Systematics, Biogeography and Echolocation of Tube-nosed Bats Genus *Murina* (Chiroptera: Vespertilionidae) in Mainland Southeast Asia

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A Thesis Submitted in Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in Biology

Prince of Songkla University

2013

Thesis Title	Systematics, biogeography and echolocation of Tube-nosed bats genus *Murina* (Chiroptera: Vespertilionidae) in mainland Southeast Asia
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ABSTRACT

The Tube-nosed bat genus *Murina* in mainland Southeast Asia is reviewed. Eighteen species are currently recorded from the region. A new cryptic species of the '*cyclotis*-complex' is described from peninsular Thailand based on a combination of external, craniodental and genetic differences. The population previously referred to *M. cyclotis* from the Nicobar Islands is described as a new subspecies of this new species. Another new species belonging to '*suilla*-group' is described based on two specimens from the southernmost part of peninsular Thailand. *M. walstoni*, *M. annamitica*, and *M. rozendaali*, are recorded from Thailand for the first time. The diagnostic characters of each species are summarised and the taxonomy is discussed. DNA barcodes support current taxonomic conclusions but do not agree with traditional morphological groupings of the '*M. cyclotis*-group' and '*M. suilla*-group'. In most cases, the pattern of distribution of *Murina* in mainland Southeast Asia is strongly related with the zoogeographical division between the Indochinese and Sundaic Subregions but with one exception in the case of *M. huttoni*. Additional data on the ecology, distribution and conservation, where available, are included and discussed. A key to the species of *Murina* known to occur in mainland Southeast Asia is provided. Echolocation call and social call characters were described. Results of a field experiment on the efficacy of acoustic lures strongly indicate that a harp trap with acoustic lure, AutoBat, attached have a significantly higher trapping success than normal harp trapping. A random variety of *Murina* species were caught in the 'AutoBat traps'; individuals responded to all social calls not just to those of their own species.

ACKNOWLEDGEMENTS

I am deeply grateful to my thesis advisors Assoc. Prof. Dr. Chutamas Satasook and Dr. Paul J. J. Bates for their support, encouragement, guidance, proofreading and corrections on the draft of my thesis. I also grateful to the thesis examiners, Asst. Prof. Dr. Sara Bumrungsri and Dr. Vu Dinh Thong, for valuable comments and suggestions to improve this study. I am thankful to the Darwin Initiative, DEFRA, UK for a fully financial support of this study. I thank the Graduate School, PSU for financial support for fieldwork in Thailand and study visit to the UK.

I am indebted to Sunate Karapan and staff of the Halabala Wildlife Research Station, as well as Prateep Rojanadilok, Mongkol Safoowong and staff of the Wildlife Research Division, of the Department of National Parks, Wildlife and Plant Conservation (DNP). Without them, fieldwork and specimens collection would not possible. I thank David Hill for loaning me the Autobat machines and suggestions in acoustic lure. I also thank Jirapan Yimkaew, Sawwalak Billasoy, Abdullah Samoh, Bounsavane Douangboubpha, Ith Saveng, as well as all students at Mammals and Birds Research Unit and all staff at the PSUNHM for their help and support during the field expeditions and with specimen preparation.

I would like to thank Robert Baker, M. T. Abdullah, Faisal Anwarali Khan, Ibnu Maryanto, Vu Dinh Thong, Gabor Csorba, Neil Furey and Pichai Sonchaeng for kindly loaning me specimens under their care. I thank Evgeny Zhakarov, Alex Borisenko and Nataly Ivanova for coordinating the analyses of the DNA Barcode. Thanks also go to David Harrison, Nikky Thomas, Malcolm Pearch and Beatrix Lanzinger at the Harrison Institute, UK for their suggestions and help. I thank Tigga Kingston and Joe Chun-Chia Huang (TTU) and the Southeast Asian Bat Conservation and Research Unit (SEABCRU) for supporting networking between researchers. Special thanks go to Stephanie Beattie for her warm welcome and all her help during my stay in the UK. I am fully appreciate to Roberto Portela Miguez and staff at mammal collection and library of Natural History Museum, London, for the permission to study the bat collection.

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CHAPTER 1

GENERAL INTRODUCTION AND LITURATURE REVIEW

INTRODUCTION

Thirty-six vespertilionid bat species in the subfamily Murininae are currently known to science. Approximately one-third of these have been discovered and described in the recent years (Simmons, 2005; Csorba and Bates, 2005; Kuo *et al*., 2006, 2009; Csorba *et al*., 2007; Kruskop and Eger, 2008; Furey *et al.*, 2009; Csorba *et al.*, 2011; Ruedi *et al.*, 2012; Francis and Eger, 2012).

The subfamily Murininae comprises one or two species of *Harpiocephalus* depending on authors (i.e. Simmons, 2005; Francis *et al.*, 2010), two species of *Harpiola* and 33 species of *Murina.* The rapid increase in the number of species of these forest-dwelling bats has resulted from a wider use of harp traps in tropical forests and the consequent greater number of museum specimens available to study (Csorba *et al.*, 2011). However, the diversity as understood today still seems to be an underestimate and new species, particularly cryptic species, are waiting to be described (Francis *et al*., 2010).

Bats in subfamily Murininae are known from India, Russia, China, Korea, Japan to mainland Southeast Asia, where the group is found to be most abundant, down to the Indonesia, Philippines and northern Australia. Southeast Asia is also regarded as one of the most important 'Biodiversity Hotspots' (Mayer, 2000), especially for bat fauna with more than 310 species recorded from the region (approximately 25% of bats of the world). This represents the highest diversity of bats in the world (Simmons, pers. comm.). The Murininae is one of the most interesting groups of bats in term of genetic variation (Francis *et al.*, 2010). From a morphological viewpoint, this subfamily is known to be 'rich in cryptic species', which are defined as those that are difficult to distinguish from each other (Simmons, 2005; Csorba *et al.*, 2011).

In mainland Southeast Asia, which here includes Myanmar, Thailand, Laos, Vietnam, Cambodia, peninsular Malaysia and Singapore (Francis, 2008), at least 16 species of two genera *Murina* (14 species) and *Harpiocephalus* (two species) are currently known.

The genus *Murina* has traditionally been divided into two species groups, the '*cyclotis* group' and the '*suilla* group' based on the position of the upper incisors (I^2, I^3) and crown area of the first premolar (P^2) relative to the second upper premolar (P^4) (Corbet and Hill, 1992; Csorba *et al.*, 2007). However, the species composition of each group is still uncertain and varies among authors (Corbet and Hill, 1992; Maeda and Matsumura, 1998; Kawai *et al*., 2002). A recent genetic study also suggested that this traditional grouping does not reflect the true phylogenetic relationship between species of the genus (Francis *et al.*, 2010).

In term of cryptic diversity, one of the most widely distributed species *M. cyclotis*, which was considered to have three subspecies, is now regarded as a species complex and may comprise at least three species (P. Soisook, unpublished data.). Prior to this study, one of these taxa was the Sundaic subspecies '*Murina cyclotis peninsularis*', which is much larger than the nominate subspecies and exhibits considerable genetic divergence from it (Francis *et al.*, 2010). Another form (=*Murina* sp. B in Francis *et al.*, 2010) is found in the Indochinese subregion. It occurs sympatrically with *M. cyclotis* but is larger than the nominate subspecies. It has similar body size and skull shape with the '*peninsularis'* but large genetic differences were observed between them. Furthermore, within Sundaic subregion where only the taxon '*peninsularis'* was thought to occur, a preliminary survey showed that at least three size classes of this taxon can be found in the area. This marked variation in morphology within the taxon suggests the occurrence of unnamed cryptic species and a taxonomic study, with a support of molecular genetics, is urgently needed.

Within the '*suilla* group', many species have been reported new to science recently from mainland Southeast Asia (Kruskop and Eger, 2008, Furey *et al.*, 2009; Csorba *et al.*, 2011). However, they are known from a relatively few localities in Vietnam or Cambodia, or, in some cases, only from type locality. Results of preliminary surveys suggest that the species in the '*suilla* group' are more broadly

distributed in the forest areas of Southeast Asia than previously known (P. Soisook, unpublished data). The maps of their ranges must be redrawn.

Known as forest-dwelling species and difficult to catch, knowledge of the ecology and echolocation of these bats is very rare. Acoustic characters of only a few species of Southeast Asian *Murina* have been illustrated from peninsular Malaysia (Kingston *et al.,* 1999) and *Murina tiensa* (regarded as *M. harrisoni* in this study; see also Francis and Eger, 2012) from Vietnam (Thong *et al.,* 2011). Using echolocation may be useful for discriminating *Murina* species but very little is currently known about their acoustic behaviour. Moreover, with their highly effective echolocation, *Murina* spp. are difficult to catch either in a harp trap or a mist net.

A technique developed by Hill and Greenaway (2005) showed that using an acoustic lure, the AutoBat, can lead to a significant increase in the number of bats captured in British woodlands. However, until this current study, this technique had not been tested with bats in tropical forests. Our preliminary surveys of *Murina* using the AutoBat in tropical forests of peninsular Thailand showed very promising results. Using harp traps/mist nets with the Autobat, which played simulated social calls of *M. cyclotis peninsularis* and some other *Murina* and *Kerivoula* species, increased the numbers of *M. cyclotis peninsularis* and *M. suilla* that were caught when compared to previous surveys without the AutoBat. However, these results are based on short preliminary surveys, rather than a systematic experiment. So there is a need to test the technique in a more rigorous way. Moreover, a systematic experiment will allow the relative effectiveness of different calls to be assessed.

Major goals of this study are to elucidate taxonomic problems of *Murina* in mainland Southeast Asia by using a combination of relevant datasets (morphology, morphometric, genetic and acoustic), to summarise systematic description, phylogenetic relationship, ecology and biogeographic patterns and acoustic characters of bats in the genus *Murina* in mainland Southeast Asia, and also test and develop techniques for increasing capture success by comparing standard capture techniques with those including the application of an acoustic lure (Autobat).

GENERAL LITERATURE REVIEW

Diversity and distribution

With over 310 species of bats recorded, of about 1200 species around the world, Southeast Asia represents the highest diversity of bats in the world (Simmons, pers. comm.). The region is also a 'hot spot' where many 'rare and endemic species' can be found but most are severely threatened by habitat loss (IUCN, 2013). However, the number of species in the region is still increasing due to new species discoveries recently. Among these, most are small insectivorous bats belong to the family Vespertilionidae, e.g. Woolly bats *Kerivoula* spp. (Bates *et al.*, 2004; Bates *et al.*, 2007; Francis *et al.*, 2007) and Tube-nosed bats *Murina* spp. (Csorba and Bates, 2004; Csorba *et al*., 2007; Kruskop and Eger, 2008, Furey *et al.*, 2009; Csorba *et al.*, 2010). This high and increasing number, along with evidence of cryptic diversity from genetic data (Francis *et al.*, 2010), suggests that the true number of bat diversity of the region may be twice that presently known (Racey, pers. comm.).

Tube-nosed bats, genus *Murina* Gray, 1842, are one of three genera in the subfamily Murininae. This subfamily has a geographical range encompassing India, Russia, China, Japan, throughout Southeast Asia to northern Australia (Corbet and Hill, 1992; Simmons, 2005). *Murina* and the two other genera in the Murininae, *Harpiocephalus* and *Harpiola*, have the same diagnostic character of distinctly projecting, tubular nostrils (Francis, 2008). Outside the Murininae, only the unrelated Tube-nosed fruit bat genus *Nyctimene*, which is found in Philippines, E Indonesia, Papua New Guinea and N Australia, has a similar shape of nostrils (Simmons, 2005). In the dentition, the two upper and lower premolars are well developed (Bates and Harrison, 1997).

Taxonomic background

The family Vespertilionidae (or Vesper bats), although most common in warmer parts of the world, is distributed worldwide owing to the maneuverability of its flight and the extensive availability of insect prey in various types of vegetation, globally. Prior to Hoofer and Van Den Bussche (2003) published the work on

phylogenetics of the family published in 2003, the systematics was based almost entirely on traditional anatomical characters (e.g. Corbet and Hill, 1992), and contained five subfamilies, including Kerivoulinae, Murininae, Miniopterinae, Nyctophilinae and Vespertiloninae. Hoofer and Van Den Bussche (2003), based on phylogenetic analyses of mtDNA of 171 taxa, revealed new phylogenetic relationships within the family and suggested promoting the Miniopterinae to its own family level, Miniopteridae.

The subfamily Murininae is one of the groups that still requires much systematic research, in part because of the small number of specimens available. It is currently considered to have three genera. Genus *Harpiola* Thomas, 1915, which was considered a subgenus of *Murina* by Corbet and Hill (1992) and Simmons (2005) but is now regarded as a valid genus and includes *H. grisea* from India and *H. isodon* from Taiwan by Kuo *et al*. (2006). In addition, a specimen referred to *H. isodon* is also reported from Vietnam (Kruskop *et al*., 2006). However, good genetic data are still needed to test its relationship with the other genera.

The genus *Harpiocephalus* Gray, 1842 differs from genus *Murina* in its larger body size, shorter and broader rostrum, and greater reduction of the molars. It has been considered to have only one species (Koopman, 1993) or two species (Corbet and Hill 1992; Simmons, 2005) depending upon whether *H. mordax* is treated as being conspecific with *H. harpia*. Matveev (2005) suggested that the apparent morphological differences between *H. mordax* and *H. harpia* in mainland Southeast Asia could be explained by sexual dimorphism and only one species could be recognized genetically. Results from analysis of DNA barcodes, by Francis *et al.* (2010), for specimens from Laos, Vietnam and S. China support the conclusion that existing specimens from this region belong to only one species. However, further systematics studies need to be conducted on specimens from other localities in the range, including specimens from the type localities of *H. harpia* in Java and *H. mordax* in N. Myanmar.

As mentioned above, the genus *Murina* has been traditionally divided to two species groups, the '*cyclotis* group' and the '*suilla* group' (sensu Corbet and Hill, 1992; Koopman, 1994). However, DNA barcode studies suggest that this grouping does not reflect the actual phylogeny of the genus (Francis *et al.*, 2010). A

study of *Murina* phylogeny based on other genetic markers to reveal the true phylogenetic relationship of this group is ongoing (J. Eger, personal communication.).

One of the most widely distributed species of the genus, *M. cyclotis*, which previously was considered to have three subspecies, is regarded as a species complex (Francis and Eger, 2012.). Although currently the Sundaic subspecies '*M. c. peninsularis*', is regarded as a separate species and the larger form in the Indochinese subregion has been named as *M. fionae,* the taxonomic status of bats in this group is still uncertain (Francis and Eger, 2012). A specimen (ROM 110439) collected from Krabi Province, peninsular Thailand by Antonio Guillén-Servent, although morphologically similar to the taxon '*cyclotis',* has been reported as having about 15% genetic divergence from the population referred to the same species in Laos (Francis and Eger, 2012). This marked variation in morphology within and between taxa suggests the occurrence of unnamed cryptic species and a taxonomic study, with a support of molecular genetics, is urgently needed.

Two species of *Murina* in the '*cyclotis* group' are recently described from Indochina. *Murina harrisoni* was described from single locality in Cambodia (Csorba and Bates, 2005) and later found in China (Wu *et al.,* 2010). *M. tiensa* was described from Vietnam based on difference in the skull shape and some differences in the dentition. Interestingly, genetic divergence based on mtDNA between the two species is very little compared to other species in the genus (Francis *et al.,* 2010) and suggests that *M. tiensa* is a synonym of *M. harrisoni* (Francis and Eger, in preparation). Nevertheless, recent publications indicated that mtDNA is not always useful to discriminate between different species and the small genetic divergence observed may be explained by mtDNA introgression events (Berthier *et al.,* 2006; Hulva *et al.,* 2010; Nasi *et al.,* 2011).

Another interesting species, in term of biogeography, is *M. huttoni,* which is widely distributed in the Indian Subcontinent, but seems to be rare, with small disjunct populations recorded in Southeast Asia. A recent record of this species from Pu Mat, Vietnam may represent an undescribed species (Francis *et al.,* 2008). Another disjunct record from Gunong Benom, Malaysia by Hill (1972), who referred the single specimen to *M. huttoni rebella* (similar to specimens from China), seems to be questionable since it would be the only taxon that is found both in Indochinese and

Sundaic subregion. More material and taxonomic research, particularly in the case of the Malaysian specimen, needs to be undertaken in order to support appropriate zoogeographical explanations.

Ecology and conservation

Until present, the ecology of *Murina* was very little known. Together with the related insectivorous bats belonging to the genus *Kerivoula,* it was considered to be a forest-dependent. Francis (2008) noted that *Murina* can be found in variety forest habitats, from lowland dipterocarp, semi-evergreen to hill-evergreen forest. In Sri Lanka, *M. cyclotis* was found seeking small flying insects in damp forests and roosts under cardamom dry leaves (Phillips, 1980). In China, *M. leucogaster* was reported to have small Coleoptera, i.e. soldier beetles, Cantharidae, and ladybugs, Coccinellidae in the diet (Ma *et al.,* 2008). Csorba *et al.* (2011) noted that the three new species recently described from Cambodia and Vietnam were found in various type of forests, from disturbed secondary forest to evergreen forest mixed with deciduous forest. In Malaysia, *M. cyclotis* was usually captured in harp traps set in the understorey of primary forest and was once found flying from a banana tree (Kingston *et al.,* 2006). In Thailand, *Murina* spp. are usually caught in harp traps set over, or near to, small seasonal streams in variety of forest types (P. Soisook, unpublished data)**.**

Although the number of records of these tube-nosed bats is relatively small, most of currently known *Murina* are listed as 'Least Concern' in the IUCN Red List of Threatened Species (IUCN, 2013). There are only two Japanese's island species, *M. tenebrosa* and *M. ryukyuana* listed as 'Critically Endangered' and 'Endangered' respectively. Two of the Sunda species, *M. aenea* and *M. rozendaali* are listed as 'Vulnerable' due to loss of forest habitat (IUCN, 2013).

Echolocation

Since Griffin *et al.* (1958) revealed the mystery of bat navigation in the dark, insectivorous bats are now known to use echolocation calls to locate objects and find their preys (Altringham, 1996). Echolocation call characters have proved useful for species identification in the case of bats that use constant frequency (CF bats) and

for those that have frequency modulated (FM bats) calls (i.e. Russo and Jones, 2002; Fukui *et al.*, 2004; Soisook *et al.,* 2008; Hughes *et al.,* 2010). Monitoring bats by using a bat detector is also an effective way for studying the ecology and conservation of bats (Fenton, 1990) because acoustic data also provide patterns of habitat use and foraging behaviour, and thus are useful for habitat management and conservation (Fukui *et al.,* 2004).

Nevertheless, it should be borne in mind that differences in echolocation call parameters are not found only between species but are also observed within species. Previous studies have clearly shown geographical variation of call frequency among populations of a single species (i.e. Soisook *et al.,* 2008; Dejtaradol, 2009; Ith *et al.*, 2010). Call characters, particularly the frequency, can also vary because of the influence of age, sex, body condition, foraging habitat and foraging mode (Jones and Ransome, 1993; Barclay *et al.,* 1999)

Echolocation call of vespertilionids is usually FM type and is characterised by a broadband signal of relatively short duration. These characters assist vesper bats forage in cluttered space or dense vegetation (Schnitzler and Kalko, 2001). Fukui *et al.* (2004) described call characters of eight bat species in Japan. Seven of these are Vespertilionids and two of them are *Murina* who emit FM type of echolocation call. Discriminant function analysis used in this study correctly classified calls to species at a 92% confidence level (Fukui *et al.,* 2004).

In Southeast Asia, knowledge of the echolocation of *Murina* is poor. Acoustic characters of *M. suilla, M. aenea* and *M. cyclotis* have been described from peninsular Malaysia where it was found that there was overlap between species (Kingston *et al.,* 1999). The call of another species found in Vietnam, *M. tiensa* (currently referred as *M. harrisoni*) was recently illustrated by Thong *et al.* (2011). Hughes *et al.* (2011) described echolocation call characters of 10 Vespertilionids from Thailand including three species of *Murina*; *M. cyclotis, M. suilla* and *M. tubinaris* (=*M. feae*). However, these species, particularly *M. cyclotis*, comprise cryptic species as suggested by DNA Barcode (Francis *et al.,* 2010). Therefore, their call characters need to be re-described based on current, up to date data and knowledge of taxonomy.

CHAPTER 2

AN OVERVIEW OF MATERIALS AND METHODS

Details of current and existing knowledge of the taxonomy, diversity, distribution, ecology, and echolocation of bats in the subfamily Murininae were reviewed thoroughly from published literature accessed from several archives, including the PSU e-library and Taxonomic library (provided by Harrison Institute). Additional data were compiled personally during 2010–2013 from specimens studied in museums and collected in the field. Echolocation and ecological data were also collected in the field. Genetic data were obtained from specimens held in a number of zoological collections. General details are outlined below. More details of specific protocols and analyses are described in each chapter.

Morphometric and morphological data

Existing specimens housed in natural history museums were examined either during visits to the museum or through inter-museum loans. The museums or institutes that specimens were from and their acronyms are as follow.

- Centre for Biodiversity Conservation, Royal University of Phnom Penh, Phnom Penh, Cambodia (CBD)
- Harrison Institute, Sevenoaks, UK (HZM)
- Hungarian Natural History Museum, Budapest, Hungary (HNHM)
- Institute of Ecology and Biological Resources, Vietnamese Academy of Science and Technology, Hanoi, Vietnam (IEBR)
- Museum of Texas Tech University, Texas, USA (MoTTU)
- Museum Zoologicum Bogoriense, Indonesian Institute of Sciences [LIPI], Bogor, Indonesia (MZB)
- Natural History Museum, London, UK (BMNH)
- Princess Maha Chakri Sirindhorn Natural History Museum [here after

PSUNHM], Prince of Songkla University [PSU], Hat Yai, Thailand (PSUZC)

- Royal Ontario Museum, Ontario, Canada (ROM)
- Thailand Natural History Museum, Pathum Thani, Thailand (THNHM)
- Bat collections of the local wildlife research stations of the Department of National Park, Wildlife and Plant Conservation (DNP) in Thailand, including Chiangdao Wildlife Research Station, Chiang Mai (CDWRS) and Halabala Wildlife Research Station, Narathiwat (HBRWS).

Additional specimens

Bats were collected by using 4-bank harp traps (Francis, 1989) in combination with mist nets and hoop nets. Field surveys were focused on a variety of wide ranging localities in Thailand:

- Chiang Mai Province – a field survey was conducted in Chiangdao WS which is characterised by a huge limestone mountain range. The major vegetation types are mixed deciduous forest and hill evergreen forest. (1) Khun Huay Mae Kok, Chiangdao District, 19°22’N 98°50’E, 1200 m a.s.l. (metres above sea level) [loc. 1; Fig. 2-1], specimens were collected in mist net set along a streamlet in hill evergreen forest, on 24–25 June 2011. (2) Khun Mae Ngai, Chiangdao District , 19°30’N, 98°55’E, 800 m a.s.l [loc. 2; Fig. 2-1], specimens were collected in harp traps and mist nets set over and by the side of a stream at the edge of a hill evergreen forest, on 27–28 June 2011. Specimens of *M. annamitica* and *M. feae* were collected from these sites together with other insectivorous bats included *Rhinolophus affinis, R. lepidus, Hipposideros cineraceus, H. larvatus, Myotis horsfieldii, Kerivoula hardwickii* and *K. titania*.

- Kamphaeng Phet Province – a field survey was conducted between May and August 2013 by the field research team of HBWRS and P. Soisook in Mae Rewa Guard St., Mae Wong NP., Klong Lan District, 15°55’N, 99°19’E, 220 m a.s.l [loc. 3; Fig. 2-1]. The area is characterised by lowland dipterocarp forest and mixed deciduous forest dominated by teak (*Tectona grandis* L.f.). Bat was captured in a harp trap set over seasonal stream and across a forest trail in mixed deciduous forest. A specimen of *M. walstoni* was collected from this site. The other insectivorous bats

found at the same site included *R. acuminatus, H. larvatus, H. pomona, H. cineraceus, My. siligorensis, My. rosseti, Glischropus bucephalus, K. hardwickii.*

- **Chumphon Province –** a field survey was conducted at Phato Watershed Conservation and Management Unit, Phato District, 9°45'N, 98°38'E, 190 m a.s.l. [loc. 4; Fig. 2-1]. Bats were captured in a mist net and a harp trap set over a stream in evergreen forest. A specimen of *M. suilla* was collected together a specimen of *My. horsfieldii.*

- **Surat Thani Province** – a series of field surveys was conducted between 2010 and 2011 by PS during the study of small mammal and bird diversity in Rajjaprabha Dam, under the 'Plant Genetic Conservation Project under the Royal Initiation of Her *Royal Highness* Princess Maha Chakri Sirindhorn (RSPG)', 8°57'N, 98°47'E, 400 m. a.s.l. [loc. 5; Fig. 2-1]. Specimens were collected in a harp trap and mist net in secondary evergreen forest. Two species of *Murina* were collected including *M. suilla* and *M.* sp. [A] (described in Chapter 3) together with 25 other species of bats (Soisook *et al.*, 2011).

- **Trang Province** – a field survey was conducted at Ton Tae Waterfall, Pa Lien District, 7°19'N 99°50'E, 400 m a.s.l. [loc. 6, Fig. 2-1], on 11 January 2012. A specimen of *M. suilla* and a *M.* sp. were collected in a harp trap set across a forest trail in lowland evergreen forest. The other insectivorous bats found in the same site included *R. lepidus, R. affinis, R. malayanus* and *Kerivoula hardwickii.*

- **Phattalung Province** – a field survey was conducted around Ton Phrae Thong Waterfall, Kong Ra District, 7°29'N, 99°54'E, 70 m a.s.l. [loc. 7; Fig. 2-1], on 13 March 2012. A specimen of *M.* sp. was collected in a harp trap set by a stream, between a tree and a small bamboo grove. The other insectivorous bats found in the same area included *R. affinis, R. coelophyllus, R. lepidus, Hipposideros atrox, H. bicolor, H. larvatus* and *H. pendleburyi.*

- **Songkhla Province** – a field survey was conducted around Pha Dam Waterfall, Hat Yai District, 6°49'N 100°13'E, 150 m a.s.l. [loc. 8; Fig. 2-1] on 4–7 February 2012. The area is covered by evergreen forest. Specimens of *M. peninsularis* and *M. suilla* were collected in a harp trap set across a forest trail. The other insectivorous bats found in this site included *Nycteris tragata, R. affinis, R.*

trifoliatus, H. atrox, H. doriae, Hesperoptenus blanfordi, Tylonycteris pachypus, K. hardwickii, K. pellucida, K. minuta and *Phoniscus atrox.*

- Satun Province – a field survey was undertaken at Wang Tai Nan Waterfall, Manang District, 7°10'N, 100°00'E, 240 m a.s.l. [loc. 9; Fig. 2-1]. The area is characterised by lowland primary evergreen forest. Bats were captured in harp traps set across forest trails. Bat species found at this site included *N. tragata, R. affinis, R. malayanus, R. stheno, R. robinsoni, R. coelophyllus, H. atrox, H. larvatus, H. diadema, K. hardwickii, K. pellucida* and *K. minuta.*

- Narathiwat Province – a bat survey was conducted between September and October 2012 by staff of the HBWRS at Bala Forest, Halabala WS (ca. 5°48'N 101°50'E, 200 m a.s.l.) [loc. 10; Fig. 2-1]. The general vegetation mainly comprises Malaysian type tropical rain forest. Bats were captured in a harp trap set across forest trails or over small streams. Specimens of *M.* sp. [B] (describe in Chapter 4), *M. suilla, M. peninsularis, M. aenea* and *M. rozendaali* were collected. Other insectivorous bats captured during the survey included *R. lepidus, R. trifoliatus, R. affinis, R. trifoliatus, H. atrox, H. bicolor, Pipistrellus stenopterus, Harpiocephalus harpia, K. papillosa, K. pellucida, K. minuta, Ph. atrox* and *Ph. jagorii.*

Fig. 2-1. Localities where the additional field surveys were undertaken in Thailand.

Measurements

External measurements were taken with a dial caliper to the nearest 0.1 mm or a digital caliper to the nearest 0.01 mm in the field. Specimens are preserved in 70% ethanol. Some of specimens were prepared as dry study skin. Skulls and some bacula were extracted. All cranial and dental measurements were taken with a Mitutoyo digital caliper under the microscope (in mm; to the nearest 0.01 mm). The definition of measurements followed Bates and Harrison (1997), Csorba *et al.* (2011) and Francis and Eger (2012) unless otherwise stated (see also Fig. 2-2 to 2-5 for illustration of measurements). Body mass (MASS) was taken with Pesola scale (in grams; to the nearest 0.5 g).

- MASS: weight of the bat (newly sacrificed) – taken with Pesola scale to the nearest 0.5 g.

- FA: forearm length, from the extremity of the elbow to the extremity of the carpus with the wings folded.

- HB: head and body length, from the tip of the snout to the base of the tail, dorsally.

- TL: tail length, from the tip of the tail to its base adjacent to the anus.

- HF: hind foot length, from the extremity of the heel behind the os calcis to the extremity of the longest digit, not including the hair or claws.

- TIB: length of tibia, from the knee joint to the ankle.

- 5MET, 4MET, 3MET: length of the metacarpal of the fifth, fourth and third digits respectively, taken from the extremity of the carpus to the distal extremity of each metacarpal.

- 3D1P/3D2P: first/second phalanx respectively of the third digit – taken from the proximal to the distal extremity of the phalanx.

- E: ear length, from the lower border of the external auditory meatus to the tip of the pinna; Tragus: tragus length, as ear length but to the tip of the tragus.

- GTL: greatest length of skull, the greatest antero-posterior length of the skull, taken from the most projecting point at each extremity.

- CBL: condylobasal length, from the exoccipital condyle to the anterior part of the upper incisor.

- CCL: condylo-canine length, from an exoccipital condyle to the anterior alveolus of the canine.

- ZB: zygomatic breadth, the greatest width of the skull across the zygomatic arches; BB: breadth of braincase, greatest width of the braincase at the posterior roots of the zygomatic arches.

- IC: interorbital constriction, taken at least width of the interorbital constriction.

- LW: lacrimal width, greatest width across the lacrimal tubercles at the rostral margins of the orbits.

- BCH: braincase height – from the basisphenoid at the level of the hamular processes to the highest part of the skull, including the sagittal crest (if present).

- $C–M^3$: maxillary toothrow length, from the front of the upper canine to the back of the crown of the third upper molar.

- $C–P^4$: upper canine–premolar length, from the front of the upper canine to the back of the crown of the second premolar.

- $M^3–M^3$: palatal width, taken across the outer borders of the third upper molar, taken at the widest part.

- $C^1–C^1$: greatest anterior palatal width measured across the outer borders of the canines, taken at the widest part.

- $C–M_3$: mandibular toothrow length, from the front of the lower canine to the back of the crown of the third lower molar.

- $C–P_4$: lower canine–premolar length, from the front of the lower canine to the back of the crown of the second premolar.

- M: mandible length, from the most posterior part of the condyle to the most anterior part of the mandible.

- CPH: least height of the coronoid process – from the tip of the coronoid process to the apex of the indentation on the inferior surface of the ramus adjacent to the angular process.

- TRM_1: length of the trigonid of the first lower molar – measured on the lingual side of the tooth when viewed from above, from the most anterior part to the most posterior part of the trigonid cusp.

- TAM_1: length of the talonid of the first lower molar – measured on the lingual side of the tooth when viewed from above, from the most posterior part of the trigonid cusp to the most posterior part of the talonid.

- BL: greatest length of the baculum – measured from the most posterior to the most anterior part.

Statistical analyses were performed in PCORD 4.17 (McCune and Mefford, 1999) and MINITAB 14 (Minitab Inc., State College, PA., USA).

Acoustic data

Acoustic data were collected during field work and were also incorporated from existing data provided by a network of international collaborative colleagues and literature (i.e. Kingston *et al*., 1999, 2003). Bat calls were recorded from flying individuals in flight cage, i.e. mosquito net (3x4 m width and 3 m height) or room with a Pettersson D-1000X ultrasound detector set in 10x time-expansion mode and sampling rate of 768 kHz, or with a Pettersson D-240X set in 10x time expansion connected to iRiver iHP-120 Multi-Codec Jukebox Recorder. Calls were transferred to a computer for analysis in BatSound – Sound Analysis Version 4.1.4 (Pettersson Electronics and Acoustic AB). Four standard call parameters were generally measured (unless stated otherwise) including: start frequency (*sf*) and terminal frequency (*tf*) (in kHz) measured by using measurement curser in spectrogram, the frequency of maximum energy (*fmaxe*) measured in the Power spectrum, and call duration (*d*) (in ms) measured by using marking cursor in spectrogram. A sampling frequency of 44.10 kHz was used and produced a spectrogram using Automatic Fast Fourier Transform (FFT) with Hanning window. Five to ten calls with good signal to noise ratio for each individual were chosen for analysis. Discriminant analysis was used to test acoustic differences between species. Statistical analysis was performed in MINITAB 14.1 (Minitab Inc., State College, PA., USA).

Genetic data

To support taxonomic conclusions and construct phylogenetic trees, samples for DNA analysis were taken. Genetic materials were collected either from

spirit specimens or fresh specimens immediately after bats were sacrificed. The tissue samples were taken from wing membrane, tongue or liver and stored in 1.5 ml microtubes with absolute alcohol. The DNA Barcodes were analysed following standard protocols of DNA extraction, gene amplification, and nucleotide sequencing as outlined in Francis *et al.* (2010) and Ivanova *et al.* (2012). Sequences were analysed using the neighbour-joining tree algorithms on the Barcode of Life Data Systems (BOLD). Evolutionary analyses were conducted in MEGA version 5 (Tamura *et al.*, 2011).

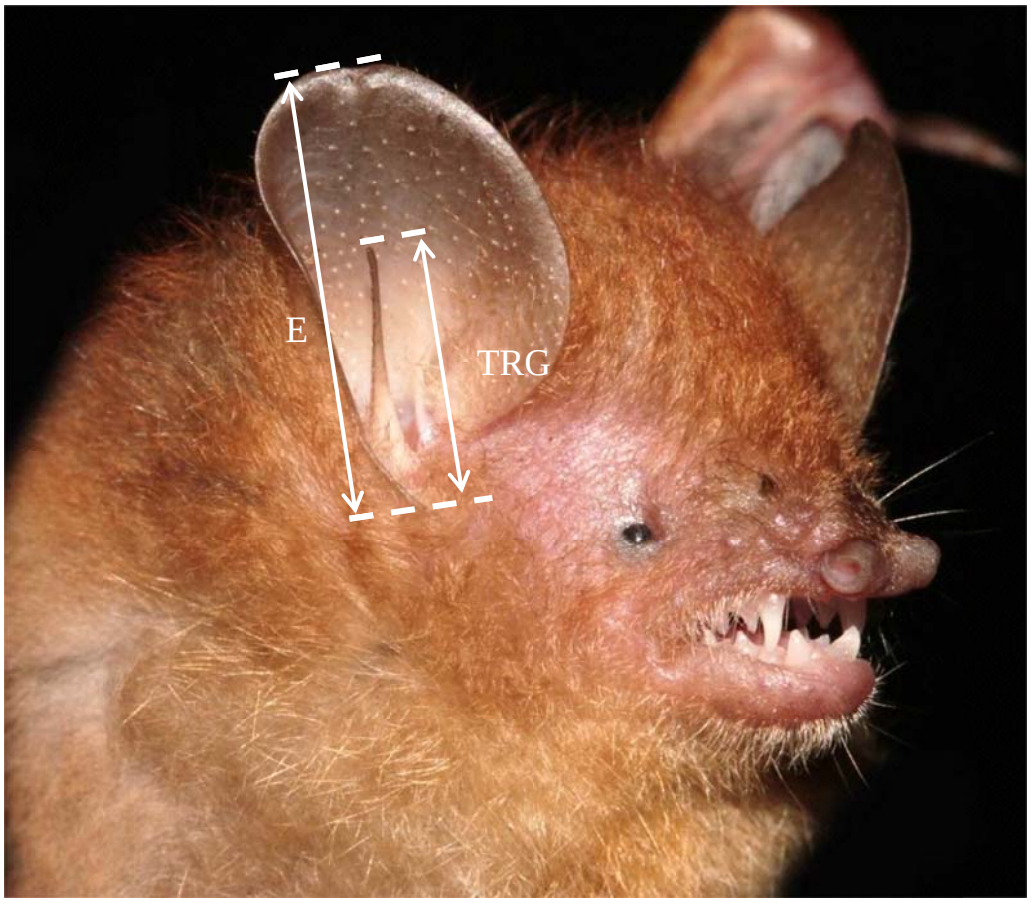

Fig. 2-2. Antero-lateral view of the head of *Murina* and the measurements of the ear length (E) and the tragus length (TRG).

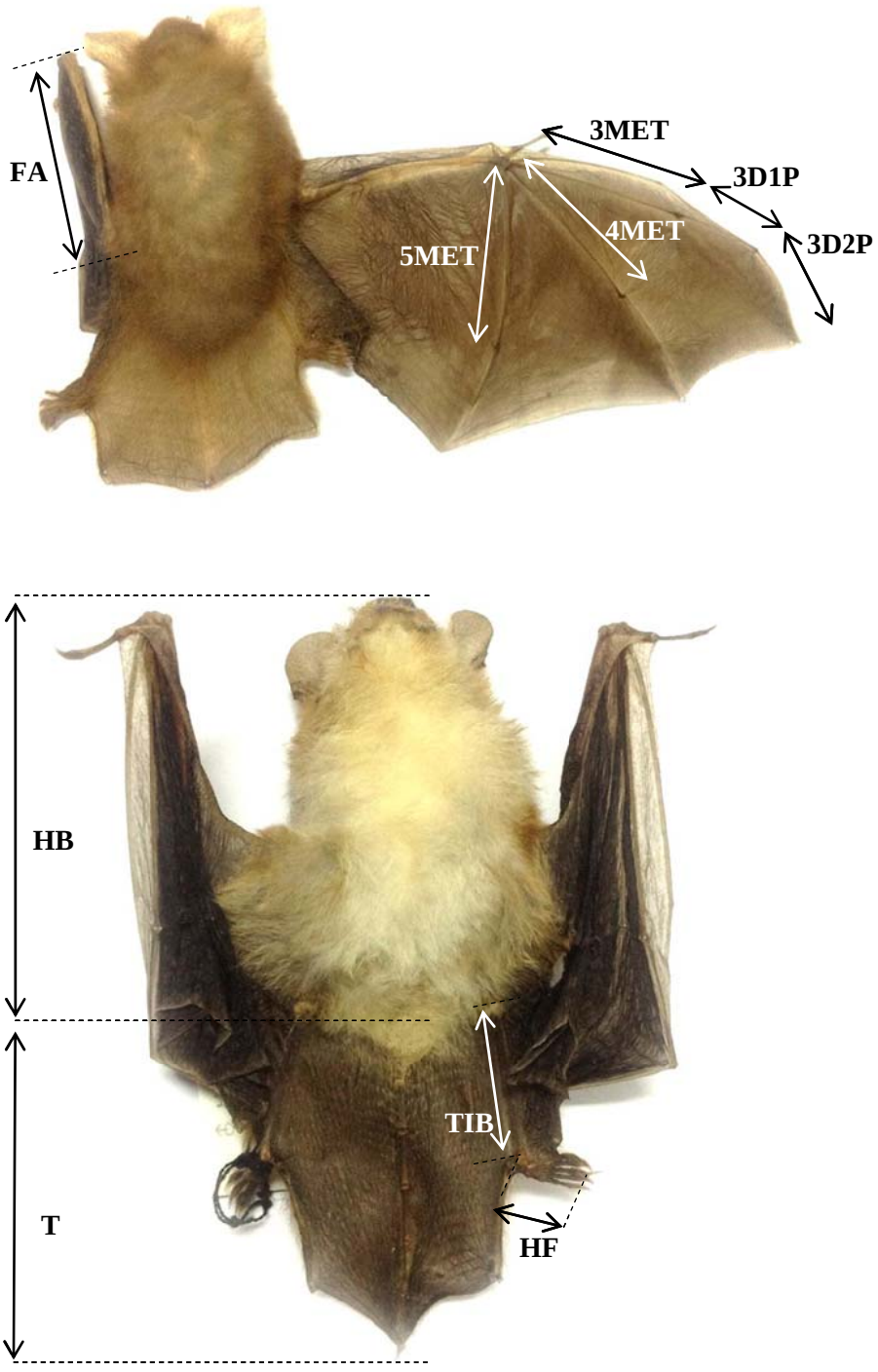

Fig. 2-3. External measurements of *Murina*.

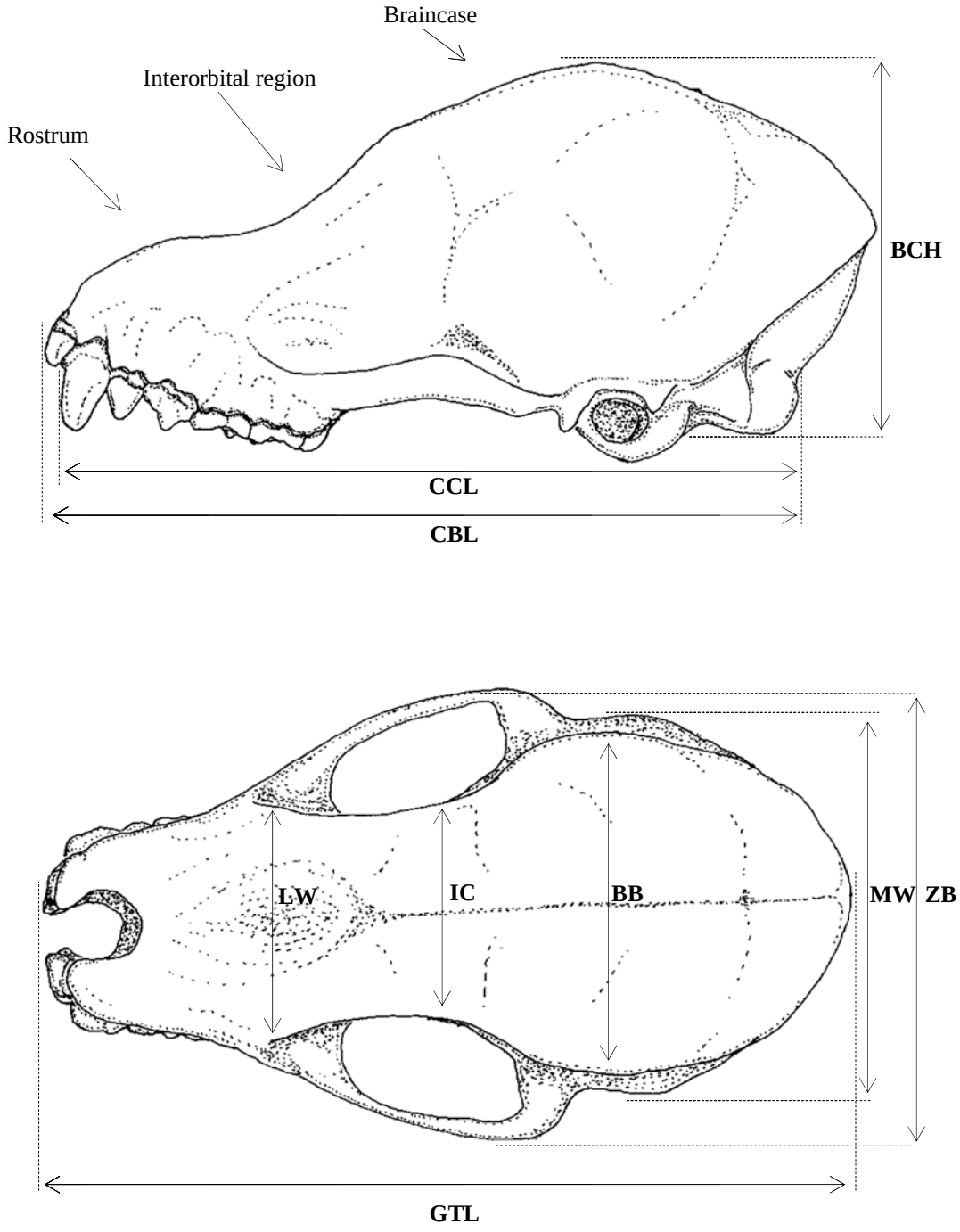

Fig. 2-4. Cranial measurements of *Murina*.

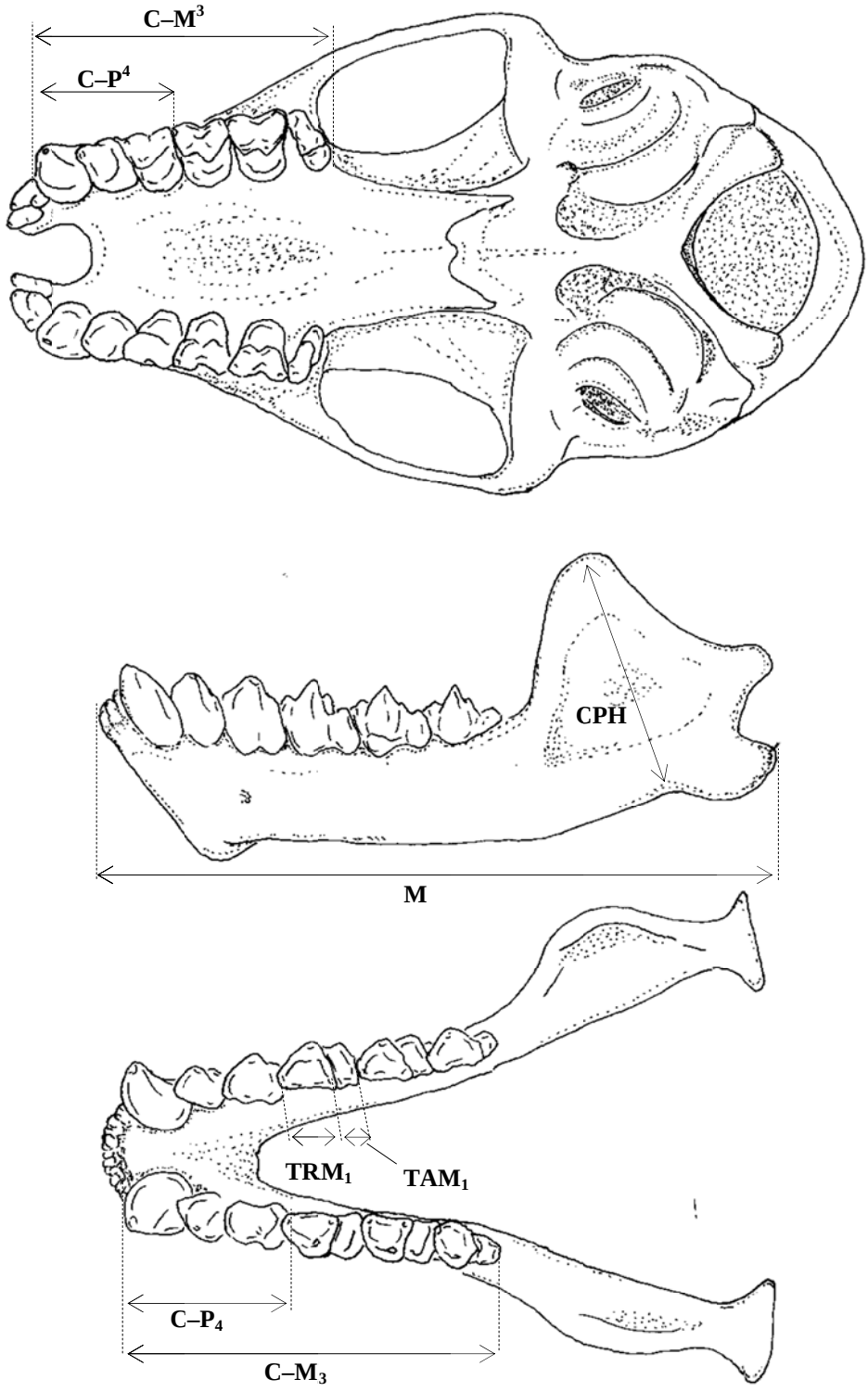

Fig. 2-5. Dental measurements of *Murina*.

