasite load and body condition of bats possibly because low ectoparasite load. If more number of ectoparasites on these bats, the effect of ectoparasites on body condition of these bats may be occurs.

5.6 Conclusion

The data from this study reveal that 31.82% of total captured bats were infested by ectoparasites, including *Hipposideros larvatus*, *Rhinolophus affinis*, *Myotis muricola*, and *Cynopterus sphinx*. Ectoparasites were comprised of bat flies, mites, and tick. Mean intensities of ectoparasites were low in all bat species. Number of ectoparasites between male and female bats and among bat species were not different. There was no correlation between ectoparasite loads and bat weights.

This study is the first quantitative assessment of ectoparasites on bats in Thailand. However, some data limit to statistical analyses due to small sample size of hosts. It should be noted that number of hosts is important for quantitative study on ectoparasites of bats. In addition, ectoparasites are only classified to genus level because lack of study on ectoparasites of bats as well as no identification key of ectoparasites in Thailand. Further collection of ectoparasite specimens and species level identification should be carried out to improve knowledge of ectoparasites of tropical bats.

5.7 References

Aguiar, L. M. S. and Antonini, Y. (2011). Descriptive ecology of bat flies (Diptera: Hippoboscoidea) associated with vampire bats (Chiroptera: Phyllostomidae) in the cerrado of Central Brazil. **Memórias do Instituto Oswaldo Cruz**. 106: 170-176.

Ahamad, M., Ibrahim, H., Bujang, M. K., Sah, S. A., Mohamad, N., Nor, S. M., Ahmad, A. H., and Ho, T. M. (2013). A survey of acarine ectoparasites of bats (Chiroptera) in Malaysia. **Journal of Medical Entomology**. 50(1): 140-146.

Almeida, J. C., Silva, S. S. P., Serra-Freire, N. M., and Valim, M. P. (2011). Ectoparasites (Insecta and Acari) associated with bats in southeastern Brazil. **Journal of Medical Entomology**. 48: 753-757.

Autino, A. G., Claps, G. L., Barquez, R. M., and Díaz, M. M. (2011). Ectoparasitic insects (Diptera: Streblidae and Siphonaptera: Ischnopsyllidae) of bats from

Iquitos and surrounding areas (Loreto, Peru). **Memórias do Instituto Oswaldo Cruz**. 106: 917-925.

Bartonicka, T. and Gaisler, J. (2007). Seasonal dynamics in the numbers of parasitic bugs (Heteroptera, Cimicidae): a possible cause of roost switching in bats (Chiroptera, Vespertillionidae). **Parasitology Research**. 100(6): 1323-1330.

Bertola, P. B., Aires, C. C., Favorito, S. E., Graciolli, G., Amaku, M., and Pinto-da-Rocha, R. (2005). Bat flies (Diptera: Streblidae, Nycteribiidae) parasitic on bats (Mammalia: Chiroptera) at Parque Estadual da Cantareira, São Paulo, Brazil: parasitism rates and host-parasite associations. **Memórias do Instituto Oswaldo Cruz**. 100: 25-32.

Bush, A. O., Lafferty, K. D., Lotz, J. M., and Shostak, A. W. (1997). Parasitology meets ecology on its own terms: Margolis et al. revisited. **Journal of Parasitology**. 83: 575-583.

Bush, S. E. and Robbins, R. G. (2012). New host and locality records for *Ixodes simplex* Neumann and *Ixodes vespertilionis* Koch (Acari: Ixodidae) from bats (Chiroptera: Hipposideridae, Rhinolophidae and Vespertilionidae) in southern China. **International Journal of Acarology**. 38(1): 1-5.

Camilotti, V. L., Graciolli, G., Weber, M. M., Arruda, J. L. S., and Cáceres, N. C. (2010). Bat flies from the deciduous Atlantic forest in southern Brazil: host-parasite relationships and parasitism rates. **Acta Parasitologica**. 55: 194-200.

Changbunjong, T., Jirapattharasate, C., Buddhirongawatr, R., Chewajon, K., Charoenyongyoo, P., Suwanapakdee, S., Waengsothorn, S., Triwitayakorn, K., Chaichoun, K., and Ratanakorn, P. (2010). Ectoparasitic fauna of birds, and volant and non-volant small mammals captured at Srinakarin Dam, Kanchanaburi, Thailand. **The Southeast Asian Journal of Tropical Medicine and Public Health**. 41(3): 526-535.