CHAPTER 3

A REVIEW OF THE *MURINA CYCLOTIS* COMPLEX WITH DESCRIPTIONS OF A NEW SPECIES AND SUBSPECIES

ABSTRACT

Until recently, the taxon *Murina cyclotis* was considered to be a widespread species, albeit one that exhibited considerable individual, sexual and geographical variation. Subsequently however, it was recognised that this taxon was in fact a complex of species. As such, in 2012, two larger forms were recognised as separate and distinct species, namely: *M. peninsularis* in the Sunda region and *M. fionae* in Laos and Vietnam. In the current paper, a new cryptic species of the *cyclotis*-complex is described from peninsular Thailand based on a combination of external, craniodental and genetic differences. In addition, the population previously referred to *M. cyclotis* from the Nicobar Islands is described as a new subspecies of this new species. Despite this work and the research of others, the taxonomy of *M. cyclotis* still requires further study. The description of *M. peninsularis* is emended and the extensive variation in its morphological characters is addressed. The diagnostic characters of each taxon, as well as the additional data on ecology, zoogeography, distribution, echolocation and genetics, where available, are summarised and discussed.

Keywords: cryptic species, DNA barcode, Southeast Asia, taxonomy, Tube-nosed bat, Thailand, zoogeography

Manuscript of this chapter entitled '**A review of the *Murina cyclotis* complex (Chiroptera: Vespertilionidae) with descriptions of a new species and subspecies'** has been submitted to ACTA CHIROPTEROLOGICA.

INTRODUCTION

Southeast Asian *Murina* have high cryptic diversity (Francis *et al.,* 2010). With a series of intensive field surveys using harp traps in the forested areas of Southeast Asia (SE Asia), the total number of the *Murina* species known from the region has increased rapidly in recent years (Csorba *et al.,* 2011; Francis and Eger, 2012). To date, 33 species of *Murina* are known to science, 19 of which are reported from mainland SE Asia (Simmons, 2005; Francis 2008; Eger and Lim, 2011; Csorba *et al.,* 2011; Francis and Eger, 2012).

M. cyclotis, until recently, was considered to be one of the most widely distributed species of the genus. As formerly understood, it comprised three subspecies: *M. c. cyclotis* from India to mainland SE Asia; *M. c. peninsularis* from peninsular Thailand to Malaysia and Indonesia; and *M. c. eileenae* restricted to Sri Lanka (*sensu* Corbet and Hill, 1992). Exhibiting much morphological variation and strong sexual dimorphism, it has been regarded as a species complex (Francis *et al.,* 2010; Francis and Eger, 2012). The Sundaic subspecies '*M. c. peninsularis*', which is much larger in external and cranial dimensions than the nominate subspecies and exhibits distinct genetic divergence (Francis *et al.,* 2010), is currently regarded as a separate species (Francis and Eger, 2012). Another larger form that is found in the Indochinese subregion (referred to as taxon '*peninsularis'* in Matveev and Csorba, 2007; and as '*Murina* sp. B' in Francis *et al.,* 2010), although occurring sympatrically with the nominate subspecies *M. c. cyclotis,* has a generally larger size and has been named recently as *M. fionae* (Francis and Eger, 2012). A specimen (ROM 110439) collected from Krabi Province, peninsular Thailand by Antonio Guillén-Servent, although morphologically similar to the taxon '*cyclotis',* has been reported as having about 15% genetic divergence from the population referred to the same species in Laos (Francis and Eger, 2012).

During 2011–2013, specimens of *Murina* belonging to the *'cyclotis*–complex' were examined in various museums and additional specimens from Thailand were collected. Specimens referred to *M. cyclotis, M. fionae,* and *M. peninsularis* from mainland SE Asia with some additional specimens from India, Malaysia and Indonesia, and also *M.* cf. *cyclotis* from peninsular Thailand were

compared. Based on external, craniodental and bacular morphology, as well as genetic differences, the specimens of *M.* cf. *cyclotis* from peninsular Thailand are here described as a new species. Specimens of *M. cyclotis* from Nicobar Islands, which are larger than the nominate subspecies, are also described as a new subspecies (of the new species) herein.

MATERIALS AND METHODS

Specimens of *Murina* deposited in various collections were examined (see Method section, Chapter 2). Additional specimens were collected during field surveys in Thailand undertaken jointly between 2010 and 2013 by PSU and the wildlife teams of the DNP. The new material was collected from several localities as described in Chapter 2. Distribution map of each species is based on specimens examined and literature records (Fig. 3-1; Appendix 1).

External and craniodental measurements were taken following definitions described in Chapter 2. Drawings were made under microscope with a camera lucida.

Calls were recorded from individual bats flying freely in a 4x4 m room or 3x3 m mosquito nets with a Pettersson D-1000X ultrasound detector set in 10x time-expansion mode and a sampling rate of 768 kHz, some specimens were recorded with a Pettersson D-240X set in 10x time expansion connected to an iRiver iHP-120 Multi-Codec Jukebox Recorder. Calls were transferred to a computer for analysis in BatSound – Sound Analysis Version 4.1.4 (Pettersson Electronics and Acoustic AB). Four call parameters were measured including: start frequency (*sf*) and terminal frequency (*tf*) (in kHz) measured by using the measurement curser in the spectrogram, the frequency of maximum energy [*fmaxe*] measured in the power spectrum, and call duration (*d*) (in ms) measured by using the marking cursor in the amplitude window. A sampling frequency of 44.10 kHz was used and produced a spectrogram using Automatic Fast Fourier Transforms (FFT) with a Hanning window. At least ten calls with good signal-to-noise ratio from each individual were chosen for analysis.

Genetic materials were taken from the wing membrane, tongue or liver and stored in 1.5 ml microtubes with absolute alcohol. Tissue materials were analysed following standard protocols of DNA extraction, gene amplification, and nucleotide

sequencing as outlined in Francis *et al.* (2010) and Ivanova *et al.* (2012) for mammalian DNA Barcode analyses. The cytochrome oxidase-I (COI) gene of 657 bp sequences from our samples were analysed using the Neighbour-joining tree algorithms (NJ) implemented within the Barcode of Life Data Systems (BOLD) using *Harpiocephalus harpia* as an outgroup (e.g. Khan *et al.,* 2010). Public data, as published in Francis *et al.* (2010) deposited in BOLD are also included in the analysis for allowing comparison of samples from different geographic are from *cyclotis*-complex. Genetic divergence values between samples were calculated using the Kimura-2-parameter model.

SYSTEMATIC DESCRIPTION

M. cyclotis Dobson, 1872

Round-eared Tube-nosed bat

M. cyclotis Dobson, 1872: 210; Darjeeling, NE India

M. eileenae Phillips, 1932: 329; Mousakande, Gammaduwa, East Matale Hills, Sri Lanka

Description and taxonomic notes

This is a small-medium sized tube-nosed bat with a FA of 29.4–36.8 mm (Table 3-1). Females have an average larger body size than males, with a mean FA of 33.9 mm versus 30.9 mm, respectively (Table 3-1). Ear length (E) is 12.0–17.6 mm. However, the shape of the pinna is variable between individuals, from broadly round with a convex anterior border to narrower, somewhat more elliptical and less convex. Dorsal pelage is dark grey basally and orange–brown at the hair tips; the pelage extends onto the tail membrane and the hindfeet. The hairs of the ventral pelage are grey basally with light grey to whitish–brown tips (Fig. 3-2b), or with a light orange–brown tinge in some individuals. Each wing membrane is attached near the base of the claw of the outer toe.

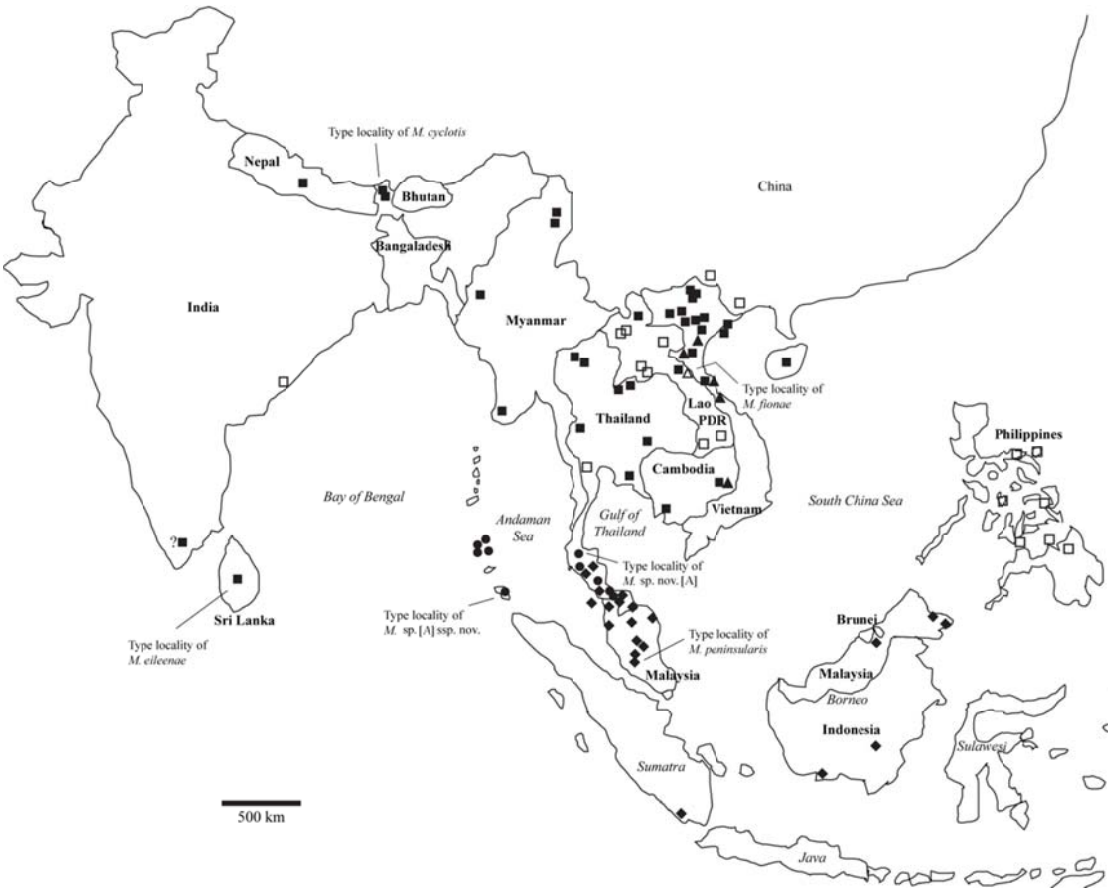

Fig. 3-2. Distribution of *M.* sp. nov. [A] (circles), *M. cyclotis* (squares), *M. fionae* (triangles) and *M. peninsularis* (diamonds). The black symbols refer to specimens examined by the authors, whereas the blank symbols refer to records from literature or released individuals. The list of specimens is included in the Appendix 1.

In the skull, the GTL is 15.86-18.18 mm and the CCL is 13.60–16.17 mm (Table 3-2). The rostral profile is relatively long with a well-defined concavity (Fig. 3-3b). The braincase is relatively low, with the BCH of 6.08–7.22 mm (Table 2), and the sagittal crest is poorly present (Fig. 3b). The upper canine exceeds the P^4 in height. The height of the P^2 is about two–thirds that of the P^4. In occlusal view, the shape of P^2 and P^4 are rounded and similar in size (Fig. 3-4b). The M^1 and M^2 are without mesostyles, and their labial surfaces have a U–shaped indentation. In the lower dentition, P_2 and P_4 are equal in height and about two-thirds that of the C_1. The crown area of the P_2 is slightly more than half that of the P_4. The talonid of the M_1 is more than half to two–thirds the crown area of its respective trigonid, averaging 62.0% in males and 60.5% in females, range for both sexes is 46.5–71.8% (n=23). The entoconids of the M_1 and M_2 are equal or exceeded in height by their hypoconids. The baculum is very small (BL 0.8 mm). The dorsal surface is arched upwards and the ventral surface is deeply concave. It is almost round in shape with a W–shaped indendation on the anterior end and a distinct concavity on the posterior end (Fig. 3-5b).

The specimens referred to the taxon *eileenae* from Sri Lanka (four male specimens examined) are very similar morphologically to *cyclotis* from elsewhere in its range. The differences, included in the original description of Phillips (1932), such as having less bright pelage colour and darker wing membranes are actually very slight as noted by Hill (1964). Following Bates and Harrison (1997), we here regard *eileenae* as a synonym of *M. cyclotis.*

However, much of the taxonomy of *M. cyclotis* remains unresolved, especially since morphological and genetic data from India are difficult to access, particularly from the type locality. In Indochina, extreme morphological variation has been observed, notably in hair colour and ear shape (as above). However, curiously there is remarkably little variation in craniodental characters. Further intensive taxonomic study of this species, with a combination of morphological and genetic data, especially from Indian specimens, would be of particular interest.

The specimens from the Philippines, which previously have not been assigned to any subspecies of *M. cyclotis* (e.g. Corbet and Hill 1992; Ingle and Heaney, 1992; Simmons, 2005), were not available for examination in this study.

Based on the description, measurements and drawings provided in Ingle and Heaney (1992); i.e. with FA 36–39 mm, CCL 15.8–16.8 mm, C–M^3 5.9–6.3 mm, it appears that they agree closely with either *M. peninsularis* from the Sundaic subregion, or *M. fionae* from Indochina (see below). However, currently, it is too speculative to assign this population to either recognised subspecies. Therefore, it is here considered to be retained in *M. cyclotis* until further material is available. Further study with genetic data and specimens from major islands of the Philippines may prove that it is distinct from all other recognised taxa.

Echolocation

Based on two individuals from Loei Province, northeast Thailand, it is apparent that *M. cyclotis* uses typical broadband frequency-modulated (FM) signals with an *fmaxe* of 96.3–109.0 kHz and *d* of 1.5–2.3 ms. The *sf* and *tf* are 141.0–163.0 kHz and 56.0–72.0 kHz, respectively.

Ecology and habitat

The species is recorded in various types of forest habitat, including lowland, wet and hill evergreen forest, mixed deciduous forest and dry dipterocarp forest from the elevation of about sea level (PSUZC) to 1,650 m a.s.l. (BMNH). A pregnant female was captured in a harp trap, which was set over a streamlet in evergreen forest of Ratchaburi Province, W. Thailand in April 2008. This individual was subsequently released (PS, unpublished data).

Distribution

M. cyclotis ranges from India, Sri Lanka, and Nepal to Myanmar, Laos, Vietnam, China (Guangxi and Hainan Island), Thailand (north of the Isthmus of Kra), Cambodia and the Philippines (Fig. 3-1).

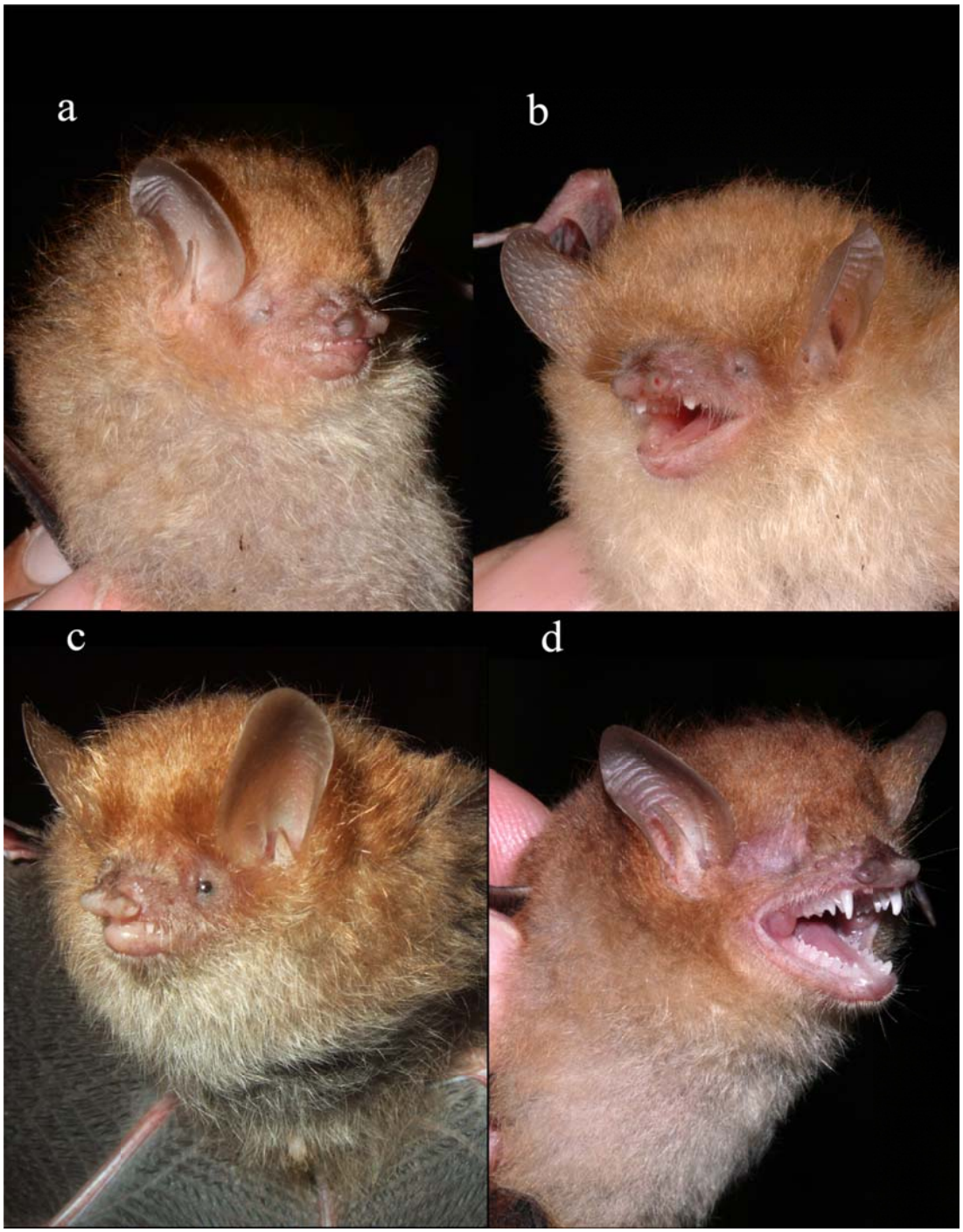

Fig. 3-2. Four *Murina* species: (a) *M.* sp. nov. [A] PSUZC-MM2013.15 male (paratype) from peninsular Thailand, (b) *M. cyclotis* PSUZC-MM2006.179 male, from NE Thailand, (c) *M. fionae* T.160811.3 male, from Vietnam, (d) *M. peninsularis* PSUZC-MM2012.12 male, from peninsular Thailand. Not to scale.

***Murina* sp. nov. [A]**

(Figs. 3-1–3-8, Tables 3-1–3-3)

Holotype

PSUZC-MM2010.22 (field number PS100419.2), adult male, body in alcohol, skull and baculum extracted, collected by P. Soisook on 19 April 2010.

Type locality

Rajjaprabha Dam, Ban Ta Khun District, Surat Thani Province, peninsular Thailand, 8°57'N, 98°47'E, 80 m a.s.l. (Fig. 3-1).

Paratypes

PSUZC-MM2010.23 (field number PS100419.3), lactating female, from the same site as the holotype; PSUZC-MM2012.7 (field number PS120111.2), adult male, from Ton Tae waterfall, Trang Province, Thailand; PSUZC-MM2013.15 (field number PS130625.1), adult male, from Wang Tai Nan Waterfall, Satun Province, Thailand.

Referred specimen

ROM 110439 (field number AGS 970412-01), adult female, from Khao Nor Chuchi Reserve (=Khao Pra Bang Kram WS), Klong Tom District, Krabi Province, Thailand.

Diagnosis

This is a small-medium sized *Murina* with an average FA of 34.0 mm (range 31.9–35.9 mm). Males have a slightly smaller body size than females, with an average FA of 33.2 and 35.4 mm respectively. The dorsal pelage is grey basally with orange-brown tips. The ventral pelage is less bright, being uniformly dark grey except around the neck and over the chest where the hairs have a dark grey base and are tinged with orange-brown at the tip. The plagiopatagium is dark brown and attached to the side of the foot near the base of the claw of the outer toe. The GTL is 16.40–18.10 mm, and the CCL is 14.47–15.76 mm. The upper and lower canines exceed the

respective premolars in height. The upper premolar (P^2) is subequal in height to the P^4. The first and second upper molars (M^1 and M^2) are without a mesostyle and the labial surfaces have a V–shaped indentation. The crown area of the talonid of the first lower molar (M_1) is about half or only slightly more than half that of its respective trigonid.

Measurements of the holotype (in mm) are as follows: FA: 34.0, E: 12.6, HB: 48.0, TL: 35.2, HF: 8.1, TIB: 19.6, 3MET: 31.4, 4MET: 29.2, 5MET: 31.1, 3D1P: 15.3, 3D2P: 14.4, GTL: 17.03, CBL: 15.62, CCL: 14.88, ZB: 9.72, BB: 7.74, BCH: 6.57, MW: 8.15, IC: 4.31, LW: 5.17; C–M^3: 5.44, C–P^4: 2.85, C^1–C^1: 4.16, M^3–M^3: 5.80, C–M_3: 6.00, M: 11.43, CPH: 4.78, TRM_1: 0.8; TAM_1: 0.4, BL: 1.0, MASS: 6.5 g.

Etymology

The species will be named in honour of Antonio Guillén-Servent, who collected the first specimen of this species (ROM 110439) from Krabi, peninsular Thailand in 1997.

Description

This is a small-medium sized *Murina* with a FA of 31.9–35.9 mm, HB 43.2–51.6 mm and a body mass of 3.0–8.0 g (Table 3-1). Males are slightly smaller than females, with an average FA of 33.2 mm versus 35.4 mm, and a CCL of 14.85 versus 15.43 mm (Tables 3-1 and 3-2). The ear is 11.4–15.2 mm in height, and is rounded with no distinct emargination on the posterior border of the pinna. The tragus is white and short, 8.3–9.2 mm, which is more than half the height of the ear (Fig. 3-2a). The dorsal pelage is grey basally with orange-brown tips. The ventral pelage is almost uniformly dark grey, although around the neck and chest there is an orange-brown tinge (Fig. 3-2a).

In the wings, the plagiopatagium is naked and dark brown in colour, and is attached to the distal phalanx, near the base of the claw of the outer toe. The third metacarpal (3MET), 30.9–32.6mm, is the longest but only slightly longer than the fifth metacarpal (5MET), which is 30.6–31.8 mm. The fourth metacarpal (4MET) is the shortest, 29.2–31.3 mm in length (Table 3-1). The first (3D1P) and second

phalanges (3D2P) of the third digit are 14.3–15.3 mm and 14.0–14.5 mm, respectively. The feet are covered with orange-brown hairs dorsally and are relatively small, 7.7–9.4 mm, which is 40–50% of tibia length (17.7–19.7 mm). Orange-brown hairs are also found on the back and the uropatagium. The tail is 28.1–42.0 mm in length.

In the skull, the greatest length (GTL) is 16.40–18.10 mm, CBL 14.93–16.43 mm, and CCL 14.47–15.76 mm (Table 3-2). The zygoma is thin and without a distinct process; the breadth (ZB) is 9.29–10.02 mm. The breadth of braincase (BB) and mastoid (MW) are 7.53–7.82 mm and 8.00–8.43 mm, respectively. In lateral view, the rostrum is relatively short and exhibits a very slight concavity (Fig. 3-3a). The basioccipital pit is very shallow. The braincase is relatively high, with the BCH of 6.57–7.10 mm, and the sagittal crest is poorly developed, with a slight indication over the anterior part of the braincase (Fig. 3-3a). The upper toothrows converge anteriorly; the width at C^1–C^1 (4.12–4.44 mm) is 71.70–78.08% of that at M^3–M^3 (5.36–5.87 mm). The upper canine–second upper premolar length (C–P^4; 2.69–2.94 mm) is 48.04–52.39% of the maxillary toothrow length (C–M^3; 5.44–5.91 mm). The inner upper incisor (I^2) and the outer upper incisor (I^3) are about equal in height. I^2 is placed almost in line with I^3, so in lateral view, I^2 is almost obscured by I^3 (Fig. 3-3a). The upper canine (C^1) is relatively large in comparison to the first (P^2) and second upper premolars (P^4). The crown area and the height of the P^2 are subequal to that of P^4, and are about two-thirds that of the upper canine (Fig. 3-4a). P^2 and P^4 are both wider than long and somewhat elliptical in shape. The first (M^1) and second molars (M^2) are without a mesostyle, and the labial surface of both teeth is concave with a well-defined V–shape.

In the lower jaw, the mandible length (M) is 11.13–12.34 mm. The lower incisors (I_1 to I_3) are all tricuspidate. The mandibular toothrow length (C–M_3) is 5.83–6.43 mm. The height of the lower canine (C_1) exceeds that of the first (P_2) and second lower premolars (P_4), which are equal in height. P_2 is about half that of the C_1 and about two-thirds that of the P_4 in crown area. The anterior and posterior basal cusps of P_2 are partially placed above the posterior border of C_1 and the anterior border of P_4 (Fig. 3-4a). P_4 is relatively large and rectangular in shape, with a crown area of about two-thirds that of the lower canine. The talonid of the first (M_1) and

second lower molars (M_2) is about half or slightly more than half that of its respective trigonid in size; 50.0–59.5% and 51.2–65.0% on the M_1 and M_2, respectively. The height of the hypoconid exceeds that of its entoconid in both M_1 and M_2. The coronoid process is well developed, 4.33–5.15 mm in height.

The baculum is heart shaped, with a W-shape concavity on the anterior margin and a pointed projection on the posterior margin. The greatest length of the baculum (BL) is 1.0 mm and the width is 0.8 mm. The dorsal surface is arched upwards and the ventral surface is deeply concave (Fig. 3-5a).

Echolocation

M. sp. nov. [A] emits typical broadband frequency-modulated (FM) signals with the energy distributed throughout the call. The *fmaxe* of two male specimens is 120.1–155.7 kHz, with a *d* of 1.8–3.8 ms. The *sf* and *tf* are 175.0–184.0 kHz and 53.0–63.0 kHz, respectively. The call parameters of a female specimen are similar to those of the two male specimens, except for the *sf* which is lower, 159.0–167.0 kHz; other measurements overlap, *tf* of 50.0–57.0 kHz, *fmaxe* of 120.7–157.7 kHz, and *d* 2.4–3.0 ms.

Ecology and reproduction

This species is found in disturbed secondary forest and undisturbed primary evergreen forest in peninsular Thailand. It was captured along forest trails, by a stream and in the understorey. It shares these habitats with several other insectivorous bat species (see method section). In April 2010, a pair of male and female specimens was captured together in harp trap at the type locality; the female appeared to be lactating. The female specimen ROM 110439 collected from Khao Pra Bang Kram WS on 12 April 1997 was lactating (A. Guillén-Servent, personal communication).

Distribution and conservation notes

Currently, this species has been found in seven localities in six provinces of peninsular Thailand (Fig. 3-1). It was found sympatrically with the larger

species, *M. peninsularis,* but there is no overlap in the range with *M. fionae* or *M. cyclotis* (Fig. 3-1).

Comparison with other species

This species is very similar to *M. cyclotis.* However, it can be distinguished by its relative larger size and various craniodental characters. Although the size of *M.* sp. nov. [A] falls within at least part of the range of *M. cyclotis*, the mean scores of all the measurements in both sexes show that it is generally larger (Table 3-1 and 3-2). In *M.* sp. nov. [A], male and female have an average FA of 33.2 mm and 35.4 mm, and a CCL of 14.85 and 15.43 mm, respectively. These are larger than that of *M. cyclotis,* which has an average FA of 30.7 mm and 33.9 mm; CCL 14.45 mm and 15.22 mm, in males and females, respectively (Fig. 3-6, Table 3-1 and 3-2). The dorsal pelage of *M.* sp. nov. [A] resembles that of *M. cyclotis* but differs somewhat in the ventral pelage, in which *M.* sp. nov. [A] is duller being dark grey rather than the whitish-brown of *M. cyclotis* (Fig. 3-2). In the skull, the rostral concavity is less pronounced in *M.* sp. nov. [A] than that of *M. cyclotis.* The braincase of *M.* sp. nov. [A] is more domed and higher, with an average BCH of 6.68 mm and 6.94 mm in males and females, respectively, whereas in *M. cyclotis* it is 6.49 mm and 6.57 mm in males and females, respectively (Fig. 3-3, Table 3-2). The first upper premolar (P^2) of *M.* sp. nov. [A] is subequal to that of the second (P^4) in height and crown area, whereas in *M. cyclotis,* the height of P^2 is two-thirds and the crown area about equal to that of the P^4 (Fig. 3-4). The relative size of the talonid in comparison to its respective trigonid of the first (M_1) and second lower (M_2) molars of *M.* sp. nov. [A] is smaller, about half, whereas in *M. cyclotis* this proportion is variable from more or less about half to about two-third (Fig. 3-4). For example in *M.* sp. nov. [A], the size of TAM_1 in M_1 is 50.0–59.5% (n=9) of the TRM_1, versus 46.5–71.8% (n=23) in *M. cyclotis*.

In the baculum, the posterior margin of *M.* sp. nov. [A] is pointed whereas it is W–shaped in *M. cyclotis* (Fig. 3-5). However, it is noteworthy that the baculum of *Murina* could be variable, and using bacular morphology in the identification of *Murina* species has not been widely accepted. Based on our

examination, the baculum of *Murina* is generally very small, fragile and easy to crack, which may lead to misleading conclusions in species identification.

M. sp. nov. [A] is distinctly smaller in external and cranial characters compared to both *M. fionae* and *M. peninsularis* (Fig. 3-6, Table 3-1 and 3-2). Besides size, the skulls of *M. fionae* and *M. peninsularis* are more robust, each with a massive upper canine and heavy rostrum (Fig. 3-3). It also differs from *M. fionae* and *M. peninsularis* in the general appearance of the pelage, the height of the P^2 and the shape of the baculum (Fig. 3-2, 3-3 and 3-5).

A multivariate analysis based on one external (FA) and nine craniodental measurements of a total of 124 specimens clearly separates *M. cyclotis, M. fionae* and *M. peninsularis* from each other, whereas *M.* sp. nov. [A] is situated midway between the three species (Fig. 3-7).

Genetic analyses

Although similar morphologically, results from the genetic analyses showed approximately 15–17% divergence between *M. sp. nov.* and *M. cyclotis* from Indochina. *M.* sp. nov. [A] also form a statistically supported (bootstrap > 80%) monophyletic sister clade with a genetic divergence value of 10% to a specimen identified as *M.* cf. *cyclotis* from South India (Fig. 3-8). The morphological comparison of the external (i.e. FA of 34.2 mm), craniodental (i.e. CCL of 15.25 mm) and bacular characters of the male specimen (HZM.17.36447) from South India (Tamil Nadu) suggest that it is more similar to *M.* sp. nov. [A] than specimens referred to *M. cyclotis* from elsewhere. However, with only a single specimen from the area, it is premature to determine whether this specimen represents a new species or belongs to a recognised species. Further study with more samples from the area and additional genetic analyses is recommended.

_M._ sp. [A] subsp. nov.

(Figs. 3-1, 3-6–3-9, Tables 3-1–3-3)

Holotype

HZM.14.35312 (field number 15304336), adult male, body in alcohol, skull extracted, exact date not known.

Type locality

Great Nicobar Island, Nicobar Islands, India (exact coordinates not known).

Paratypes

HZM.12.35277 (field number TIL09 34), adult male, dry skin, skull extracted, from Tillanchong, Nicobar Islands, India; HZM.15.35319 (field number 15322338), adult female, body in alcohol, skull extracted, from Trinket, Nicobar Islands, India; HNHM.2004.13.1 (field number BOMBAT27), adult female, body in alcohol, skull extracted, from Bompuka, Nicobar Islands, India.

Diagnosis

This taxon is described as a subspecies of *M.* sp. nov. [A] based on its general similarity in external and craniodental characters. In contrast to the nominate race, males appear to be slightly larger than females in FA and skull size (Fig. 3-6; Table 3-1–3-2). The dorsal and ventral pelage, as in the nominate subspecies, has a grey base with orange-brown tips on the back, and is uniformly dark grey on the underside.

Etymology

The subspecific name refers to the Nicobar Islands, where specimens of this taxon were collected.

Description and taxonomic notes

This is a small-medium sized *Murina* with a FA of 32.6–35.3 mm (Table 3-1) and a CCL of 14.65–15.38 mm (Table 3-2). The dorsal pelage is grey at the base and orange-brown at the tip. The ventral pelage is uniformly dark grey. Each wing is attached near the base of the claw of the outer toe. The braincase is relatively high, with a BCH of 6.57–6.79 mm and a poorly developed sagittal crest. The upper

canine exceeds that of the P^4 in height. P^2 is about two-thirds the height and the crown area of P^4 (Fig. 3-9). The upper (C–M^3) and the lower (C–M_3) toothrow lengths are 5.39–5.73 mm and 5.91–6.26 mm, respectively. The height of the first and second (P_2 and P_4) lower premolars are about equal and about two-thirds that of the lower canine in height. The crown area of the talonid of M_1 and M_2 is about half to two-thirds that of the trigonid, and the entoconid is about equal in height to the hypoconid. The coronoid process (CPH) is 4.01–4.44 mm. The baculum is essentially similar to the nominate subspecies from peninsular Thailand.

As in *M.* sp. [A] the taxon 'subsp. nov.' is larger than *M. cyclotis* and smaller than *M. fionae* and *M. peninsularis*. It is, in general, very similar to the taxon *M.* sp. nov. [A]. However, the skull size of 'subsp. nov.' is slightly smaller than the mainland subspecies, as described above. The ventral pelage, although very similar to those specimens from peninsular Thailand, is somewhat darker. A future study with a greater sample size and including genetics may prove that this geographically isolated population is specifically distinct.

Ecology and reproduction

The specimens of this taxon were netted in gallery forest and over streams. An individual was observed flying in and around foliage of a tree at about 4.5 m above ground. Proportion between male and female captured in mist net was 2:1 (Bandana Aul, personal communication).

Distribution and conservation notes

It is currently only known from five specimens collected from the Nicobar Islands (Fig. 3-1).

M. fionae **Francis and Eger, 2012**

Fiona's tube-nosed bat

M. fionae Francis and Eger, 2012: 32; Pha Deng, ≈8 km E of Ban Navang, Khammouan Province, Laos

M. peninsularis: Matveev and Csorba, 2007

M. CMF sp. B: Francis *et al.,* 2010

Description and taxonomic notes

This is a medium-large sized *Murina* with a FA of 34.5–40.1 mm (Table 3-1). The ear is rounded with a pinna height (E) of 12.1–15.6 mm (Table 3-1). The dorsal pelage is pale buff basally and orange–brown at the tips, with longer guard hairs scattered from the head, over the back and to the uropatagium. The ventral pelage is uniformly pale buff-orange, but more whitish near the chin (Fig. 3-2c). The third metacarpal (3MET) is about equal in length with the fifth (5MET), 32.5–35.4 mm and 32.5–36.0 mm, respectively. The fourth metacarpal (4MET) is the shortest, 31.1–34.7 mm (Table 3-1). The plagiopatagium is attached to the distal phalanx near the base of the claw. The skull is relatively large and heavily-built, with a GTL of 17.53–19.26 mm and the CCL of 15.32–16.87 mm (Table 3-2). The braincase is relatively high (BCH 6.53–7.50 mm) with a well-developed sagittal crest which is connected to the lambda (Fig. 3-3c). The maxillary toothrow length ($C–M^3$) is 5.72–6.40 mm, and is slightly convergent anteriorly, with the ratio between $C^1–C^1$ and $M^3–M^3$ of 72.76–80.34%. The upper canine (C^1) is rounded, very large, and greatly exceeds the second upper premolar (P^4) in size (Fig. 3-3c). The mesostyle of both the first (M^1) and second (M^2) upper molars is greatly reduced. The size of the talonid of the M_1 and M_2 is half that of the trigonid (Fig. 3-4c), and the entoconid is about equal in height to the hypoconid. The baculum is almost similar to that *M.* sp. nov. [A] but somewhat less rounded and the pointed projection on the posterior margin is more elongated (Fig. 3-5c). The dorsal surface is arched upwards and the ventral surface is deeply concave with a total length (BL) of 1.1 mm.

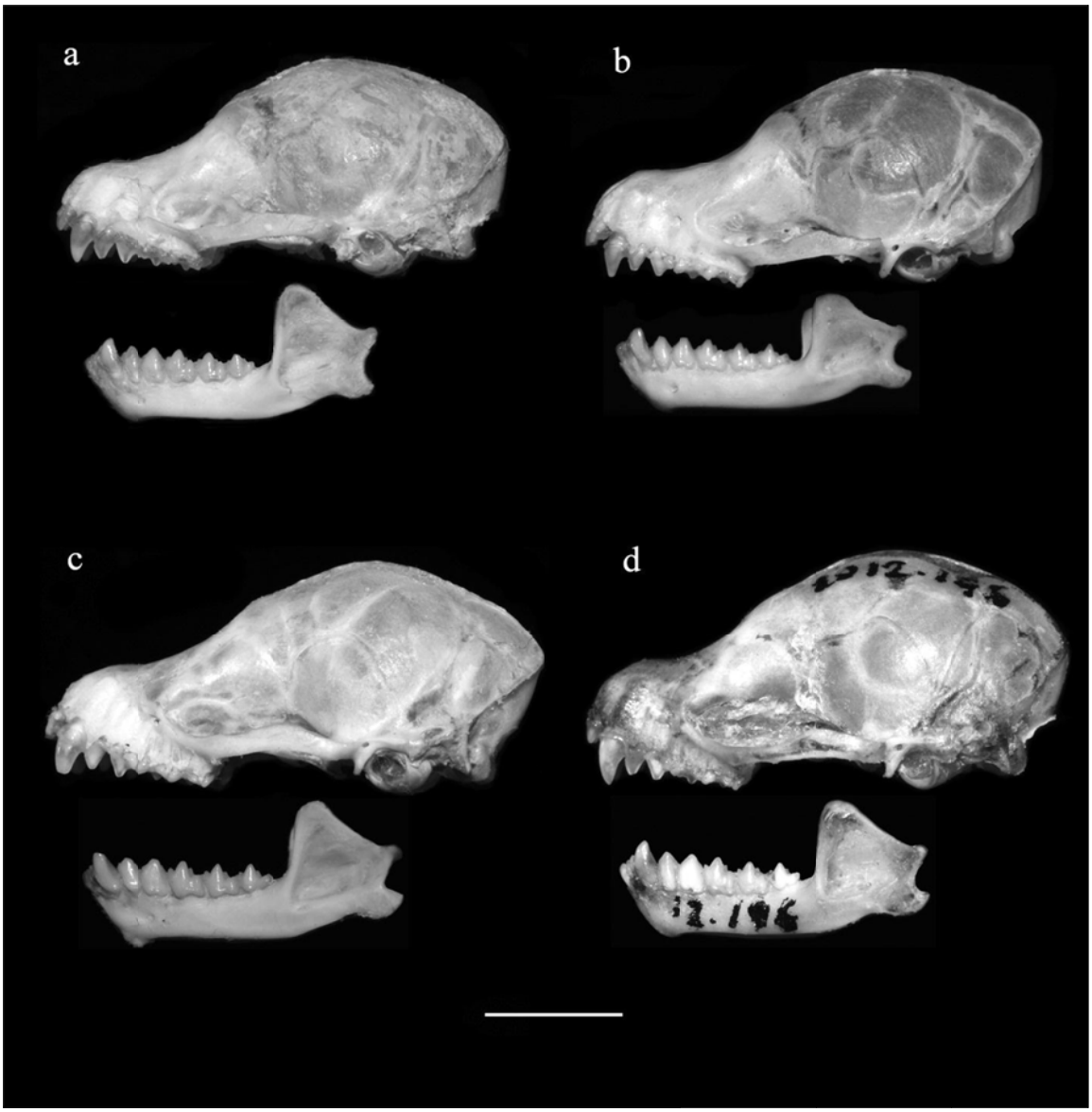

Fig. 3-3. Lateral view of the skulls of four *Murina* species*:* (a) *M.* sp. nov. [A] PSUZC-MM2010.22 male (holotype) from peninsular Thailand, (b) *M. cyclotis* PSUZC-MM2006.179 male, from NE Thailand, (c) *M. fionae* field no. 025 male, from Vietnam, (d) *M. peninsularis* PSUZC-MM2012.196 male, from peninsular Thailand. Scale = 5 mm.

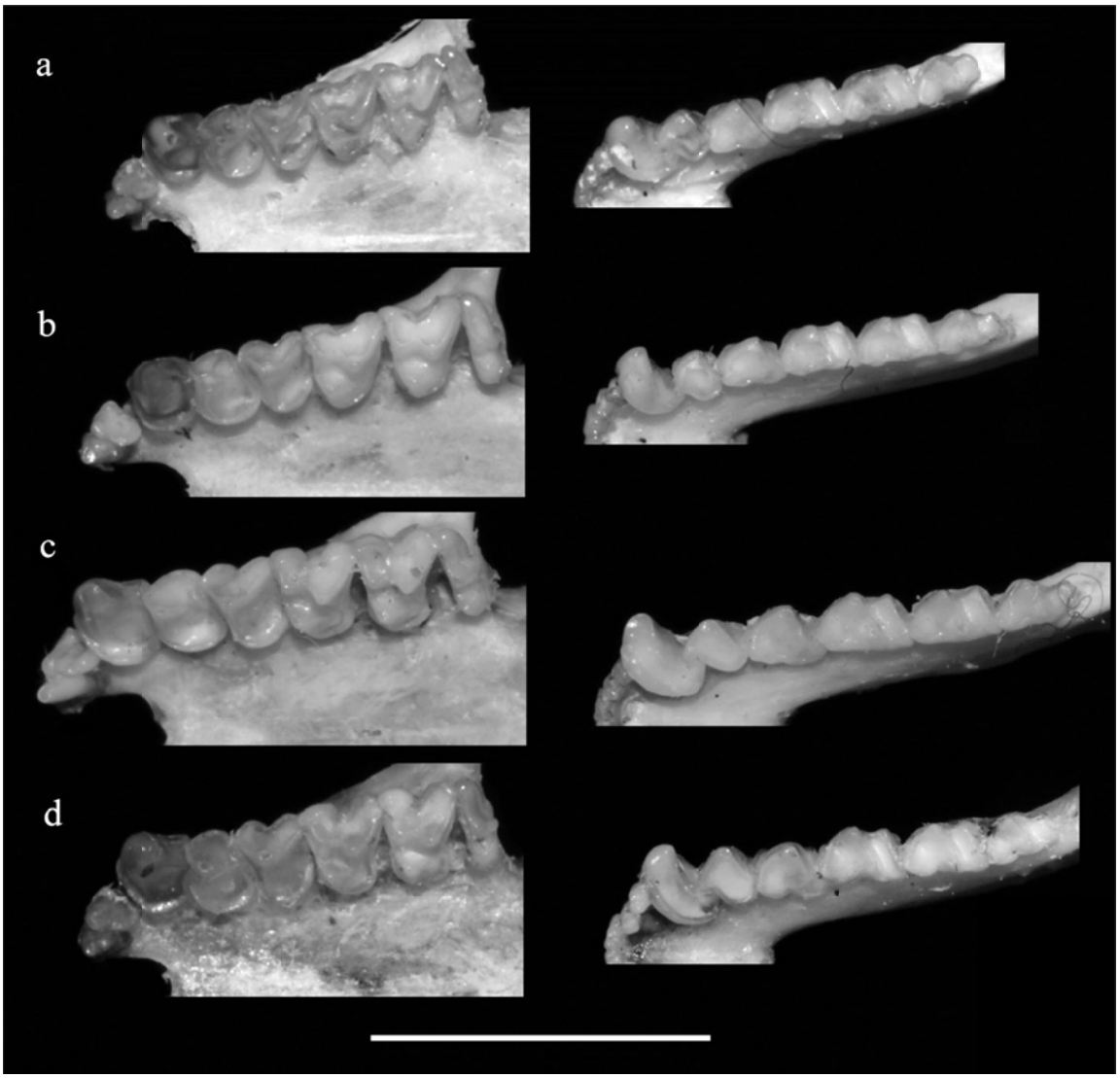

Fig. 3-4. Occlusal view of left upper (left of each pair) and right lower dentition (right of each pair) of four species of *Murina:* (a) *M.* sp. nov. [A] ♂PSUZC-MM2010.22 (holotype) from peninsular Thailand, (b) *M. cyclotis* ♂PSUZC-MM2006.179 from NE Thailand, (c) *M. fionae* ♂field no. 025 from Vietnam, (d) *M. peninsularis* ♂PSUZC-MM2012.196 from peninsular Thailand. Scale = 5 mm.

Morphologically, *M. fionae* is very similar to *M. peninsularis* (see below). However, the skull size (for example, CCL) of *M. fionae* averages larger than that of *M. peninsularis* (Fig. 3-6; Table 3-2). The upper canine of *M. fionae* is more massive and its crown area greatly exceeds that of the second upper premolar whereas it only slightly exceeds it in *M. peninsularis*. In the DNA barcode, there is an approximately 16% difference between specimens from Laos and peninsular Thailand. Furthermore, geographically the two species are isolated from each other. Clearly, the two taxa represent distinct species.

Ecology and habitat

This species has been collected in wet, hill evergreen forest at an altitude of 830–1,140 m a.s.l. on the Annamite Mountains (Francis and Eger, 2012). The specimen from Cambodia (HNHM.2005.81.16) was collected in semi-deciduous forest at an altitude of 290 m.