Chilton, G., Vonhof, M. J., Peterson, B. V., and Wilson, N. (2000). Ectoparasitic insects of bats in British Columbia. **Canadian Journal of Parasitology**. 86: 191-192.

Christe, P., Arlettaz, R., and Vogel, P. (2000). Variation in intensity of a parasitic mite (*Spinturnix myoti*) in relation to the reproductive cycle and immunocompetence of its bat host (*Myotis myotis*). **Ecology Letters**. 3: 207-212.

Christe, P., Giorgi, M. S., Vogel, P., and Arlettaz, R. (2003). Differential species-specific ectoparasitic mite intensities in two intimately coexisting sibling bat species: resource mediated host attractiveness or parasite specialization?. **Journal of Animal Ecology**. 72(5): 866-872.

Christe, P., Glaizot, O., Evanno, G., Bruyndonckx, N., Devevey, G., Yannic, G., Patthey, P., Maeder, A., Vogel, P., and Arlettaz, R. (2007). Host sex and ectoparasites choice: preference for, and higher survival on female hosts. **Journal of Animal Ecology**. 76(4): 703-710.

Clayton, D. H. and Tompkins, D. M. (1994). Ectoparasite virulence is linked to mode of transmission. **Proceedings of the Royal Society of London, Series B: Biological Sciences**. 256: 211-217.

Czenze, Z. J. and Broders, H. G. (2011). Ectoparasite community structure of two bats (*Myotis lucifugus* and *M. septentrionalis*) from the Maritimes of Canada. **Journal of Parasitology Research**. 2011: 1-9.

Dahal, S. and Thapa, S. (2010). **A report on preliminary study of ectoparasites of bats of Kathmandu Valley**. Nepal: Tribhuvan University. 19p.

Dick, C. W. (2007). High host specificity of obligate ectoparasites. **Ecological Entomology**. 35(5): 446-450.

Dick, C. W., Gannon, M. R., Little, W. E., and Patrick, M. J. (2003). Ectoparasite associations of bats from Central Pennsylvania. **Journal of Medical Entomology**. 40: 813-819.

Dick, C. W. and Patterson, B. D. (2006). **Bat flies: Obligate ectoparasites of bats**. In: Morand, S., Krasnov, B., and Poulin, R. (Eds.). Micromammals and macroparasites: from evolutionary ecology to management. Tokyo: Springer-Verlag. pp. 179-194.

Dick, C. W. and Patterson, B. D. (2007). Against all odds: explaining host specificity in dispersal-prone ectoparasites. **International Journal of Parasitology**. 37: 871-876.

Dick, C. W. and Patterson, B. D. (2008). An excess of males: skewed sex ratios in bat flies (Diptera: Streblidae). **Evolution Ecology**. 22: 757-769.

Esbérard, C. E. L., Martins-Hatano, F., Bittencourt, E. B., Bossi, D. E. P., Fontes, A., Lareschi, M., Menezes, V., Bergallo, H. G., and Gettinger, D. (2005). A method for testing the host specificity of ectoparasites: give them the opportunity to choose. **Memórias do Instituto Oswaldo Cruz**. 100: 761-764.

Findley, J. S. (1993). **Bats: A community perspective**. Cambridge: Cambridge University Press. 167p.

Fritz, G. N. (1983). Biology and ecology of bat flies (Diptera: Streblidae) on bats in the genus *Carollia*. **Journal of Medical Entomology**. 20: 1-10.

Furman, D. P. and Catts, E. P. (1982). **Manual of medical entomology** (4th ed.). Cambridge: Cambridge University Press. 224p.

Gay, N., Olival, K. J., Bumrungsri, S., Siriaroonrat, B., Bourgarel, M., and Morand, S. (2014). Parasite and viral species richness of Southeast Asian bats: fragmentation of area distribution matters. **International Journal for Parasitology: Parasites and Wildlife**. 3: 161-170.

Giorgi, M. S., Arlettaz, R., Christe, P., and Vogel, P. (2001). The energetic grooming costs imposed by a parasitic mite (*Spinturnix myoti*) upon its bat host (*Myotis myotis*). **Proceedings of the Royal Society of London, Series B: Biological Sciences**. 268: 2071-2075.