Distribution

M. fionae is known from Laos, Vietnam and Cambodia (Fig. 3-1).

***M. peninsularis* Hill, 1964**

Peninsular tube-nosed bat

M. cyclotis peninsularis Hill, 1964: 55; UIu Chemperoh, near Janda Baik, Bentong District, Pahang, Malaysia

Re-description and taxonomic notes

This is a medium-large sized *Murina* with a FA of 33.8–39.4 mm. Males average smaller than females; mean FA of 35.7 mm (33.8–38.1 mm) versus 37.7 mm (34.5– 39.4 mm) (Table 3-1). The ear is curved anteriorly and is without a distinct emargination on the posterior border; the tip is rounded and the height is 11.9–18.8 mm. The tragus is buff and relatively high; 7.4–10.3 mm, exceeding half the height of the pinna (Table 3-1). The dorsal pelage is buff basally and copper-brown to orange-brown at the tips with guard hairs of the same colour scattered over the dorsal side. The ventral pelage is relatively short, pale buff basally and greyish-

brown or white at the tips, with more orange near the chin and on the side of the abdomen (Fig. 3-2d). In the wing, the third metacarpal (3MET) is slightly longer than the fifth (5MET); 32.0–37.7 mm and 31.3–36.8 mm, respectively; whereas the fourth (4MET) is the shortest, with 29.9–36.4 mm (Table 3-1). The plagiopatagium is dark brown and attached to the distal phalanx near the base of the claw.

The skull is heavily-built and relatively large, with a GTL of 17.39–19.33 mm and CCL of 14.90–16.89 mm (Table 3-2). The braincase is domed with a well-developed sagittal crest (Fig. 3-3d). However, the braincase shape is variable, particularly in female specimens, from slightly domed to highly domed, with a BCH of 6.79–8.37 mm (Table 3-2). The rostrum is short and bulbous; it accommodates a massive upper canine, which exceeds the height and crown area of the second upper premolar (Fig. 3-3–3-4). The inner upper incisor (I^2) is placed lateral to the outer incisor (I^3) and is almost invisible from side view (Fig. 3-3). The first upper premolar (P^2) is subequal to that of the second (P^4) in height, and about two-thirds in crown area (Fig. 3–4). The first and second upper molars are without a mesostyle, and the labial surface has a deep V-shape indentation (Fig. 3-4d). The maxillary toothrow is almost parallel, with the ratio between C^1–C^1 and M^3–M^3 is 76.30–86.52%; the C–M^3 is 5.52–6.39 mm. All three lower incisors are tricuspidate. The first (P_2) and second (P_4) lower premolars are about equal in height and about two-thirds that of the lower canine. The talonid of the first and second lower molars is about half the size of its respective trigonid (Fig. 3-4d); the height of the entoconid is equal or slightly less than that of its respective hypoconid.

The baculum is almost oval in shape; the anterior margin is rounded or very slightly concave, the posterior margin is pointed (Fig. 3-5d). The dorsal side is arched upwards and the ventral side is deeply concave. The total length of the baculum (BL) is of 1.8 mm.

As mentioned above that the ventral pelage colour (Fig. 3-10) and the shape of the braincase (Fig. 3-11) are highly variable. External, dental and bacular morphology, however, show no significant difference between specimens examined. DNA barcodes also reveal a genetic distance of only about 1–2% among specimens from peninsular Thailand to Sumatra. However, further genetic studies, particularly

between populations from the major islands of the Sunda, would be of particular interested.

As above, although the measurements of specimens from the Philippines in Ingle and Heaney (1992) agree with *M. peninsularis,* it is not advisable to assign them to this species without examining any material.

Echolocation

Free-flying individuals of *M. peninsularis* collected in peninsular Thailand emitted typical broadband FM signals with the energy distributed almost evenly throughout the call. The mean *fmaxe* is of 112.7 kHz (range 79.0–142.6 kHz, n=10); *sf* 163.3 kHz (range 139.0–182.0 kHz, n=10); *tf* 50.2 kHz (range 40.0–64.0 kHz, n=10). The *d* is of 2.6 ms (range 1.5–4.9 ms, n=10).

Ecology and habitat

In peninsular Thailand, it was mostly captured in harp traps set across forest trails or streams in both primary and secondary evergreen forests. During fieldwork in 2011–2012, female specimens were found to be pregnant between February and April, and lactating between April and July (PSUZC). In Sumatra, it was also captured in harp traps set in forest areas (MZB). In peninsular Malaysia, it was found from lowland to hill and montane terrain (e.g. Kingston *et al.,* 2006; Tingga *et al*., 2012). Its roosting behaviour is very little known, although an individual of *Murina* sp., with the size and colour comparable to this taxon, was found flying around banana trees in the afternoon during a search for a trapping site in peninsular Thailand. Kingston *et al.* (2006) reported an individual flying from a wild banana tree; it was subsequently caught in a mist net set nearby.

Distribution

M. peninsularis is found in peninsular Thailand and Malaysia through to Sumatra, Java, Borneo (Fig. 3-1).

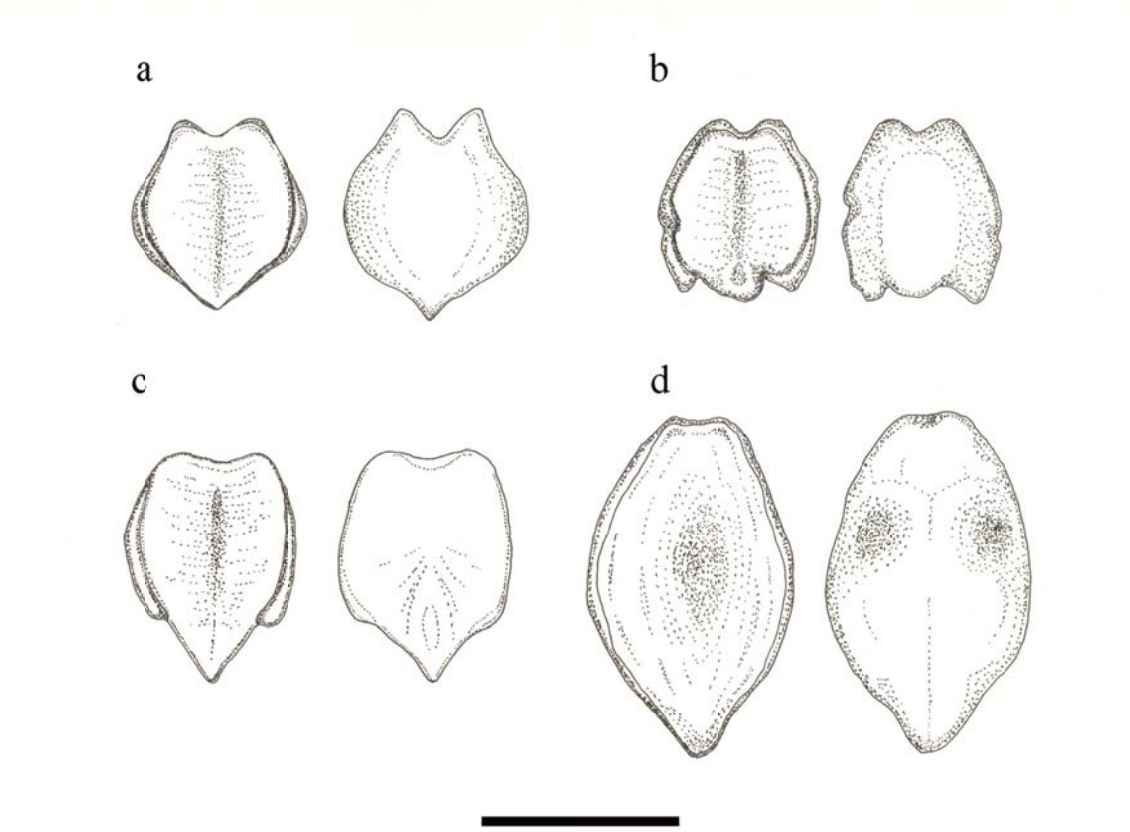

Fig. 3-5. Ventral (left of each pair) and dorsal (right) views of the bacula of four species of *Murina:* (a) *M.* sp. nov. [A] ♂PSUZC-MM2010.22 (holotype), from peninsular Thailand, (b) *M. cyclotis* ♂PSUZC-MM2005.203 from SE Thailand, (c) *M. fionae* ♂field no. 18 from Vietnam, (d) *M. peninsularis* ♂PSUZC-MM2006.160 from peninsular Thailand. Scale = 1 mm.

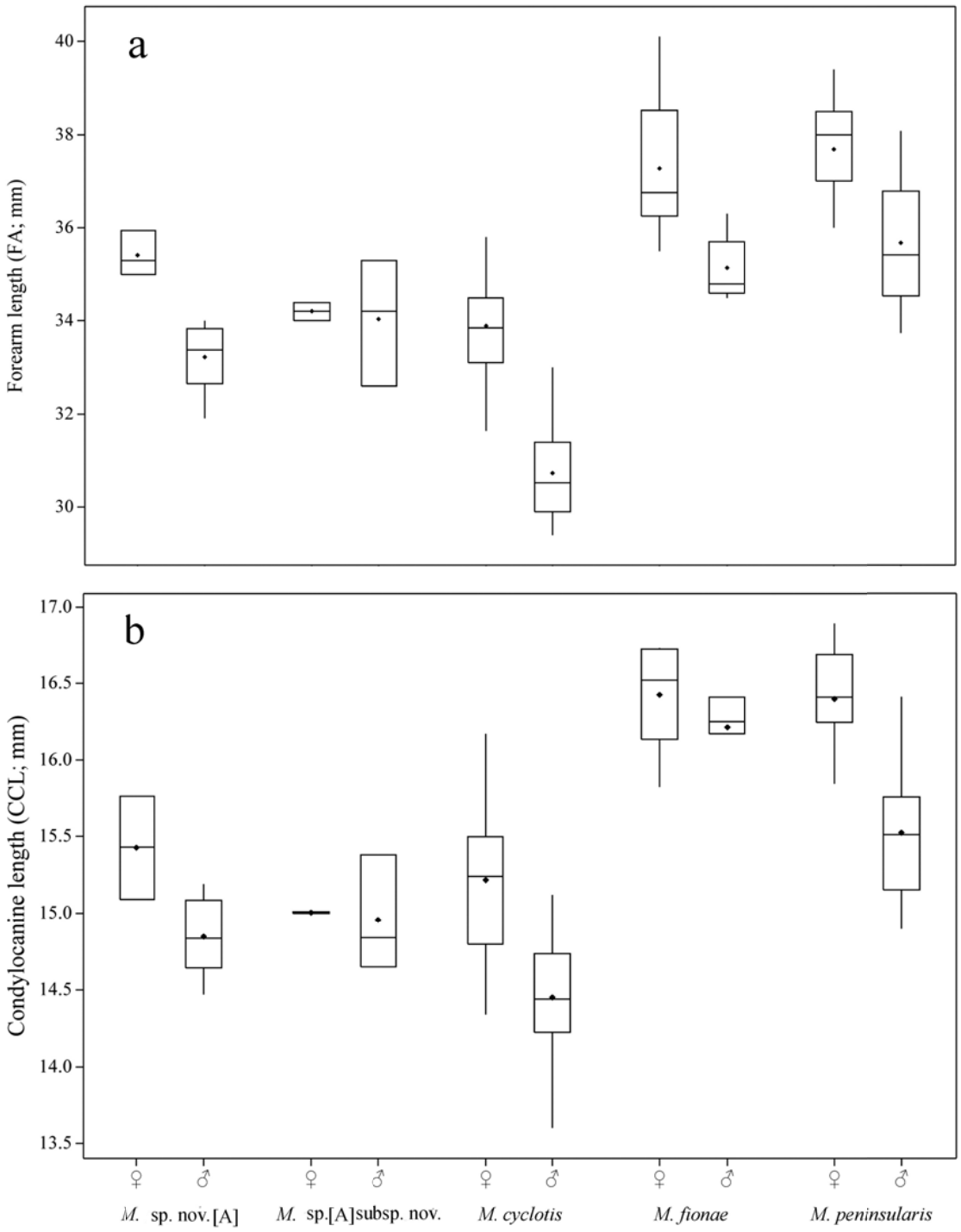

Fig. 3-6. Boxplots of the minimum, 1st quartile, median, mean (diamond), 3rd quartile and maximum value of the measurements of FA (a) and CCL (b) for females (left of each taxon) and males (right of each taxon) of *M.* sp. nov. [A], *M.* sp. [A] subsp. nov., *M. cyclotis, M. peninsularis* and *M. fionae.*

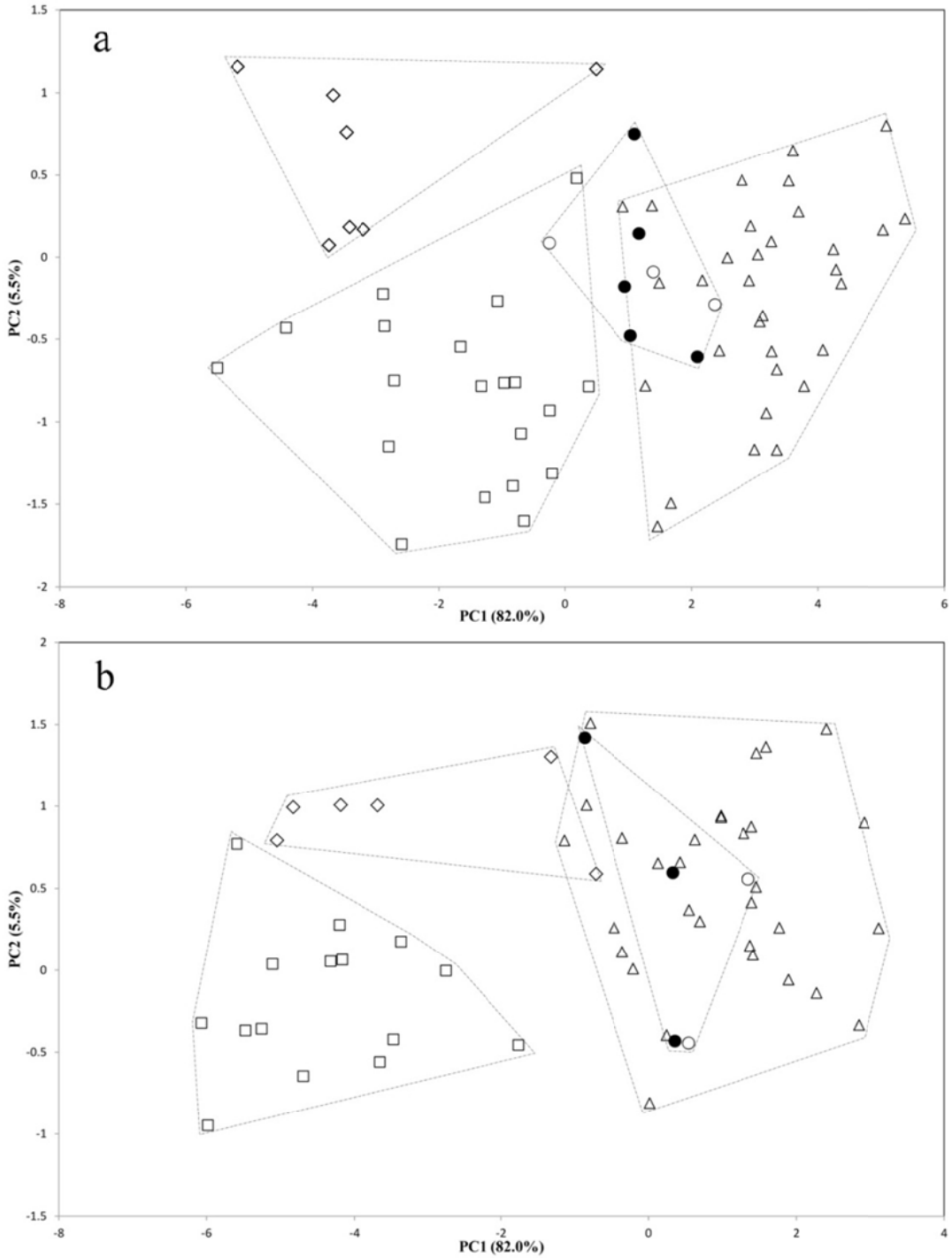

Fig. 3-7. Principal component analysis (first and second components) based on one external and nine craniodental characters of 67 male specimens (a), and 57 female specimens (b) of *M.* sp. nov. [A] **(**black circles), *M.* sp. [A] subsp. nov. (white circles), *M. cyclotis* (triangles), *M. fionae* (diamonds) and *M. peninsularis* (squares). Loading scores are in Table 3-3.

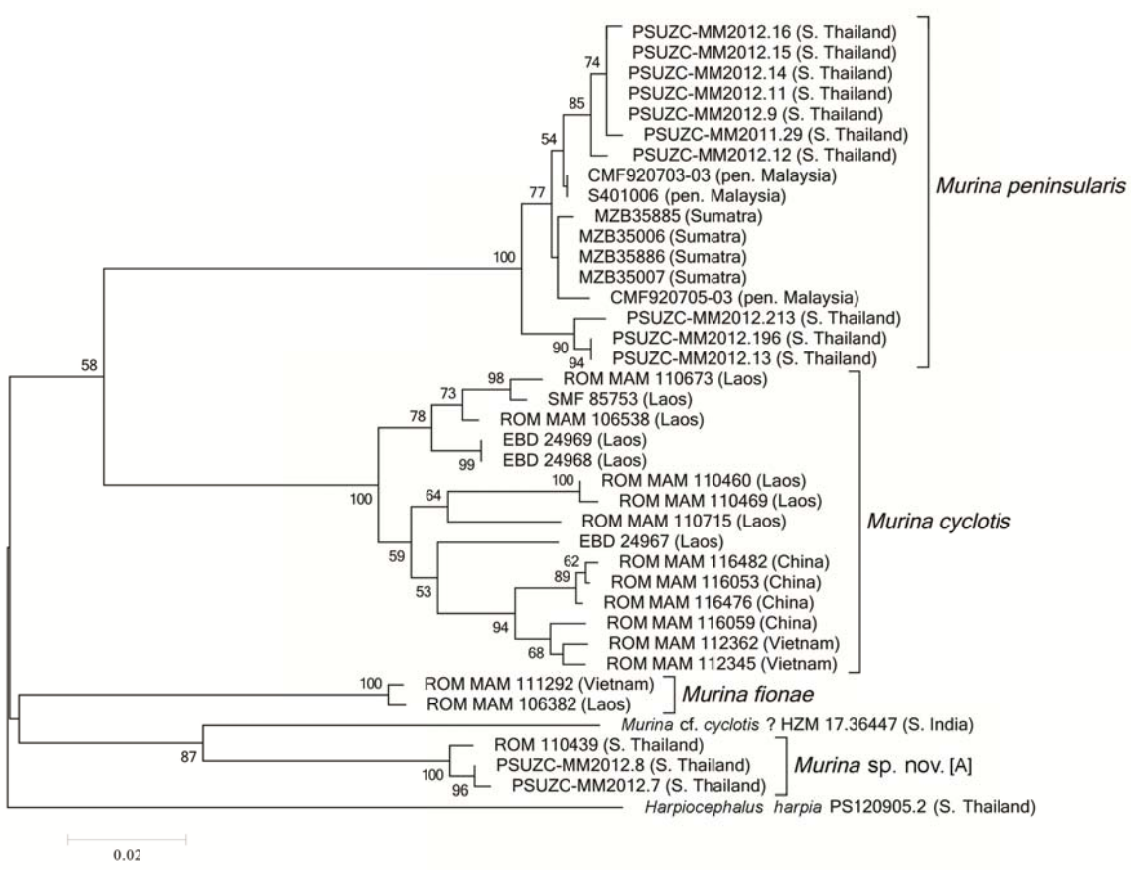

Fig. 3-8. Neighbour-joining tree based on DNA barcodes of *M.* sp. nov. [A], *M. cyclotis, M. fionae* and *M. peninsularis.* Numbers close to tree branches/node indicate the NJ bootstrap support value.

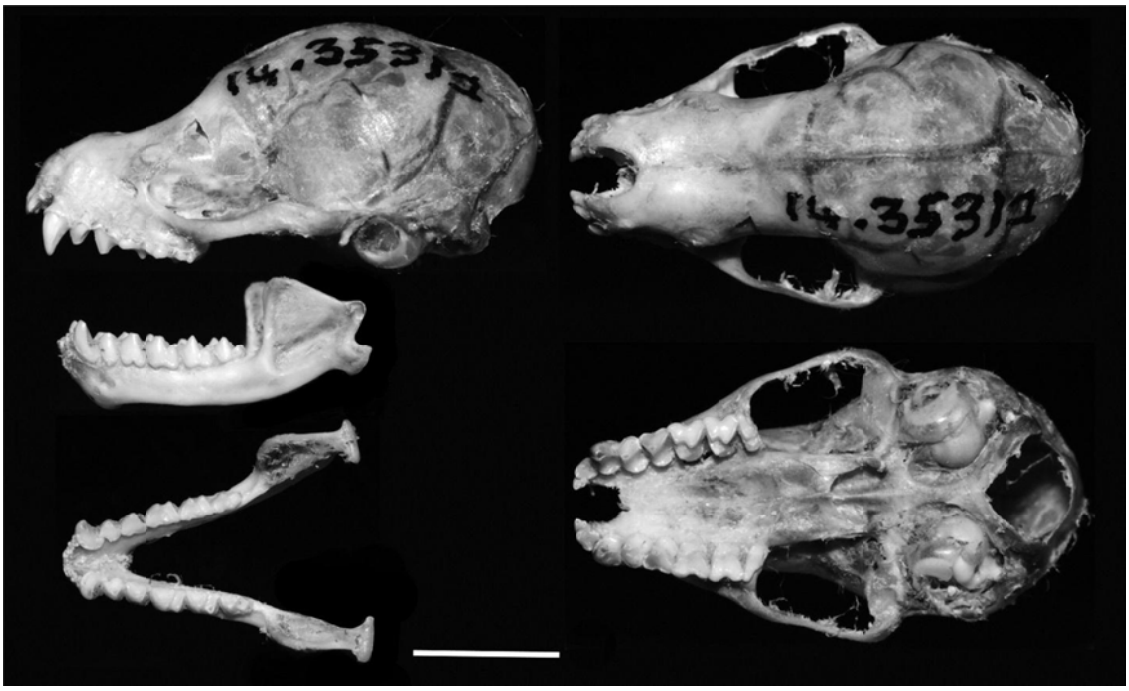

Fig. 3-9. Skull of *M.* sp. [A] subsp. nov. HZM. 14.35312, male (holotype) from Great Nicobar Island, India. Scale = 5 mm.

Fig. 3-10. Variation of the ventral pelage colour in *M. peninsularis*. The specimens ♂field number PS130825.2 (left) and ♂field number PS130825.1 (right) were collected from the same site at Halabala Wildlife Research Station, Narathiwat, S. Thailand.

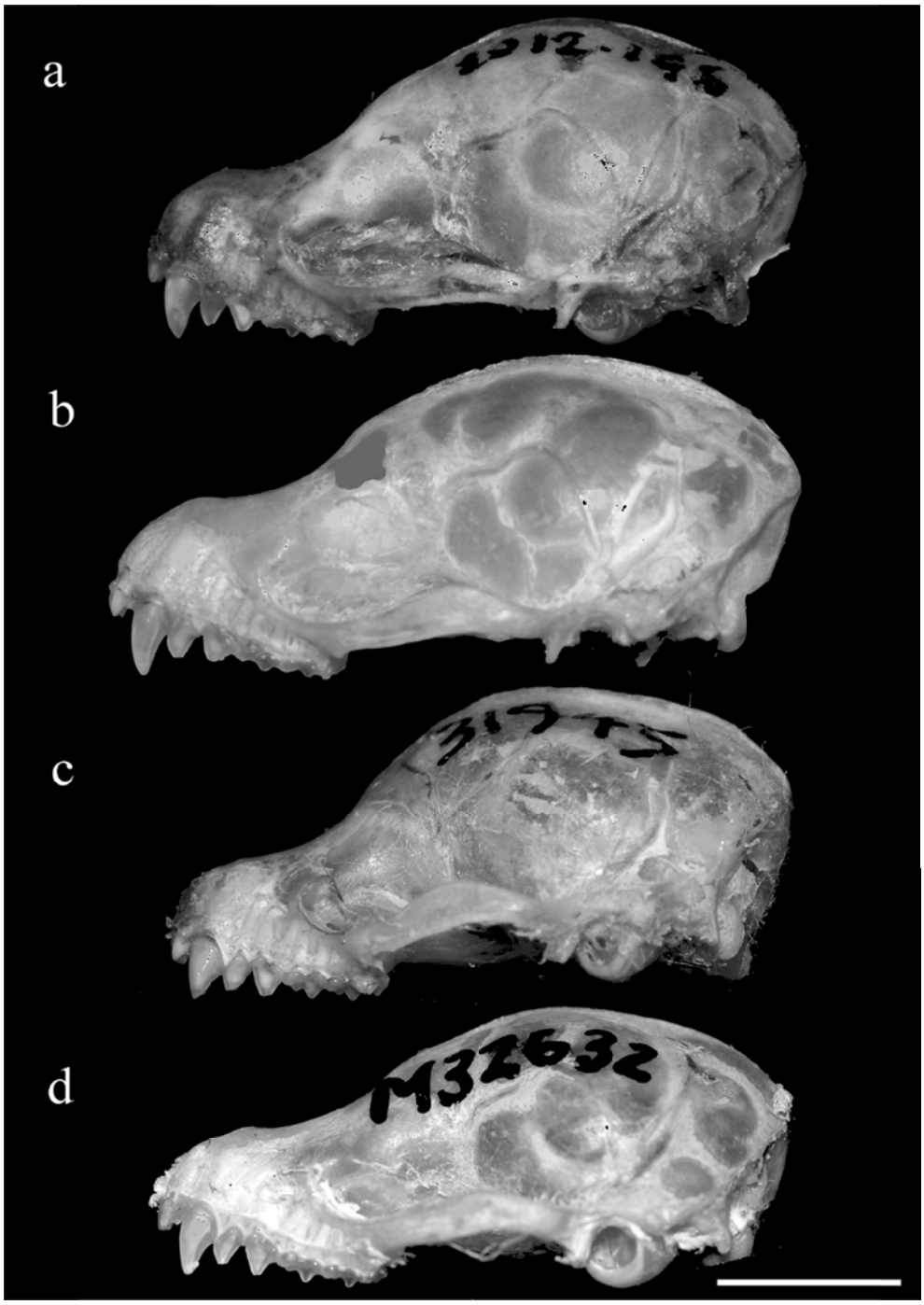

Fig. 3-11. Cranial shape variation in *M. peninsularis*: a) ♂PSUZC-MM2012.196 from peninsular Thailand; b) ♂BMNH.64.771 (holotype) from peninsular Malaysia; c) ♂MZB31945 from Kalimantan, Indonesia; d) ♀MZB29315 from Lombok, Indonesia. Scale bar = 5 mm.

Table. 3-1. External measurements (in mm) and body mass (MASS) (in gram) of *M.* sp. nov. [A], *M.* sp. [A] subsp. nov., *M. cyclotis, M. fionae* and *M. peninsularis.* Sample sizes of male and female specimens examined, mean ±SD, min–max values are given. A sample size that differs from the total number of specimens is given in brackets. Definitions of measurements are listed in the Chapter 2.

n/sex	FA	E	TRG	HB	TAIL	TIB	HF
				M. sp. nov. [A]			
6♂♂	33.2±0.7	13.7±1.4	8.6±0.5	48.0±3.2	35.9±4.0	18.4±0.8	8.5±0.6
	31.9–34.0	11.4–15.2	8.3–9.2 [3]	43.2–51.6	28.1–39.2	17.7–19.7	7.7–9.4
3♀♀	35.4±0.5	14.4±0.8	–	48.2±0.2	39.1±3.1	18.9±0.8	8.2±0.2
	35.0–35.9	13.5–15.1	–	48.0–48.3	35.9–42.0	18.1–19.7	8.0–8.4
				M. sp. [A] subsp. nov.			
3♂♂	34.0±1.4	13.7±0.9	7.7±0.2	43.7±2.1	38.3±1.2	17.8	8.1±0.3
	32.6–35.3	12.7–14.5	7.6–8.0	42.0–46	37.0–39.0	[1]	7.8–8.3
2♀♀	34.0, 34.4	14.2	–	44.0	34.0	–	8.2
	[2]	[1]	–	[1]	[1]	–	[1]
				M. cyclotis			
36♂♂	30.7±0.9	14.0±1.3	8.1±0.6	42.3±2.3	34.9±3.9	17.6±1.1	7.9±0.6
	29.4–33.0 [35]	12.0–17.6 [17]	6.8–9.3 [13]	38.7–46.4 [16]	26.2–39.0 [17]	14.5–19.3 [18]	6.5–8.8 [17]
40♀♀	33.9±1.0	14.5±1.0	7.9±0.9	45.1±2.8	37.4±2.5	18.8±0.9	8.3±0.8
	31.6–36.8	12.7–16.0 [17]	5.8–9.2 [14]	41.1–50 [17]	32–41.1 [17]	17.3–20.3	7.0–9.7 [17]
				M. fionae			
7♂♂	35.1±0.7	14.2±1.3	7.6±0.6	45.4±3.4	37.3±2.5	19.6±06	8.8±0.5
	34.5–36.3	12.1–15.6 [6]	6.8–8.4 [6]	41.0–51.0 [6]	33.7–40.6 [6]	19.1–20.5 [6]	7.8–9.3 [6]
6♀♀	37.3±1.6	15.2±0.3	7.1±1.0	46.3±8.4	37.2±2.1	20.6±0.4	8.6±0.8
	35.5–40.1	14.9–15.5 [3]	6.2–8.2 [3]	37.3–54.0 [3]	35.0–39.1 [3]	20.2–21.1 [3]	7.8–9.3 [3]
				M. peninsularis			
23♂♂	35.7±1.3	14.2±1.7	8.4±0.9	46.6±3.0	38.7±3.3	19.5±1.0	7.8±0.9
	33.8–38.1 [22]	11.9–18.8 [13]	7.4–10.3 [8]	39.9–50.1 [14]	32.4–42.8 [12]	18.2–21.6 [14]	5.6–9.1 [14]
19♀♀	37.7±1.2	15.1±1.2	8.3±0.5	49.9±3.7	42.3±1.9	19.3±2.5	9.0±0.8
	34.5–39.4	13.0–17.0 [12]	7.6–9.0 [9]	42–55.1 [12]	38.5–46 [12]	11.1–21 [14]	7.1–10 [14]

Table 3-1. (Continued).

n/sex	5MET	4MET	3MET	3D1PH	3D2PH	MASS
			M. sp. nov. [A]			
6♂♂	31.0±0.4	29.5±0.9	31.5±0.6	15.0±0.4	14.4±0.2	6.5±0.3
	30.6–31.8	29.2–31.3	30.9–32.6	14.3–15.3	14.0–14.5	6.0–6.8 [5]
3♀♀	31.1	29.2	31.4	15.3	14.4	5.7±2.5
	[1]	[1]	[1]	[1]	[1]	3.0–8.0
			M. sp. [A] subsp. nov.			
3♂♂	–	–	–	–	–	–
	–	–	–	–	–	–
2♀♀	–	–	–	–	–	–
	–	–	–	–	–	–
			M. cyclotis			
36♂♂	29.0±1.6	28.3±1.7	29.2±1.5	13.6±0.4	13.0±0.7	5.0, 5.8
	25.1–31.8 [16]	24.7–31.9 [16]	26.5–32.4[16]	12.8–14.5[16]	11.1–14.1 [16]	[2]
40♀♀	32.3±1.2	31.4±1.3	32±1.2	14.8±0.7	14.4±0.9	6.1
	30.8–35.1 [11]	29.7–34.4 [11]	30.4–34.9 [11]	13.7–16.2 [11]	12.7–15.4 [11]	[1]
			M. fionae			
7♂♂	33.5±0.7	32.6±1.1	33.6±0.8	15.6±0.7	14.9±0.3	–
	32.5–34.1 [4]	31.1–33.4 [4]	32.5–34.2 [4]	14.7–16.4 [4]	14.5–15.2 [4]	–
6♀♀	33.8, 36.0	33.3, 34.7	34.9, 35.4	16.7, 16.9	15.5, 15.6	6.6
	[2]	[2]	[2]	[2]	[2]	[1]
			M. peninsularis			
23♂♂	33.3±1.5	32.7±1.3	34.0±1.5	15.9±0.9	15.1±1.0	7.0±0.9
	31.3–36.8 [12]	29.9–35.4 [11]	32.0–37.6 [11]	14.5–17.6 [11]	13.8–16.8 [11]	5.5–8.3 [9]
19♀♀	35.6±0.5	35.1±0.6	36.5±0.6	17.1±0.8	15.8±0.3	9.7±1.1
	35.0–36.5 [9]	34–36.4 [9]	35.7–37.7 [9]	15.4–18.2 [9]	15.5–16.4 [9]	8.5–11.9 [12]

Table. 3-2. Craniodental measurements (in mm) of *M.* sp. nov. [A], *M.* sp. [A] subsp. nov., *M. cyclotis, M. fionae* and *M. peninsularis*. Sample sizes of male and female specimens, mean ±SD; min–max values are given. A sample size that differs from the total number of specimens is given in brackets. Definitions of measurement are listed in Chapter 2.

n/sex	GTL	CBL	CCL	ZB	BB	BCH	MW	IC	LW
				M. sp. nov. [A]					
6♂♂	17.10±0.4	15.46±0.3	14.85±0.3	9.60±0.2	7.76±0.1	6.68±0.1	8.12±0.1	4.34±0.1	5.16±0.1
	16.40–17.54	14.93–15.83	14.47–15.19	9.29–9.93	7.65–7.82	6.57–6.91	8.00–8.28	4.24–4.44	5.09–5.23
3♀♀	17.65±0.5	16.1±0.3	15.43±0.3	9.92±0.1	7.64±0.1	6.94±0.2	8.34±0.1	4.32±0.1	5.34±0.1
	17.12–18.10	15.79–16.43	15.09–15.76	9.75–10.02	7.53–7.74	6.78–7.10	8.18–8.43	4.20–4.44	5.31–5.4
				M. sp. [A] subsp. nov.					
3♂♂	17.22±0.4	15.55±0.4	14.96±0.4	9.43±0.3	7.88±0.2	6.66±0.1	8.03±0.3	4.41±0	5.21±0.1
	16.87–17.62	15.26–15.98	14.65–15.38	9.12–9.75	7.73–8.13	6.57–6.74	7.68–8.29	4.37–4.46	5.18–5.27
2♀♀	17.45 [1]	15.65 [1]	15.00, 15.01	9.23, 9.52	7.55, 8.01	6.72, 6.79	7.93, 8.35	4.44, 4.46	5.20
				M. cyclotis					
36♂♂	16.47±0.3	14.97±0.4	14.45±0.3	9.36±0.3	7.64±0.3	6.49±0.3	7.90±0.3	4.17±0.1	4.95±0.2
	15.86–17.08 [27]	14.00–15.67 [27]	13.60–15.12	8.78–10.05 [35]	7.16–8.10	6.08–7.22 [34]	7.11–8.48	3.92–4.48	4.26–5.42 [27]
38♀♀	17.21±0.5	15.85±0.5	15.22±0.4	9.84±0.3	7.71±0.2	6.57±0.2	8.2±0.2	4.25±0.1	8.71±17.1
	16.60–18.18 [25]	14.95–16.86 [24]	14.34–16.17	9.33–10.43 [37]	7.40–8.17	6.10–7.21 [37]	7.64–8.58	3.99–4.52	4.67–88.84 [24]
				M. fionae					
7♂♂	18.54±0.6	16.80±0.5	16.21±0.5	10.48±0.4	8.12±0.3	7.25±0.3	8.65±0.3	4.66±0.2	5.72±0.3
	17.53–19.26	15.99–17.49	15.32–16.87	9.78–10.89	7.75–8.39	6.53–7.50	8.10–8.91	4.26–4.85	5.11–6.07
6♀♀	18.80±0.4	17.06±0.3	16.43±0.4	10.56±0.3	8.20±0.3	7.18±0.2	8.69±0.3	4.51±0.2	5.44±0.2
	18.12–19.19	16.48–17.45	15.82–16.73	10.19–10.85	7.84–8.49	6.98–7.48	8.22–8.92	4.23–4.75	5.15–5.61
				M. peninsularis					
23♂♂	17.79±0.3	16.06±0.3	15.52±0.4	10.36±0.4	8.12±0.2	7.32±0.3	8.74±0.3	4.57±0.2	5.47±0.3
	17.39–18.52 [17]	15.68–16.91 [17]	14.90–16.41	9.76–11.31	7.72–8.48	6.79–8.22	8.32–9.39	4.31–4.97 [22]	4.97–5.86 [16]
17♀♀	18.70±0.5	17.11±0.4	16.40±0.4	10.80±0.3	8.22±0.2	7.48±0.3	9.02±0.3	4.68±0.1	5.88±0.2
	17.59–19.33 [13]	16.11–17.69 [13]	15.53–16.89 [16]	10.12–11.22	7.7–8.58	7.10–8.37	8.08–9.62	4.46–4.88 [16]	5.47–6.21 [13]

Table 3-2. (Continued).

n/sex	C–P^4	C–M^3	M^3–M^3	C^1–C^1	C–M_3	M	CPH	TRM1	TAM1
					M. sp. nov. [A]				
5♂♂	2.81±0.1	5.58±0.1	5.54±0.2	4.19±0.1	6.00±0.1	11.38±0.2	4.63±0.2	0.81±0.0	0.43±0.0
	2.69–2.85	5.44–5.72	5.36–5.80	4.12–4.31 [5]	5.83–6.12	11.13–11.74	4.33–4.93	0.80–0.82	0.40–0.48
3♀♀	2.81±0.1	5.67±0.2	5.79±0.1	4.34±0.1	6.18±0.2	12.11±0.2	5.10±0.1	0.82±0.0	0.47±0.0
	2.69–2.94	5.50–5.91	5.68–5.87	4.28–4.44	6.01–6.43	11.95–12.34	5.05–5.15	0.80–0.84	0.44–0.5
					M. sp. [A] subsp. nov.				
3♂♂	2.50, 2.60	5.52±0.2	5.55±0.3	3.98±0.1	6.08±0.2	11.5±0.4	4.17±0.2	0.83±0.0	0.47±0.1
	[2]	5.39–5.71	5.24–5.71	3.90–4.13	5.91–6.21	11.27–11.96	4.01–4.44	0.80–0.86	0.42–0.56
2♀♀	2.78, 3.05	5.70, 5.73	5.27, 5.31	3.86, 4.16	6.19, 6.26	11.47, 11.74	4.15, 4.2	–	–
	[2]	[2]	[2]	[2]	[2]	[2]	[2]	–	–
					M. cyclotis				
36♂♂	2.66±0.2	5.41±0.2	5.39±0.2	4.00±0.1	5.84±0.1	11.17±0.3	4.14±0.2	0.79±0.0	0.47±0.0
	2.21–2.96	5.12–5.68	5.07–5.79 [35]	3.73–4.27	5.57–6.18	10.52–11.68 [35]	3.77–4.60 [35]	0.74–0.84 [13]	0.40–0.56 [13]
38♀♀	2.76±0.2	5.61±0.2	5.57±0.2	4.25±0.1	6.11±0.2	11.86±0.3	4.71±0.3	0.82±0.0	0.49±0.0
	2.21–3.11	5.06–6	5.18–6.05	4.00–4.68 [37]	5.75–6.49 [37]	11.32–12.78 [37]	4.16–5.3	0.76–0.9 [10]	0.40–0.54 [10]
					M. fionae				
7♂♂	3.03±0.2	6.14±0.2	6.03±0.2	4.64±0.2	6.65±0.2	12.48±0.4	4.64±0.3	0.90±0.1	0.49±0.1
	2.68–3.24	5.72–6.40	5.74–6.25	4.18–4.88	6.30–6.95	11.99–13.19	4.24–4.88	0.82–1.00 [6]	0.44–0.54 [6]
6♀♀	2.79±0.1	6.11±0.2	6.06±0.2	4.57±0.2	6.63±0.3	12.82±0.2	5.08±0.2	0.88±0.1	0.51±0.0
	2.7–2.89 [5]	5.78–6.32	5.71–6.24	4.34–4.72	6.33–6.89	12.56–13.01	4.7–5.36	0.80–0.92 [3]	0.48–0.54 [3]
					M. peninsularis				
22♂♂	2.99±0.2	5.76±0.2	5.72±0.2	4.66±0.3	6.31±0.4	11.92±0.4	4.86±0.3	0.87±0.1	0.43±0.0
	2.73–3.3 [17]	5.52–6.09	5.45–6.22	4.28–5.28	5.94–8.02	11.25–12.92 [21]	4.30–5.33	0.79–1.00 [15]	0.38–0.50 [15]
17♀♀	2.90±0.7	6.07±0.2	5.94±0.2	4.97±0.2	6.55±0.2	12.75±0.4	5.51±0.4	0.91±0.0	0.46±0.0
	0.14–3.36	5.68–6.39	5.69–6.22 [16]	4.46–5.26 [16]	6.28–6.94 [16]	12.09–13.59	4.72–6.08 [16]	0.84–1.00 [12]	0.40–0.52 [12]

Table 3-3. Factor loading scores of the characters used in Fig. 3-7 and variance explained between the first three components. Definitions of measurements are listed in Chapter 2.

Characters	**PC1**	**PC2**	**PC3**
FA	-0.313	0.115	-0.692
CCL	-0.330	0.293	-0.102
BB	-0.309	-0.373	0.253
BH	-0.300	-0.454	-0.163
MW	-0.327	-0.261	-0.112
IC	-0.308	-0.312	0.465
C^1-M^3	-0.320	0.381	0.167
M^3-M^3	-0.309	0.234	0.126
C^1-C^1	-0.327	-0.093	-0.231
C-M_3	-0.319	0.426	0.308
Variance explained	82.0%	5.5%	2.9%

CHAPTER 4

SYSTEMATICS OF *MURINA* IN MAINALND SOUTHEAST ASIA WITH DESCRIPTION OF A NEW SPECIES

ABSTRACT

The Tube-nosed bat genus *Murina* in mainland Southeast Asia is reviewed. Eighteen species are currently recorded from the region. A new species of *Murina* belonging to '*suilla*-group' is described based on two specimens from the southernmost part of peninsular Thailand. These were collected in a harp trap in lowland evergreen forest. The morphology and DNA barcode sequences suggested the new species is most closely related to *M. eleryi,* which is currently known from Indochina. However, it can be distinguished by the size and shape of the upper canine, the shape of the upper and lower premolars and the colour of the ventral pelage. Moreover, three species including *M. walstoni, M. annamitica,* and *M. rozendaali*, are firstly recorded from Thailand. The diagnostic characters of each species and the discussion of their taxonomic notes are summarised. The DNA barcode supported current taxonomic conclusion but does not agree with traditional morphological groupings of the '*M. cyclotis*-group' and '*M. suilla*-group'. In most cases, the pattern of distribution of *Murina* in mainland Southeast Asia is strongly related with zoogeographical division between the Indochinese and Sundaic Subregion. An only exception is the case of *M. huttoni,* which most of records were from the Indian Subcontinent and Indochinese Subregion but with a single specimen from peninsular Malaysia. Additional data on ecology and echolocation, where available, are included and discussed. A key to species of *Murina* known to occur in mainland Southeast Asia is provided.

Keywords: biogeography, DNA barcode, new record, new species, Southeast Asia, taxonomy, zoogeography

Manuscript of a part of this chapter entitled '**A new species of *Murina* (Mammalia: Chiroptera: Vespertilionidae) from peninsular Thailand**' has been submitted to ZOOTAXA.

INTRODUCTION

Subfamily Murininae is known to occur in the Indian subcontinent, Russia, China, Korea, Japan, mainland SE Asia, the Philippines, Indonesia and down to northern Australia (Simmons, 2005). The bat of this subfamily is characterised by projected tubular nostrils (Corbet and Hill, 1992). Genus *Murina* and *Harpiocephalus* were both originally described from type species *Vespertilio suillus* (=*Murina suilla*) and *Vespertilio harpia* (=*Harpiocephalus harpia*) respectively, from Java by Temminck (1840). Then Gray (1842) subsequently promoted each to its own genus. Genus *Harpiola,* on the other hand, was originally regarded as a subgenus of *Murina,* with the type species *M. grisea* from NW India by Peters (1872). Thomas (1915), and followed by Tate (1941) accommodated *grisea* in a separated genus *Harpiola.* However, Corbet and Hill (1992) kept it as a subgenus of *Murina.* Kuo *et al,* (2006) then validated the characters of *Harpiola* and described a second species of the genus from Taiwan. Although genetic difference between genera have not been tentatively analysed, it is currently accepted to have three genera comprising Hairy-winged bat genus *Harpiocephalus,* Tube-nosed bats genus *Murina* and *Harpiola* (Simmons, 2005; Kuo *et al.,* 2006; Francis, 2008).

Bat species in the genus *Murina* are generally identified by combination of external and craniodental characters, including forearm length, dorsal and ventral pelage colour ; point of attachment of the plagiopatagium to the hindfoot; size and shape of the skull; arrangement, size and shape of the incisors, canines and premolars; presence/absence and size of the mesostyle on the first and second upper molars; size of the talonid in comparison to the trigonid of the first and second lower premolars, and also the height of their hypoconid and entoconid (Csorba *et al.,* 2011; Francis and Eger, 2012). They are traditionally separated into two species-groups, the '*cyclotis*-group' and '*suilla*-group' (sensu Koopman, 1994), based on the relative height and crown area of the first upper premolar (P^2) compared to the second upper premolar (P^4).

Murina specimens, until recently, were poorly represented in museum collections. Their ecology was also very little known. However, with intensive field surveys using harp trap in forest areas, the total number of *Murina* known to science

has increased rapidly in recent years (Csorba *et al.,* 2011). Before 2005, there were only 17 species of *Murina* (Simmon, 2005). This is hugely different from the current number of at least 31 species (Csorba and Bates, 2005; Csorba *et al*., 2007, 2011; Kuo *et al*., 2009; Kruskop and Eger, 2008, Furey *et al.,* 2009; Eger and Lim, 2011; Ruedi *et al.,* 2012; Francis and Eger, 2012; Soisook *et al.,* submitted). However, genetic data still suggest a presence of high cryptic diversity within this genus which future intensive study may turn out some described species to be junior synonyms (Francis *et al.,* 2010; Francis and Eger, 2012).

Most of the new *Murina* species are recently described from Indochina. They are summarised here as follows. *M. harrisoni* was described from Cambodia (Csorba and Bates, 2005) and is now also known from China, Lao PDR, Vietnam and N. Thailand (Wu *et al.,* 2010; Francis and Eger, 2012). *M. tiensa* was described from Vietnam (Csorba *et al.,* 2007) but there is some disagreement about its taxonomic status and is regarded by some as a junior synonym of *M. harrisoni* based on genetic data (Francis and Eger, 2012); *M. hapioloides* was described from Vietnam (Kruskop and Eger, 2008). *M. eleryi* was described from N. Vietnam (Furey *et al.,* 2009) and is currently regarded to be widespread in Indochina and all specimens of *M. aurata* previously recorded in SE Asia are now referred to *M. eleryi* (Eger and Lim, 2011; Francis and Eger, 2012). Csorba *et al.* (2011) described *M. walstoni* from Cambodia*, M. beelzebub* from Vietnam, and *M. cineracea* from Indochina. They also referred the previous records of *M. tubinaris* from Southeast Asia to *M. cineracea* and restricted *M. tubinaris* to Pakistan. However, Francis and Eger (2012) argued that *M. cineracea* may not be a distinct species and suggested that it is a junior synonym of *M. feae.* Francis and Eger (2012), recently reported 12 species of *Murina* from Lao PDR, commenting on several species as mentioned above, and described *M. annamitica* and *M. fionae* as new species.