Hart, B. L. (1994). Behavioural defense against parasites: interaction with parasite invasiveness. **Parasitology**. 109: 139-151.

Hill, J. E. and McNeely, J. A. (1975). **The bats and bat's parasites of Thailand**. U.S. Army Research and Development Group (Far East). 87p.

Hopla, C. E., Durden, L. A., and Keirans, J. E. (1994). Ectoparasites and classification. **Revue Scientifique et Technique**. 13(4): 985-1017.

Kolonin, G. V. (2003). New data on the ixodid tick fauna of Vietnam. **Entomological Review**. 83(2): 190-192.

Komeno, C. A. and Linhares, A. X. (1999). Bat flies parasitic some phyllostomid bats in Southeastern Brazil: parasitism rates and host-parasite relationships. **Memórias do Instituto Oswaldo Cruz**. 94: 151-156.

Krebs, C. J. (1998). **Ecology methodology** (2nd ed.). California: Benjamin/Cummings. 624p.

Krichbaum, K., Perkins, S., and Gannon, M. R. (2009). Host-parasite interactions of tropical bats in Puerto Rico. **Acta Chiropterologica**. 11(1): 157-162.

Kurta, A., Whitaker, J. O., Jr., Wrenn, W., and Soto-Centeno, A. (2007). Ectoparasitic assemblages on mormoopid bats (Chiroptera: Mormoopidae) from Puerto Rico. **Journal of Medical Entomology**. 44(6): 953-958.

Lewis, S. E. (1995). Roost fidelity of bats: a review. **Journal of Mammalogy**. 76: 481-496.

Lewis, S. E. (1996). Low roost-site fidelity in pallid bats: associated factors and effect on group stability. **Behavioral Ecology and Sociobiology**. 39: 335-344.

Lourenço, S. I. and Palmeirim, J. M. (2007). Can mite parasitism affect the condition of bat hosts? implications for the social structure of colonial bats. **Journal of Zoology**. 273: 161-168.

Lučan, R. K. (2006). Relationships between the parasitic mite *Spinturnix andegavinus* (Acari: Spinturnicidae) and its bat host, *Myotis daubentonii* (Chiroptera: Vespertilionidae): seasonal, sex- and age-related variation in infestation and possible impact of the parasite on the host condition and roosting behavior. **Folia Parasitologica**. 53(2): 147-152.

Maa, T. C. (1962). Records and descriptions of Nycteribiidae and Streblidae (Diptera). **Pacific Insects**. 4: 417-436.

Magurran, A. E. (1988). **Ecological diversity and its measurement**. Princeton: Princeton University Press. 179p.

Mariana, A., Zuraidawati, Z., Ho, T. M., Kulaimi, B. M., Saleh, I., Shukor, M. N., and Shahrul-Anuar, M. S. (2005). A survey of ectoparasites in Gunung Stong Forest Reserve, Kelantan, Malaysia. **Southeast Asian Journal Tropical Medicine and Public Health**. 36(5): 1125-1131.

Mariana, A., Zuraidawati, Z., Ho, T. M., Kulaimi, B. M., Saleh, I., Shukor, M. N., and Shahrul-Anuar, M. S. (2008). Ticks (Ixodidae) and other ectoparasites in Ulu

Muda Forest Reserve, Kedah, Malaysia. **Southeast Asian Journal Tropical Medicine and Public Health**. 39(3): 496-506.

Marshall, A. G. (1976). Host-specificity amongst arthropods ectoparasitic upon mammals and birds in the New Hebrides. **Ecological Entomology**. 1: 189-199.

Marshall, A. G. (1981). **The ecology of ectoparasitic insects**. London: Academic Press 459p.

Marshall, A. G. (1982). **Ecology of insects ectoparasitic on bats**. In: Kunz, T. H. (Ed.). Ecology of bats. New York: Plenum. pp. 369-401.

May, R. M. (1975). **Patterns of species abundance and diversity**. In: Cody, M. and Diamond, J. (Eds.). Ecology and evolution of communities. Cambridge: Harvard University Press. pp. 81-120.

McLean, J. A. and Speakman, J. R. (1997). Non-nutritional maternal support in the brown long-eared bat. **Animal Behaviour**. 54: 1193-1204.