Whilst the genus *Murina* in Vietnam, Cambodia and Lao PDR has been being well studied (as mentioned above), the current knowledge of *Murina* in Thailand is still lacking. Thailand is important because it has a large land area and is situated in the middle of the region covering both Indochinese and Sundaic subregions.

The earliest known recorded of the *Murina* in Thailand can be tracked back to 1904, when Pousargues (1904) reported *Harpiocephalus cyclotis* (= *M. cyclotis*). This species was reported again in Hill and Thonglongya (1972). The most comprehensive monograph of the mammals of Thailand was made by Lekagul and McNeely (1977). They included only two *Murina* species, *M. cyclotis* and *M. huttoni*. Hill (1983) as well as Melville (1984) recorded *M. aurata* and *M. tubinaris* based on specimens collected from Doi Inthanon, Chiang Mai. However, as mentioned above, *M. aurata* is now thought to be restricted to its type locality and its previous records in Indochina are now referred to *M. eleryi* (Eger and Lim, 2011; Francis and Eger, 2012). Subsequently, McBee *et al.* (1986) added *M. leucogaster* to the list. *M. cyclotis* and *M. huttoni* were also reported in Yenbutra and Felten (1986). Corbet and Hill (1992) followed the above records and listed five *Murina* from Thailand. The number was raised again when Bumrungsri *et al.* (2006) reported *M. suilla* and *M. aenea* for the first time to the country. Francis (2008) in his excellent illustrated guide book of mammals of mainland SE Asia, listed six species of *Murina* in Thailand. He omitted *M. leucogaster*. The previous records of *M. tubinaris* were replaced by the newly described species *M. cineracea* (Csorba *et al.,* 2011), whereas the record of *M. leucogaster* from northwest Thailand was subsequently referred to *M. harrisoni* in Francis and Eger (2012). In the same paper, Francis and Eger (2012), suggested the name *M. feae* instead of *M. cineracea* and promoted the Sunda subspecies *M. cyclotis peninsularis* to be specifically distinct. A most recent new species being described from Thailand (*M.* sp. nov. [A], see Chapter 3), provisionally added the number of *Murina* in Thailand to nine species.

On the basis of field surveys for bats in forest areas of Thailand, as well as the examination of specimens of *Murina* in various museums between 2010 and 2013, a putative new species of *Murina* in the *'suilla*-group' from peninsular Thailand is here described. A number of specimens referred to three *Murina* species, which have not been recorded elsewhere in Thailand, was found and reported here for the first time. Morphological descriptions of the species are included together with taxonomic remarks, and ecological, distribution, echolocation and genetic data, where available, for each of the species. A key to species of *Murina* known to occur in in

mainland Southeast Asia is provided. The information described in this paper is based on dataset collected for this study only, unless stated otherwise.

MATERIALS AND METHODS

To collate data on Thai *Murina,* published records of *Murina* in mainland Southeast Asia were collected. In addition, specimens of *Murina* spp. deposited in various museums were examined by visit or loan (see Method section, Chapter 2. Additional specimens were collected during field surveys which focused on Thailand and were undertaken between 2010 and 2013 by a field research team from PSU working jointly with wildlife research teams of the DNP. The new material was collected from the localities listed in Chapter 2.

External measurements were taken with a dial caliper to the nearest 0.1 mm in the field. Specimens are preserved in 70% ethanol. Some of specimens were prepared as dry study skin. Skulls and some bacula were extracted. Craniodental measurements were taken by digital caliper (to the nearest 0.01 mm) under a stereo microscope. The definitions of measurements are as listed in Chapter 2.

Call recording, measurements and analysis were followed the protocols as outlined in Chapter 2. Genetic analyses followed the protocols for mammalian DNA Barcode analyses as outlined in Ivanova *et al.* (2012). The cytochrome oxidase-I (COI) gene of 657 bp sequences from our samples were analysed using the Neighbour-joining tree algorithms (NJ) implemented within the Barcode of Life Data Systems (BOLD). Public data, as published in Francis *et al.* (2010) deposited in BOLD are also included in the analyses. Genetic divergence values between samples were calculated using the Kimura-2-parameter model (K2P). Bootstrap analyses of 1000 replicates were performed. All analyses were performed in MEGA 5 (Tamura *et al.,* 2011).

RESULTS

A total of 300 specimens of *Murina* from the Indian Subcontinent, Russia, China, Taiwan and Southeast Asia, was examined. These specimens represented 25 species, of which 17 were from mainland Southeast Asia. Only *M.*

hapioloides, which is restricted to Vietnam, was not available to examine personally but was included in the genetic analysis.

Morphologically, they can be separated into two species group as '*M. suilla*-group' and '*M. cyclotis*-group' as traditionally divided by Corbet and Hill (1992) and Koopman (1994). However, genetic analyses based on NJ of the DNA barcodes suggested that the phylogenetic relationship between species is not correlated with this classification (see below). Descriptions of all 18 *Murina* currently known from mainland Southeast Asia, with genetic, echolocation, ecology and geographical distribution data, are provided below.

Systematic description

'*M. SUILLA*-GROUP'

Murina species in the '*M. suilla*-group' are differentiated primarily on the size of the first upper premolar (P^2) which is relatively small, only about half or less that of the second upper premolar (P^4) in height and crown area. Nine species are currently known from mainland Southeast Asia. Descriptions of each species are given below.

M. sp. nov. [B]

(Fig. 4-1–4-4, Table 4-1–4-3)

Holotype

PSUZC-MM2012.214, field number PS121013.1, adult ♂, dry skin with skull and baculum extracted, collected by Abdullah Samoh, Saowaluk Binlasoi and Jirapan Yimkaew on 13 October 2012, on behalf of faunal diversity survey of Halabala Wildlife Research Station.

Measurements of the holotype (in mm) are as follows: MASS: 3.5 g, FA: 28.0, HB: 34.5, TL: 30.7, HF: 7.0, TIB: 14.5, 3MET: 26.8, 4MET: 26.5, 5MET: 26.6, 3D1P: 11.3, 3D2P: 10.4, E: 12.8, Tragus: 7.4, GTL: 14.42, CBL: 13.10, CCL:

12.31, ZB: 8.21, BB: 6.86, MW: 7.11, PC: 4.12, BCH: 5.33, C–M^3: 4.66, C–P^4: 2.03, C^1–C^1: 3.44, M^3–M^3: 4.90, C–M_3: 5.04, C–P_4: 1.93, M: 9.63, CPH: 3.13, TRM_1: 0.68;TAM_1: 0.56; BL: 1.0.

Type locality

Second bridge trail, Bala Forest, Halabala WS, Wang, Narathiwat Province, S. Thailand, approx. 5°48.9'N 101°48.1'E, 370 m a.s.l.

Paratype

PSUZC-MM2012.215, field number PS120928.1, adult ♀, dry skin with skull extracted, collected from the same area as the holotype, but at approx. 5°48.5'N 101°48.4'E, 340 m a.s.l., collected by Abdullah Samoh, Saowaluk Binlasoi, Jirapan Yimkaew and Pipat Soisook on 28 September 2012.

Diagnosis

This is a small bat, with a FA of 28.0–30.4 mm, STOTL 14.03–14.81 mm and CCL of 12.31–12.98 mm. The dorsal pelage is dark-grey at the base and orange-reddish brown distally; some hairs are charcoal black at the tip; longer shiny golden hairs are scattered over the dorsal side. The ventral pelage is dark-grey basally and whitish grey at the hair tips. The wing membrane is attached to the distal phalanx of the outer toe, 2 mm above base of the claw. The actual height of upper canine is slightly exceeded that of the second upper premolar but it is only about equal or slightly less that of the P^4 when view laterally. The cingular cusp on the lingual surface of the upper canine is very well developed. The outer upper incisor is large, with a crown area about twice that of the inner incisor. The first upper premolar is elliptical. The second upper premolar is rounded. The lower canine exceeds in height the second lower premolar. The talonid in both the first and second lower molars is slightly less in crown area than that of the respective trigonid and the entoconid is less than that of hypoconid in height.

Etymology

The name of this species will be named to refer to the type locality, Bala Forest, where the type specimen was collected.

Description

This is a small *Murina* with a FA of 28.0–30.4 mm, HB 34.5–42.5 mm and the body mass of 3.5–4.0 g. The ear, which is 12.3–12.8 mm in height, is rounded with no distinct emargination on the posterior border of the pinna. The pinna is almost naked and brown in colour, except at the anterior base, which is paler. The tragus is white throughout and short, 7.4–7.6 mm; it is less than half the height of the ear (Fig.4-1a). The dorsal pelage is ashy–grey basally for about 40% of hair length; most of the hair tips are yellowish-brown but some have a charcoal black tip. Bright shiny silver–golden guard hairs are scattered from the head to the back to the base of the uropatagium and on the dorsal side of the foot (Fig.4-1b–c). The ventral pelage is dark grey basally and whitish-grey on the hair tips (Fig.4-1d).

In the wings, the thumb is relatively long, 8.2–8.8 mm. The 3rd metacarpal (3MET), 26.8–28.0 mm, is slightly longer than that of the 4th and 5th metacarpals (4MET and 5MET), which are about subequal in length, 26.5–27.7 mm and 26.6–27.7 mm, respectively. The first (3D1P) and second phalanges of the third digit are 11.3–13.1 mm and 10.4–11.9 mm, respectively. The plagiopatagium is naked and dark brown in colour on both dorsal and ventral side and is attached to the distal phalanx, 2 mm above the base of the claw of the outer toe (Fig.4-1b). The feet are hairy dorsally, relatively small, 6.6–7.0 mm, and less than half of tibia length, which is 14.3–14.5 mm. Tail length is 30.6–30.7 mm. Each calcar is well developed and without a keel, its length is 47–53% of the trailing edge of the uropatagium.

In the skull, the greatest length (GTL) is 14.42–14.95 mm, CBL 13.10–13.68 mm, and CCL 12.31–12.98 mm. Each zygoma is very thin and without a process; the breadth (ZB) is 8.21 mm. The breadth of braincase (BB) and mastoid (MW) are 6.86–6.90 mm and 7.11–7.52 mm, respectively. In lateral view, the profile from the posterior part of the rostrum to the anterior part of the braincase exhibits only a slight concavity (Fig. 4-2). The braincase and lambdoid is without a sagittal crest and is relatively low (Fig. 4-2a), with the BCH of 5.33–5.52 mm. The

basioccipital pit and the palatal depression are very shallow (Fig. 4-2c–d). The upper toothrows converge anteriorly; the width at C^1–C^1 is 70.20–71.26% of that at M^3–M^3. The maxillary toothrow length (C–M^3) is 4.66–4.88 mm. The upper canine–second upper premolar length (C–P^4) is 1.99–2.03 mm, which is 41.60–42.70% of the maxillary toothrow length. The inner upper incisor (I^2) is placed forward of the outer upper incisor (I^3). In lateral view, they are both clearly seen and are about equal in height. The upper canine (C^1) is relatively small in comparison to the second upper premolar (P^4); its crown area is about two-thirds or slightly less than that of P^4; its actual height slightly exceeded that of P^4 but is about equal or slightly less that of the P^4 in lateral view (Fig. 4-2a, 4-3). The cingular cusp on the lingual surfaces of both C^1 and P^4 is very well developed (Fig. 2e). The first upper premolar (P^2) is somewhat elliptical, its crown area is about half that of the P^4, and its height is about half that of C^1 and P^4 (Fig. 3). P^4 is relatively large, rounded in shape (Fig. 4-3). The mesostyle of the first (M^1) and second molars (M^2) are well developed and the shape of the labial surface of both teeth are convex.

The length of the mandible (M) is 9.63–10.44 mm. The mandibular toothrow length (C–M_3) is 5.04–5.38 mm. The C–P_4 is short, 1.83–1.93 mm, which is 35.87–36.31% of mandibular toothrow length. The lower incisors (I_1 to I_3) are all tricuspidate. The crown area and height of the lower canine (C_1) exceed those of the first (P_2) and second lower premolars (P_4). P_2 is about two-third that of the P_4 in crown area and they are about equal in height. The anterior and posterior basal cusps of the P_2 are well developed and are partially situated above the posterior border of C_1 and the anterior border of P_4 (Fig. 4-3). The second lower premolar (P_4) is relatively large, with a crown area of about two-thirds that of the lower canine. The talonid of the first (M_1) and second lower molars (M_2) is slightly smaller than that of its respective trigonid in size. The height of the entoconid is two-thirds that of its hypoconid on M_1; it is subequal in M_2. The coronoid process is well developed, 3.13–3.48 mm in height.

The baculum is almost rectangular in shape but with rounded corners and a slight concavity on the anterior and posterior margins; it is very small, with a greatest length (BL) of 1.0 mm and a width of 0.6 mm. The dorsal surface is arched upwards and the ventral surface is deeply concave throughout its length (Fig. 4-4a).

Comparative specimens

Murina eleryi – Vietnam: ♀HZM.1.39006 (paratype), Kim Hy Nature Reserve, An Tunh Commune, Na Rai District, Bac Kan Province; ♀field number T120 (ROM field no.29013), Huu Lien Nature Reserve, Lang Son Province; ♂field number T.241107.1, Muong Do Commune, Phu Yen District, Son La Province; Thailand: ♂BMNH.82.162 (labeled as *M. aurata*), Doi Inthanon, Chom Thong District, Chiang Mai Province.

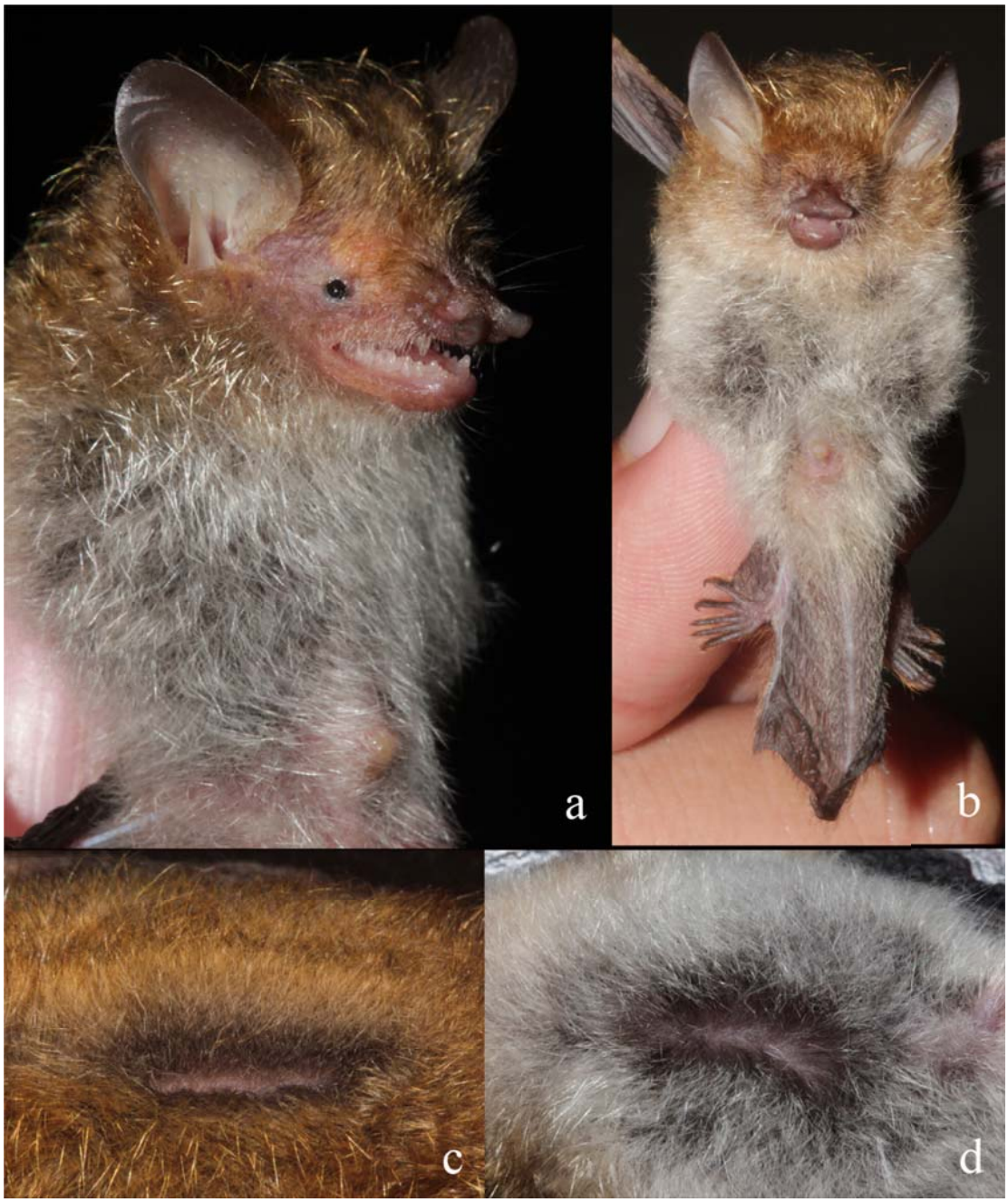

Fig. 4-1. a) antero-lateral view of the *M.* sp. nov. [B], paratype ♀PSUZC-MM2012.215 from Thailand; b) ventral view of the whole body of the holotype, ♂PSUZC-MM2012.214; c) – d) dorsal and ventral pelages of the holotype, respectively. Not to scale.

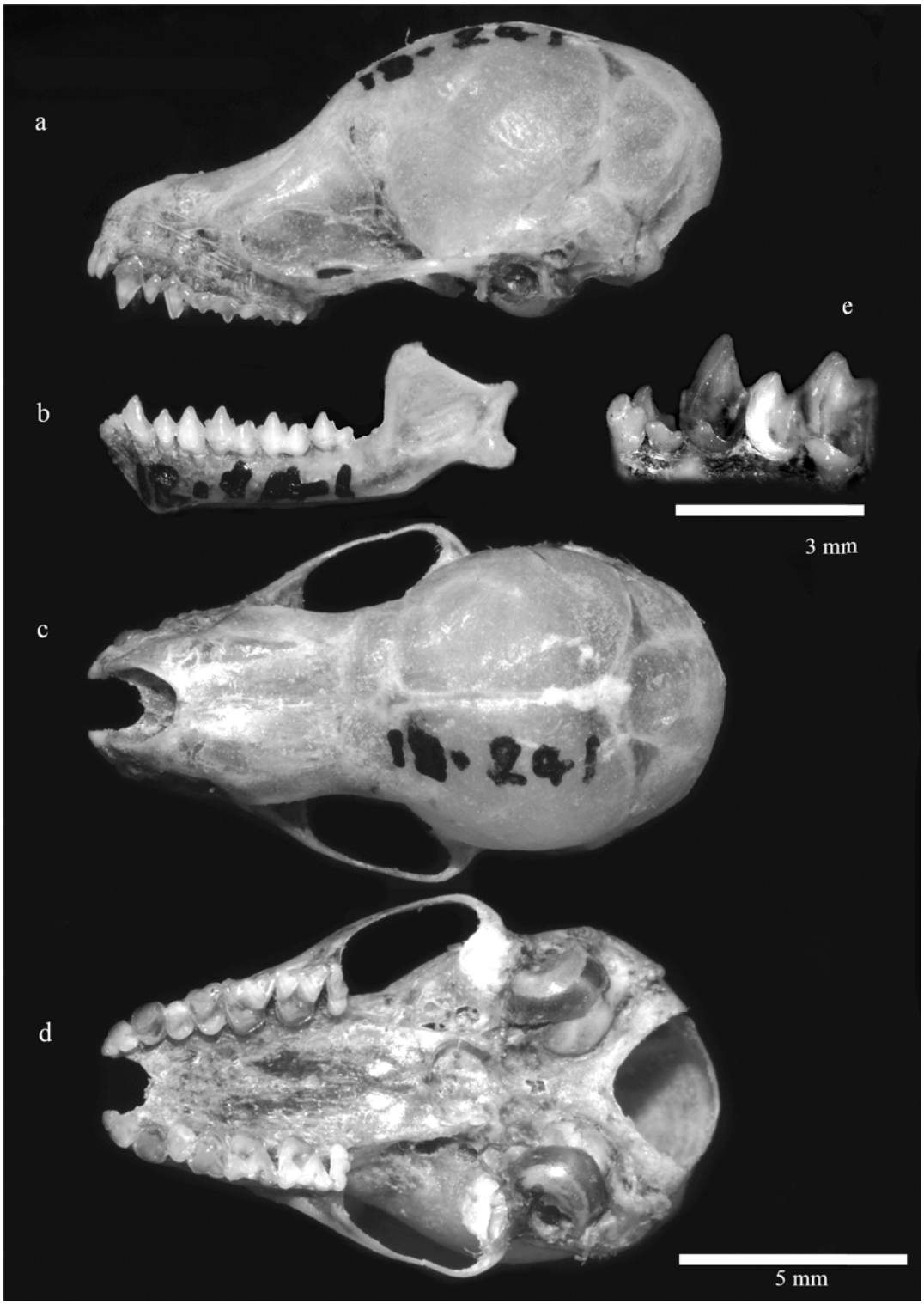

Fig. 4-2. a) – d) skull of the holotype of *M.* sp. nov. [B], ♂PSUZC-MM2012.214 from Thailand; e) lingual view of upper left I^2– P^4 of the holotype. Scale bars = 5 mm and 3 mm, as indicated. The lower toothrow is shown in the Fig. 4-3.

Comparison with similar species

According to the dental characters, *M.* sp. nov. [B] belongs to the *'suilla*-group' (*sensu* Corbet and Hill, 1992). It can be separated from all other *Murina* species in the *'cyclotis*-group' in having a relatively small P^2 and C^1; crown area of P^2 is about half that of the P^4; crown area of the upper canine (C^1) is about two-third or slightly less that of the P^4. In the *'suilla*-group', it can be distinguished from other species by its distinct pelage colour and a very well developed cingular cusp of the upper canine. The only two species that share a similar pelage colour and have a well-developed cingular cusp on the upper canine are *M. eleryi* which is known from northern Vietnam and Lao PDR (Furey *et al.,* 2009; Francis and Eger, 2012) and *M. aurata* which is thought to be restricted to mountains in and around Moupin, Tibet (Eger and Lim, 2011).

M. sp. nov. [B] is most similar to *M. eleryi*, but differs significantly in a very well-developed cingular cusp of the upper canine observed in *M.* sp. nov. [B] whereas it is much less developed in *M. eleryi.* In the horizontal pane of lateral view, the C^1 of *M. eleryi* exceeds P^4 in height, but it is only about equal or less that of P^4 in *M.* sp. nov. [B] (Fig. 4-3). The tragus of *M.* sp. nov. [B] is white but in *M. eleryi* (although this may not constant in every individual), it appears to have a dark tip (Furey *et al.,* 2009; Fig. 4-1A). The hair colour of both species is very similar. However, the ventral pelage of *M.* sp. nov. [B] is somewhat duller, light grey rather than creamy white in *M. eleryi.* In the skull, *M.* sp. nov. [B] has a more elongate rostral–interorbital region and lambdoid (Fig. 3), with a relatively lower braincase height (BCH) 5.33–5.52 mm versus 5.44–5.78 mm in Furey *et al.* (2009). The lateral profile from the interorbital region to the anterior part of the braincase of *M.* sp. nov. [B] is gradually rising but it is more markedly concave in *M. eleryi* (Fig. 4-3). The basioccipital pit and palatal depressions of *M.* sp. nov. [B] are very shallow whereas in *M. eleryi* these depressions are distinctly deeper. In *M.* sp. nov. [B], the P^4 is somewhat rounded, being wider than long, but *M. eleryi* has a more rounded P^4 (Fig. 3). In the mandible, the crown area of the talonid of M_1 and M_2 is less or only about equal to its respective trigonid, in *M. eleryi,* the talonid exceeds the trigonid in crown area (Fig. 4-3; see also Furey *et al.,* 2009). The specimens of *M. eleryi* examined have

a proportion of the talonid to the trigonid of the M_1 of 85.7–90.6% (n=3) in length, versus 80.6–82.4% of in *M.* sp. nov. [B]. Moreover, the height of the entoconid is less than that of its respective hypoconids in M. sp. nov. [B], but in *M. eleryi* the entoconid exceeds that of the hypoconid in both M_1 and M_2. The baculum of *M.* sp. nov. [B] is shorter than that of *M. eleryi* (1.0 versus 1.4 mm, respectively); there is only a very slight concavity on the anterior and posterior margins whereas in *M. eleryi* both these borders are strongly concave (Fig. 4-4).

Although the general appearance of the pelage and the length of the upper canine of *M.* sp. nov. [B] are similar to the Tibetan species *M. aurata* and the Vietnamese species *M. hapioloides, M.* sp. nov. [B] can be differentiated from the latter two species on the basis dental shape and size. The crown area of the C^1 of *M.* sp. nov. [B] is about two-third or subequal that of P^4 whereas the C^1 is only slightly more than half that of the P^4 in *M. aurata.* Furthermore, the lower canine (C_1) of *M. aurata* is very small and does not exceed that of P_4 in height, which is in contrast to a high and well developed C_1 of *M.* sp. nov. [B] (Fig. 4-2a; see also Maeda, 1980; Kruskop and Eger, 2008; Furey *et al*., 2009). In *M. hapioloides,* the C^1 is without the cingular cusp, and much smaller in size, and the P^4 is more rounded than in *M.* sp. nov. [B]. Furthermore, the talonid of the M_2 of *M. hapioloides* exceeds that of the trigonid in size but in *M.* sp. nov. [B], the talonid never exceeds that its trigonid (Fig. 4-3; see also Kruskop and Eger, 2008).

Echolocation

The free flying individuals emitted a typical broadband Frequency-modulated (FM) signal. There is a slight difference between the male and female specimens in call parameters, which are as follows; *fmaxe* male = 90.7–107.3 kHz, female = 84.6–95.3 kHz; *sf* male = 145.9–159.7 kHz, female = 159.0–164.0 kHz; *tf* male = 65.5–67.0 kHz, female = 62.0–66.9 kHz; *d* male = 1.7–2.6 ms, female = 1.9–3.0 ms.

Ecology and reproduction

The male specimen (holotype) was collected in harp trap set across a forest trail leading uphill in moist evergreen forest at an elevation of 370 m. It was caught at 19.45 hrs just before it started to rain. The female specimen (paratype) was collected in a harp trap set in the understorey of a lowland moist evergreen forest at an elevation of 340 m and approximately 800 m away from the site where holotype was collected. It was found together in the same trap with *Hipposideros atrox, Kerivoula hardwickii, K. minuta, K. pellucida* and *Murina suilla.*

Genetic analyses

A preliminary result of the DNA barcode of the COI gene sequences revealed an approximately 8% difference between *M.* sp. nov. [B] and *M. eleryi* (see also Fig. 4-5). This is relatively low, as suggested that a difference approximately 5% is in the range observed within intraspecific variation of *Murina* species (Francis *et al.,* 2010; Francis and Eger, 2012). However, with the disjunct distribution as well as the habitat and morphological differences as described above, we here regard *M.* sp. nov. [B] as a distinct species. Further genetic study, particularly the relationship with other species, is recommended.

Distribution and conservation notes

M. sp. nov. [B] is only currently known from its type locality at Bala forest, Narathiwat Province (Fig. 4-6). The conservation status of this species has not been evaluated. However, according to very low capture rate compared to other *Murina* species in the same area, and also the level of forest degradation in peninsular Thailand, it is here considered to be at risk.

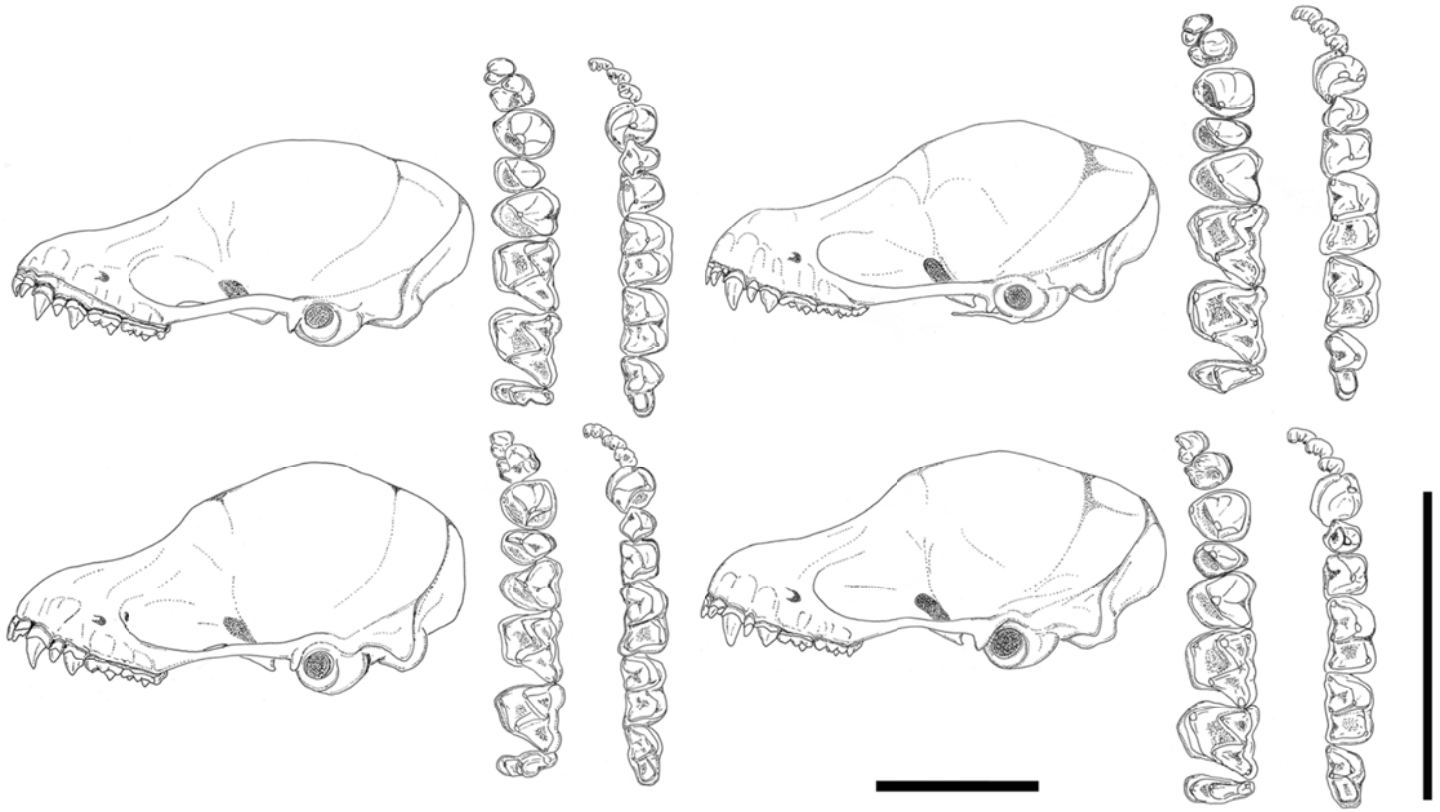

Fig. 4-3. Lateral view of cranial and occlusal view of dental (upper left and lower right toothrow) comparison between *M.* sp. nov. [B], from Thailand (top left: ♂PSUZC-MM2012. 214, holotype; top right: ♀PSUZC-MM2012.215, paratype) and *M. eleryi* from Vietnam (bottom left: ♂T.241107.1, bottom right: ♀HZM.1.39006, paratype). Scale bar = 5 mm (horizontal bar for the cranium and vertical bar for the toothrow).

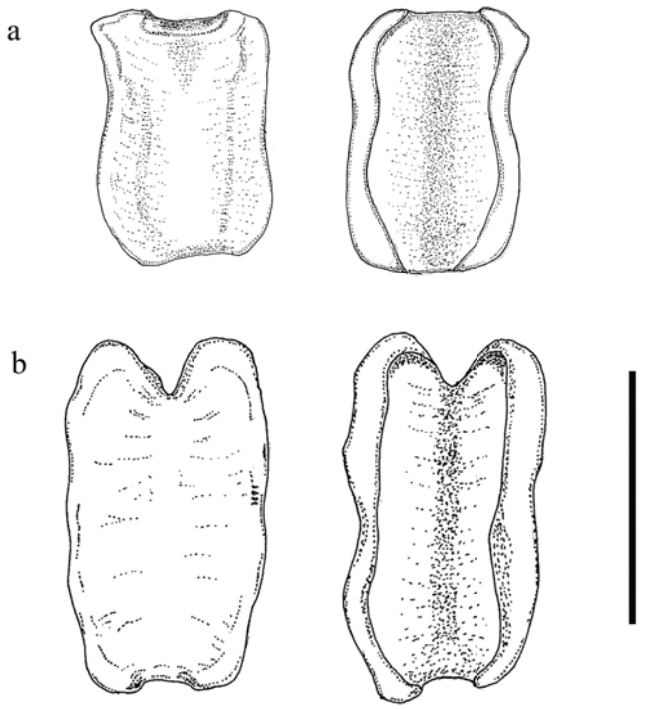

Fig. 4-4. Dorsal (left) and ventral view (right) of the baculum of a) *M.* sp. nov. [B]. PSUZC-MM2012.214, male (holotype) from Thailand. b) *M. eleryi* T.241107.1, male from Vietnam. Scale bar = 1 mm.

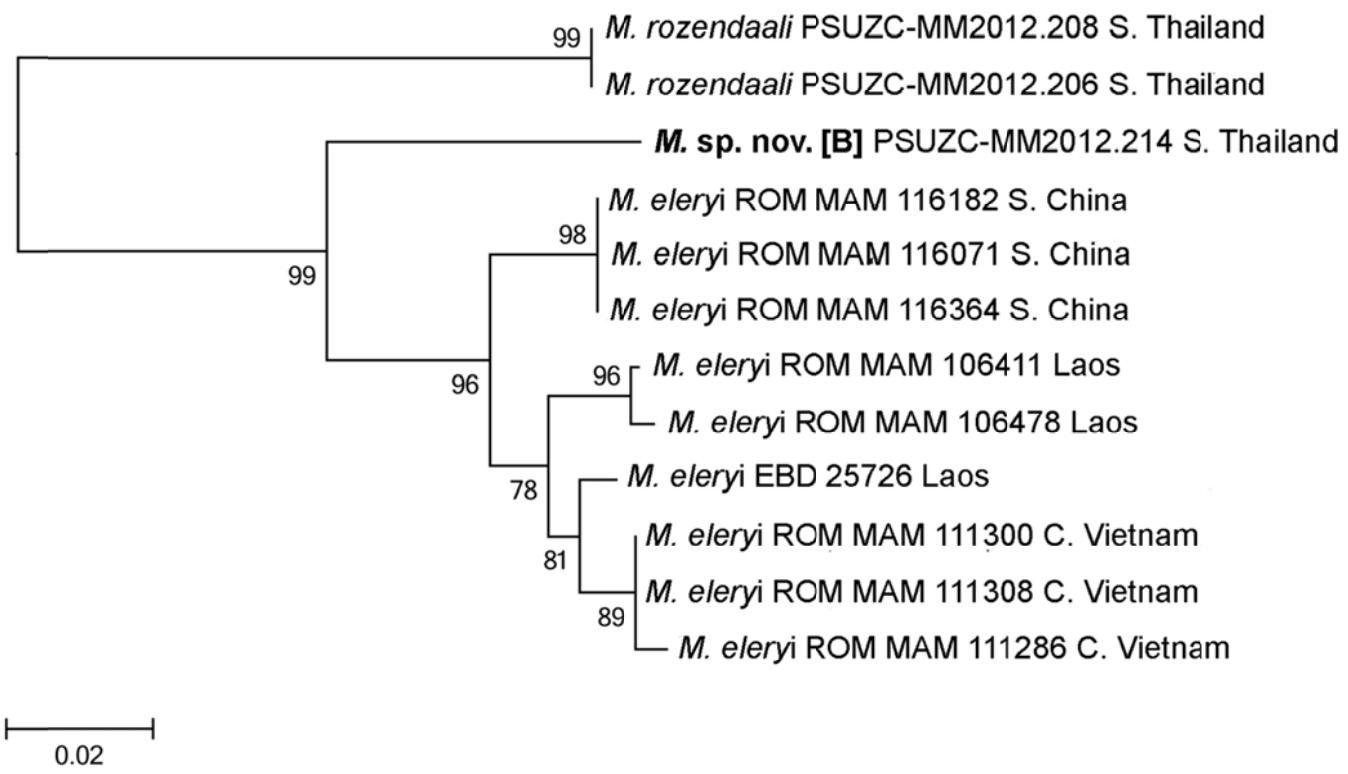

Fig. 4-5. Neighbour-joining tree based on DNA barcodes of *M.* sp. nov. [B] and *M. eleryi. M. rozendaali* is included as an outgroup. Numbers close to tree branches/node indicate the NJ bootstrap support value.

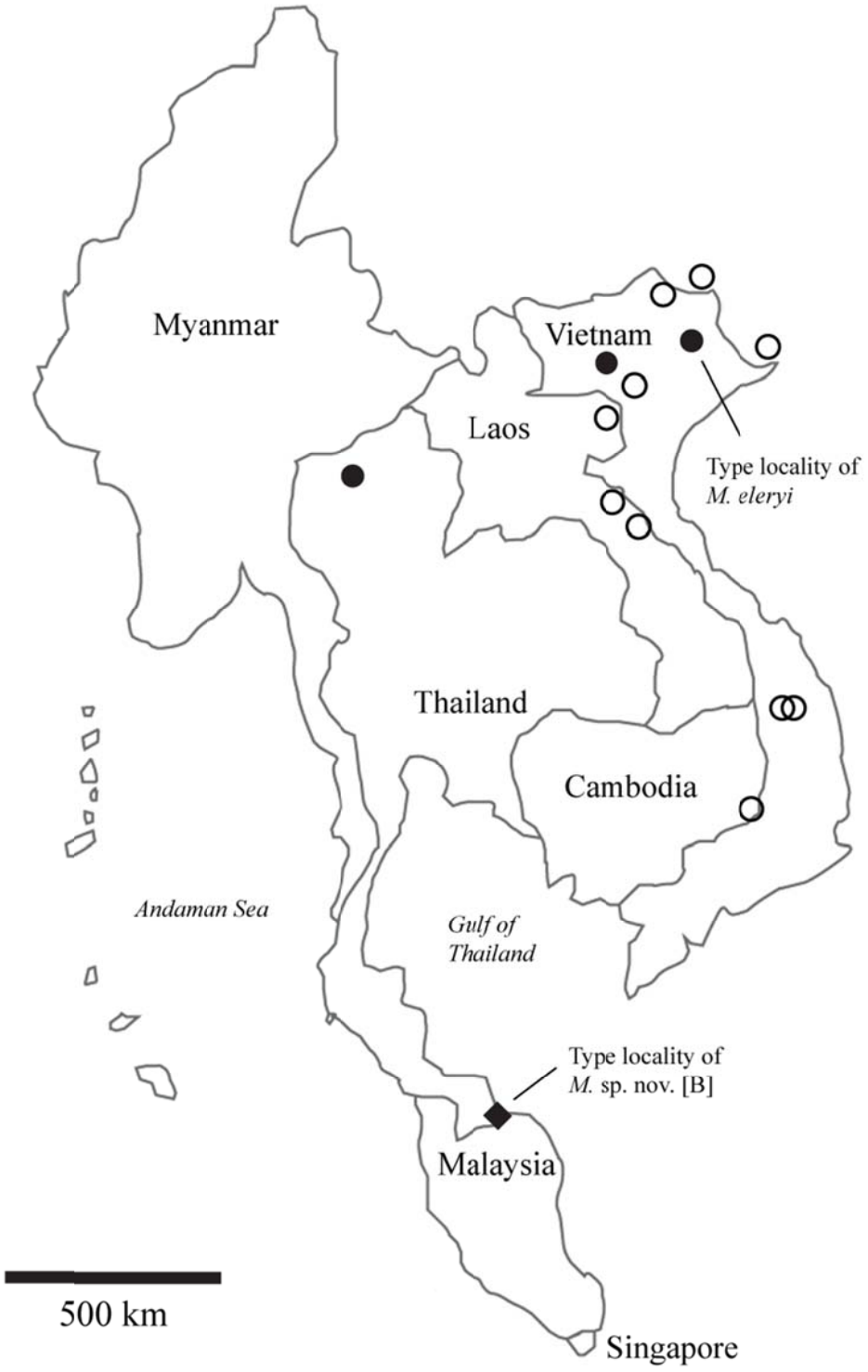

Fig. 4-6. Distribution of *M. eleryi* (dot) and *M.* sp. nov. [B] (diamond). Black symbols represent specimens examined in this study; blank symbols represent records from the literature.

M. eleryi Furey *et al.*, 2009

Elery's Tube-nosed Bat

M. eleryi Furey *et al.,* 2009: Kim Hy Commune, Na Ri district of Kim Hy Nature Reserve, Bac Kan Province, Vietnam (22˚16.392'N, 106˚03.427'E, 525 m).

M. aurata: Hill, 1983: 190, Melville, 1984: 158, Corbet and Hill, 1992: 149, Francis *et al*., 1999: 233, 2010: 6; Francis 2008: 253.

Identification and taxonomic notes

This is a small *Murina* with a FA of 27.7–30.4 mm (Table 4-1). The dorsal pelage is dark brown at the base of the hairs, grey-yellow in the middle and dark copper-reddish at the tip, with shiny golden guard hairs scattered over the dorsal side. The ventral pelage is black in the basal half of the hairs and creamy white in the upper half. The wing membrane is attached about 1 mm above the base of the claw of the outer toe. In the skull, the GTL is of 14.15–15.04 mm and the CCL of 12.09–13.05 mm (Table 4-2). The rostral part is not inflated and there is a very shallow concavity (Fig. 4-3). The braincase is not highly domed, with a BCH of 5.60–5.86 mm. The maxillary toothrow (C–M^3) is of 4.52–4.84 mm in length and slightly converged anteriorly; ratio between C^1–C^1 and M^3–M^3 is 67.4–69.4%. The upper canine (C^1) is equal or exceeds that of the second upper premolar (P^4) in height; its crown area is about two-thirds of the P^4. The upper canine has a distinct basal cusp on its lingual side. The first (P^2) upper premolar is about half of the second (P^4) in height. The mesostyles on the first and second upper molars (M^1, M^2) are well developed. The lower canine (C_1) exceeds the height of its respective lower premolars (P_2, P_4). The talonids of the first and second lower molars (M_1, M_2) are about equal or exceed the crown area of their respective trigonids.

Previous records of *M. aurata* from Indochina are now referred *M. eleryi,* whereas the actual range of *M. aurata* is thought to be restricted to in and around its type locality in Tibet (Eger and Lim, 2011; Francis and Eger, 2012).

Ecology and reproduction

A specimen collected by Boonsong Lekagul in 1980 from Doi Inthanon NP., Chiang Mai (BMNH.82.162), previously regarded as *M. aurata,* was collected in montane evergreen forest at an elevation of 2550 m.

Distribution and conservation notes

M. eleryi is found from China, Laos, Vietnam, Thailand and Cambodia (Fig. 4-6). The only confirmed record in Thailand is from Doi Inthanon NP., Chiang Mai. The conservation status of this species has not been evaluated in the IUCN Red List. However, according to its distribution which is widespread over Indochina, it is currently unlikely to be at risk.

***M. feae* (Thomas, 1891)**

Fea's Tube-nosed Bat

Harpiocephalus feae Thomas 1891: 884; Biapo, Burma.

Murina tubinaris: Hill, 1983, Melville, 1984, Corbet and Hill, 1992, Francis *et al*., 1999, 2010, Francis, 2008 (see Csorba *et al*., 2011 for summary).
Murina cineracea: Csorba and Furey 2011: 896; Sei ma Biodiversity Conservation Centre, Mondulkiri, Cambodia.

Identification and taxonomic notes

This is small *Murina* with a FA of 28.6–36.0 mm, HB of 35.0–48.0 mm (Table 4-1). The ear is relative short; E of 8.2–14.5 mm. The dorsal pelage is dark grey with black hair bases and whitish-grey tips (Fig. 4-7). The ventral pelage has hairs that are black basally for about 75% of the hair length but with a greyish-white tip. Each wing is attached to the side of toe about 2 mm above the base of the claw. The third (3MET) is the longest metacarpal (27.0–33.0 mm) and the fifth (5MET) is about equal or only slightly longer than the fourth (4MET); 26.1–32.0 mm and 26.1–31.7 mm, respectively (Table 4-1). In the skull, the rostral profile is with a distinct concavity (Fig. 4-8). The braincase is slightly domed with a BCH of 5.80–6.89 mm, and there is a weak sagittal crest. The GTL is of 14.71–16.74 mm; CCL 12.96–14.78

mm (Table 4-2). The upper canine exceeds the P^4 in height. The P^2 is about half that of the P^4 in height. The mesostyles on the M^1 and M^2 are present but poorly developed. The upper toothrow, with a length (C–M^3) of 4.81–5.59 mm, converges anteriorly; the width of C^1–C^1 is 66.79–74.62% that of the M^3–M^3. The lower canine exceeds the height of the P_2 and P_4. The talonids of the M_1 and M_2 are about equal to that of their respective trigonids (Fig. 4-9).

As above, specimens of this species were earlier referred to *M. tubinaris* and some were subsequently included in *M. cineracea* (Csorba *et al.,* 2011). However, it has been suggested recently that *M. cineracea* is a junior synonym of a valid species name *M. feae* (Francis and Eger, 2012).

Echolocation

Two specimens of *M. feae* collected from Chiang Mai emitted a typical broadband FM signal with an average *fmaxe* of 132.9 kHz (102.1–148.1 kHz); *sf* of 170.1 kHz (161–180 kHz); *tf* of 50.7 kHz (34.0–66.0 kHz) and *d* of 2.5 ms (2.4–3.4 kHz).

Ecology and reproduction

M. feae was collected from hill evergreen forest at an elevation of about 1200 m a.s.l. in Chiang Mai. In Laos, it was recorded from mixed forest to montane evergreen rainforest (Francis and Eger, 2012). Csorba *et al.* (2011), referring to specimens of *M. cineracea,* noted that this species appears to be associated with mountainous areas. The reproductive biology of this species is not known.

Distribution and conservation notes

M. feae is found from Myanmar, Laos, Thailand, Vietnam and Cambodia (Fig. 4-10). In Thailand, it is recorded from Chiang Mai and Loei Provinces. The conservation status of this species has not been evaluated in the IUCN Red List. According to its widespread distribution in Indochina and relatively common in the forest of mountainous areas, it is not currently at risk.