Millar, I. M., Uys, V. M., and Urban, R. P. (1999). **Collecting and preserving insects and arachnids: A manual for entomology and arachnology**. Johannesburg: Ultra Litho. 122p.

Moras, L. M., Bernardi, L. F. O., Graciolli, G., and Gregorin, R. (2013). Bat flies (Diptera: Streblidae, Nycteribiidae) and mites (Acari) associated with bats (Mammalia: Chiroptera) in a high-altitude region in southern Minas Gerais, Brazil. **Acta Parasitologica**. 58(4): 556-563.

Nadchatram, M. and Mitchell, C. J. (1965). New bat chiggers from Thailand and the Solomon Islands with notes on the subgenus *Vercammen-Grandjean* (Acarina: Trombiculidae). **Journal of Medical Entomology**. 2(1): 70-74.

Patterson, B. D., Dick, K. W., and Dittmar, K. (2007). Roosting habits of bats affect their parasitism by bat flies (Diptera: Streblidae). **Journal of Tropical Ecology**. 23: 177-189.

Pearce, R. D. and O'Shea, T. J. (2007). Ectoparasites in an urban population of big brown bats (*Eptesicus fuscus*) in Colorado. **Journal of Parisitology**. 93: 518-530.

Price, M. A. and Graham, O. H. (1997). **Chewing and sucking lice as parasites of mammals and birds**. United States: US Department of Agriculture Technical Service Bulletin Number 1849. 309p.

Rajasekar, R., Chattopadhyay, B., and Sripathi, K. (2006). Depositing masticated plant materials inside tent roosts in *Cynopterus sphinx* (Chiroptera: Pteropodidae) in Southern India. **Acta Chiropterologica**. 8(1): 269-274.

Reckardt, K. and Kerth, G. (2006). The reproductive success of the parasitic bat fly *Basilia nana* (Diptera: Nycteribiidae) is affected by the low roost fidelity of its host, the Bechstein's bat (*Myotis bechsteinii*). **Parasitology Research**. 98(3): 237-243.

Reckardt, K. and Kerth, G. (2007). Roost selection and roost switching of female Bechstein’s bats (*Myotis bechsteinii*) as a strategy of parasite avoidance. **Oecologia**. 154: 581-588

Reisen, W. K., Kennedy, M. L., and Reisen, N. T. (1976). Winter ecology of ectoparasites collected from hibernating *Myotis velifer* (Allen) in Southwestern Oklahoma (Chiroptera: Vespertilionidae). **Journal of Parasitology**. 62(4): 628-635.

Ritzi, C. M. and Whitaker, J. O., Jr. (2003). Ectoparasites of small mammals from the Newport Chemical Depot, Vermillion County, Indiana. **Northeastern Naturalist**.

10: 149-158.

Rózsa, L., Reiczigel, J., and Majoros, G. (2000). Quantifying parasites in samples of hosts. **Journal of Parasitology**. 86: 228-232.

Sharifi, M., Mozafari, F., Taghinezhad, N., and Javanbakht, H. (2008). Variation in ectoparasite load reflects life history trades in the lesser mouse-eared bat, *Myotis blythii* (Chiroptera: Vespertilionidae) in Western Iran. **Journal of Parasitology**. 94(3): 622-625.

Sharifi, M., Taghinezhad, N., Mozafari, F., and Vaissi, S. (2003). Variation in ectoparasite load in the Mehely's horseshoe bat, *Rhinolophus mehelyi* (Chiroptera: Rhinolophidae) in a nursery colony in western Iran. **Acta Parasitologica**. 58(2): 180-184.

ter Hofstede, H. M. and Fenton, M. B. (2005). Relationships between roost preferences, ectoparasite density, and grooming behaviour of neotropical bats. **Journal of Zoology**. 266: 333-340.

ter Hofstede, H. M., Fenton, M. B., and Whitaker, J. O., Jr. (2004). Host and host-site specificity of bat flies (Diptera: Streblidae and Nycteribiidae) on Neotropical bats (Chiroptera). **Canadian Journal of Zoology**. 82: 616-626.

Theodor, O. (1955). On the genus *Eucampsipoda*, Kol and *Dipseliopoda*, n.g. (Nycteribiidae, Diptera). **Parasitology**. 45: 195-229.

Uchikawa, K. and Kobayashi, T. (1979). A contribution to the ectoparasite fauna of bats in Thaland I. fur mites of the family Myobiidae (Acarina; Trombidiformes). **Acarologia**. 20(3): 368-384.

Wall, R. and Shearer, D. (1997). **Veterinary entomology: Arthropod ectoparasites of veterinary importance**. London: Chapman and Hall. 439p.

Whitaker, J. O., Jr. (1982). **Ectoparasites of mammals of Indiana**. Indianapolis: Indiana Academy of Science. 240p.

Whitaker, J. O., Jr., Deunff, J., and Belwood, J. (2000). Ectoparasites of neonate Indiana bats, *Myotis sodalis* (Chiroptera: Vespertilionidae), with description of male of *Paraspinturnix globosa* (Acari: Spinturnicidae). **Journal of Medical Entomology**. 37: 445-453.

Whiteman, N. K. and Parker, P. G. (2004). Effects of host sociality on ectoparasite population biology. **Journal of Parasitology**. 90: 939-947.

Zahn, A. and Rupp, D. (2004). Ectoparasite load in European vespertilionid bats. **Journal of Zoology**. 262: 383-391.

Zar, J. H. (1999). **Biostatistical Analysis** (4th ed.). New Jersey: Prentice Hall. 662p.

Zhang, L., Parsons, S., Daszak, P., Wei, L., Zhu, G., and Zhang, S. (2010). Variation in the abundance of ectoparasitic mites of flat-headed bats. **Journal of Mammalogy**. 91(1): 136-143.

CHAPTER VI

CONCLUSION

This research was a study of community, diet, and ectoparasites of bats in SERS. The objectives of this study were; to survey bat community in dry evergreen forest, dry dipterocarp forest, ecotone area, and plantation forest in SERS, to investigate variation in diet, food niche breath, and food niche overlap among bats, and to identify ectoparasites associated with bats. The major results were concluded as the fallowing.

A total of 66 individuals of 9 bat species were captured in SERS. The diversity of bats are considered low. Bat species richness differ among habitat types. Therefore, most bats were captured in dry evergreen forest and few bats were captured ecotone. There was no captured bat in dry dipterocarp forest and plantation forest. Bat species richness also differed among seasons. Therefore, bat species in the rainy season were higher than in the winter and the summer.

The insectivorous bats in this area consumed 7 orders of insects i.e. Coleoptera, Lepidoptera, Diptera, Hymenoptera, Hemiptera, Isoptera, and Orthoptera. Of these, Coleopterans and Lepidopterans were the most important diet of insectivorous bats. However, there was no relationship between bat abundance and food availability in this study. The diet of bats slightly differ among bat species. Then, these bats exhibited narrow trophic niche breadth and low trophic niche overlap.

In total, 4 bat species were infested by ectoparasite i.e. *Hipposideros larvatus, Rhinolophus affinis, Myotis muricola, and Cynopterus sphinx.* Ectoparasites of bats included bat flies, mites, and tick. Number of parasite loads among bat species were not different. The prevalence of ectoparasites on bats was 31.82% and mean intensity of ectoparasites on bats was 0.435. Ectoparasites loads were not differ male and female bats and among bat species. There was no correlation between ectoparasite load and bat weight.This study provides important data on community structure, diet, and ectoparasites of bats in SERS which can be used in conservation and management of forest bats in Thailand. However, some data of this study are still incomplete. Further studies on bat ecology should be focused on more sample size of bats as well as carry out in other areas. Moreover, genetic techniques are also important methods to improve various knowledge on bats such as taxonomy, diet, and ectoparasites.

APPENDICES

APPENDIX A

FIGURES OF BAT SPECIES

Figure 1 Intermediate roundleaf bat (*Hipposideros larvatus*).

Figure 2 Wrinkle-lipped free-tailed bat (*Chaerephon plicata*).

Figure 3 Lesser false vampire bat (*Megaderma spasma*).

Figure 4 Wall-roosting mouse-eared bat (*Myotis muricola*).

Figure 5 Intermediate horseshoe bat (*Rhinolophus affinis*).

Figure 6 Diadem roundleaf bat (*Hipposideros diadema*).