M. walstoni Furey, Csorba and Son, 2011

Walston's Tube-nosed bat

M. walstoni Csorba *et al.,* 2011: 900; Veun Sai Protected Forest, Veun Sai District, Ratanakiri Province, Cambodia (14°01'49"N, 106°45'06"E, 110 m).

M. CMF sp. A: Francis *et al*., 2010: 6.

Identification and taxonomic notes

This is a small-medium size *Murina* with a FA of 28.1–34.7 mm and HB of 34.8–45.4 mm (Table 4-1). The ear is rounded without a distinct emargination on the posterior border, with an ear length (E) of 11.9–14.7 mm. The dorsal pelage is whitish-grey basally with a greyish-brown tip (Fig. 4-7). The ventral pelage is white throughout the hair. The wing is attached at the side of the toe about 2 mm above the base of the claw. The fifth metacarpal (5MET) is slightly longer than the third (3MET) with the length of 26.8–32.0 mm and 26.4–31.9 mm, respectively, and the fourth (4MET) is the shortest, 26.1–31.3 mm. In the skull, the GTL is of 14.48–16.37 mm and the CCL is 12.35–14.11 mm (Table 4-2). The lateral profile is with a distinct concavity on the interorbital region (Fig. 4-8). The braincase is without a sagittal crest and the BCH is of 6.03–6.42 mm. The inner incisor (I^2) is placed slightly anterior to the I^3. The upper canine (C^1) exceeds the second upper premolar (P^4) in both height (Fig. 4-8) and crown area (Fig. 4-9). The first (P^2) upper premolar is short, only about half or less that of the P^4. On the M^1 and M^2, the mesostyles are well developed and the labial surfaces are convex. The upper toothrow is C–M^3 of 4.50–5.47 mm in length; it converges anteriorly such that the width of C^1–C^1 is 70.47–75.82% of the M^3–M^3. The lower canine (C_1) exceeds the height of both lower premolars (P_2 and P_4). The talonids of the M_1 and M_2 are about equal in size to their respective trigonids (Fig. 4-9).

M. walstoni is morphologically very similar to a Sunda species *M. suilla* (see below). However, *M. walstoni* differs significantly in the ventral pelage which is much paler, white rather than greyish-brown in *M. suilla.* The DNA barcode showed that specimens of *M. walstoni* from Laos differ about 13% from *M. suilla* from peninsular Thailand (Francis and Eger, 2012).

Echolocation

The male specimen PSUZC-MM2013.17 from Kamphaeng Phet emitted typical FM signals with a *sf* of 140.0–153.0 kHz, *tf* 52.0–65.0 kHz, *fmaxe* 117.2–128.0 kHz and *d* of 1.70–2.37 ms. The female PSUZC-MM2006.181 from Loei emitted a call with a *sf* of 145.0–149.0 kHz, *tf* 46.0–49.0 kHz, *fmaxe* 108.8–113.7 kHz and *d* of 3.10–4.00 kHz.

Ecology and reproduction

This species is found from open, heavily disturbed to undisturbed forests. It was caught in lowland mixed deciduous forest, semi-evergreen forest, and dry forest at an elevation 100–400 m. In Thailand, an individual was found roosting under dead part of a banana leaf, which the trees stand in a large paddy field, in Ban Pa Po, Ban Phai, Khon Kaen Province (M. D. Tuttle, personal communication). At Mae Wong NP., a female, captured in harp trap set across a trail in the ecotone between lowland mixed deciduous forest and dipterocarp forest in August 2013, was lactating (it was subsequently released).

Distribution and conservation notes

M. walstoni is currently known from Thailand, Laos, Cambodia and Vietnam (Fig. 4-10). Its conservation status has not been evaluated in the IUCN Red List. However, it is considered unlikely to be at risk based on its widespread distribution and because it frequents disturbed habitats.

***M. suilla* (Temminck, 1840)**

Brown Tube-nosed bat

Vespertilio suillus Temminck, 1840: 224; Tapos, Java.

M. balstoni Thomas, 1908: 370; Tasimalaja, Preangar, Java

M. canescens Thomas, 1923: 254; Nias Island, W. Sumatra.

Identification and taxonomic notes

This is a small *Murina* with a FA of 29.3–33.2 mm (Table 4-1). The ear is relatively narrow and short with the height (E) of 11.1–14.2 mm and a distinct emargination on the posterior border of the pinna. The dorsal pelage is brown basally and orange-reddish brown at the tip (Fig. 4-7). The ventral pelage is greyish-brown or occasionally dark brown in some individuals. The wing is attached to the side of the toe near base of the claw. The third metacarpal (3MET) is the longest, with the length of 27.1–29.2 mm. The fourth (4MET) and the fifth (5MET) are about equal; 26.4–27.4 mm and 26.5–28.0 mm, respectively. When the skull is viewed in lateral profile, the rostrum appears relatively inflated; the interorbital region is only slightly concave and rises smoothly to the forehead (Fig. 4-8). The braincase is domed, with a BCH of 5.65–6.44 mm (Table 4-2). The GTL and CCL are of 14.02–15.53 mm and 12.31–13.57 mm, respectively. The inner incisor (I^2) is situated anteriorly to the outer (I^3). The upper toothrow length ($C–M^3$) is 4.63–5.09 mm; it is distinctly converged anteriorly with a ratio between the $C^1–C^1$ and $M^3–M^3$ is 62.99–72.99%. The upper canine (C^1) exceeds the height of the second upper premolar (P^4). The first (P^2) upper premolar is about half the height of the P^4. On the first (M^1) and second upper molars (M^2), the mesostyle is well developed. The labial surface of both teeth is convex with a W-shape. The talonid of both first (M_1) and second (M_2) lower molars exceed their respective trigonids in size (Fig. 4-9).

Although common and widespread in the Sundaic subregion, this species exhibits very slight geographical variation in morphology. The DNA barcode of specimens collected from peninsular Thailand showed about 4% different from specimens from Sumatra and Borneo.

Echolocation

Specimens of *M. suilla* from peninsular Thailand (n=7; 4 males and 3 females) emitted typical FM signals with an average *sf* of 171.0 kHz (146–246 kHz), *tf* 58.4 kHz (48.0–85.0 kHz), *fmaxe* 97.0 kHz (74.1–146.1 kHz) and a *d* of 2.7 ms (1.7–4.9 ms).

Ecology and reproduction

In Thailand, *M. suilla* is collected in both disturbed and undisturbed mixed deciduous, semievergreen and primary lowland evergreen forest at an elevation of the sea level to about 500 m (PSUZC). The released female individuals captured in February and May 2012 in peninsular Thailand were lactating.

Distribution and conservation notes

This is a very common *Murina* in Sundaic subregion. It is found from the Isthmus of Kra of peninsular Thailand and peninsular Malaysia (Fig. 4-10) down to Sumatra, Java, Sulawesi and Borneo. It is listed as 'Least Concern' in IUCN Red List (2013).

M. beelzebub **Son, Furey and Csorba, 2011**

Beelzebub Tube-nosed bat

M. beelzebub Csorba *et al.,* 2011: 899; Bac Huong Hoa Nature Reserve, Huong Hoa District, Quang Tri Province, Vietnam (ca. 16°56'15"N, 106°34'52"E, 400 m).

Description and taxonomic notes

This is a small–medium size *Murina* with a FA of 33.70–36.30 mm (Csorba *et al.,* 2011). The ear is with a slight emargination on the posterior border. The dorsal pelage is dark brown (almost black) with longer silver guard hairs. The ventral pelage is dark brown (almost black) with white tips. The wing is attached to the side of the outer toe near base of the claw. The third metacarpal (3MET) is the longest and the fourth (4MET) is about equal to the fifth (5MET) (Table 4-1). In the skull, the GTL is 16.54–16.77 mm and CCL of 14.53–14.99 mm (Csorba *et al.,* 2012). The rostrum is relatively inflated. The interorbital region is distinctly concave. The braincase is not highly inflated, with a BCH of 6.28–6.44 mm, and is without a sagittal crest. In lateral view, the height of the upper canine (C^1) is less than that of the second upper premolar (P^4). The first upper premolar (P_2) is relatively short and small; its height is of about half the crown area and about half or slightly more than

half that of the P^4. The mesostyle on both first (M^1) and second upper molars (M^2) is greatly reduced and the labial surface of both teeth is flat. On the first (M_1) and second lower molars (M_2), the talonid is equal to that of the respective trigonid in size.

M. beelzebub is most similar to *M. tubinaris,* which is known only from Pakistan, and another species, which occurs in sympatry in Indochina *M. feae.* However, *M. beelzebub* is readily distinguished from *M. feae* by its darker, almost black pelage colour and its distinctly larger in cranial and dental measurements (Table 4-2). It is distinctly larger than *M. tubinaris,* whose FA is 31.0–32.9 mm (Csorba *et al.,* 2011). The genetic data of *M. beelzebub* and the relationship with other species are currently not known.

Echolocation

Information on echolocation of *M. beelzebub* is currently not known.

Ecology and reproduction

Csorba *et al.* (2011) recorded that the type series of *M. beelzebub* was collected in harp traps set on forest trails near a stream in disturbed secondary forest at an elevation of 400 m. A specimen from Kon Ka Kinh Nature Reserve was collected on a ridge top in primary montane forest at an elevation of 1,600 m

Distribution and conservation notes

Until now, *M. beelzebub* is only known from Bac Houng Hoa Nature Reserve in Quang Tri Province and Kon Ka Kinh Nature Reserve in Gai Lai Province, Vietnam (Fig. 4-10). Its conservation status has not been evaluated in IUCN Red List.

M. hapioloides **Kruskop and Eger, 2008**

M. hapioloides Kruskop and Eger, 2008: 215; 30 km north-east from Da Lat, Lam Dong Province, Vietnam (12°09’N, 108°39’E, 1800 m).

Identification and taxonomic notes

Based on the original description in Kruskop and Eger (2008), this is a small *Murina* with a FA of 28.4–29.7 mm. The dorsal pelage is dark brown; the guard hairs have bright orange-gold tips. The ventral pelage is dark brown with pale silver grey tips. Each wing is attached to the side of the outer toe near base of the claw. In the skull, the CCL is 12.34 mm (Table 4-2). The rostrum is relatively slender; the interorbital region is very slightly concave. The braincase is not highly inflated and is without a sagittal crest. The upper toothrow is converged anteriorly with a ratio between C^1–C^1 and M^3–M^3 of 69.5%. The upper canine (C^1) is small in comparison to the second upper premolar (P^4). It is about two-thirds that of the P^4 in both height and crown area. The first upper premolar (P^2) is very small and is less than half the height of the P^4. The mesostyle on first (M^1) and second upper molar (M^2) is present but not very well developed. The labial surface of both teeth is slightly convex. On the lower toothrow, the talonid of both M_1 and M_2 is about equal to that of its respective trigonid.

Echolocation

Echolocation data of *M. hapioloides* are currently not known.

Ecology and reproduction

Kruskop and Eger (2008) stated that the holotype was collected in a 'small humid ravine surrounded by deciduous mixed forest with distinct presence of *Manglietia* and *Solonea* trees' at an elevation of 1800 m. Several individuals of *Rhinolophus affinis* were also found in the same place.

Distribution and conservation status

The only record of this species is from the type locality in Vietnam (Fig. 4-10). The status of *M. hapioloides* has not been evaluated in IUCN Red List. Based on the single record, which was taken at a higher elevation, it is considered highly at risk according to the rapid loss of forest areas in Southeast Asia.

M. leucogaster Milne-Edwards, 1872

Greater Tube-nosed bat

M. leucogaster Milne-Edwards, 1872: 252; Moupin District, Sichuan, China

Description and taxonomic notes

This is a large *Murina* with a FA of 40.8–41.8 mm (Table 4-1). The dorsal pelage is dark brown basally and reddish-brown at the hair tips. The ventral pelage is yellowish-white. Each wing is attached to the side of the outer toe near the base of the claw. The third metacarpal (3MET) is the longest but only slightly longer than the fourth (4MET) and the fifth (5MET) respectively (Table 4-1). In the skull, the GTL and CCL are 17.81–18.65 mm and 15.92–16.97 mm, respectively (Table 4-2). In the skull profile, the rostrum and the interorbital region are inflated and only slightly concave (Fig. 4-8). The braincase is slightly inflated, with a BCH of 6.93–7.60 mm with a very weak sagittal crest. The inner incisor (I^2) is placed anterior to the outer (I^3). The upper canine (C^1) is about equal to or slightly exceeds the second upper premolar (P^4) in height and is about two-third in crown area. The first upper premolar (P^2) is about half the height and less than half the crown area of the P^4. The mesostyle on both first (M^1) and second upper molars (M^2) is present and the labial surface of both teeth is flat or very slightly convex. The lower canine (C_1) exceeds the height of both first (P_2) and second lower premolars (P_4). The height of P_2 is about half that of the C_1 and about two-third that of the P_4. The talonid of both first (M_1) and second (M_2) is equal to that of the respective trigonid in size (Fig. 4-9).

Previous records of this species in Thailand were based on misidentification and are actually currently referred as *M. harrisoni* (see below). The specimens from Indochina are referred to the nominate subspecies, whereas specimens from the Indian Subcontinent are regarded as subspecies *M. l. rubex* (BMNH; Thomas, 1916).

Echolocation

Ma *et al.* (2008) described the call characters of *M. leucogaster* from China having a *sf* and *tf* of 104.10±5.94 kHz and 34.88 ±8.20 kHz, respectively; the *fmaxe* of 88.8 ±1.09 kHz and *d* of 4.1 ± 0.4 ms.

Ecology and reproduction

In China, diet analysis of *M. leucogaster* showed 82.3% by volume of its fecal pellets was Coleoptera (Ma *et al.,* 2008). It has been found over streams in disturbed secondary forest (Francis, 2008).

Distribution and conservation notes

It is known from India, Nepal, China and Vietnam (Fig. 4-10). The Vietnamese specimen is the only current record of this species in mainland Southeast Asia. IUCN Red List (2013) listed the status of this species as 'Data Deficient'.

***M. jaintiana* Ruedi, Biswas and Csorba, 2012**

Jaintia Tube-nosed bat

M. jaintiana Ruedi *et al.,* 2012: 120; Jaintia Hills, 2.3 km east of the village of Kseh, Meghalaya, India (25°26'N, 92°36'E, 720 m).

Description and taxonomic notes

This is a small *Murina* with a FA of 28.9–31.1 mm (Table 4-1; see also Ruedi *et al.,* 2012). The dorsal pelage is dark grey basally (almost black), greyish-white in the midpart of the hairs and brownish-grey at the tip. The ventral pelage is black basally and white at the tip. Each wing is attached near base of claw of the outer toe. The skull has a GTL and CCL of 14.75–15.25 mm and 13.02–13.61 mm, respectively (Table 4-2; see Ruedi *et al.,* 2012). The rostrum is slightly inflated. The interorbital region is distinctly concave. The braincase is domed with a BCH of 5.96–6.17 mm and without a sagittal crest. The inner upper incisor (I^2) is placed lateral to the outer (I^3). The upper canine (C^1) is about equal to that of the second upper premolar (P^4). The first upper premolar (P^2) is less than two-third the height and about

half the crown area of the P^4. The mesostyle on both first (M^1) and second upper molars (M^2) is absent. The talonid of both first (M_1) and second lower molars (M_2) is equal that of the respective trigonid.

This species is very similar to *M. feae, M. tubinaris* and *M. beelzebub* but it can be readily distinguished from these three species by the absence of the mesostyle on the M^1 and M^2. The Cytochrome B sequences of *M. jaintiana* differs by at least 9.6% from other *Murina* (Ruedi *et al.,* 2012).

Echolocation

There is no information on the acoustic characters of this species.

Ecology and reproduction

In India, this species was found in the understorey of a bamboo grove by a river surrounded by semi-deciduous forest at an elevation of 720 m (Ruedi *et al.,* 2012). Specimens from Myanmar were collected in Chin Hill at an elevation of 1500 m (BMNH).

Distribution and conservation notes

M. jaintiana is currently known from India and upper Myanmar (Fig. 4-10). Its conservation status has not been evaluated.

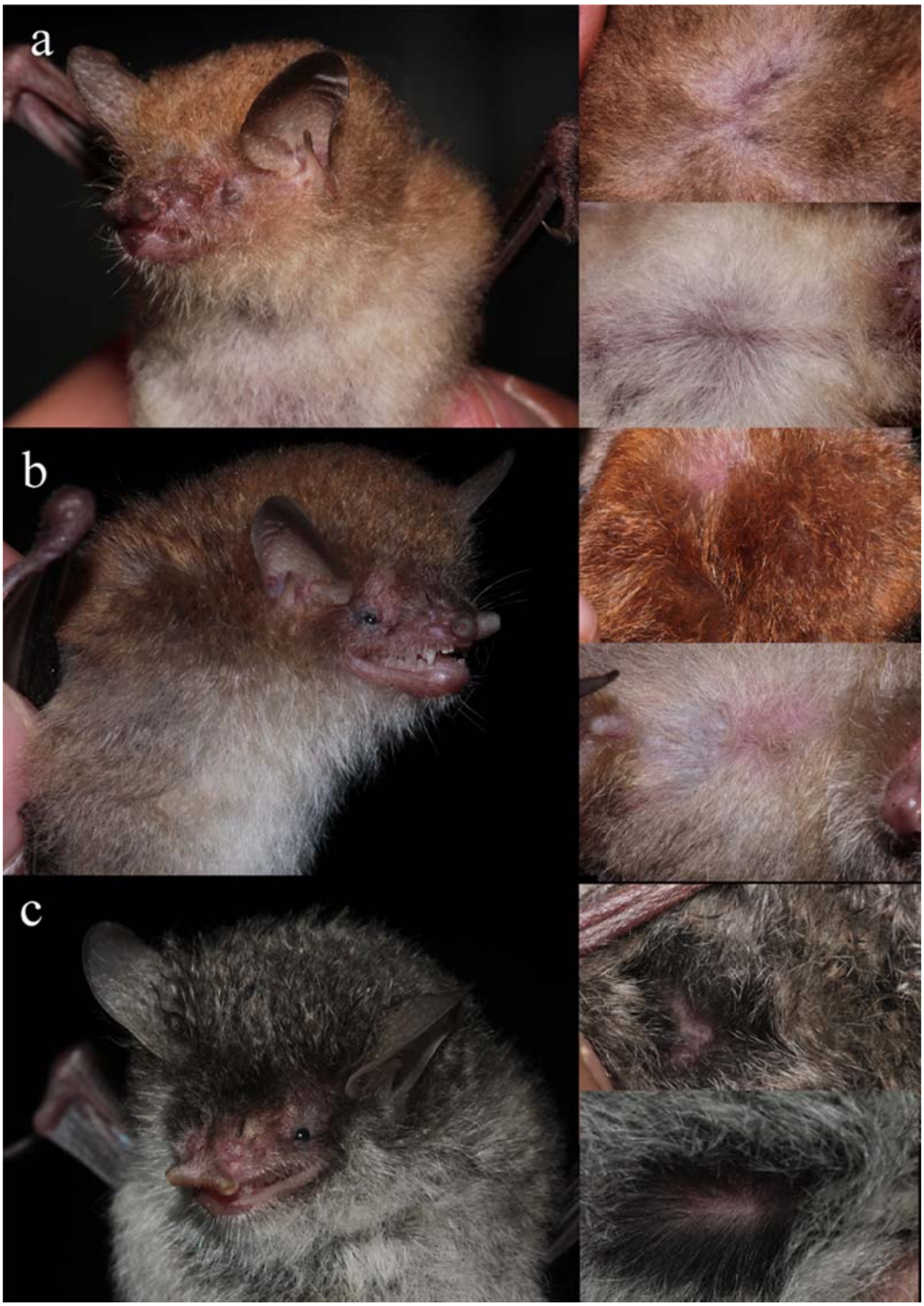

Fig. 4-7. Antero-lateral view of the head and dorsal (upper right of each species) and ventral pelage (lower right of each species) of a) *M. walstoni,* b) *M. suilla,* and c) *M. feae.*

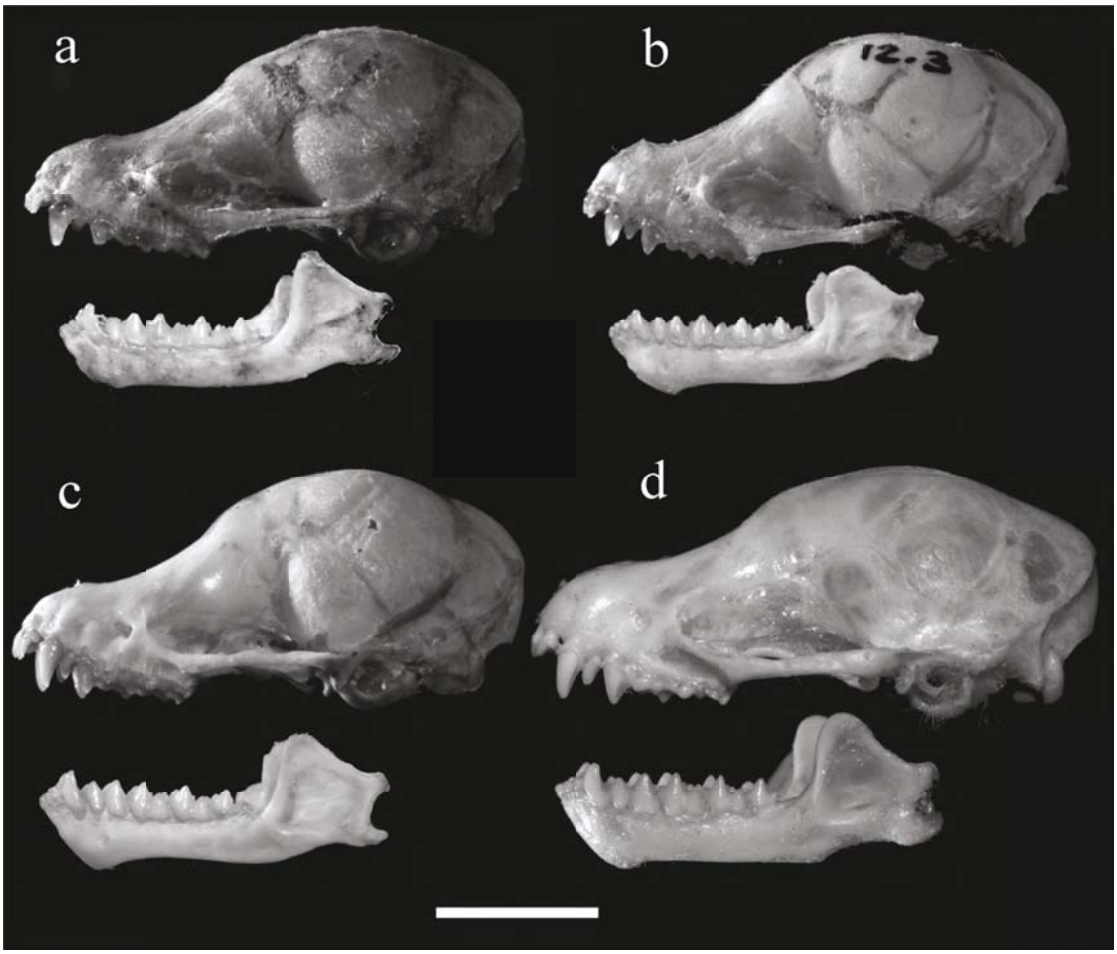

Fig. 4-8. Lateral view of skulls and mandibles of a) *M. walstoni* ♂PSUZC-MM2013.17 from W. Thailand, b) *M. suilla* ♂PSUZC-MM2012.3 from S. Thailand, c) *M. feae* ♀PSUZC-MM2011.25 from N. Thailand and d) *M. leucogaster* ♂PSUZC-MM2013.18 from Heilongjiang, China. Scale bar = 5 mm.

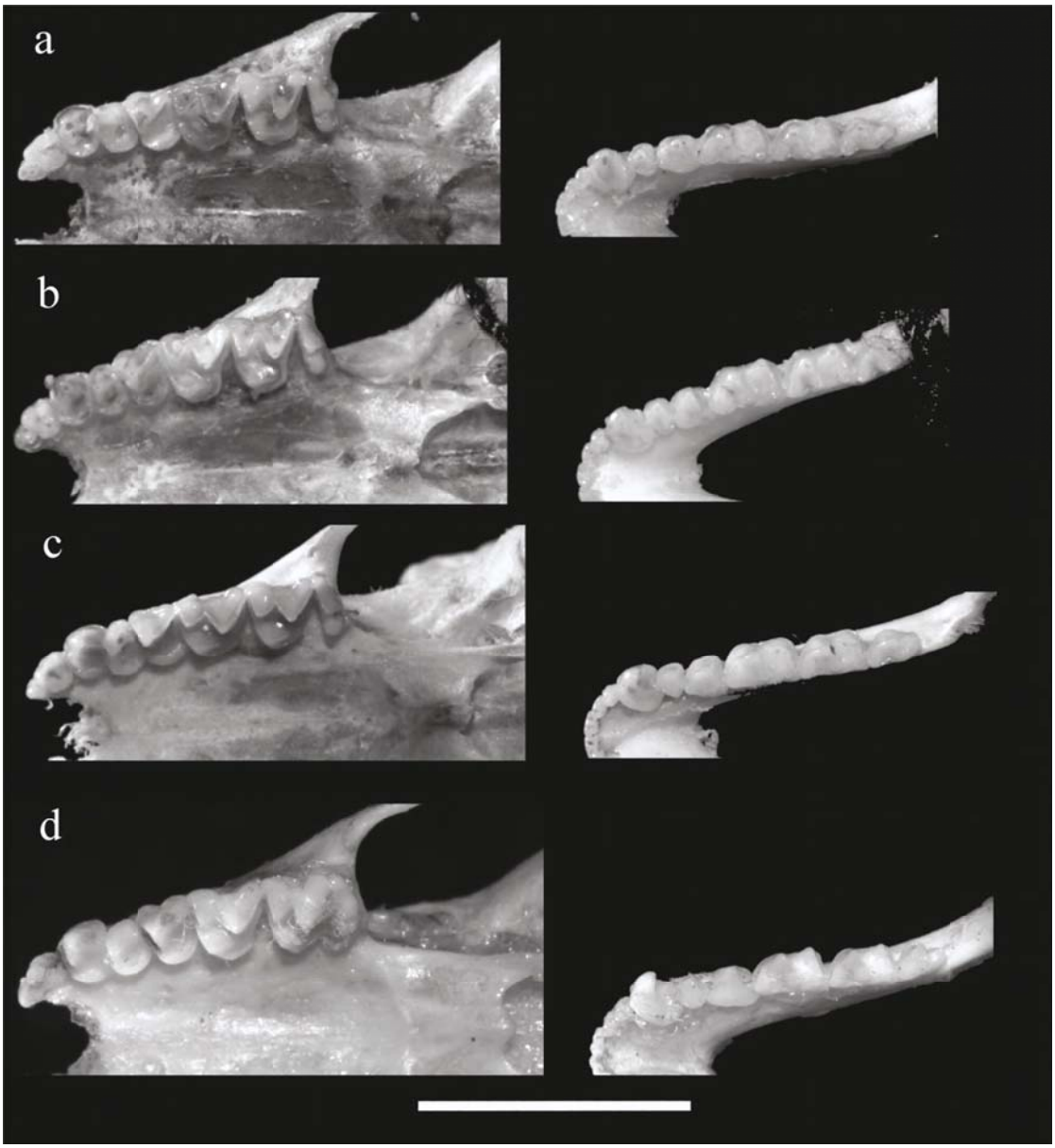

Fig. 4-9. Occlusal view of the upper (left) and lower toothrow (right) of a) *M. walstoni* ♂PSUZC-MM2013.17 from W. Thailand, b) *M. suilla* ♂PSUZC-MM2012.3 from S. Thailand, c) *M. feae* ♀PSUZC-MM2011.25 from N. Thailand and d) *M. leucogaster* ♂PSUZC-MM2013.18 from Heilongjiang, China. Scale bar = 5 mm.

Fig. 4-10. Distribution of *M. walstoni* (dot), *M. suilla* (square), *M. feae* (diamond), *M. beelzebub* (triangle), *M. hapioloides* (star) and *M. jaintiana* (reversed triangle). Black symbols represent specimens examined in this study; blank symbols represent records from literatures.

'*M. CYCLOTIS*-GROUP'

Murina in the '*M. cyclotis*-group' in mainland Southeast Asia comprise nine species. The completed descriptions of ***M.* sp. nov. [A]**, ***M. cyclotis, M. fionae*** and ***M. peninsularis*** are given in Chapter 2. The other five species are described below.

M. huttoni (Peters, 1872)

Hutton's Tube-nosed Bat

Harpiocephalus huttoni Peters, 1872: 257; Dehra Dun, Kumaon, NW. India.

M. huttoni rubella Thomas, 1914: 440; Kuatun, Fujian, China.

Identification and taxonomic notes

This is a medium sized *Murina* with a FA of 32.8–38.1 mm (Table 4-1). The ear is relatively high with an ear length (E) of 13.1–16.3 mm and with a tragus that exceeds half the height of the pinna, 6.7–9.6 mm (Table 4-1). The dorsal pelage is somewhat similar to *M. cyclotis,* with dark grey hair bases and reddish-brown tips (Fig. 4-11). The ventral pelage is grey-brown base and whitish-brown tip. Each wing is attached at approximately 1 mm below the base of the claw of the outer toe. The GTL and CCL are 16.77–19.30 mm and 14.96–16.94 mm, respectively (Table 4-3). The rostral part exhibits a very slight concavity (Fig. 4-12). The braincase has a poorly developed sagittal crest and the BCH of 6.07–6.97 mm. The upper canine (C^1) exceeds the second upper premolar (P^4) in height. The height of the first (P^2) upper premolar is about two-thirds that of the P^4. The mesostyle on both the first (M^1) and second (M^2) upper molars is well defined; the labial surface is slightly convex. The talonid of the first (M_1) and second (M_2) lower molars is about equal that to the trigonid (Fig. 4-13). The baculum is very small, with a BL of 1.5 mm. The anterior margin is with a slight concavity whereas the posterior margin is with a very distinct concavity. The dorsal side is arched upward and the ventral side is deeply concave throughout its length.

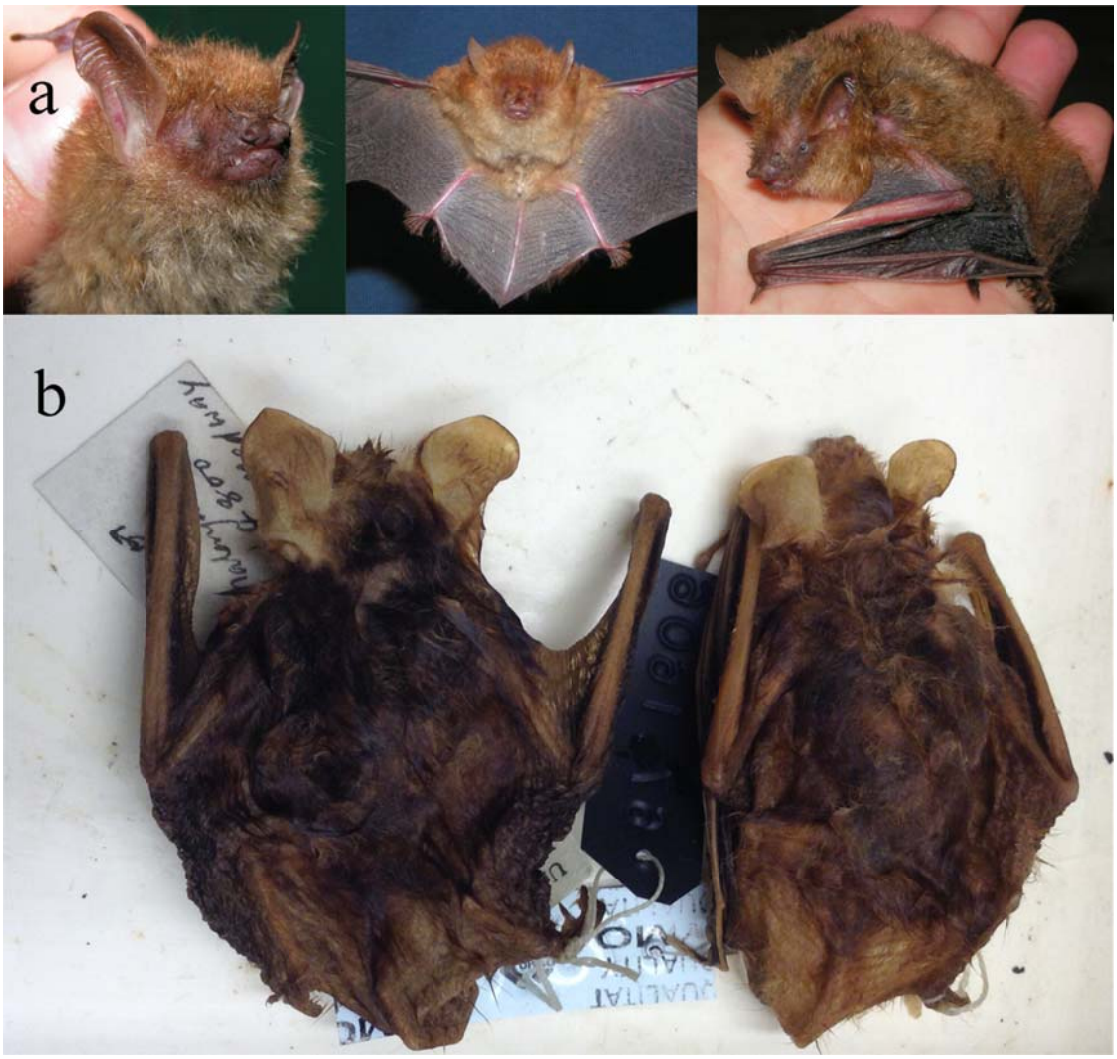

Fig. 4-11. Pelage colour of *M. huttoni*; a) ♂PSUZC-MM2011.33 from Chiang Mai, N. Thailand, b) ♂BMNH.67.1606 from Pahang, peninsular Malaysia (left) and ♂BMNH.79.1418 from Chiang Mai, N. Thailand (right).

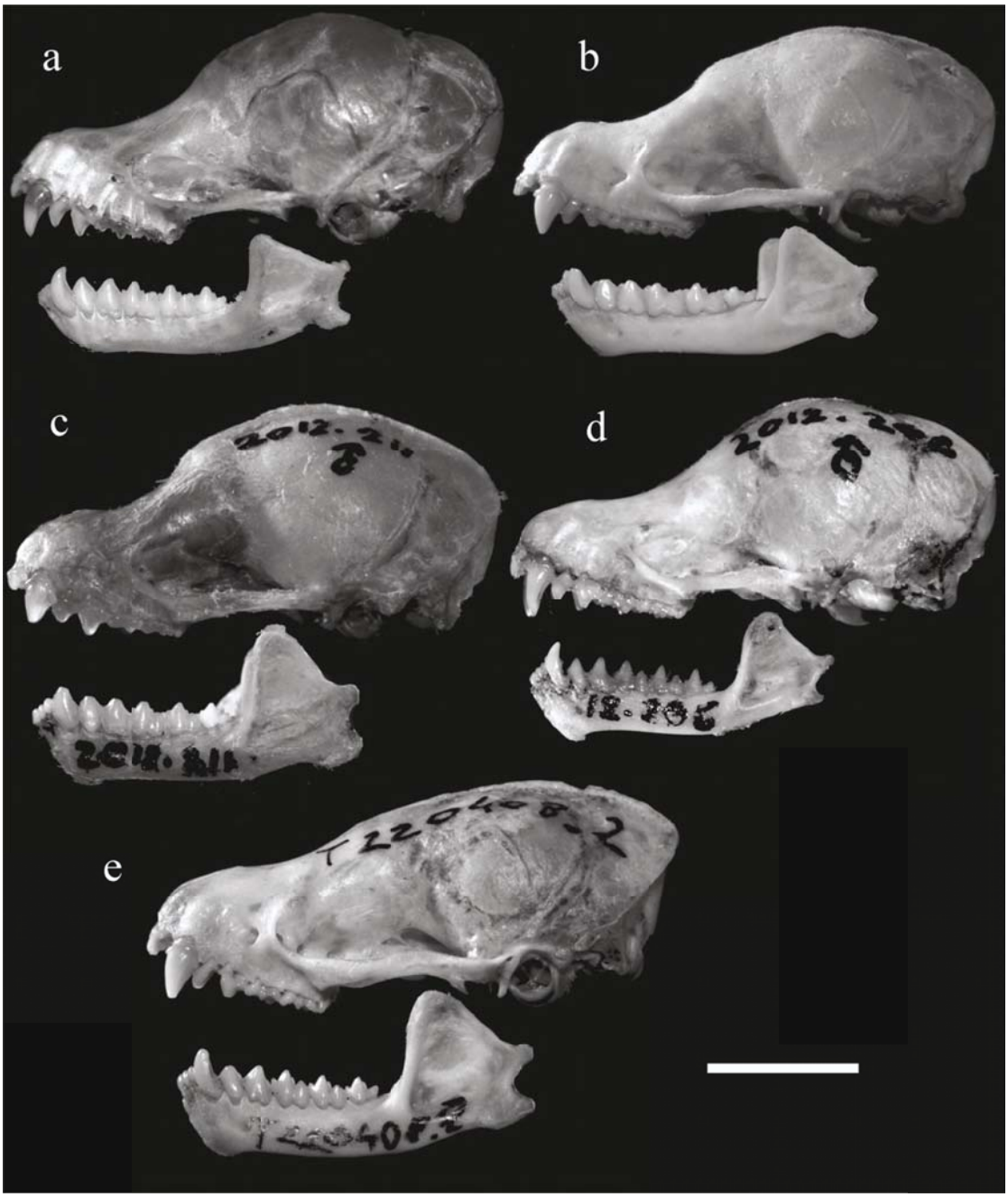

Fig. 4-12. Lateral view of the skulls and mandibles of a) *M. annamitica* ♂PSUZC-MM2011.31 from N. Thailand, b) *M. huttoni* ♂PSUZV-MM2011.33 from N. Thailand, c) *M. aenea* ♂PSUZC-MM2012.211 from S. Thailand, d) *M. rozendaali* ♂PSUZC-MM2012.206 from S. Thailand and e) *M. harrisoni* ♂field number T.220408.2 from Vietnam. Scale bar = 5 mm.

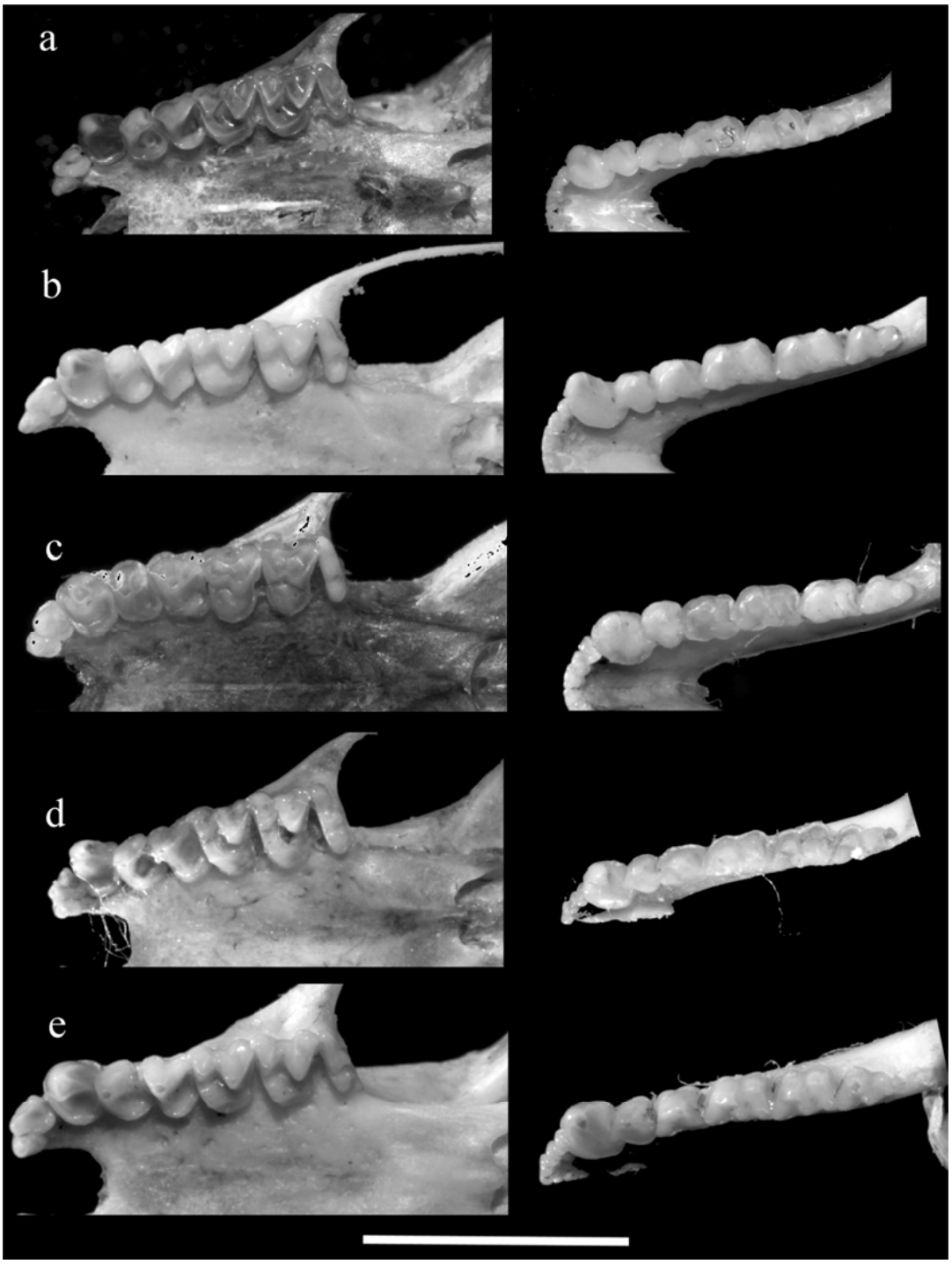

Fig. 4-13. Occlusal view of the upper (left) and lower toothrow (right) of a) *M. annamitica* ♂PSUZC-MM2011.31 from N. Thailand, b) *M. huttoni* ♂PSUZV-MM2011.33 from N. Thailand, c) *M. aenea* ♂PSUZC-MM2012.211 from S. Thailand, d) *M. rozendaali* ♂PSUZC-MM2012.206 from S. Thailand and e) *M. harrisoni* ♂field number T.220408.2 from Vietnam. Scale bar = 5 mm.

As suggested by Corbet and Hill (1992), specimens from Thailand, which are paler and more brownish in pelage colour, are referred to the subspecies *M. h. rubella*. A single specimen from Gunong Benom, Pahang, peninsular Malaysia (BMNH.67.1606), represents a disjunct distribution record of this taxon. It was included in *M. h. rubella* on the basis of dorsal pelage colour by Hill (1972). The comparison of wet specimens between this specimen and the BMNH.79.1418 from N. Thailand showed a contrast in dorsal pelage colour, in which the Malaysian specimen is much darker (Fig. 4-11). However, other external and craniodental characters, i.e. FA 34.5 mm; GTL 17.49 mm and CCL 15.3 mm, are very similar and fit very well with *M. huttoni* from elsewhere. Additional specimens from the same area are needed to help determine the taxonomic status of this southern population. It is not currently clear whether they are correctly assigned to *huttoni* or perhaps even represent a new taxon.

Ecology and reproduction

The specimen PSUZC-MM2011.33 from Chiang Mai, was caught in a net over a small stream in hill evergreen forest at an elevation of 1200 m a.s.l. Francis and Eger (2012) reported three specimens caught in the understorey of a hill forest at an elevation of 1140 m a.s.l. in Khammouan Province, Lao PDR, and another specimen collected in premontane evergreen forest in Quang Nam Province, Vietnam. In Nepal, an individual was photographed roosting in dry banana leaves (P. Acharya, pers. comm.).

Distribution and conservation notes

M. huttoni is distributed from the Indian Subcontinent to Indochina and peninsular Malaysia. As above, a single record from peninsular Malaysia needs further study. In Thailand, it was found in the north and northeastern parts of the country (Fig. 4-14). The conservation status, as listed in IUCN Red List (2013) is ‘Least Concern’.

M. harrisoni Csorba and Bates, 2005

Harrison's Tube-nosed bat

M. harrisoni Csorba and Bates, 2005: 2; O Tuk Chehn, Kirirom National Park, Kompong Speu Province, Cambodia (11°29.611'N, 104°12.746'E).

M. tiensa Csorba *et al*. 2007: 3; type locality Kim Hy Nature Reserve, Bac Kan Province, Vietnam.

M. leucogaster: McBee, 1986.

M. huttoni: Yenbutra and Felten, 1986.

Identification and taxonomic notes

This is a medium-large *Murina* with a FA of 35.4–39.8 mm and HB of 42.3–55.1 mm (Table 4-1). The dorsal pelage is orange-brown and paler at the hair bases. The ventral pelage is greyish-brown. The wing is attached to the side of the toe at the mid-part between the base of the claw and base of the toe. In the skull, GTL and CCL are 17.46–19.62 mm and 15.73–17.25 mm, respectively (Table 4-3). The rostrum is relatively inflated to accommodate a large upper canine; the interorbital region is hugely variable in shape from smooth rising with only very slight concavity to deeply concave (Fig. 4-12; see also Francis and Eger, 2012); the braincase is relatively high, BCH of 6.31–6.90 mm, with a well-developed sagittal crest. The outer upper incisor (I^3) is placed lateral to the inner (I^2) and is about two-thirds that of the I^2 in height. The upper canine (C^1) is very large, about twice that of the P^4 in both height and crown area. The mesostyles on M^1 and M^2 are very well developed. The upper toothrow is slightly convergent anteriorly; C^1–C^1 is of 75.46–81.36% of the M^3–M^3. The C–M^3 is 5.74–6.54 mm. The lower canine exceeds that of P_2 and P_4 in both height and crown area. On the M_1 and M_2, the size of the talonid is about two-thirds that of its respective trigonid (Fig. 4-13).

As mentioned above, this species exhibits considerable cranial variation, from a robust rostrum with a distinct concavity on the interorbital region like the holotype of *M. harrisoni* (HZM.1.36316) to a thinner rostrum with a smooth profile and very slight concavity as in the holotype of *M. tiensa* (HZM.2.38178) (see also figure 9 in Francis and Eger, 2012). Specimens from elsewhere are either similar

or intermediate to the two taxa. However, the DNA barcode showed about 4% difference between specimens referred to *M. harrisoni* and *M. tiensa* from China, Vietnam and Laos. Although the holotype of *M. harrisoni* has diverged about 5–6% from other specimens, it is grouped in the same cluster (figure 10 in Francis and Eger, 2012). Further study is needed to help understand the taxonomy of this species/species-complex. At this stage, until more evidence becomes available, the suggestion of Francis and Eger (2012), that *M. tiensa* should be regarded as a junior synonym of *M. harrisoni,* is followed.

Echolocation

Thong *et al.* (2011) reported echolocation call characters of *M. tiensa* (=*M. harrisoni*) from Vietnam, having similar structure of signals between handheld individuals and flying individuals which were recorded in a flight tent. The handheld bats emitted FM signals, which swept from a *sf* of 150 kHz to a *tf* of 49 kHz in a *d* of 2.2 ms, whereas the flying bats emitted a *sf* of 145 kHz to a *tf* of 50 kHz in a *d* of 1.9 ms.

Ecology and reproduction

Csorba and Bates (2005) reported that the holotype of *M. harrisoni* was captured in a mist net which was set over a river in disturbed semi-evergreen forest in Cambodia. Specimens from Myanmar and Thailand were collected from hill forest but the details of localities are unknown. In Vietnam, it was collected in dry open dipterocarp forest, whereas in China it was collected in subtropical, montane secondary forest at an altitude of 550 m (Francis and Eger, 2012). Thong *et al.* (2011) noted that it is often occurred in sympatry with *M. cyclotis* and other rhinolophids. The reproductive biology of this species is currently not known.

Distribution and conservation notes

M. harrisoni is currently known from Myanmar, China, Laos, Vietnam, Thailand and Cambodia (Fig. 4-14). IUCN Red List (2013) listed this

species as ‘Data Deficient’. Although represented by a very few specimens, based on its widely distributed over Indochina *M. harrisoni* is currently unlikely to be at risk.

M. annamitica **Francis and Eger, 2012**

Annamite Tube-nosed bat

M. annamitica Francis and Eger, 2012: 34; near Nam Pan in the Annamite Mountains, Bolikhamxai Province, Laos (18°28’N, 105°05’E, ≈1300 m).

M. CMF sp. D: Francis *et al.,* 2010: 6.

Identification and taxonomic notes

This is a small *Murina* with a FA of 29.1 mm, HB 43.5 mm (Table 4-1). The ear is 14.7 mm in height. The tragus is relatively short and less than half the height of the pinna (Fig. 4-15). The dorsal pelage is dark brown basally, orange-brown in the mid-part and darker copper reddish-brown at the tip. The ventral pelage is dark grey basally and whitish-grey at the tip (Fig. 4-15). The wing is attached to the side of the toe near the base of the claw. In the lateral profile of the skull, the rostrum is relatively inflated and the interorbital region is distinctly concave (Fig. 4-12). The braincase is relatively domed, with a BCH of 6.00 mm. The inner upper incisor (I^2) is placed almost lateral to the outer (I^3) and almost invisible in lateral view. The upper toothrow length (C–M^3) is 5.18 mm; it is slightly converged anteriorly with a ratio between the C^1–C^1 and M^3–M^3 of 74.60%. The upper canine (C^1) exceeds the height of both upper premolars (P^2 and P^4). The first (P^2) upper premolar is about two-thirds that of the second (P^4) in height. The mesostyles on the first (M^1) and second (M^2) are very well developed, so that the labial surface of these teeth are distinctly convex. The lower canine (C_1) exceeds the height of both lower premolars (P_2 and P_4). The talonids of the first (M_1) and second (M_2) are about equal or slightly exceed the size of their respective trigonids (Fig. 4-13).

This species is very similar to another sympatric species *M. cyclotis* but it differs significantly from the latter species in having a very well developed

mesostyle on the M^1 and M^2 whereas it is lacking in *M. cyclotis*. The DNA barcode suggested that it is very distinct, with at least 15% difference from other *Murina*.

Echolocation

A single specimen of male *M. annamitica* from Chiang Mai emitted typical FM signals with a *fmaxe* of 121.1–139.8 kHz, and a *sf* and *tf* of 184.0–194.0 kHz and 41.0–51.0 kHz, respectively. The *d* is of 2.38–3.41 ms.

Ecology and reproduction

In Thailand, this species is found in hill evergreen forest at an elevation of 800 m (see method section). In Laos, it was collected in wet evergreen montane forest at an elevation of 1300 m, and in a wood patch which was dominated by pine savannah and patches of evergreen and semi-deciduous woods at an altitude of about 500 m. In Vietnam, it was found in premontane secondary forest at an elevation of about 700 m (Francis and Eger, 2012).

Distribution and conservation notes

M. annamitica is found in Thailand, Laos and Vietnam (Fig. 4-14). Further surveys in forest habitats at higher elevation may show that it is widespread in Indochina. It has not been evaluated in IUCN Red List.

***M. aenea* Hill, 1964**

Bronze Tube-nosed bat

M. aenea Hill, 1964: 57; Ulu Chemperoh, near Janda Baik, Bentong District, Pahang, Malaya (c. 3°18'N, 101°50E', 2000ft.).

Identification and taxonomic notes

This is a medium size *Murina* with a FA of 34.7–37.4 mm and HB of 42.2–51.9 mm (Table 4-1). The ear is relatively long with the length (E) of 12.7–15.0 mm, with a rounded tip and without a distinct emargination on the posterior border.

The dorsal pelage is dark brown basally with shiny golden orange tips. The ventral pelage is dark grey basally with yellowish-brown tips (Fig. 4-15). Each wing is attached to the side of the outer toe near the base of the claw. In the skull, the GTL is 16.95–17.80 mm and CCL of 14.97–15.69 mm (Table 4-3). The rostrum is inflated and there is a distinct concavity in the interorbital region (Fig. 4-12). The braincase is domed, BCH of 6.92–7.67 mm, with a well-developed sagittal crest. The inner upper incisor (I^2) is placed lateral to the outer (I^3) and almost invisible in lateral view. The upper toothrow, with a C–M^3 of 5.74–6.12 mm, is slightly convergent anteriorly; ratio between C^1–C^1 and M^3–M^3 is 77.45–82.08%. The upper canine (C^1) exceeds the height of both the first (P^2) and second (P^4) premolars. The P^2 is more than half the height of the P^4. The first (M^1) and second upper molars (M^2) lack a mesostyle. The labial surface of both teeth has a V-shaped indentation. The first lower premolar (P_2) is subequal to that of the second (P_4) in height. The talonid of both M_1 and M_2 is about half that of the trigonid in size (Fig. 4-13).

Echolocation

Two specimens (one male and one female) from Narathiwat emitted typical FM signals with a *sf* of 136.0–148.0 kHz; *tf* 35.4–46.0 kHz; *fmaxe* 72.0–88.1 kHz; and *d* 1.9–2.9 ms.

Ecology and reproduction

Two female specimens (PSUZC-MM2012.209 and 2012.210) were collected in a harp trap set on the ridge of a hill in pristine evergreen rain forest at an elevation of about 220 m. A single male specimen (PSUZC-MM2012.211) from Thailand was hit by a motorbike on a local road, which runs uphill on the ridge of a hill surrounded by valleys, in evergreen forest at an elevation of about 300 m. Bumrungsri *et al.* (2006) reported two specimens of this species from Thailand for the first time and described that they were collected in lowland evergreen forest at an elevation of 200 m. In Malaysia, a female was reported being pregnant in June and lactating in March (Kingston *et al.,* 2006).

Distribution and conservation notes

M. aenea is found in Thai-Malay Peninsula and Borneo (Fig. 4-14). It is listed as 'Vulnerable' in IUCN Red List (2013).

***M. rozendaali* Hill and Francis, 1984**

Gilded Tube-nosed bat

M. rozendaali Hill and Francis, 1984: 319; Gomantong, Sabah, Borneo (5°31'N, 118°4E').

Identification and taxonomic notes

This is a small *Murina* with a FA of 29.0–32.8 mm and HB of 40.4–44.4 mm (Table 4-1). The ear is relatively narrow and long, 12.3–14.1 mm, and with a distinct emargination on the posterior border. The tragus is relatively short, with a TRG of 6.5–7.7 mm; the tip is bent posteriorly and the posterior border is concave. The dorsal pelage is dark brown basally and shiny golden orange-reddish at the tips. The ventral pelage is yellowish-white, more orange near the chin (Fig. 4-15). The wing is attached to the side of the outer toe near the base of the claw. The third metacarpal (3MET) is the shortest; it is slightly shorter than the fourth (4MET), 24.42–26.51 mm and 24.76–27.49 mm, respectively. The fifth (5MET) is the longest, 25.24–27.91 mm, but only slightly longer than 4MET. On the ventral side at the base of the tail, the scrotal area below the penis appears to have a very large gland. In the skull, the GTL and CCL are 15.47–16.42 mm and 13.48–14.10 mm, respectively (Table 4-3). The rostrum is slender and the interorbital region is low and without a distinct concavity (Fig. 4-12). The braincase is slightly inflated with a BCH of 6.15–6.86 mm. The inner incisor (I^2) is placed lateral to the outer (I^3) and is invisible in lateral view. The upper canine (C^1) is very high, about twice the height of the second upper premolar (P^4). The first upper premolar (P^2) is more than two-thirds the height of the P^4. The upper toothrow is convergent anteriorly, with a ratio between C^1–C^1 and M^3–M^3 of 72.33–78.56%; the C–M^3 is 5.20–5.50 mm. The mesostyle on both first (M^1) and second upper molars (M^2) is well developed and the labial surface of both teeth is slightly convex. On the first (M_1) and second lower molars (M_2), the talonid is equal to the size of the trigonid (Fig. 4-13).

Echolocation

Six male specimens collected from Narathiwat emitted typical FM signals with an average *sf* of 162.0 kHz (146–182 kHz); *tf* 42.1 kHz (20.4–50.6 kHz); *fmaxe* 85.4 kHz (63.9–99.7 kHz); and *d* of 5.5 ms (3.4–8.9 ms).

Ecology and reproduction

In peninsular Thailand, it was captured together with *M. peninsularis* and *M. suilla* in lowland evergreen forest at an elevation about 150 m. Male specimens captured in August to October 2012 had an enlarged scrotal area. In Malaysia, a female was found lactating in June (Kingston *et al.,* 2006).

Distribution and conservation notes

M. rozendaali is found in peninsular Thailand, peninsular Malaysia (Fig. 4-14) and additionally in Sumatra. and Borneo It is listed as 'Vulnerable' in IUCN Red List (2013).

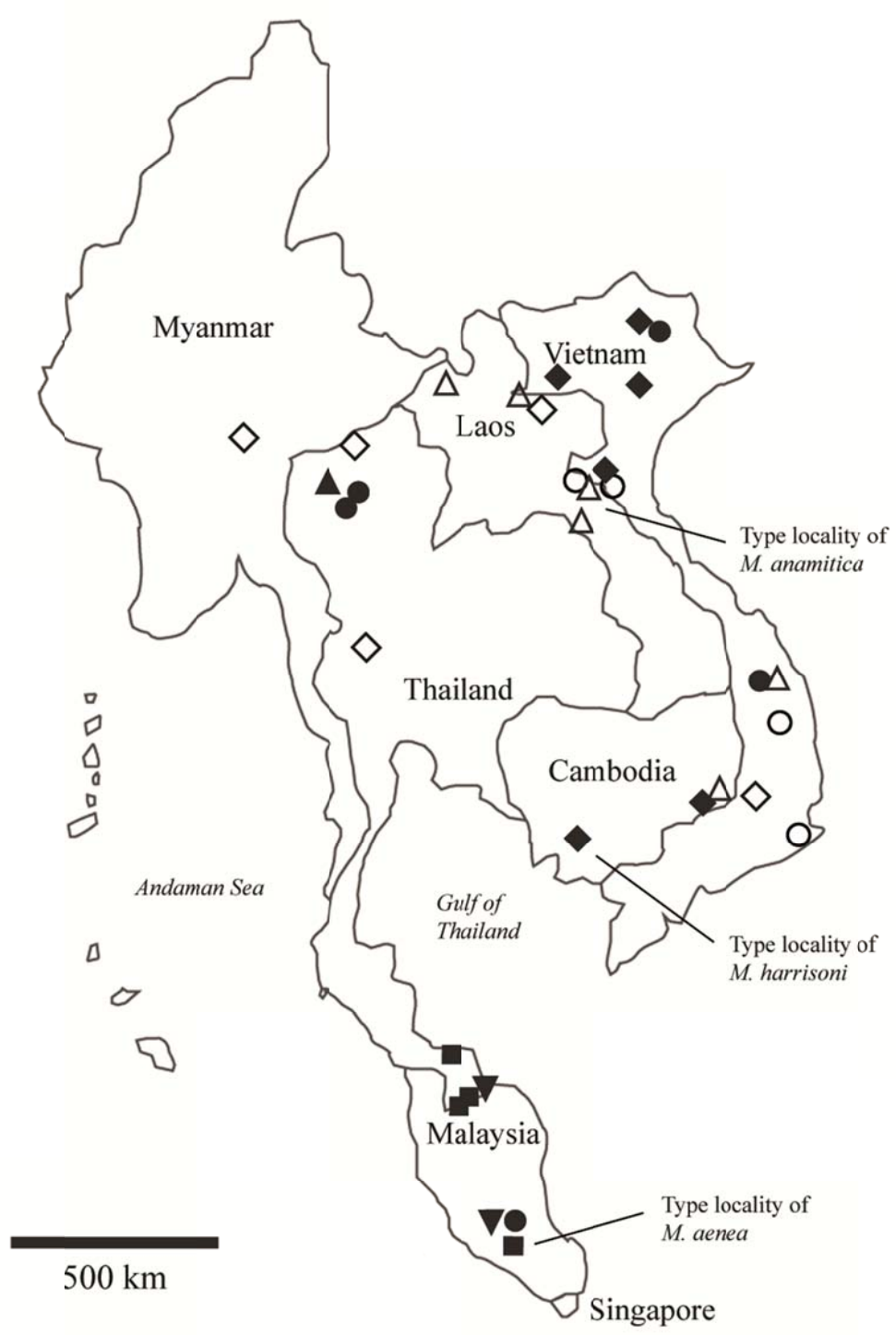

Fig. 4-14. Distribution of *M. huttoni* (dot), *M. harrisoni* (diamond), *M. annamitica* (triangle), *M. aenea* (square) and *M. rozendaali* (reversed triangle). Black symbols represent specimens examined in this study. Blank symbols represent records from literatures.

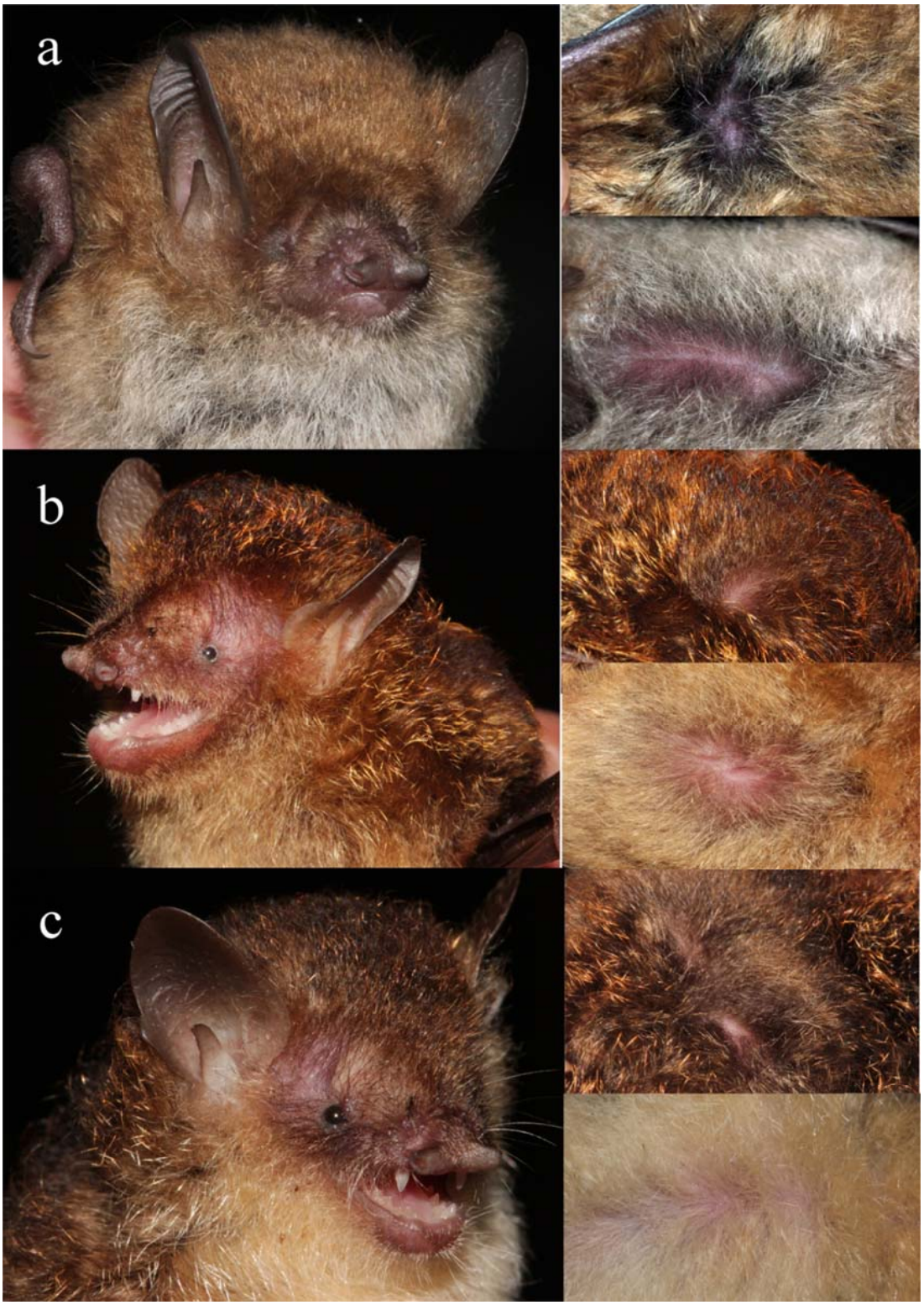

Fig. 4-15. Antero-lateral view of the head and dorsal (upper right of each species) and ventral pelage (lower right of each species) of a) *M. annamitica,* b) *M. aenea* and c) *M. rozendaali*

GENETIC AND BIOGEOGRAPHIC IMPLICATIONS

The DNA barcode using the Cytochrome C Oxidase Subunit 1 (COI gene) has proved to be an effective tool for species identification in animals (e.g. Hebert *et al.,* 2003). It has also performed very well in assisting with the alpha taxonomy of bats (Clare *et al.,* 2007; 2011; Francis *et al.,* 2010). The identifications of *Murina* in this study are also well supported by genetic analyses based on DNA barcode.

DNA barcode is also very useful in recognising the presence of cryptic species in *Murina.* The genetic results agreed very well with the taxonomic conclusion based on morphological characters (Fig. 3-8 and 4-5). However, there is an exception in the cases of *M. peninsularis* (Fig. 3-11) and *M. harrisoni,* which both showed considerable variation in cranial morphology (see Fig. 9 in Francis and Eger, 2012), but with very slightly differences in dental characters and fairly low genetic divergence. The use of a combination of morphology and genetic data in identification of bats, particularly in the complex of species, is recommended.

However, a phylogenetic tree, based on available sequences of the Murininae in Southeast Asia, does not agree with current morphological species grouping of the genus (Fig. 4-16). The traditional morphological division between '*M. cyclotis*-group' and '*M. suilla*-group', is obviously not reflected in the actual phylogenetic relationship. Further analysis using other genes and phylogenetic method is recommended to understand the phylogeny of this group. From a taxonomic point of view, however, the traditional species grouping is still very useful in species identification.

Many of samples of *Murina* from Thailand submitted to BOLD failed to yield a good quality of PCR products. This usually happens when the tissue samples are collected from old preserved specimens (A. Borisenko, personal communication). This has resulted in smaller sample sizes or an analysis of a shorter number of base pair sequences. The interpretation of the results needs to be undertaken with caution.

Biogeographically, the distribution of *Murina* species in mainland Southeast Asia (see distribution maps above) are strongly correlated with

Indochinese-Sundaic subdivision. Of the 18 *Murina* species, 11 are found only in the Indochinese Subregion include *M. cyclotis, M. annamitica, M. harrisoni, M. fionae, M. feae, M. walstoni, M. eleryi, M. beelzebub, M. leucogaster, M. hapioloides* and *M. jaintiana,* whereas six are restricted to the Sundaic Subregion, including *M.* sp. nov. [A], *M.* sp. nov. [B], *M. peninsularis, M. aenea, M. rozendaali* and *M. suilla.* The only one exception is *M. huttoni* which has a single record from peninsular Malaysia. If correctly identified, this makes it the only species of *Murina* that occurs in both the Indochinese and Sundaic Subregions. However, the taxonomic status of the Malaysian specimen requires further study, as discussed above (see also Fig. 4-11). The possibility that this specimen is actually an undescribed taxon cannot be ruled out. Unfortunately, the genetic material of this specimen is not available to study. Until further evidence become available, it is here regarded, as before, as the same species as in the Indochinese population.

Interestingly, several pairs of cryptic species are distributed across the Indochinese-Sundaic subdivision. For instance, the following morphological similar specie: *M. cyclotis* vs *M.* sp. nov [A] (Fig. 3-2 in Chapter 3); *M. fionae* vs *M. peninsularis* (Fig. 3-2 in Chapter 3); *M. eleryi* vs *M.* sp. nov. [B] (Fig. 4-6) and *M. walstoni* vs *M. suilla* (Fig. 4-6).

Until now, very little is known about their evolutionary history. It is also unknown whether each pairs evolved convergently or whether they are closely related siblings and recently separated on account of an historical zoogeographic events. The latter phenomena are known to be relatively common in several groups of animals in the region (Woodruff, 2003; Hughes *et al.,* 2003, 2010; Soisook *et al.,* 2008; Woodruff and Turner, 2009). Based on rough, preliminary divergence estimation using Cytochrome B gene, most of *Murina* diverged during 3–6 mya (P. Soisook, unpublished data) which coincide with the Pliocene transgression that sea level raised and flooded over lower elevation of the Thai-Malay Peninsula. However, using fast evolving genes (such as COI and Cyt B) may not provide a proper resolution to estimate actual phylogenic divergence between species (Khan *et al.,* 2010). Further study of their phylogeography using slower evolving markers to reveal the evolutionary history of this group of bats would be of particular interested.

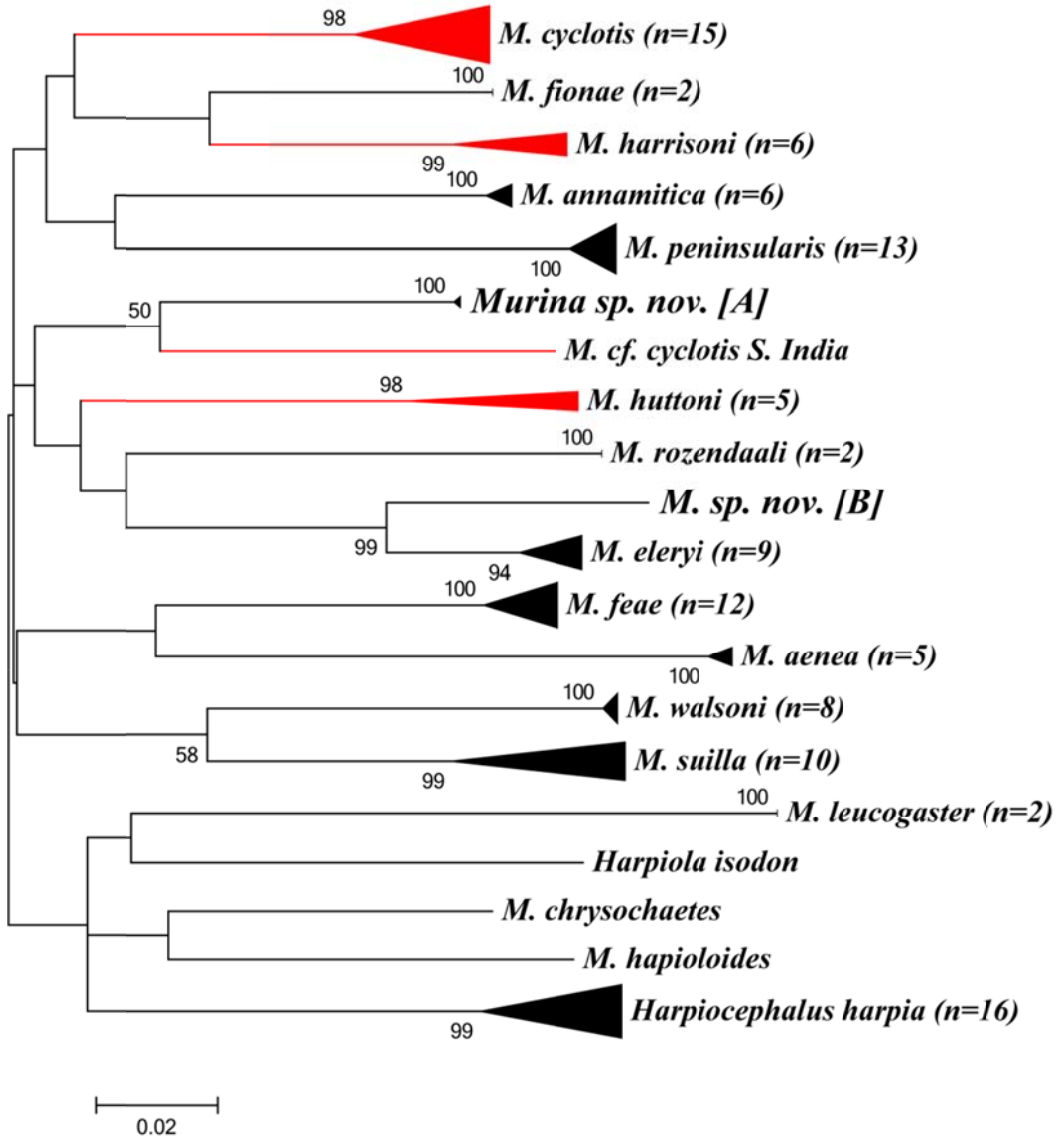

Fig. 4-16. Neighbour-joining tree based on DNA barcodes of 20 species of subfamily Murininae. Species with multiple specimens are grouped in triangles, with the vertical dimension represents proportional to the number of specimens (in parentheses), and the horizontal dimension proportional to the genetic variation within species. Red lines/symbols are unresolved groups.

Table 4-1. External measurements (in mm) and body mass (MASS) (in gram) of 14 species of *Murina.* Sample sizes of male and female specimens examined, mean ±SD, min–max values are given. A sample size that differs from the total number of specimens is given in brackets. Definitions of measurements are listed in the Chapter 2.

n/sex	FA	E	TRG	HB	TAIL	TIB	HF
				***M.* sp. nov. [B]**			
1♂	30.4	12.3	7.6	42.5	30.6	14.3	6.6
1♀	28.0	12.8	7.4	34.5	30.7	14.5	7.0
				M. eleryi			
1♂	27.7	11.8	5.6		26.5	13.9	5.6
2♀♀	29.0, 30.4	12.0, 12.4	5.7, 6.1	35.9, 37.8	31.7, 32.6	13.2, 14.8	7.4, 7.5
				M. feae			
12♂♂	30.1±0.8	11.9±2.6	6.17	38.1±2.6	34.3±3.3	17.0±0.3	5.9±1.4
	29.0-31.5 [9]	8.2-14.0 [4]	[1]	35.0-41.4 [4]	31.0-39.0 [4]	16.7-17.5 [4]	5.1-8.0 [4]
14♀♀	32.0±2.2	12.8±1.5	6.8±0.8	41.2±3.0	35.8±4.4	17.5±1.2	7.1±0.7
	28.6-36.0 [12]	9.7-14.5 [9]	5.7-7.5 [5]	39.5-48.0 [7]	28.2-40.4 [10]	16.0-19.5 [11]	5.8-7.8 [11]
				M. walstoni			
2♂♂	28.1, 33.4	11.9, 14.5	6.8, 8.2	34.8, 45.4	31.0, 33.6	15.1, 15.9	6.9, 7.0
5♀♀	32.8±2.9	13.6±1.5	7.5±0.4	42.6±1.5	33.2±1.1	16.2±0.9	7.6±0.5
	29.4-34.7 [3]	12.5-14.7 [2]	7.3-7.8 [2]	41.6-43.6 [2]	32.4-33.9 [2]	15.3-17.0 [3]	6.9-8.0 [3]
				M. suilla			
26♂♂	30.8±0.9	12.4±0.8	6.4±0.5	40.8±6.9	29.9±3.0	16.1±5.5	6.7±0.6
	29.3-32.8 [24]	11.1-14.2 [21]	5.7-7.3 [7]	33.2-62.4 [20]	22.6-35.4 [21]	13.8-38.7 [19]	5.8-8.4 [22]
8♀♀	30.8±1.2	13.3±1.1	-	40.3±3.7	29.8±0.6	14.8±0.5	6.2±0.4
	29.3-33.2 [7]	12.5-14.0 [2]	-	36.7-44.0 [3]	29.1-30.2 [3]	14.3-15.2 [4]	5.8-6.5 [3]
				M. beelzebub			
1♂	34.9	-	-	-	-	18.3	8.4
				M. hapioloides			
1♀[a]	29.7	12.3	-	35.0	30.5	-	-
				M. leucogaster			
2♀♀	40.8, 41.8	14.2, 15.0	7.3, 9.3	47.0, 49.0	40.0, 42.9	18.9 [1]	9.0, 9.8
				M. jaintiana			
1♂	28.9	-	-	-	-	-	-
				M. huttoni			
10♂♂	34.3±1.2	14.8±1.1	8.5±1.6	42.3±1.4	37.0±2.3	17.3±0.4	7.7±0.7
	32.8-37.1 [9]	13.1-16.3 [7]	6.7-9.6 [5]	40.3-43.4 [4]	34.2-40.6 [5]	16.7-17.8 [5]	6.9-8.8 [7]
2♀♀	34.6, 38.1	16.0 [1]	-	48.3 [1]	44.1 [1]	19.8 [1]	8.5 [1]
				M. harrisoni			
3♂♂	35.4, 38.9	12.2, 15.3	8.3 [1]	42.3, 47.1	38.5, 40.3	19.2, 20.0	8.5, 9.2
4♀♀	38.4±1.6	15.2±0.6	7.4±0.4	50.5±4.7	39.2±4.5	19.8±1.3	8.9±0.6
	36.1-39.8	14.7-15.8 [3]	7.1-7.9 [3]	45.7-55.1 [3]	33.8-44.7	18.2-20.9	8.4-9.8
				M. annamitica			
1♂	29.1	14.7	-	43.5	30.0	16.2	7.5
				M. aenea			
2♂♂	35.0, 35.6	14.5, 15.0	7.2 [1]	42.9, 50.0	38.0, 40.0	14.4, 16.9	7.1 [1]
4♀♀	36.0±1.1	13.7±0.9	8.3±1.1	46.3±5.0	35.7±3.8	17.7±1.0	7.9±1.2
	34.7-37.4	12.7-14.9	7.5-9.0	42.2-51.9 [3]	31.6-40.5	16.5-18.4 [3]	6.8-9.3
				M. rozendaali			
9♂♂	30.3±0.8	13.3±0.6	6.9±0.4	41.9±1.6	33.2±1.9	17.1±0.9	7.8±0.2
	29.0-31.2 [9]	12.3-14.1 [7]	6.5-7.7 [7]	40.4-44.4 [7]	29.2-34.9 [7]	16.3-19.0 [7]	7.6-8.1 [7]
1♀	32.8	-	-	-	-	-	-

- [a] after Kruskop and Eger (2008)

Table 4-1. (Continued).

n/sex	5MET	4MET	3MET	3D1PH	3D2PH	MASS
			***M.* sp. nov. [B]**			
1♂	27.7	27.7	28.0	13.1	11.9	4.0
1♀	26.6	26.5	26.8	11.3	10.4	3.5
			M. eleryi			
1♂	25.1	24.4	25.1	10.8	12.5	
2♀♀	27.3, 27.6	27.0, 27.7	27.2, 28.3	12.4, 12.4	11.0, 11.3	5.5 [1]
			M. feae			
12♂♂	27.4±1.5	27.5±1.2	28.0±1.4	13.9±0.2	9.7±2.9	4.7±0.3
	26.5-28.5 [2]	26.7-28.3 [2]	27.0-29.0 [2]	13.8-14.0 [2]	7.7-11.8 [2]	4.5-5.0 [3]
14♀♀	29.1±2.5	29.0±2.5	30.3±2.6	14.3±1.1	13.1±1.1	5.2±0.3
	26.1-32.0 [6]	26.1-31.7 [6]	27.0-33.0 [6]	13.1-15.7 [6]	11.9-1597 [6]	5.0-5.4 [2]
			M. walstoni			
2♂♂	26.8, 32.0	26.1, 31.3	26.4, 31.9	11.6, 12.9	10.5, 10.9	5.2 [1]
5♀♀	27.4 [1]	27.7 [1]	28.6 [1]	13.7 [1]	12.7 [1]	5.1 [1]
			M. suilla			
26♂♂	27.3±0.6	27.2±0.8	28.4±0.8	12.6±0.9	10.8±0.3	4.0±0.5
	26.5-28.0 [6]	26.4-28.4 [6]	27.1-29.2 [6]	11.1-13.5 [6]	10.4-11.3 [6]	3.0-5.0 [21]
8♀♀	27.3 [1]	27.8 [1]	29.0 [1]	13.1 [1]	10.8 [1]	-
			M. beelzebub			
1♂	31.3	31.4	32.4	16.2	14.1	-
			M. hapioloides			
1♀[a]	-	-	-	-	-	4.2
			M. leucogaster			
2♀♀	38.6 [1]	38.8 [1]	39.4 [1]	18.8 [1]	16.1 [1]	-
			M. jaintiana			
1♂	-	-	-	-	-	-
			M. huttoni			
10♂♂	32.7±1.4	31.9±1.5	32.8±1.5	14.5±0.2	12.7±0.3	6.9±0.8
	31.4-35.5 [6]	30.6-34.6 [6]	31.7-35.7 [6]	14.3-14.7 [6]	12.4-13.2 [6]	6.4-7.5 [2]
2♀♀	-	-	-	-	-	12.0 [1]
			M. harrisoni			
3♂♂	-	-	-	-	-	-
4♀♀	35.8±1.4	35.6±1.6	36.5±2.1	15.9±0.9	14.2±1.0	-
	34.2-36.9 [3]	33.7-36.7 [3]	34.2-38.3 [3]	15.2-17.0 [3]	13.1-14.9 [3]	-
			M. annamitica			
1♂	-	-	-	-	-	4.0
			M. aenea			
2♂♂	30.8 [1]	30.6 [1]	31.9 [1]	14.1 [1]	11.8 [1]	7.5 [1]
4♀♀	-	-	-	-	-	7.0 [1]
			M. rozendaali			
9♂♂	26.4±1.4	25.9±1.4	25.1±1.2	12.1±0.9	11.4±0.3	4.6±0.3
	25.2-27.9 [3]	24.8-27.5 [3]	24.4-26.5 [3]	11.2-12.8 [3]	11.1-11.5 [3]	4.2-5.0 [7]
1♀	-	-	-	-	-	-

- [a] after Kruskop and Eger (2008)

Table 4-2. Craniodental measurements (in mm) of nine species of *M. suilla*-group. Sample sizes of male and female specimens, mean ±SD; min–max values are given. A sample size that differs from the total number of specimens is given in brackets. Definitions of measurement are listed in Chapter 2.

n/sex	GTL	CBL	CCL	ZB	BB	BCH	MW	IC	LW
					***M.* sp. nov. [B]**				
1♂	14.95	13.68	12.98	-	6.90	5.33	7.52	4.10	4.82
1♀	14.42	13.10	12.31	8.21	6.86	5.52	7.11	4.12	4.68
					M. eleryi				
2♂♂	14.15 [1]	12.87, 13.03	12.09, 12.38	8.01, 8.05	6.74, 7.02	5.60, 5.86	7.06, 7.21	4.13, 4.16	4.52, 4.70
2♀♀	15.03, 15.04	13.65, 13.88	12.93, 13.05	8.21, 8.32	6.95, 7.05	5.61, 5.64	7.25, 7.28	3.99, 4.35	4.46, 4.77
					M. feae				
12♂♂	15.38±0.13	14.00±0.13	13.36±0.15	8.64±0.14	7.45±0.16	6.01±0.14	7.36±0.14	4.34±007	4.80±0.10
	15.25-15.55 [6]	13.77-14.14 [6]	13.10-13.54 [6]	8.438.75 [6]	7.17-7.62 [7]	5.80-6.19 [6]	7.18-7.55 [5]	4.24-4.40 [6]	4.66-4.91 [6]
14♀♀	16.07±0.56	14.72±0.52	14.01±0.47	8.84±0.34	7.50±0.32	6.36±0.21	7.56±0.18	4.43±0.19	4.91±0.22
	14.71-16.74 [13]	13.66-15.58 [13]	12.96-14.78 [13]	8.35-9.43 [12]	6.77-8.12 [13]	6.06-6.79 [13]	7.25-7.94 [13]	4.12-4.86 [13]	4.61-5.47 [13]
					M. walstoni				
2♂♂	14.48, 15.73	13.03, 14.74	12.35, 13.94	7.69, 9.04	7.08, 7.50	6.05, 6.10	7.05, 7.65	4.16, 4.20	4.50, 5.42
5♀♀	16.13±0.22	14.66±0.19	13.89±0.18	9.13±0.21	7.53±0.13	6.18±0.17	7.83±0.19	4.21±0.12	4.96±0.18
	15.89-16.37	14.43-14.90 [4]	13.68-14.11 [4]	8.93-9.42 [4]	7.37-7.68 [4]	6.03-6.42 [4]	7.68-8.11 [4]	4.08-4.37 [4]	4.71-5.15 [4]
					M. suilla				
26♂♂	14.88±0.25	13.61±0.29	12.95±0.23	8.55±0.20	7.24±0.15	6.07±0.18	7.40±0.14	4.18±0.07	4.77±0.20
	14.28-15.53 [23]	12.95-14.29 [23]	12.39-13.57 [23]	8.00-8.84 [23]	7.00-7.50 [23]	5.65-6.44 [23]	7.12-7.62 [23]	4.05-4.31 [23]	4.52-5.16 [22]
8♀♀	14.55±0.38	13.38±0.31	12.77±0.31	8.29±0.23	7.15±0.11	6.03±0.18	7.30±0.11	4.07±0.19	4.64±0.23
	14.02-14.92 [4]	12.99-13.70 [4]	12.31-13.05 [5]	8.05-8.57 [5]	7.02-7.27 [5]	5.87-6.33 [5]	7.12-7.40 [5]	3.77-4.23 [5]	4.42-4.98 [5]
					M. beelzebub				
1♂	17.11	15.51	14.73	9.31	8.10	6.85	7.96	4.73	5.26
					M. hapioloides				
1♀	-	12.34	13.02	-	-	-	-	4.09	-
					M. leucogaster				
♂	17.81	16.76	15.92	10.18	8.28	6.93	8.85	4.76	6.02
2♀♀	18.48, 18.65	17.35, 17.41	16.41, 16.57	9.97, 10.69	8.69, 8.80	7.15, 7.60	8.55, 8.88	5.37, 5.52	6.20, 6.50
					M. jaintiana				
♂	14.75	13.63	13.02	8.27	7.14	6.00	7.07	4.12	4.41

TABLE 4-2. (Continued).

n/sex	C-P^4	C-M^3	M^3-M^3	C^1-C^1	C-M$_3$	M	CPH	TRM1	TAM1
					***M.* sp. nov. [B]**				
♂	2.03	4.88	5.01	3.57	5.38	10.44	3.48	0.68	0.56
♀	1.99	4.66	4.90	3.44	5.04	9.63	3.13	0.72	0.58
					M. eleryi				
2♂♂	1.86, 2.04	4.52, 4.54	4.83 [1]	3.14, 3.35	5.04, 5.13	9.52, 9.54	3.07, 3.11	0.70 [1]	0.60 [1]
2♀♀	2.08, 2.08	4.66, 4.84	5.03, 5.21	3.46, 3.51	5.08, 5.34	9.86, 9.91	3.18, 3.43	0.62, 0.64	0.56, 0.58
					M. feae				
12♂	2.23±0.11	4.99±0.11	5.22±0.16	3.67±0.11	5.33±0.07	10.07±0.15	3.36±0.16	-	-
	2.08-2.37 [6]	4.81-5.17 [8]	5.03-5.47 [7]	3.51-3.82 [7]	5.24-5.44 [6]	9.84-10.29 [6]	3.16-3.56 [5]	-	-
14♀	2.24±0.10	5.18±0.22	5.30±0.17	3.72±0.17	5.59±0.22	10.14±2.06	3.75±0.32	-	-
	2.10-2.46 [11]	4.83-5.59 [13]	5.04-5.60 [13]	3.53-4.09 [13]	5.26-6.00 [13]	3.73-11.40 [12]	3.20-4.36 [12]	-	-
					M. walstoni				
2♂♂	1.90, 2.43	4.50, 5.40	4.63, 5.50	3.28, 4.05	4.92, 5.83	9.44, 11.02	2.83, 4.21	-	-
5♀♀	2.32±0.12	5.34±0.10	5.47±0.22	3.94±0.05	5.86±0.18	11.19±0.30	3.91±0.19	-	-
	2.21-2.48 [4]	5.24-5.47 [4]	5.17-5.69 [4]	3.88-4.01 [4]	5.59-6.01 [4]	10.84-11.54 [4]	3.65-4.08 [4]	-	-
					M. suilla				
26♂	2.04±0.12	4.87±0.11	5.16±0.10	3.57±0.11	5.35±0.12	10.13±0.26	3.63±0.20	-	-
	1.89-2.25 [23]	4.63-5.09 [23]	4.97-5.35 [23]	3.37-3.77 [23]	5.15-5.63 [23]	9.59-10.73 [23]	3.35-4.21 [23]	-	-
8♀♀	2.09±0.07	4.90±0.11	5.09±0.17	3.53±0.11	5.32±0.12	10.02±0.21	3.66±0.30	-	-
	2.02-2.20 [5]	4.72-4.99 [5]	4.90-5.35 [5]	3.43-3.71 [5]	5.15-5.46 [5]	9.68-10.25 [5]	3.37-4.14 [5]	-	-
					M. beelzebub				
♂	2.53	5.49	5.47	3.91	5.99	11.20	3.75	-	-
					M. hapioloides				
♀♀	-	4.68	4.88	3.39	5.13	9.31	-	-	-
					M. leucogaster				
♂	2.91	5.90	5.92	4.61	6.30	12.92	4.38	-	-
2♀♀	2.81, 3.00	5.95, 6.33	6.20, 6.49	4.41, 4.61	6.40, 6.78	13.10, 13.42	4.63, 4.70	-	-
					M. jaintiana				
♂	2.17	4.95	-	3.52	5.37	10.11	3.43	-	-

Table 4-3. Craniodental measurements (in mm) of five species of *M. cyclotis*-group. Sample sizes of male and female specimens, mean ±SD; min–max values are given. A sample size that differs from the total number of specimens is given in brackets. Definitions of measurement are listed in Chapter 2.

n/sex	GTL	CBL	CCL	ZB	BB	BCH	MW	IC	LW
					M. huttoni				
10♂♂	17.57±0.42	16.25±0.38	15.53±0.36	9.60±0.26	7.82±0.23	6.51±0.24	8.32±0.18	4.47±0.11	5.37±0.16
	16.77-18.33	15.63-17.06	14.96-16.34	9.2610.08	7.39-8.21	6.07-6.97	8.04-8.63	4.29-4.65	5.185.59
2♀♀	17.53, 19.30	16.03, 17.60	15.42, 16.94	9.47, 10.92	7.48, 7.96	6.65, 6.67	8.18, 8.88	4.31, 4.38	5.27, 5.46
					M. harrisoni				
3♂♂	18.16±0.69	16.59±0.37	16.05±0.32	10.54±0.26	8.04±0.12	6.54±0.31	9.04±0.32	4.46±0.15	5.48±0.27
	17.46-18.83	16.22-16.95	15.73-16.36	10.26-10.77	7.90-8.14	6.31-6.89	8.67-9.28	4.37-4.64	5.25-5.78
5♀♀	19.16±0.41	17.53±0.54	16.86±0.49	11.12±0.24	8.14±0.11	6.81±0.18	9.42±0.21	4.47±0.11	5.84±0.34
	18.64-19.62	16.79-17.98	16.13-17.25	10.73-11.33	7.98-8.28	6.53-7.00	9.07-9.60	4.27-4.54	5.26-6.10
					M. annamitica				
1♂	15.68	14.28	13.87	8.52	7.25	6.00	7.45	4.01	4.82
					M. aenea				
3♂♂	17.32±0.39	15.92±0.24	15.25±0.29	10.57±0.25	8.27±0.12	7.22±0.28	8.71±0.12	4.79±0.11	5.59±0.10
	16.95-17.73	15.73-16.19	14.97-15.55	10.29-10.76	8.15-8.38	6.927.48	8.61-8.85	4.71-4.87 [2]	5.52-5.66 [2]
4♀♀	17.57±0.32	16.06±0.30	15.36±0.35	10.65	8.11	7.67	8.90	4.83	5.86
	17.20-17.80 [3]	15.80-16.39 [3]	15.00-15.69 [3]	[1]	[1]	[1]	[1]	[1]	[1]
					M. rozendaali				
13♂♂	15.90±0.31	14.46±0.28	13.90±0.22	9.12±0.28	7.36±0.08	6.54±0.26	7.56±0.14	4.18±0.13	4.85±0.10
	15.47-16.42 [7]	13.96-14.75 [7]	13.48-14.10 [7]	8.73-9.46 [7]	7.27-7.50 [7]	6.15-6.86 [7]	7.34-7.74 [7]	3.98-4.32 [6]	4.67-4.98 [7]

Table 4-3. (Continued).

n/sex	C-P^4	C-M^3	M^3-M^3	C^1-C^1	C-M_3	M	CPH	TRM1	TAM1
					M. huttoni				
10♂♂	2.81±0.10	5.97±0.14	5.79±0.24	4.37±0.16	6.62±0.20	12.30±0.40	4.49±0.23	0.88	0.58
	2.70-2.99 [8]	5.77-6.15	5.40-6.20	4.16-4.63	6.36-6.92 [9]	11.95-13.15 [7]	4.20-4.92 [9]	[1]	[1]
2♀♀	2.84, 3.08	6.01, 6.21	5.58, 6.33	4.48, 5.19	6.54 [1]	12.10, 13.32	4.64, 5.17	-	-
					M. harrisoni				
3♂♂	2.90±0.15	6.10±0.32	6.15±0.32	4.77±0.17	6.68±0.38	12.61±0.40	4.90±0.27	-	-
	2.80-3.08	5.74-6.32	5.93-6.52	4.59-4.92	6.27-7.02	12.22-13.02	4.64-5.18	-	-
5♀♀	3.06±0.21	6.37±0.11	6.21±0.13	4.96±0.11	7.03±0.15	13.46±0.36	5.52±0.20	-	-
	2.80-3.28 [4]	6.25-6.54	6.03-6.35	4.87-5.15	6.84-7.16	12.88-13.75	5.26-5.74	-	-
					M. annamitica				
♂	2.36	5.18	5.04	3.76	5.62	10.45	3.57	-	-
					M. aenea				
3♂♂	3.13±0.14	5.94±0.19	6.17±0.17	4.93±0.26	6.57±0.06	12.27±0.39	5.81±0.22	-	-
	3.00-3.27	5.74-6.12	6.04-6.36	4.74-5.22	6.51-6.62	11.99-12.71	5.60-6.03	-	-
4♀♀	3.12	6.06	6.09	4.88	6.64	12.81	6.49	0.88	0.50
	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]
					M. rozendaali				
13♂♂	2.44±0.08	5.35±0.11	5.26±0.07	3.90±0.13	5.84±0.14	10.80±0.26	3.76±0.20	-	-
	2.29-2.51 [7]	5.20-5.50 [7]	5.17-5.35 [6]	3.77-4.14 [7]	5.62-6.02 [6]	10.55-11.22 [6]	3.47-4.03 [7]	-	-

KEY TO SPECIES OF *MURINA* IN MAINLAND SOUTHEAST ASIA

1. Crown area of C^1 about equal or less that of P^4; Crown area of P^2 about half or less that of P^4; I^2 situated anterior to I^3…… ***'suilla*-group' 2.**
Crown area of C^1 about equal or less that of P^4; Crown area of P^2 about two-thirds or more that of P^4; I^2 situated lateral to the I^3……..***'cyclotis*-group' 10.**

2. Very large; FA over 40 mm; rostrum inflated and massive…….***M. leucogaster***
Small; FA less than 40 mm; rostrum not very inflated and massive…….....**3.**

3. Dorsal pelage with shiny orange/golden guard hairs……**4.**
Dorsal pelage without shiny orange/golden guard hairs……...**6.**

4. C^1 exceeds P^4 in height……....***M. feae***
C^1 about equal or less that of P^4 in height……..……...…**5.**

5. Mesostyles on M^1 and M^2 reduced…….……***M. jaintiana***
Mesostyles on M^1 and M^2 not reduced……...……***M. beelzebub***

6. C^1 without distinct cingular cusp on the lingual side.....…….....**7.**
C^1 with a well-developed cingular cusp on the lingual side.....……....**9.**

7. C^1 about equal or less that of P^4 in height…….……...…***M. hapioloides***
C^1 exceeds P^4 in height…….…….....……...**8.**

8. Sagittal crest very weak or absent; ventral pelage greyish-brown……***M. suilla***
Sagittal crest well defined; ventral pelage paler, white rather than brown……....***M. walstoni***

9. C^1 about equal or less that of P^4 in height; ventral pelage whitish-grey…….....…***M.* sp. nov. [B]**
C^1 exceeds P^4 in height; ventral pelage creamy white…...……...***M. eleryi***

10. Mesostyles on M^1 and M^2 reduced; talonids of M_1 and M_2 are about half that of trigonids……..…**11.**
Mesostyles on M^1 and M^2 well defined; talonids of M_1 and M_2 are about two-thirds or equal that of trigonids…….……..…**16.**

11. Dorsal pelage with bright shiny golden orange guard hairs; ventral pelage yellowish-brown…….***M. aenea***

Dorsal pelage with orange reddish guard hairs, no shiny golden hairs; ventral pelage less bright, whitish-grey to greyish-brown……..**12.**

12. Relatively larger; FA 34.0–40 mm; rostrum relatively inflated; sagittal crest well developed; C^1 very large, greatly exceeding that of P^4 in height and crown area…….....…….**13.**

Relatively smaller; FA 29.0–37.0 mm; rostrum shallow; sagittal crest present but very weak; C^1 not very large, about equal or very slightly exceeding P^4 in height and crown area…..…….**14.**

13. Larger C^1; P^4 less than two-thirds that of C^1 in crown area……...….***M. fionae***

Smaller C^1; P^4 about two-thirds or subequal to that of C^1 in crown area…….***M. peninsularis***

14. FA 31.9–35.9 mm; CCL 14.47–15.76 mm; interorbital region shorter with less distinct concavity…….***M.* sp. nov. [A]**

15. FA 29.4–36.8 mm; CCL 13.60–16.17 mm; interorbital region longer with a distinct concavity……....***M. cyclotis***

16. Larger, FA more than 33.0 mm; rostrum relatively inflated; sagittal crest well developed…….**17.**

Smaller, FA less than 33.0 mm; rostrum thin; sagittal crest weak……..**18.**

17. Talonids of M_1 and M_2 about two-thirds that of trigonids…..……***M. harrisoni***

Talonids of M_1 and M_2 about equal to that of trigonids…….....***M. huttoni***

18. C^1 very large, about twice that the height of P^4; ventral pelage yellowish-brown……..….***M. rozendaali***

C^1 not very large, slightly exceeding that of P^4; ventral pelage whitish-grey……...…….***M. annamitica***

CHAPTER 5

ECHOLOCATION CALL CHARACTERS OF *MURINA* AND THE USE OF THEIR SOCIAL CALLS IN ACOUSTIC LURE

ABSTRACT

Echolocation call characters of ten *Murina* species, including *M.* sp. nov. [A], *M. cyclotis, M. peninsularis, M. aenea, M. rozendaali, M.* sp. nov. [B], *M. feae, M. walstoni* and *M. suilla* were described based on calls recorded from free-flying individuals. Social calls were also recorded from individuals kept in a bat bag. In general, *Murina* emit typical broadband frequency modulated (FM) signals as others in Vespertilionidae but with a distinct initial hook. The measurements of calls were different statistically in all measured call parameters. Their social calls exhibited a very loud and low frequency. A field experiment on the use of simulated *Murina* social calls with an acoustic lure machine, Sussex AutoBat, attached to a harp trap was conducted to test whether these social calls can increase trapping success of *Murina* spp. in the tropical rain forests of peninsular Thailand. Social calls of *M. peninsularis, M. rozendaali,* and *M. suilla* from Thailand, and *M. ussuriensis* from Japan were used. The capture success between 'AutoBat traps' and 'Control traps', as well as between 'Trail traps' and 'Forest traps' were compared. The result strongly indicated that the harp trap with AutoBat had a significantly higher trapping success than normal harp trapping. The total numbers of *Murina* caught between the AutoBat trap set across trails and AutoBat trap set in forest were equal. In addition, it was found that a random variety of *Murina* species were caught in the 'AutoBat traps'; individuals responded to all social calls not just to those of their own species.