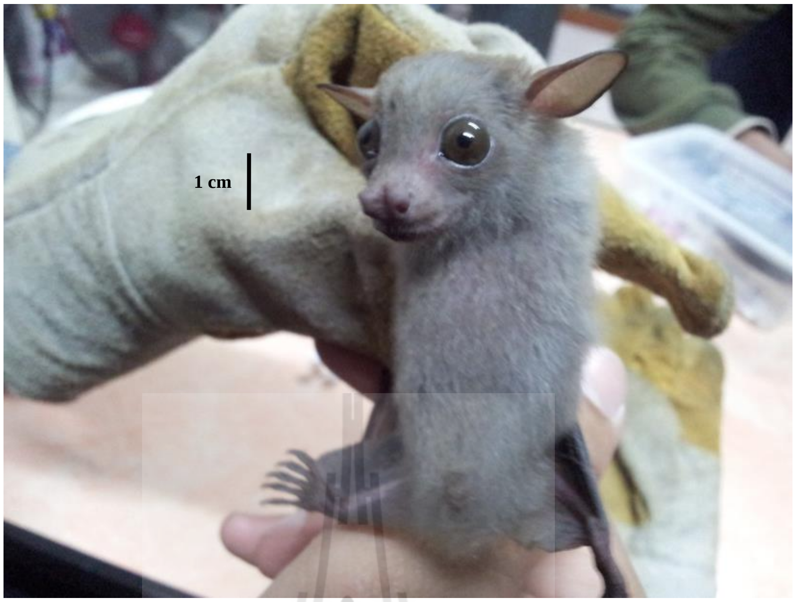

Figure 7 Ratanaworabhan's fruit bat (*Megaerops niphanae*).

Figure 8 Greater short-nosed fruit bat (*Cynopterus sphinx*).

Figure 9 Lesser short-nosed fruit bat (*Cynopterus brachyotis*).

APPENDIX B

FIGURES OF ECTOPARASITE SPECIES

Figure 1 *Brachytarsina* sp.

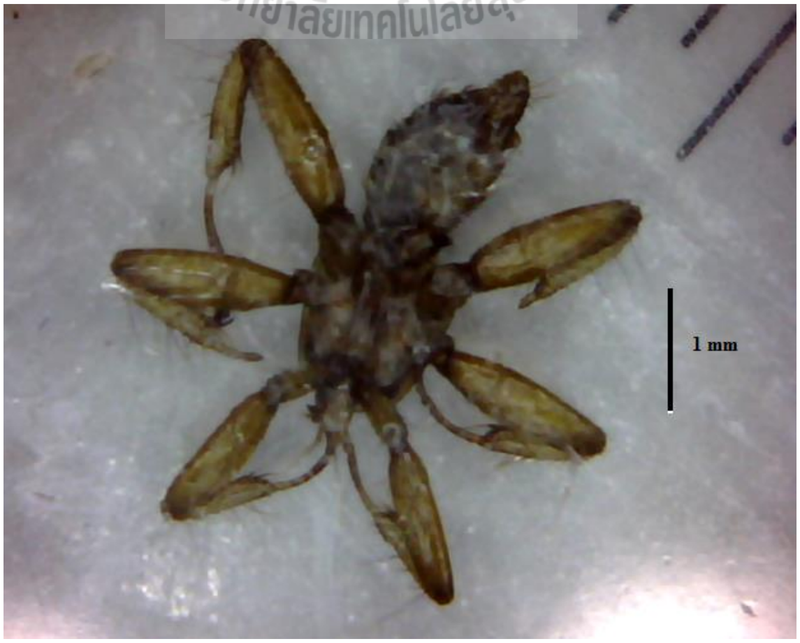

Figure 2 *Nycteribia* sp.

Figure 3 *Phthiridium* sp.

Figure 4 *Cyclopodia* sp.

Figure 5 *Raymondia* sp.

Figure 6 *Spinturnix* sp.

Figure 7 *Ixodes* sp.

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Thanee, N. and Aroon, S. (2014). Field observation of host plant and animal food preference of weaver ant (*Oecophylla smaragdina*) in mix plantation in Ubon Ratchathani province, Thailand. **Proceedings of the 10th Inter Conference Inter-University Cooperation Program. ASEAN Knowledge Networks for the Economy, Society, Culture, and Environmental Stability**. 8-12 May, 2014. Mandalay, Republic of the Union of Myanmar.