***Keywords*:** acoustic lure, echolocation, frequency modulate, *Murina,* social call, trapping efficiency.

INTRODUCTION

Echolocation call characters have been proved to be useful for species identification, particularly using the measurement of 'peak frequency of the maximum energy (*fmaxe*)' in bats in the families Hipposideridae and Rhinolophidae that use the 'Constant frequency' or CF signals (Russo and Jones, 2002; Soisook *et al.*, 2008; Douangboubpha *et al.*, 2010; Hughes *et al.*, 2010; Ith *et al.*, 2010). For those bats using 'Frequency modulated' or FM signals, many studies also proved that call parameters of these types of signals are also useful in species identification and monitoring of bats (Kingston *et al.*, 1999; Russo and Jones, 2002; Fukui *et al*., 2004; Hughes *et al.*, 2011). However, several studies have clearly shown geographical variation of call frequency among populations of a single species (i.e. Soisook *et al.*, 2008; Dejtaradol, 2009; Ith *et al.*, 2010). Moreover, the call frequency of bats from the same population can also vary between individuals because of the influence of age, sex, body condition, foraging habitat and foraging mode (Jones and Ransome, 1993; Barclay, 1999).

As in other vespertilionids, the echolocation call of *Murina* is usually FM type and is characterised by a relatively short duration broadband signal of the pulses. These bats are forest-dependent bats and are difficult to catch in harp traps or mist nets. This results in relatively small number of museum specimens available for taxonomic study (e.g. Csorba *et al.*, 2011). In consequence, knowledge of the echolocation of *Murina* is also poor. Acoustic characters of *M. suilla, M. aenea* and *M. cyclotis* have been described from peninsular Malaysia. Here it was found that there was overlap in the characters between species (Kingston *et al.*, 1999). The call of another species found in Vietnam, *M. tiensa* (referred as *M. harrisoni*, see Chapter 4) was recently illustrated by Thong *et al.* (2011). Hughes *et al.* (2011) described echolocation call characters of 10 Vespertilionids from Thailand including three species of *Murina*; *M. cyclotis, M. suilla* and *M. tubinaris* (=*M. feae*). However, these species, particularly *M. cyclotis*, comprise cryptic species as suggested by DNA Barcode (Francis *et al.*, 2010). Therefore, their call characters need to be re-described based on current, up to date data and knowledge of taxonomy.

Bats produce social calls for communication between bat individuals as well as other interactions, e.g. mother-young recognition, warning or aggressive

signals and sexual attraction (Barlow and Jones 1996; Kingston *et al.*, 2000; Altringham and Fenton, 2003). The acoustic lure technique developed by Hill and Greenaway (2005) showed that using the 'Sussex AutoBat' with simulated social calls can lead to a significant increase in the number of bats captured in British woodlands. Nevertheless, until this present study, this technique had not been tested with bats in tropical forest. Therefore it is interesting to report that a series of preliminary non-systematic surveys of *Murina* using the AutoBat in tropical forests of peninsular Thailand did show very promising results. Using harp traps/mist nets with the AutoBat, which played simulated social calls of *Murina* and *Kerivoula* species, greater numbers of *M. peninsularis* and *M. suilla* were caught than had been in previous surveys without the AutoBat.

Between September 2011 and August 2013, field surveys were made focusing on collecting and recording the calls of *Murina* spp. in peninsular Thailand. A field systematic experiment, to test the effectiveness of the use of social calls to increase trapping success of tropical *Murina,* was also undertaken in lowland evergreen rain forests of peninsular Thailand. The echolocation and social call characters of each species are described. A preliminary result of the acoustic lure experiment is shown herein.

MATERIALS AND METHODS

Study sites

Specimens of *Murina* species were captured in harp traps and mist nets from several locations during the fieldwork conducted between 2010 and 2013, as described in Chapter 2.

Echolocation calls recording and analysis

Calls characters of 10 *Murina* species were recorded and analysed in this study, including *M.* sp. nov. [A] (M[A]), *M. cyclotis* (Mc), *M. peninsularis* (Mpe), *M. annamitica* (Man), *M. aenea* (Mae), *M. rozendaali* (Mro), *M.* sp. nov. [B] (M[B]),

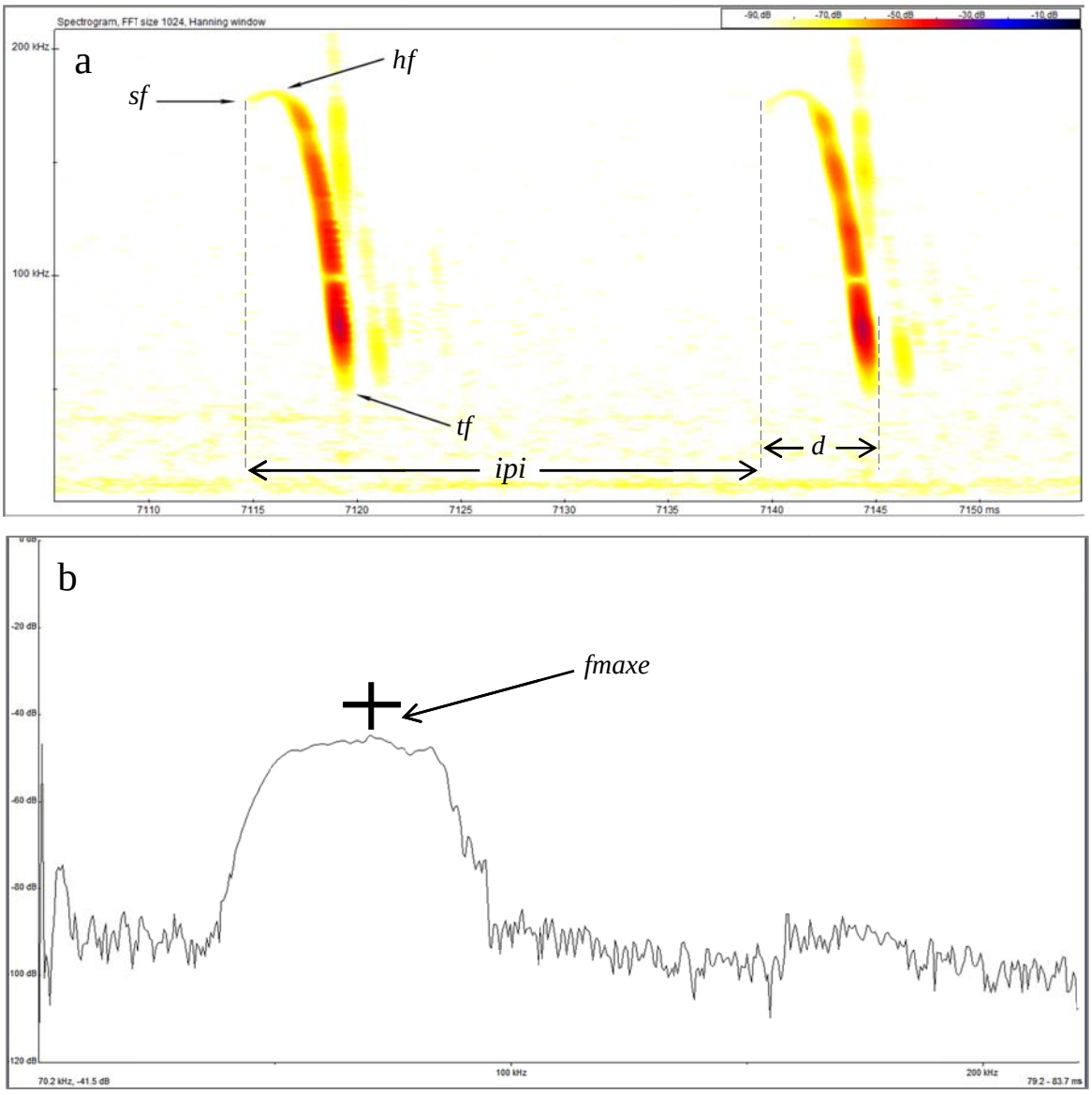

Fig. 5-1. Illustration of measurements of five call parameters, *sf*, *hf*, *tf*, *d* and *ipi* (a), and *fmaxe* (b).

M. feae (Mfe), *M. walstoni* (Mwa) and *M. suilla* (Msu). Echolocation calls were recorded with a Pettersson D-1000X ultrasound detector set in 10x time-expansion mode and sampling rate of 768 kHz. The bats were free flying either in a flight cage, i.e. mosquito net (3x4 m width and 3 m height) or in a room. Calls were analysed in BatSound – Sound Analysis Version 4.1.4 (Pettersson Electronics and Acoustic AB).

Six standard call parameters were measured including: start frequency (*sf*), highest frequency (*hf*) and terminal frequency (*tf*) (in kHz) measured by using the measurement curser in the spectrogram, the frequency of maximum energy (*fmaxe*) measured in the Power spectrum, interpulses interval (*ipi*) (in ms) and call duration (*d*) (in ms) measured by using the marking cursor in the spectrogram (Fig. 5-1). A sampling frequency of 44.10 kHz was used and produced a spectrogram using Automatic Fast Fourier Transform (FFT) with Hanning window. At least five to ten calls with good signal to noise ratio for each individual were chosen for analysis. Species with small sample size were excluded from statistical analysis but were summarised for each species in Chapter 3 and 4.

Social calls recording

Social calls were recorded from a highly active individual crawling in a bat bag. Bats that were caught together in pairs or group of individuals usually produced echolocation calls with social calls when they were kept separately in different bat bag. The bat bag, with a most highly active individual inside, was hung about 50 cm away from the other bags. The series of call sequences were listened to and recorded manually with Pettersson D-100X bat detector until the bat produced social calls.

Social calls were transferred to a laptop computer and opened in BatSound Pro. A series of 2–4 social calls was displayed on the computer screen and captured as an image. To produce a clean simulated social calls, the image of the social calls was subsequently digitally traced to a spreadsheet and uploaded to the Sussex AutoBat (Hill and Greenaway, 2005).

Acoustic lure treatment

The field experiment to test the effectiveness of the acoustic lure was undertaken in tropical rain forest in the Halabala Wildlife Research Station, Wang, Narathiwat Province, S. Thailand (see Chapter 2), between September 2012 and August 2013.

Bats were caught using 4-bank harp traps. Four harp traps were used in the experiment, with two harp traps set across ‘trails’ and another two set in the

understorey of the ‘forest’. Bats were lured to enter the harp traps by using simulated social calls in the ‘Sussex AutoBat’ with an ultrasound speaker (Hill and Greenaway, 2005). Two AutoBat machines were used in each trapping session/night; a session consisted of four trapping hours, starting at 1830 hrs (after completely dark) and ending at 2230 hrs. One of the AutoBat machine was attached to the ‘Trail trap’ and another one attached to the ‘Forest trap’ which was set at approximately 200 m away to avoid interference between the traps. The other two harp traps were set as a ‘Control’ across the ‘trail’ and in the ‘forest’, but without the AutoBat machine. The distance between ‘AutoBat traps’ and ‘Control traps’ was approximately 1.5 km and they were separated by a road to avoid interference between luring treatment and the control.

The site of on left hand side of the road is here referred to as site ‘A’ and the other side is site ‘B’. These sites were lowland evergreen forest and the presence of *Murina* was known for both sites based on previous preliminary surveys. The test for the acoustic lure had a duration of 12 trapping nights. The selection of the sites for the ‘AutoBat traps’ and ‘control traps’ on each night was made randomly by drawing cards, on which was written ‘A’ and ‘B’, from the box to avoid bias of preference between the sites.

The individual harp trap that was set in trapping position of each trapping session was randomly used by rotating the four harp traps around to reduce potential biases of the difference of capture effectiveness between individual harp traps. The position of harp traps on each following trapping sessions was approximately 200 m away from the position of previous session. Each trapping position was used only once.

Simulated social calls of four species, including one Japanese tube-nosed bat *M. ussuriensis* (here after referred as call [A]), and three local tube-nosed bats *M. rozendaali* [B], *M. peninsularis* [C], and *M. suilla* [D], were used. Social calls of each species were played for 15 minutes from 1830 hrs until 2230 hrs. So, each call was played four times per trapping session. The order in which social calls of each species were played at the starting time on each trapping night was rotated to reduce potential bias relating to activity patterns of the bats (i.e. night#1 started with [A]-[B]-[C]-[D], then the night#2 was]-[B]-[C]-[D]-[A], respectively). The numbers and

species of bat that approached the ‘AutoBat traps’ were checked continuously with the additional use of bat detector (Pettersson D240X or D1000X) to record the bats that were not trapped. The ‘control traps’ were checked regularly every 15–30 minutes.

Statistical analysis

Discriminant analysis was used to test the differences of echolocation call parameters between species. The number of *Murina* that were found in the ‘AutoBat traps’ vs the ‘controls traps’, as well as between ‘trail traps vs forest traps’, were compared by using a Kruskal-Wallis test. Statistical analyses were performed in MINITAB 14.1 (Minitab Inc., State College, PA., USA).

RESULTS

Echolocation call characters

A total of 331 calls from 47 specimens of 10 species of *Murina* were measured. The summary of the call characters of each species is shown in Table 5-1. The calls of *Murina* species analysed were single harmonic FM type with a distinct, relatively short portion of the initial ‘hook’ at the beginning of each pulse. This hook represented the start frequency and was followed by a portion on the top of the pulse, which exhibited the highest frequency (Fig. 5-2, 5-3). Then, the pulse continued with a steep broad band and very short duration portion downward to the end of a call. However, the starting hook of the call was not always fully recorded. From the field observation, it was largely affected by the direction of the bat and the microphone of the bat detector. The calls with a good signal to noise ratio and a distinct starting hook were usually recorded when the recordings were made with the bat flying toward the microphone. The recordings made otherwise usually failed to record a good series of signals.

The start frequencies (*sf*) of the 10 *Murina* species in this study were relatively similar and exhibited a very high frequency, with over 140.0 kHz (Table 5-1, Fig. 5-2). *M. annamitica* emitted the highest *sf* frequency, with 188.1±3.7 kHz (Table 5-1). The *hf* of each species, which was measured at the top of the pulse, had a

slightly higher frequency than the *sf* (Table 5-1). The FM sweep fell steeply downward to the end with the *tf* as low as 41.6 kHz in *M. rozendaali* (Table 5-1). Although the energy of the call is distributed almost evenly in the pulse, the *fmaxe* were measured at between 82.3 and 139.5 kHz, which is situated at the middle of the pulse (Fig. 5-2).

The call duration (*d*) of the pulses was very short, which most species emitting for only 2.0–3.1 ms (Table 5-1). Only *M. rozendaali* emitted distinctly longer calls than that, with 5.6±1.6 ms (Table 5-1, Fig. 5-4). This longer call duration of *M. rozendaali* was consequence of the distinctly longer starting hook of the call (Fig. 5-2). The interpulses interval (*ipi*) of each species showed a relatively large variation. Among all analysed species, the *ipi* of *M. annamitica* showed the shortest interval with the smallest variation, with a mean±SD of 31.1±7.4 ms (Table 5-1). The other nine species had a broader *ipi* and larger variation (Table 5-1). This variation reflected the pattern of the call sequences in which *Murina* tends to emit repeated pairs of pulses. These couple pulses had an *ipi* of approximately 20.0–30.0 ms, and then continued with a larger gap of approximately twice the interval of the previous couple pulses, before starting the next couple pulses (Fig. 5-5).

Table 5-1. Mean and standard deviation (SD) of six call parameters of 10 *Murina*. Number of specimens (N) and number of calls analysed (*n*) are given.

Species	***sf* (kHz)**			***hf* (kHz)**			***tf* (kHz)**			***fmaxe* (kHz)**			***d* (ms)**			***ipi* (ms)**		
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
M. sp. nov. [A] (N=3)	30	172.6	7.9	24	176.8	7.4	30	55.7	3.9	30	139.5	10.6	30	2.6	0.6	30	36.0	14.3
M. cyclotis (N=3)	23	149.0	6.1	-	-	-	23	60.0	4.4	23	104.9	6.7	23	2.0	0.3	23	56.0	23.9
M. peninsularis (N=15)	118	167.3	11.2	71	172.4	9.7	118	48.8	4.7	114	108.2	17.4	114	3.1	1.2	103	40.5	15.6
M. annamitica (N=1)	7	188.1	3.7	4	187.5	7.3	6	44.8	3.8	6	135.5	11.1	6	2.7	0.4	7	31.1	7.4
M. aenea (N=2)	14	140.9	3.9	7	143.4	7.2	14	43.2	4.4	14	82.3	5.0	14	2.4	0.3	14	42.1	14.8
M. rozendaali (N=6)	33	159.7	10.3	33	162.8	10.7	33	41.6	7.5	33	85.1	9.0	33	5.6	1.6	33	50.5	20.4
M. sp. nov. [B] (N=2)	20	156.7	5.6	8	165.5	3.1	20	67.4	4.0	20	94.4	6.6	20	2.2	0.4	20	41.9	21.0
M. feae (N=2)	15	166.7	9.0	4	162.0	8.7	15	52.9	11.1	10	132.9	16.4	10	2.5	0.4	10	43.2	16.0
M. walstoni (N=2)	10	146.4	4.0	2	148.0	0.0	10	51.6	6.2	9	114.2	6.2	9	3.1	0.8	7	94.0	16.9
M. suilla (N=11)	59	166.3	27.7	15	170.5	32.6	61	61.1	12.0	55	99.8	16.1	57	2.8	0.8	61	55.6	33.4

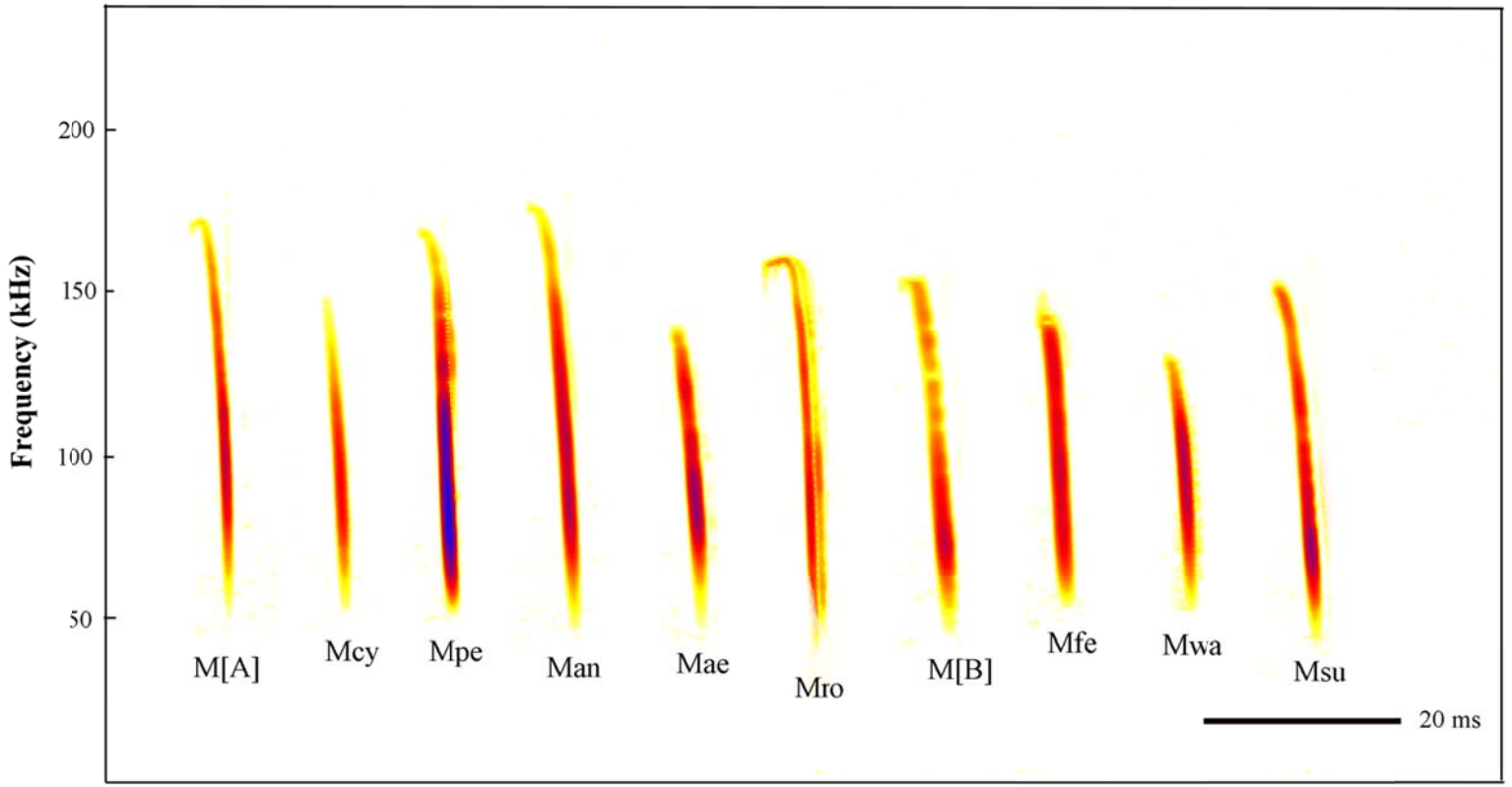

Fig. 5-2. Spectrograms of representative calls showing mean *sf*, *hf*, *tf* and *d* of 10 *Murina* performed in BatSound Pro. Abbreviations are listed in the Method section. Note that the disappearance of initial hooks in some species is due largely to zooming the calls in and out of each species into the same scale.

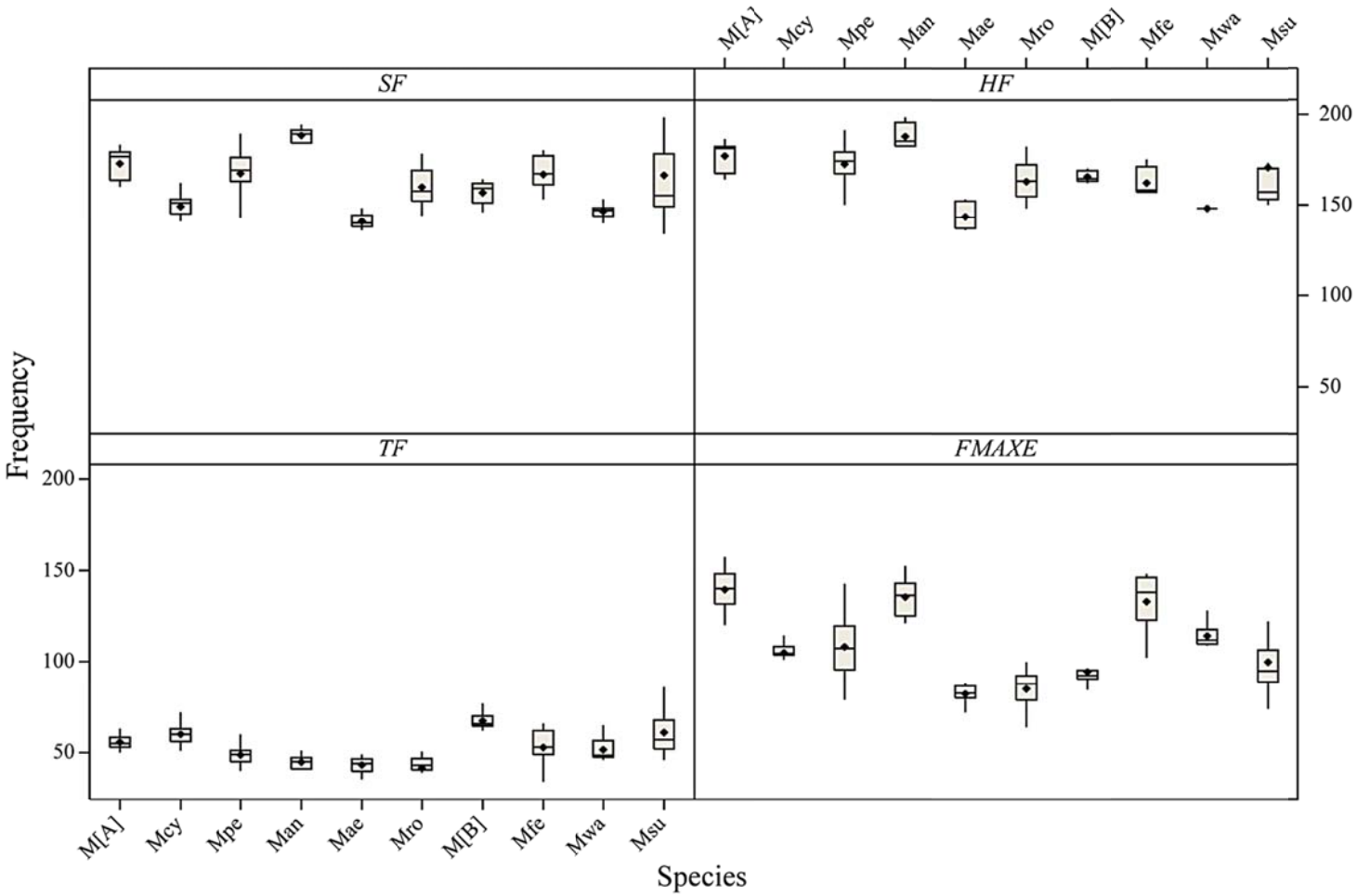

Fig. 5-3. Boxplots of call parameters; *sf, hf, tf* and *fmaxe* (kHz) of 10 *Murina*. Abbreviations are listed in the Method section.

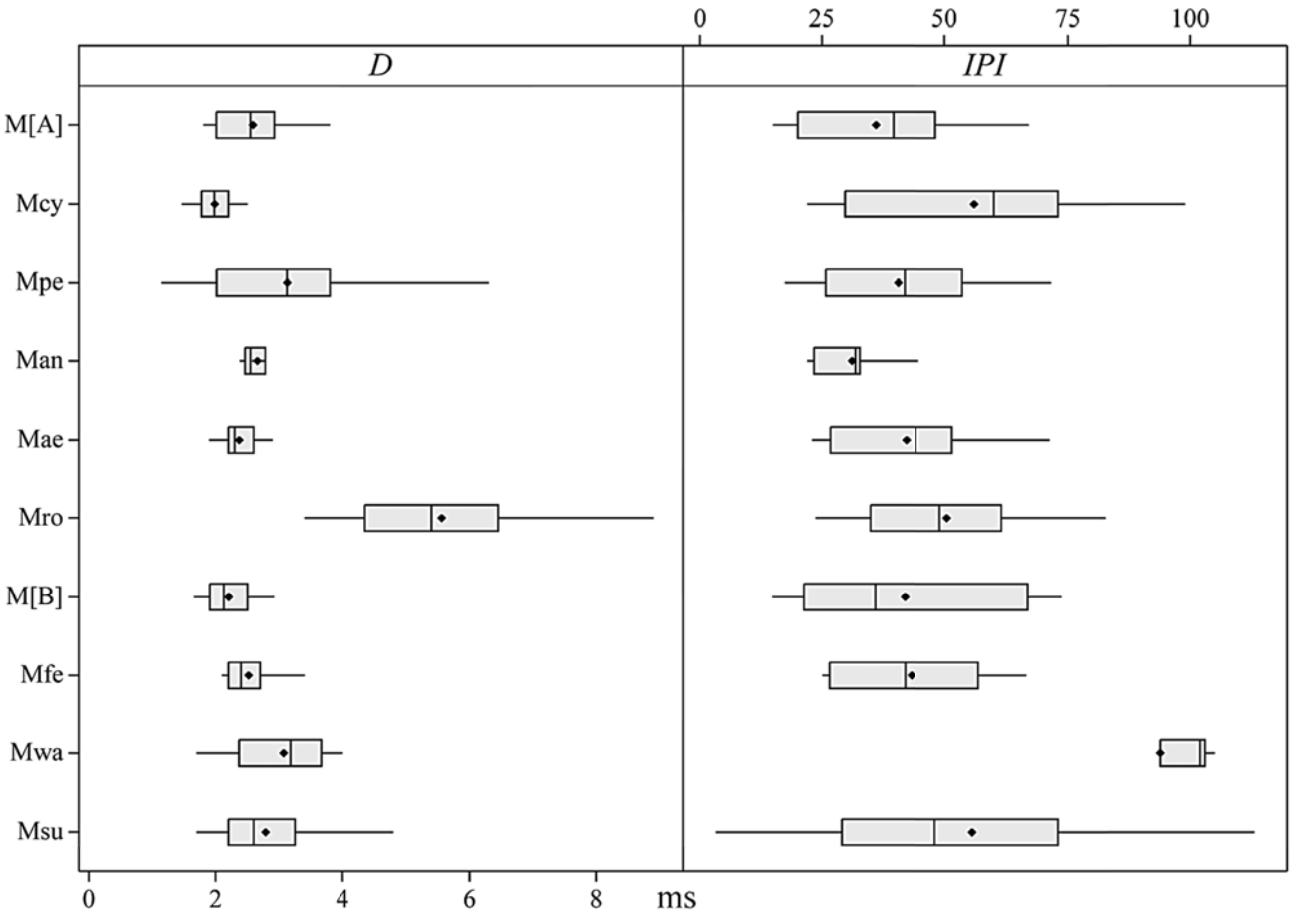

Fig. 5-4. Boxplots of call parameters; *d* and *ipi* (ms) of 10 *Murina*. Abbreviations are listed in Method section.

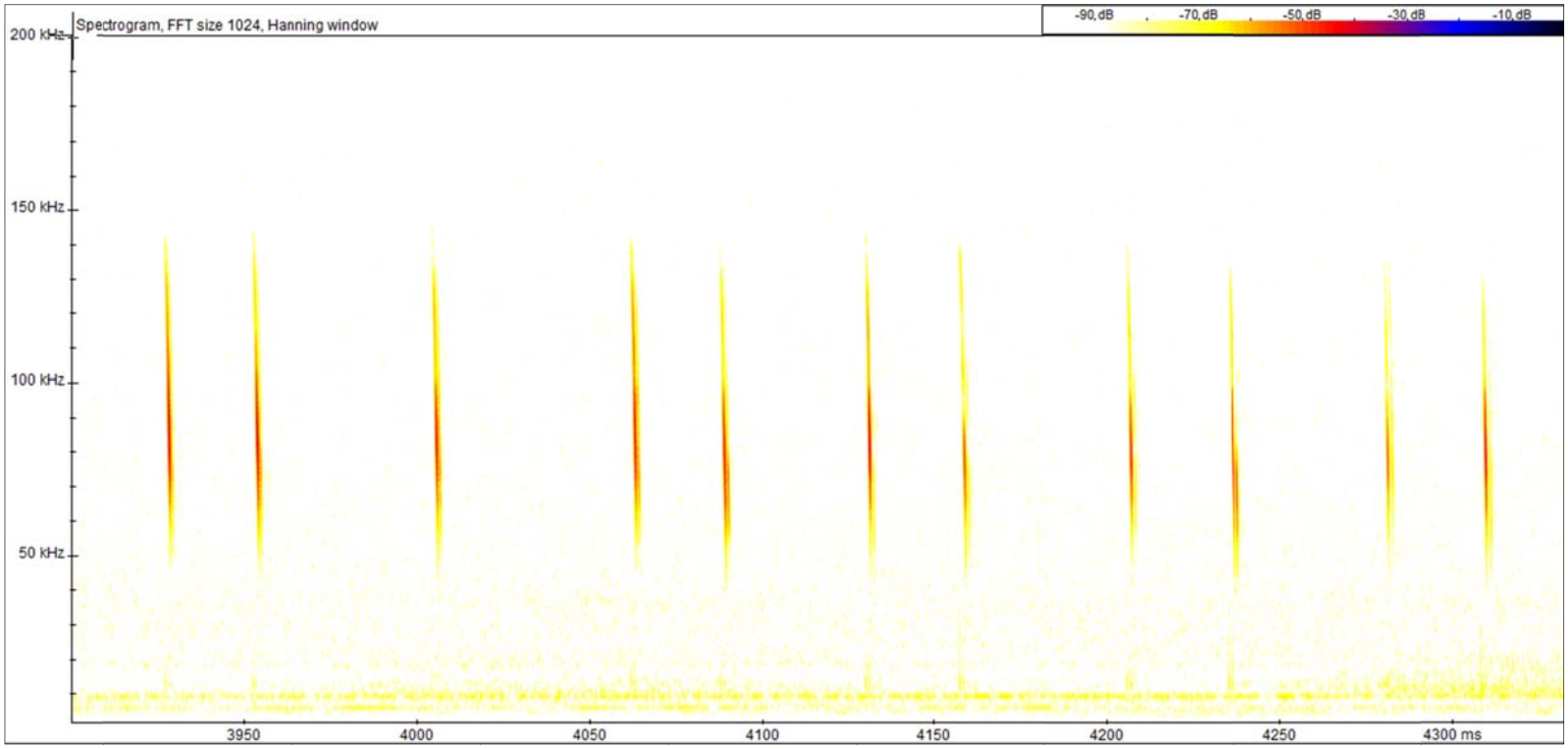

Fig. 5-5. A series of echolocation calls of *M. aenea* showing pattern of call sequence.

Table 5-2. Summary of classification with cross validation based on five call parameters of six *Murina* species by discriminant analysis. The parameter *hf*, and species *M. annamitica*, *M. aenea*, *M. feae* and *M. walstoni* were excluded from the analysis because of small sample size.

Classification	True Species					
	M. sp. nov. [A]	*M. cyclotis*	*M. peninsularis*	*M. rozendaali*	*M.* sp. nov. [B]	*M. suilla*
M. sp. nov. [A]	27	0	22	0	0	3
M. cyclotis	0	17	4	0	2	9
M. peninsularis	3	1	67	2	0	10
M. rozendaali	0	0	5	31	0	4
M. sp. nov. [B]	0	4	1	0	18	13
M. suilla	0	1	4	0	0	16
Total N	30	23	103	33	20	55
Correct N	27	17	67	31	18	16
% Correct	90.0%	73.9%	65.0%	93.9%	90.0%	29.1%

Note: Overall correct classification rate is 66.7%

Calls identification

Although the call characters of *Murina* species were generally similar, the discriminant analysis was able to classify these six species analysed from each other based on five call parameters with an overall 66.7% of correct classification (Table 5-2). Most of the cases were correctly classified with % correct over 70%. Only in the case of classification between *M. suilla* and other species whose % correct was very low, 29.1%, would not be possible. Similarly, the classification between *M. peninsularis* and other species could be difficult; % correct was 65.0% (Table 5-3).

Statistical analysis with Kruskal-Wallis test showed significant differences between all call parameters of 10 *Murina* species analysed; ***sf*** H_9= 128.25, $P < 0.001$; ***hf*** $H_8 = 65.99$, $P < 0.001$ (*M. cyclotis* was excluded due to small sample size); ***tf*** $H_9 = 197.96$, $P < 0.001$; ***fmaxe*** $H_9 = 164.11$, $P < 0.001$; ***d*** $H_9 = 111.65$, $P < 0.001$; ***ipi*** $H_9 = 41.40$, $P < 0.001$. Although overall species comparison was relatively high significant difference, identifications between similar species were not always convenient. For instance, call identification between the two cryptic species with sympatric distribution, *M.* sp. nov. [A] and *M. peninsularis,* can be relied only on *fmaxe* and *tf* (Table 5-3). Another similar pairs, *M. walstoni* and *M. suilla,* were even less identifiable by using call characters. However, the latter pairs were not overlap in the distribution. In general, the *fmaxe* and *sf* were the most reliable characters in identifications between species. In contrast, *ipi* and *d* were much less reliable (Table 5-3).

Social call characters

Social calls from four *Murina, M. peninsularis, M. aenea, M. rozendaali* and *M. suilla* were recorded. In general, these calls were very loud and usually audible to human ear. It comprises a sequence of, usually multi-harmonic, relatively long duration and low frequency of FM signals (Fig. 5-6). In most cases, the most energy was distributed evenly in the first harmonic except in *M. suilla* where the most energy was sometimes observed in the second harmonic. The pulses exhibited much narrower band than the echolocation calls described above, with a start frequency between 35.0–70.0

kHz for the vertical FM sweep, followed by a short shallow slope and ending with a frequency of 5.0–25.0 kHz (Fig. 5-6).

In *M. peninsularis*, its social calls were a series of about three or four calls with a *sf* of 55.0–65.0 kHz and a lowest frequency of 22.0–30.0 kHz. A short upward terminal hook was usually observed (Fig. 5-6). The *d* was of 2.0–3.5 ms. In *M. aenea*, it emitted a much narrower band of social calls, with a *sf* of 28.0–38 kHz and *tf* of 8.0–10.0 kHz. In contrast to *M. peninsularis*, the terminal part of the social calls of *M. aenea* was usually with a short, horizontal more or less constant frequency portion (Fig. 5-6). The *d* was of 5.0–25.0 ms. In *M. rozendaali* and *M. suilla*, the social calls were very similar in both shape and measurements. The *sf* was of 45.0–85.0 kHz in both species. The *tf* of *M. rozendaali* was 18.0–20.0 kHz whereas it was 17.0–25.0 kHz in *M. suilla* (Fig. 5-6). The *d* was 7.0–15.0 ms in both species. The *ipi* of the social calls of *M. aenea*, *M. rozendaali* and *M. suilla* were all about 90.0–110.0 ms. In *M. peninsularis*, the *ipi* was much shorter, about 25.0 ms.

Acoustic lure

During the 48 trapping hours (12 nights), 117 individuals of 19 bat species from four families were captured. Most of them were in the family Vespertilionidae (9 species; 63 individuals). The second most frequent captured was the Hipposideridae, with 36 individuals of 5 species. The other two were Nycteridae (1 species, *Nycteris tragata*) and Rhinolophidae (4 species), with 10 and 8 individuals, respectively (Fig. 5-7).

In the AutoBat traps, 79 individual were caught, most of them were Vespertilionidae (51 individuals). The rest were Hipposideridae (18), Nycteridae (8) and Rhinolophidae (2). In contrast, the most captured in the Control traps were Hipposideridae (18), followed by Vespertilionidae (12), Rhinolophidae (6) and Nycteridae (2) (Fig. 5-7).

Within the family Vespertilionidae, all bats captured belonged to only two genera, *Murina* and *Kerivoula*, with 5 and 4 species, respectively. Of the 63

vespertilionids collected, 51 of them were found in AutoBat traps and 12 were found in Control traps (Fig. 5-8). The five *Murina* species captured in the AutoBat traps are *M. rozendaalii* (8 male), *M. peninsularis* (2 male, 5 female), *M. suilla* (1 male, 3 female, 3 unknown), *M. aenea* (1 male, 1 female) and *M.* sp. nov. [B] (1 female).

The result of the number of *Murina* individuals captured showed a significant different between the four trapping treatments (Kruskal-Wallis test, H_3 = 14.85, $P < 0.005$). The number of *Murina* captured in the two AutoBat traps that were set across trails and in the forest were equal, with 13 individuals in both conditions (Fig. 5-9). In the control conditions, the control trail trap captured four *Murina* whereas one was caught in the control forest trap (Fig. 5-9). The post-hoc comparisons between pairs of both lure conditions and both control conditions were all significant different statistically (Mann-Whitney *U* Test, $P<0.05$) (Fig. 5-9).

Response of Murina to the social calls

As above, the result of trapping success between lure and control conditions was significantly different. It strongly indicates that the bats responded to the social calls emitted by the AutoBat. *M. rozendaali* was the most frequently captured species, with 8 individuals, whereas *M. peninsularis* and *M. suilla* were equally captured at 7 individuals. *M. aenea* and *M.* sp. nov. [B] were the least captured species, with 2 and 1 individuals, respectively. However, none of these species showed a specific correlation with the social calls that were being played (Chi-square test, $P> 0.05$) (Fig. 5-10). The social calls of *M. peninsularis* attracted most individuals to the trap (9 individuals). However, the most individuals that were captured while the social calls of *M. peninsularis* were being played were referable to *M. rozendaali.* In contrast, the most individuals that were captured while the social calls of *M. rozendaali* were being played were assigned to *M. peninsularis* (Fig. 5-10). In terms of number of species, the social calls of *M. rozendaali* attracted the most species (4 species) to the trap; the other social

calls each attracted 3 species. This included the social calls of the Japanese species, *M. ussuriensis*, which was equally successful.

DISCUSSION

Echolocation and social calls

The use of a broadband FM sweep in *Murina*, as in most vespertilionids, has been explained as being well suited to their foraging strategy. With a very high start frequency call, they are able to correctly detect and classify objects in highly cluttered spaces within a forest interior (Schnitzler and Kalko, 1999; Kingston *et al.,* 1999). This type of echolocation allows them to glean their insect prey flying near, or sitting on, the ground or leaves (Schnitzler and Kalko, 1999). However, the characteristic of the presence of a lower frequency initial hook is still unknown. It may possible that *Murina* uses this hook for the initial detection and then slightly increase call frequency for a obtaining a more accurate details of the object. Further study is needed to reveal the function of this initial hook.

The call characters of *M. peninsularis, M. aenea* and *M. suilla* described in this study generally agree with those calls of the same species described from peninsular Malaysia (Kingston *et al.,* 1999), but in contrast in the *fmaxe* of *M. peninsularis* and *M. suilla*. However, the *fmaxe* of *M. peninsularis* (=*M. cyclotis* in Kingston *et al.,* 1999) in this study had a much higher frequency, whereas *M. suilla* had much lower frequency of *fmaxe* than described in Kingston *et al.,* 1999. However, the most energy can be fairly variable (Hughes *et al.,* 2011). The authors of the same study also mentioned the presence of the initial hook in the call records with good signal to noise ratio (Kingston *et al.,* 1999).

Table 5-3. Statistical comparison of six call parameters between species by Mann-Whitney *U* test. The *hf* of *M. cyclotis* was excluded from the analysis because of small sample size. *, ** and *** represent significant differences at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively. NS represents non-significant difference ($P > 0.05$).

Species	*sf*	*hf*	*tf*	*fmaxe*	*d*	*ipi*
M. sp. nov [A] vs *M. cyclotis*	***	-	***	***	***	**
M. sp. nov [A] vs *M. peninsularis*	*	*	***	***	*	NS
M. sp. nov [A] vs *M. annamitica*	***	**	***	NS	NS	NS
M. sp. nov [A] vs *M. aenea*	***	***	***	***	NS	NS
M. sp. nov [A] vs *M. rozendaali*	***	***	***	***	***	**
M. sp. nov [A] vs *M.* sp. nov. [B]	***	**	***	***	*	NS
M. sp. nov [A] vs *M. feae*	*	**	NS	NS	NS	NS
M. sp. nov [A] vs *M. walstoni*	***	*	*	***	*	***
M. sp. nov [A] vs *M. suilla*	***	**	NS	***	NS	**
M. cyclotis vs *M. peninsularis*	***	-	***	NS	***	**
M. cyclotis vs *M. annamitica*	***	-	***	***	**	*
M. cyclotis vs *M. aenea*	***	-	***	***	**	*
M. cyclotis vs *M. rozendaali*	***	-	***	***	***	NS
M. cyclotis vs *M.* sp. nov. [B]	**	-	***	***	NS	NS
M. cyclotis vs *M. feae*	***	-	NS	**	**	NS
M. cyclotis vs *M. walstoni*	*	-	**	***	**	**
M. cyclotis vs *M. suilla*	**	-	NS	**	***	NS
M. peninsularis vs *M. annamitica*	***	**	*	**	NS	NS
M. peninsularis vs *M. aenea*	***	***	***	***	*	NS
M. peninsularis vs *M. rozendaali*	***	***	***	***	***	*
M. peninsularis vs *M.* sp. nov. [B]	***	*	***	***	**	NS
M. peninsularis vs *M. feae*	NS	*	*	***	NS	NS
M. peninsularis vs *M. walstoni*	***	*	NS	NS	NS	***
M. peninsularis vs *M. suilla*	**	**	***	**	NS	**
M. annamitica vs *M. aenea*	***	**	NS	**	NS	NS
M. annamitica vs *M. rozendaali*	***	**	NS	***	***	**
M. annamitica vs *M.* sp. nov. [B]	***	**	***	***	*	NS
M. annamitica vs *M. feae*	***	*	NS	NS	NS	NS
M. annamitica vs *M. walstoni*	**	NS	*	**	NS	**
M. annamitica vs *M. suilla*	**	*	***	***	NS	*
M. aenea vs *M. rozendaali*	***	***	NS	NS	***	NS
M. aenea vs *M.* sp. nov. [B]	***	**	***	***	NS	NS
M. aenea vs *M. feae*	***	**	**	***	NS	NS
M. aenea vs *M. walstoni*	**	NS	**	***	*	***
M. aenea vs *M. suilla*	***	**	***	***	NS	NS
M. rozendaali vs *M.* sp. nov. [B]	NS	NS	***	**	***	NS
M. rozendaali vs *M. feae*	*	NS	***	***	***	NS
M. rozendaali vs *M. walstoni*	***	*	***	***	***	***
M. rozendaali vs *M. suilla*	NS	NS	***	***	***	NS
M. sp. nov. [B] vs *M. feae*	**	NS	***	***	*	NS
M. sp. nov. [B] vs *M. walstoni*	***	***	***	***	**	***
M. sp. nov. [B] vs *M. suilla*	NS	NS	**	NS	**	NS
M. feae vs *M. walstoni*	***	*	NS	*	NS	**
M. feae vs *M. suilla*	NS	NS	NS	***	NS	NS
M. walstoni vs *M. suilla*	**	*	**	**	NS	**

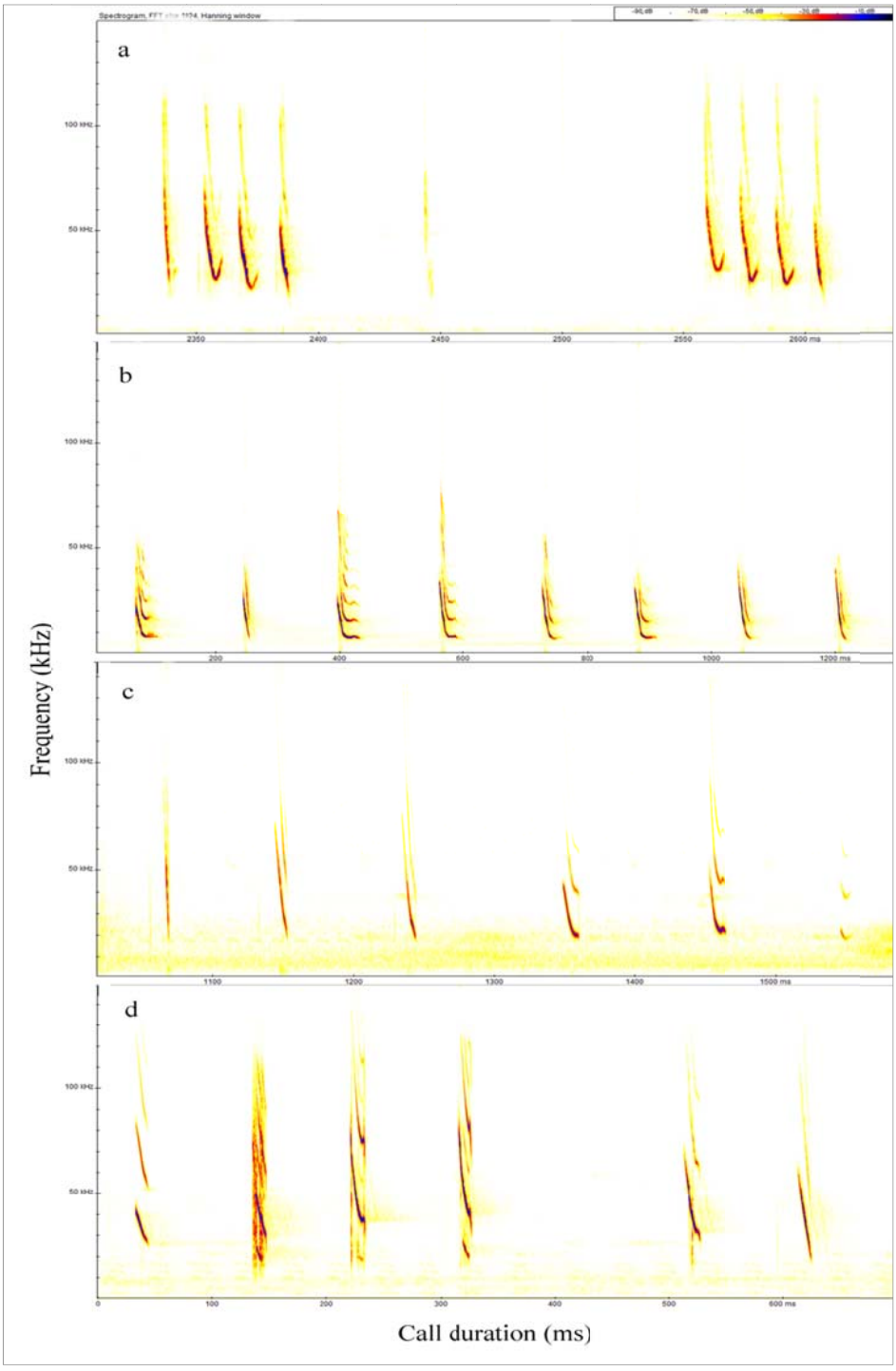

Fig. 5-6. Representative social calls of four *Murina*, a) *M. peninsularis*; b) *M. aenea*; c) *M. rozendaali* and d) *M. suilla.*

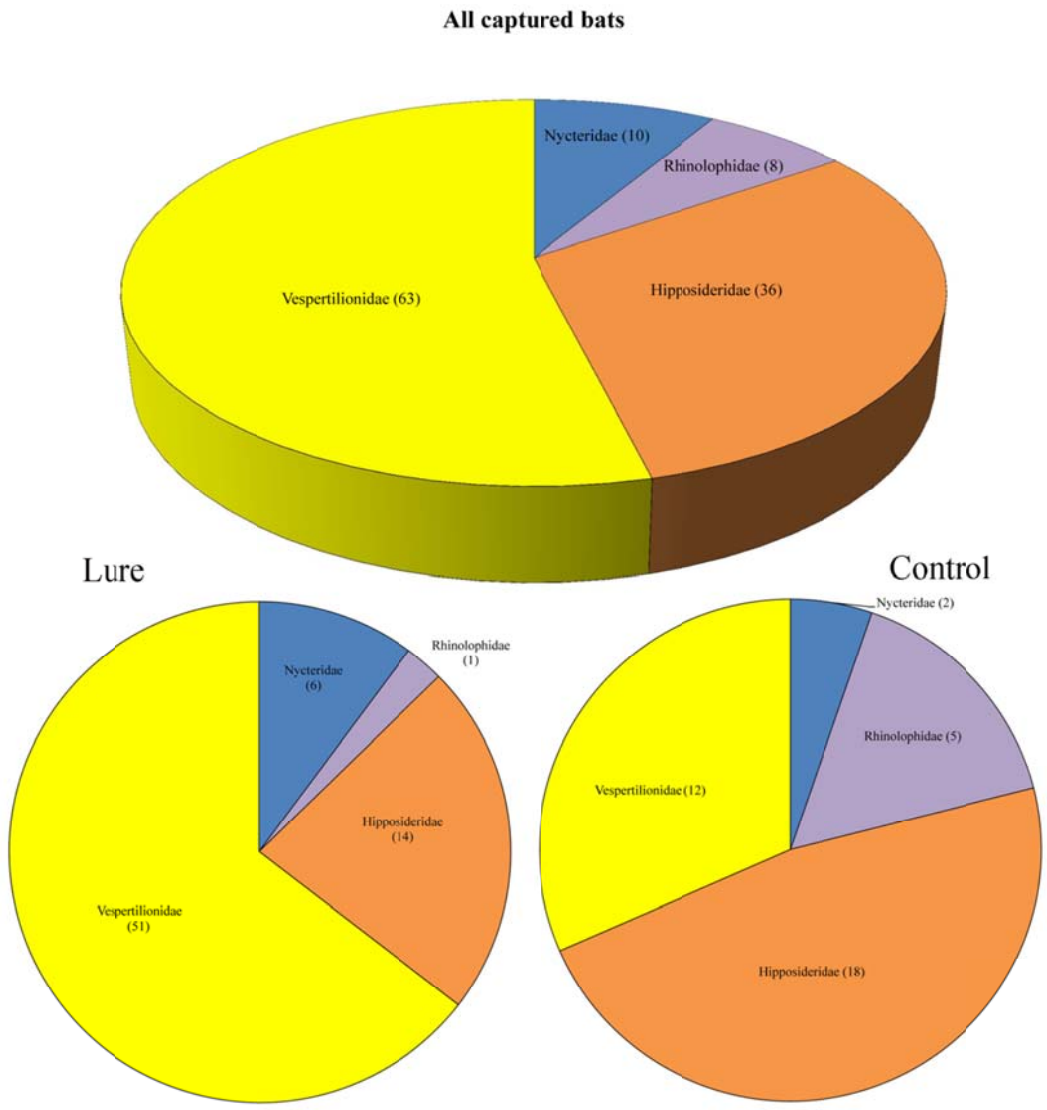

Fig. 5-7. Number of individual bats in each family that were captured during the trapping sessions.

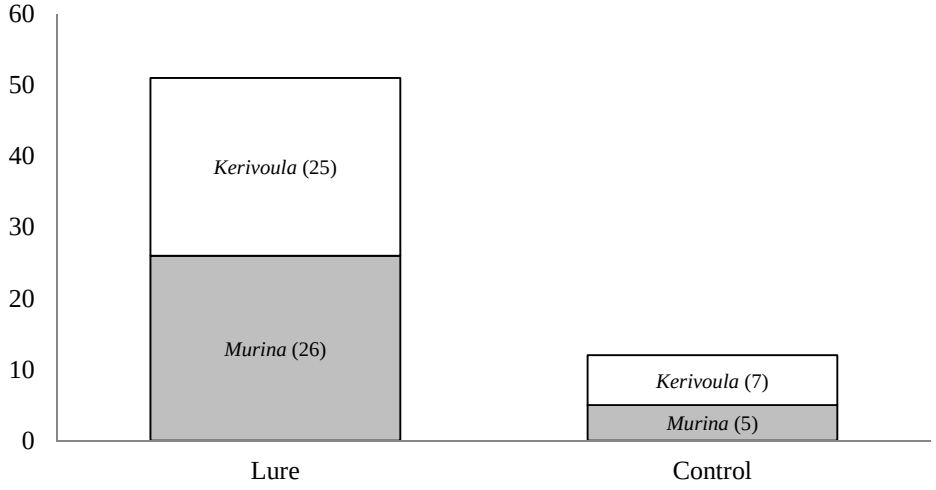

Fig. 5-8. Numbers of bats of the Vespertilionidae captured between Lure and Control conditions.

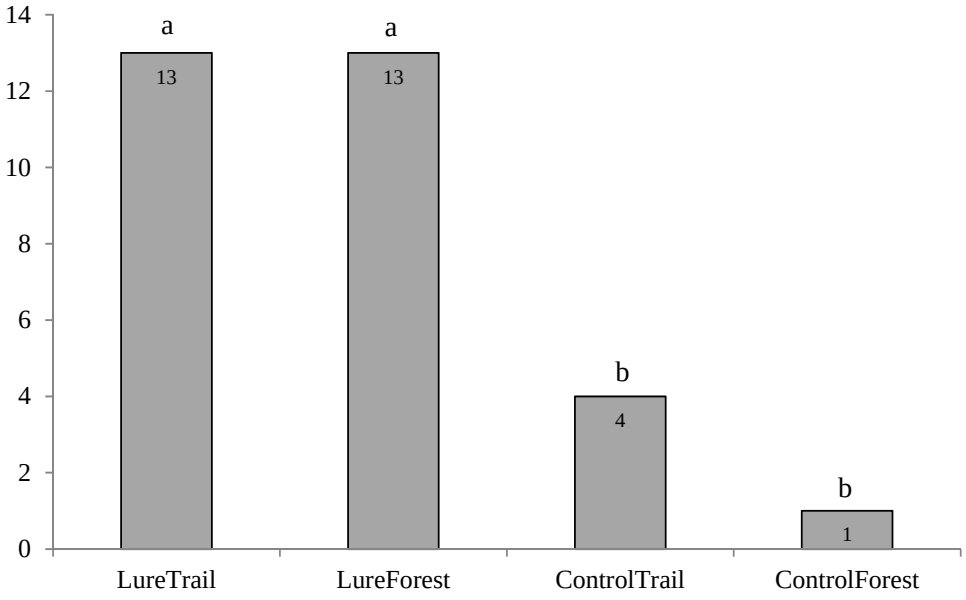

Fig. 5-9. Numbers of *Murina* captured between four trapping conditions. Different letters above the bars represented significant differences (Mann-Whitney *U* Test, $P<0.05$) between trapping conditions.

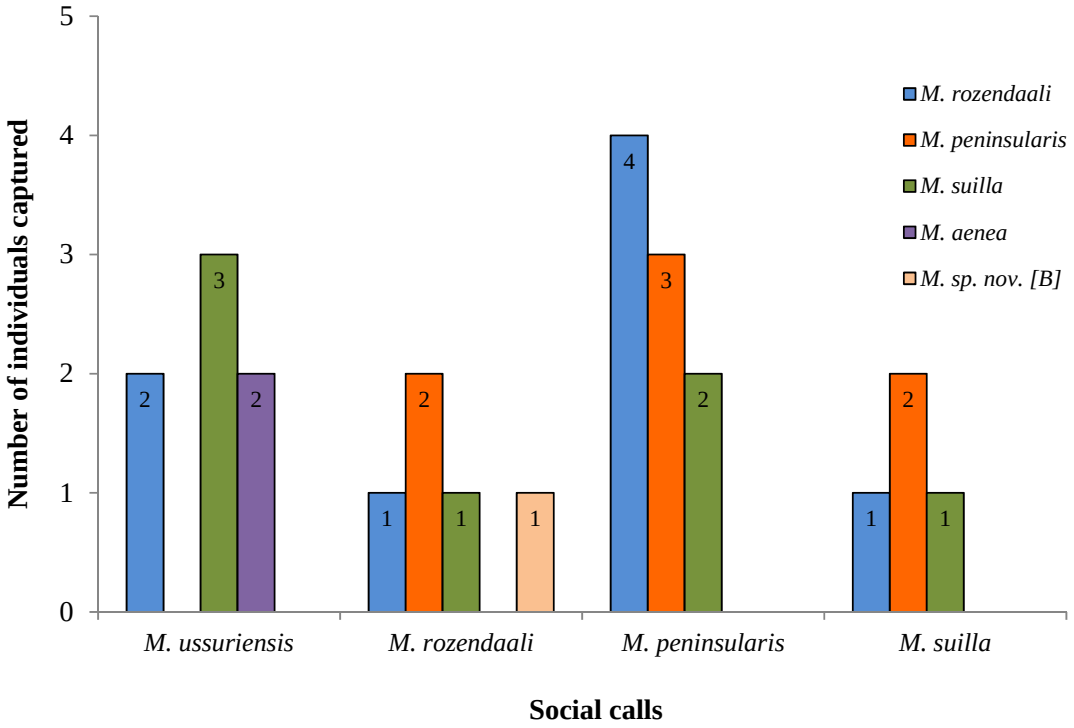

Fig. 5-10. Number of individuals of each *Murina* species captured in each social calls.

This study provides the description of the echolocation calls and social calls characters of Southeast Asian *Murina*. Based on the social calls of the four species recorded (Fig. 5-6), they are likely to be able to identified by using social call characters. However, these data were from very small sample size and future study to obtain larger sample size is needed in order to describe either these are consistent or intraspecific variation. According to the rich diversity and complexity of the calls, it would be useful to have a larger dataset to support our understanding of the echolocation characters of each species. Using this acoustic data, even of such complex group, as a baseline for acoustic surveys or monitoring could be possible, but it must be borne in mind that is the identifications will be much less reliable than those for species-specific CF bats, as suggested in Hughes *et al.* (2011). Moreover, recording such high frequency FM signals

in the field is usually difficult in order to gain a good series of calls. Therefore, unless a very good calls database is available, future acoustic survey and analysis must be undertaken with caution.

Acoustic lure

The proportion of bats captured in each family from the study area was interesting. The Hipposideridae were the most common bats captured in the control traps whereas the Vespertilionidae were the most common when the lure technique was applied. This reflects the situation in the forest where the Hipposideridae are the most common bat family in the area and is normally captured in large numbers in harp traps set across trails (P. Soisook, unpublished data). Interestingly, very few of Rhinolophidae were captured during the trapping sessions. One of the possible reasons is that the rhinolophids are less common in the study area which is Malaysian type lowland evergreen forest in which no caves were observed around the trapping sites. Moreover, many of Rhinolophidae were captured before dark (before 1830 hrs) whereas this experiment started post 1830 hrs. Therefore, perhaps they were excluded from the data set, especially as they seemed to avoid using the foraging paths after this time (P. Soisook, personal observation). Therefore this experiment is in contrast with the capture data in Krau Wildlife Reserve, peninsular Malaysia by Kingston *et al.* (2003) the result of which showed that Rhinolophidae were the most common bats captured in both mist nets and harp traps.

The result from acoustic lure experiment strongly suggests that the acoustic lure technique can increase trapping success of *Murina.* Although it is known to forage in highly cluttered space in forest habitats the control forest traps captured only one individual of *Murina.* This low capture rate is as expected from the normal harp trap, with the size of only 1.8 x 2.0 m, and set in forest understorey where the flight path of bats is impossible to predict. The difference between these control forest traps and the ones that were also set in the forest but with the AutoBat, shows the efficacy of this technique in attracting *Murina* to harp traps and increasing trapping success.

It is very interesting to note that the Woolly bats *Kerivoula* spp. were also usually captured, in equal numbers to the *Murina* when the acoustic lure was deployed (Fig. 5-8). As in *Murina*, bats in the genus *Kerivoula* are also known to be common in the forest understorey and forage in highly cluttered space (Francis, 1990; Kingston *et al.*, 1999, 2003). Their echolocation call characters are very similar to those of *Murina* but exhibit an average higher start frequency (Kingston *et al.*, 1999; Hughes *et al.*, 2011; P. Soisook, unpublished data). In contrast, the only known social calls of this genus, *K. pellucida* recorded from peninsular Malaysia (Kingston *et al*., 2000), were completely different from the social calls of *Murina* described in this study. Although in some cases, social calls of a genus of bat, i.e. *Myotis*, showed that it can also attracted other groups of bat such as *Pipistrellus* very well (P. Soisook, personal observation). In this case, it is still uncertain that whether these particular *Kerivoula* were responding to the social calls of *Murina*, or whether they were just very common in forest area.

Although the social calls of *M. peninsularis* were the most effective for luring *Murina*, individuals of *Murina* that entered the traps were not specifically correlated with their own social calls that were being played. As it increases the capture rate up to three times more than normal harp trapping, application of this technique is recommended with future surveys of *Murina* to reduce field working time. However, the use of the social calls in acoustic lure must be undertaken with care. It is currently not known how many other bat species at the luring site have been disturbed by these calls. Using this technique only once per site is strongly recommended to reduce potential disturbance to other bat population within the area.

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APPENDIX

APPENDIX 1. List of *Murina* specimens examined.

***M.* sp. nov. [A]**

– ***Thailand***: ♂PSUZC-MM2010.22 (holotype), ♀PSUZC-MM2010.23 (paratype), Rajjaprabha Dam, Ban Takhun, Surat Thani, S. Thailand; ♂PSUZC-MM2012.7 (paratype), Ton Tae Waterfall, Pa Lien, Trang, S. Thailand; ♀ROM110439, Khao Nor Chuchi Reserve (=Khao Pra Bang Kram WS.), Krabi, S. Thailand; ♂PSUZC-MM 2013.15 (paratype), Wang Tai Nan Waterfall, Manang, Satun, S. Thailand; ♂PSUZC-MM2012.8, Ban Ton St., Khao Bantad WS, Phattalung, S. Thailand; ♂PSUZC-MM2008.3, Yaroi Waterfall, Taleban NP., Satun, S. Thailand; ♂PSUZC-MM2007.350, Ban Vang Pha, Songkhla, S. Thailand; ♀PSUZC-MM2011.42, Rajjaprabha Dam, Ban Takhun, Surat Thani, S. Thailand; ♀PSUZC-MM2007.154, Makling Waterfall, Rattaphum, Songkhla, S. Thailand.

– ***India*:** ♂HZM.14.35312 (holotype of *M.* sp. nov [A] subsp. nov.), Great Nicobar Island, Nicobar Islands, India; ♂HZM.12.35277 (paratype), Tillanchong, Nicobar Islands, India; ♂HZM.13.35278, Camorta, Nicobar Islands, India; ♀HNHM.2004.13.1 (paratype), Bompuka, Nicobar Islands, India; ♀HZM.15.35319, Trinket, Nicobar Islands, India (paratype).

M. cyclotis

– ***India***: ♂BMNH.9.4.4.4 (holotype), Darjeeling, NE. India; ♂BMNH.16.3.25.28, Gopaldara, Darjeeling, NE. India; ♂BMNH.16.3.25.29, Pashok, Darjeeling, NE. India; ♂BMNH.20.6.24.1, Teesta Valley, West Bengal, NE. India.

– ***Sri Lanka***: ♂BMNH.31.9.4.2 (holotype of *M. eileenae*); ♂BMNH.59.5.31.63; ♂BMNH.66.5543; ♂BMNH.72.42.56, Mousakande, Gammaduwa, Sri Lanka;

– ***Nepal*:** ♂HNHM.98.7.3, Island Jungle Resort, Chitwan NP, Nepal.

– ***Myanmar***: ♀HZM.17.35961, Madanyan Forest, Manse Township, Kachin, N. Myanmar; ♀BMNH.50.484, Sumka Uma, Kachin, N. Myanmar; ♀BMNH.16.3.26.3; ♀BMNH.16.3.26.4, Chin Hills, W. Myanmar; ♀BMNH.16.3.26.89, 50 miles from Kindat, Sagaing, W. Myanmar.

– ***China***: ♂field number B050023, Hainan Island, China.

– ***Vietnam***: ♂NF.160906.4; ♂NF.170906.5; ♀NF.030706.6; ♀NF.170906.4; ♀NF.230706.4, Kim, Hy Nature Reserve, Bac Kan, N. Vietnam; HZM.31760, Ke Bang, Quang Binh, C. Vietnam; ♂HNHM.98.3.3, Pac Ban Village, Tuyen Quang, N. Vietnam; ♂HNHM.2000.84.3, Ben En NP., Thanh Hoa, Vietnam; ♂HNHM.2010.42.3; ♂field number T.291107.3; ♀field number T.241107.2; ♀field number T.251107.1, Son La, N. Vietnam; ♂field number T.050808.8, Bai Tu Long NP, Quang Ninh, N. Vietnam; ♂field number T.120806.2; ♂field number T.230408.1; ♀field number T.220908.1, Cat Ba Island, Hai Phong, N. Vietnam; ♂field number 11, Than Sa, Thai Nguyen, N. Vietnam; ♂field number B46, Pu Hoat NR., Nghe An, C. Vietnam; ♀HZM.1.30708; ♀HNHM.208.23.1, Cuc Phong NP., Ninh Binh, N. Vietnam; ♀HZM.3.31526; ♀HZM.9.31777, Pu Mat NP., Nghe An, C. Vietnam; ♀BMNH.1997.384, Na Hang NR., Tuyen Quang, N. Vietnam; ♀field number T85; ♀field number T03; ♀field number T.270308.2, Me Linh, Vinh Phuc, N. Vietnam; ♀HNHM.2007.27.7; ♀NTS1597, Ba Be NP., Bac Kan, N. Vietnam; ♀field number T.010908.10; ♀field number T.010908.6, Tam Dao, Vinh Phuc, N. Vietnam; ♀field number T.210708.2; ♀field number T.260607.2; ♀field number T.270607.1; ♀PSUZC-MM.2011.54, Phuong Vien, Phu Tho, N. Vietnam; ♀field number T.290708.6, Xuan Son, Phu Tho, N. Vietnam; ♀field number 06, Tamtri, Tam Ky, Quang Nam, C. Vietnam.

– ***Laos***: ♂BMNH.1999.854, Ban Vieng, Khammouan, C. Laos; ♀BMNH.1999.51, Tham Houay Si, 6.5 km SW. of Ban Vieng, Khammouan, C. Laos; ♀field number BD100320.2; ♀field number BD100320.5, Vang Vieng, Vientiane, C. Laos; ♀ROM MAM 110673, Phou Khao Kouay, Vientiane, C. Laos; ♂SMF85753, Ban Keng Bit, Nam Kading, Khammouan, C. Laos; ♀MHNG.1926.033, Sopkhang, Phongsaly, N. Laos;

– ***Thailand***: ♂BMNH.82.164, Doi Inthanon NP., Chom Thong, Chiang Mai, N. Thailand; ♂BMNH.78.2383, Tham Tab Tao, Fang, Chiang Mai, N. Thailand; ♂BMNH.82.165, Doi Pha Hom Pok, Fang, Chiang Mai, N. Thailand; ♀PSUZC-MM2011.32, Chiangdao WS, Chiang Mai, N. Thailand; ♀THNHM-M-821, Klong Lan NP., Kampangphet, NW. Thailand; ♂PSUZC-MM2006.179; ♀PSUZC-MM2006.178, Phu Suan Sai NP., Na Haew, Loei, NE. Thailand; ♂TISTR54-7170, Phu Rua, Loei, NE. Thailand; ♂THNHM-M-735, Mo Sing To, Khao Yai NP.,

Nakhon Ratchasima, NE. Thailand; ♀THNHM-M-775, Dong Sua Parn, Khao Yai NP., Nakhon Ratchasima, NE. Thailand; ♂PSUZC-MM.2005.203, Klong Klang Khao Ang Ru Nai WS., Chacherngsao, SE. Thailand.

– ***Cambodia***: ♂HNHM.2007.49.10, Phnom Samkos, Pursat, W. Cambodia; ♂HNHM.2006.34.38; ♂HNHM.2005.81.33; ♀HNHM.2005.81.48, Seima BCA, Mondol Kiri, E. Cambodia; ♀HNHM.2006.34.2, Bokor NP., Kampot, SW. Cambodia.

M. fionae

– ***Vietnam***: ♂field number 025; ♂field number 12; ♂field number 18, Tam Tri, Tam Ky, Quang Nam, C. Vietnam; ♂HZM.8.31764; ♂HZM.6.31759, ♂HZM.7.31762, Phong Nha, C. Vietnam; ♂HNHM.2007.50.3; ♀HNHM.2007.50.4, Huong Hoa Nature Reserve, Quang Tri, C. Vietnam; ♀HZM.10.31776, Pu Mat NP., Nghe An, C. Vietnam; ♀HZM.11.32353, Kon Cha Rang Nature Reserve, Gai Lai, C. Vietnam; ♀HZM.4.31761, Ke Bang, Quang Binh, C. Vietnam; ♀HNHM.2008.23.7, Pu Huong, Nghe An, C. Vietnam; ♀ROM MAM 111292, Ngoc Linh Nature Reserve, 10 Km SW Nuoc Xa, Quang Nam, C. Vietnam

– ***Cambodia***: ♀HNHM.2005.81.16, Seima BCA, Mondol Kiri, E. Cambodia.

M. peninsularis

– ***Thailand***: ♂PSUZC-MM.2012.9; ♂PSUZC-MM2012.11; ♂PSUZC-MM2012.12; ♀PSUZC-MM2012.14, Khao Pra Bang Kram WS, Klong Tom, Krabi, S. Thailand; ♀PSUZC-MM2007.349, Huay Lek, Khao Nan NP., Nop Pitam, Nakhon Sithammarat, S. Thailand; ♂PSUZC-MM 2011.29, Khao Pu Khao Ya NP., Phattalung, S. Thailand; ♂PSUZC-MM2007.348, Kachong, Khao Bantad WS., Trang, S. Thailand; ♂PSUZC-MM2006.160, Taleban NP., Satun, S. Thailand; ♂PSUZC-MM2008.137, Talow Udang St., Tarutao Island, Satun, S. Thailand; ♂PSUZC-MM2012.10; ♂PSUZC-MM2012.12; ♀PSUZC-MM2012.15; ♀PSUZC-MM2012.16, Pha Dum Waterfall, Ton Nga Chang WS, Songkhla, S. Thailand; ♂PSUZC-MM2007.336; ♂PSUZC-MM2011.30; ♀PSUZC-MM2006.120; ♀PSUZC-MM2012.155; ♀PSUZC-MM2012.156, Ton Nga Chang WS, Songkhla, S. Thailand;

♂PSUZC-MM2012.13; ♂PSUZC-MM2012.196; ♀PSUZC-MM2012.212; ♀PSUZC-MM2012.213, Hala-Bala WS., Wang, Narathiwat, S. Thailand.

– ***Malaysia***: ♂BMNH.64.771 (holotype); ♀BMNH.64.772 (paratype), Ulu Chemperoh, Janda Baik, Pahang, peninsular Malaysia; ♂BMNH.73.630; ♀BMNH.67.1607, Gunong Benom Base Camp, Bentong, Pahang, peninsular Malaysia; ♀TK153526, Taman Negara, Pahang, peninsular Malaysia; ♂CMF920703-03; ♂CMF920705-03, Kuala Lampat, Pahang, peninsular Malaysia; ♀S401006, Krau Wildlife Reserve, Pahang, peninsular Malaysia; ♀BMNH.1880.744, Pinang, peninsular Malaysia; ♀BMNH.75.1294, Sungei Relembany Camp, Ulu Setiu, Besut, Trengganu, peninsular Malaysia; ♂BMNH.73.631, Pahang, peninsular Malaysia; ♂BMNH.68.845, Batu Pahat, Kangar, Perlis, peninsular Malaysia; ♂BMNH.64.773, Fraser Hill, Selangor, peninsular Malaysia; ♂TK172744, Lojing Highlands, Kelantan, peninsular Malaysia; ♂BMNH.78.1543, Melinau, Gunung Mulu NP., Sarawak, Borneo; ♂BMNH.82.556; ♀BMNH.84.2019; ♀TK168706, Sepilok, Sabah, Borneo; ♂BMNH.84.2020, Lumerau, Sabah, Borneo.

– ***Indonesia***: ♂MZB35006; ♂MZB35007; ♀MZB35885; ♀MZB35886, Way Canguk, Bukit Barisan Selatan NP., Lampung, Sumatra; ♂MZB23925; ♂MZB31945, Marawi, Kalimantan, Borneo; ♀HZM.18.36541, Tanjung Putting National Park, C. Kalimantan, Borneo; ♀MZB29315, Nusa Tenggara Barat, Lombok.

M. huttoni

– ***India***: ♂BMNH.79.11.21.685 (holotype), Dehra, Kumaon, Uttar Pradesh; ♂BMNH.14.7.10.32, Khati, Kumaon, Uttar Pradesh; ♂BMNH.16.3.25.25, Tong Song, Darjeeling

– ***China*****:** ♂BMNH.8.8.11.6 (holotype of *M. h. rubella)*, Tokien; ♂BMNH.75.11.3.19, Tibet.

– ***Vietnam*****:** ♂HZM.2.32351, ♂HZM.3.32352, Kon Ka Khin Nature Reserve, Gai Lai C. Vietnam.

– ***Thailand***: ♂BMNH.79.1418, Doi Rei, Chiang Mai; PSUZC-MM2011.33, Khun Huay Mae Kok, Chiangdao WS., Chiang Mai.

– ***Malaysia***: ♂BMNH.67.1606, near Camp 4, Gunong Benom, Pahang.

M. harrisoni

– ***Cambodia***: ♀HZM.1.36316 (holotype), O Tuk Chehn, Kirirom NP., Kompong Speu.

– ***Vietnam*:** ♂HNHM.2010.42.1, Coma Nature Reserve, Thuan Chau, Son La; ♂field number NF.280707.1, ♂field number NF.301006.1, ♀HZM.2.38178 (holotype of *M. tiensa*), Kim Hy Nature Reserve, Bac Kan, N. Vietnam; ♀HZM.1.31525, Pu Mat Reserve, Nghe An, C. Vietnam; ♀HNHM.2009.6.2, Tam Dao, Vinh Phuc, N. Vietnam; ♀field number T.220408.2, Cat Ba NP., Hai Phong, N. Vietnam

M. annamitica

– ***Thailand***: ♂PSUZC-MM2011.31 (field number PS110627.12), Khun Mae Ngai, Chiangdao WS., Chiangdao, Chiang Mai

M. aenea

– ***Thailand***: ♂PSUZC-MM2012.211, ♀PSUZC-MM2005.6, ♀PSUZC-MM2012.209, ♀PSUZC-MM2012.210, Halabala Wildlife Research Station, Wang, Narathiwat; ♀PSUZC-MM2005.7, Boripatr Waterfall, Ton Nga Chang WS., Rattaphum, Songkhla.

– ***Malaysia***: ♂BMHN.64.770, Ulu Chemperoh, Janda Baik, Pahang.

– ***Indonesia*:** ♂MZB30648, Lampunat, Marawi, Kalimantan.

M. rozendaali

– ***Thailand***: ♂PSUZC-MM2012.206, ♂PSUZC-MM2012.207, ♂PSUZC-MM2012.208, ♂field number PS130824.3, ♂field number PS130824.4, ♂field number PS130824.6, ♂field number PS130824.7, Halabala Wildlife Research Station, Wang, Narathiwat.

– ***Malaysia***: ♂BMNH.83.360 (holotype), ♀BMNH.84.2025, Gomantong, Sabah; ♂BMNH.1999.300, ♂BMNH.1999.301, Krau Wildlife Reserve, Pahang; ♂TTU-M 108241, Park Mongis Substation, Kinabalu NP., Sabah.

– ***Indonesia***: ♂MZB26735, Suatan, Kaltim, Kalimantan; ♂MZB34991, Way Canguk, Lampung, Sumatra.

M. leucogaster

– *China*: ♂PSUZC-MM2013.18, Yi Chun, Hei Long Jiang.

– *India*: ♀BMNH.16.3.25.111, Pashok, Darjeeling.

– *Vietnam*: ♀HZM.1.31758, Pu Mat NP., Nghe An, C. Vietnam.

M. jaintiana

– *Myanmar*: ♂BMNH.16.3.26.5, Chin Hill, W. Myanmar.

***M.* sp. nov. [B]**

– ***Thailand*:** ♂ PSUZC-MM2012.214, ♀ PSUZC-MM2012.215, Second bridge trail, Bala Forest, Halabala WS, Wang, Narathiwat.

M. eleryi

– ***Thailand*:** ♂BMNH.82.162 (labeled as *M. aurata*), Doi Inthanon, Chom Thong, Chiang Mai.

– ***Vietnam***: ♀HZM.1.39006 (paratype), Kim Hy Nature Reserve, An Tunh Commune, Na Rai District, Bac Kan Province; ♀field number T120 (ROM field no.29013), exact locality not available; ♂field number T.241107.1, Muong Do Commune, Phu Yen District, Son La Province.

M. feae

– ***Myanmar***: ♂BMNH.16.3.26.85, ♂BMNH.16.3.26.86, ♂BMNH.16.3.26.86, ♀BMNH.16.3.26.88, 50 miles west of Kindat, Chindwin; ♂BMNH.50.486, Nam Tamai, Kachin; ♀HZM.3.39984, ♀HZM.2.35960, Nanti Hill Forest, Bhamo Township, Kachin.

– *Vietnam*: ♂field number NF.050207.1, ♀field number NF.071206.2, Kim Hy Nature Reserve, Bac Kan; ♀field number T.270607.3, Pu Mo Forest, Na Don Village, Phuong Vien Commune, Cho Don, Bac Kan; ♀HZM.1.31524, ♀HZM.1.31780, Pu Mat NP., Nghe An, C. Vietnam; ♂field number B13, ♀011-T18 (T122), ♀field number VN 04-112, ♀field number XS-47, exact locality not known.

– ***Thailand***: ♂BMNH.82.163, BMNH.82.165, Doi Inthanon NP., Chom Thong, Chiang Mai; ♂PSUZC-MM2006.180, ♀PSUZC-MM2006.7, Phu Suan Sai NP., Na Haew, Loei; ♂PSUZC-MM2011.26, ♀PSUZC-MM2011.25, Khun Mae Ngai, Chiangdao WS., Chiangdao, Chiang Mai; ♂PSUZC-MM2011.27, Khun Huay Mae Kok, Chiangdao WS., Chiangdao, Chiang Mai.

– ***Cambodia***: ♀HNHM.2005.81.36, ♀HNHM.2005.81.50, Seima BCA, Mondulkiri.

M. walstoni

– ***Vietnam***: ♀HNHM.2008.23.15, Yok Don NP., Dak Lak; ♂field number VN014-S102, ♀field number B-16, exact locality not known.

– ***Laos***: ♀BMNH.1999.50, Tham Houay Si, 6.5 km SW. of Ban Vieng, Gnommalat District, Khammouan.

– ***Thailand***: ♂PSUZC-MM2013.17 (field number PS130515.1), Khun Nam Yen, Mae Wong NP., Klong Lan, Kamphaeng Phet; ♀PSUZC-MM2006.181 (field number SB060519.3), Pha Kor Waterfall, Phu Suan Sai NP., Na Haew, Loei.

– ***Cambodia***: ♀HNHM.2010.20.1 (holotype), Veun Sai Protected Forest, Veun Sai District, Ratanakiri Province.

M. beelzebub

– ***Vietnam*****:** ♂HZM.3.32053, Kon Ka Khin Nature Reserve, Gai Lai C. Vietnam.

M. suilla

– ***Thailand***: ♂PSUZC-MM2011.44, Phato Watershed Management St., Phato, Chumphon; ♂PSUZC-MM2011.24, Kra Buri NP., Ranong; ♂PSUZC-MM2011.23, ♂PSUZC-MM 2011.45, Rajjaprabha Dam, Ban Takhun, Surat Thani; ♂PSUZC-MM2008.55, Mai Ngam Beach, Surin Island, Phang Nga; ♂PSUZC-MM2007.17, Khao Chong, Khao Bantad WS., Trang; ♂PSUZC-MM2011.22, Khao Bantad WS., Trang; ♂PSUZC-MM2012.2, ♂PSUZC-MM 2012.4, ♂PSUZC-MM 2012.5, Khao Pra Bang Kram WS., Klong Tom, Krabi; ♂PSUZC-MM2005.13, ♂PSUZC-MM 2012.1, ♂PSUZC-MM 2012.3, ♂PSUZC-MM 2012.6, Ton Nga Chang

WS., Songkhla; ♂PSUZC-MM2011.43, Khuan Khao Wang, Rattaphum, Songkhla; ♂PSUZC-MM2006.158, ♂PSUZC-MM 2007.151, ♂PSUZC-MM 2008.138, ♂PSUZC-MM 2009.42, ♂PSUZC-MM 2009.43, Tarutao Island, Satun; ♂PSUZC-MM2005.5, Namsai St., Halabala WS., Yala; ♂PSUZC-MM2005.4, ♀field number PS120125.4, Halabala Wildlife Research Station, Wang, Narathiwat; ♀PSUZC-MM2011.21, Khao Pu Khao Ya NP., Phattalung.

– ***Malaysia***: ♂field number FSL131, Taman Negara, Pahang; ♂BMNH.84.2017, Silau Silau Trail, Mt. Kinabalu, Sabah; ♀BMNH.84.2018, Segarong, Sabah; ♀BMNH.84.2012, Sepilok, Sabah; ♀TTU-M 108216 (original labeled as *M. rozendaali*), Krau Wildlife Reserve, Pahang.

– ***Indonesia***: ♂BMNH.79.11.15.15, Mt. Willis, Java; ♂MZB34699, ♀MZB34998, Way Canguk, Lampung, Sumatra; ♀BMNH.5.354 (holotype of *balstoni*), Tasimalaja, Preangar, Java; ♀HNHM.200.13.2, Tjidjagoeng, West Java.

APPENDIX 2. List of genetic samples analysed.

Catalog Number	Field number	Species	Process ID	State/Province	Country
ROM MAM 118232	AGS 980322-67	*Harpiocephalus harpia*	ABBM266-05	Houaphan	Laos
EBD 25700	AGS 980404-39	*Harpiocephalus harpia*	ABBM320-05	Louangphrabang	Laos
ROM MAM 110692	CMF 980215-10	*Harpiocephalus harpia*	BM071-03	Khammouan	Laos
SMF 85763	CMF 950118-07	*Harpiocephalus harpia*	ABBM388-05	Khammouan	Laos
INECOL M0064	AGS 980427-33	*Harpiocephalus harpia*	ABBM342-05	Louang Namtha	Laos
ROM MAM 110684	CMF 980213-11	*Harpiocephalus harpia*	BM086-03	Khammouan	Laos
ROM MAM 110667	CMF 980128-07	*Harpiocephalus harpia*	BM035-03	Khammouan	Laos
ROM MAM 114934	F46241	*Harpiocephalus harpia*	BM379-04	Hunan	China
ROM MAM 112344	F48200	*Harpiocephalus harpia*	BM396-04	Lang So'n	Vietnam
ROM MAM 118368	AGS 980427-32	*Harpiocephalus harpia*	ABBM341-05	Louang Namtha	Laos
EBD 25707	AGS 980322-41	*Harpiocephalus harpia*	ABBM258-05	Houaphan	Laos
ROM MAM 118236	AGS 980322-73	*Harpiocephalus harpia*	ABBM269-05	Houaphan	Laos
MZB31483	-	*Harpiocephalus harpia*	BTSEA009-13	Sumatra	Indonesia
-	PS120905.2	*Harpiocephalus harpia*	BTSEA025-13	Narathiwat	Thailand
ZMMU S-180001	-	*Harpiola isodon*	SKBPA030-06	Lam Dong	Vietnam
PSUZC-MM2012.211	PS121019.1	*Murina aenea*	BTSEA033-13	Narathiwat	Thailand
PSUZC-MM2012.210	PS121010.2	*Murina aenea*	BTSEA032-13	Narathiwat	Thailand
ROM MAM 113106	F50312	*Murina aenea*	ABBM458-05	Johor	Malaysia
ROM MAM 117935	CMF 960518-20	*Murina aenea*	BM314-04	Sabah	Malaysia
ROM MAM 113014	F50220	*Murina aenea*	BM421-04	Johor	Malaysia
PSUZC-MM2011.31	PS110627.12	*Murina annamitica*	BTSEA023-13	Chiang Mai	Thailand
ROM MAM 118394	AGS 980429-16	*Murina annamitica*	ABBM351-05	Louang Namtha	Laos
ROM MAM 106466	CMF 960418-04	*Murina annamitica*	BM319-04	Khammouan	Laos
ROM MAM 106467	CMF 960418-05	*Murina annamitica*	ABBM404-05	Khammouan	Laos
ROM MAM 106492	CMF 960427-02	*Murina annamitica*	BM308-04	Khammouan	Laos
ROM MAM 106468	CMF 960418-06	*Murina annamitica*	BM316-04	Khammouan	Laos
ROM MAM 116181	F47407	*Murina chrysochaetes*	ABBM452-05	Guangxi	China
ROM MAM 110469	CMF 970512-05	*Murina cyclotis*	ABBM154-05	Attapu	Laos
EBD 24967	AGS 980322-34	*Murina cyclotis*	ABBM255-05	Houaphan	Laos
HZM 17.36447	BRL16 JV1	*Murina cyclotis*	ABBM421-05	Tamil Nadu	India
ROM MAM 110715	CMF 980228-54	*Murina cyclotis*	BM159-03	Champasak	Laos
ROM MAM 110673	CMF 980203-44	*Murina cyclotis*	BM056-03	Vientiane	Laos
ROM MAM 106538	CMF 960505-22	*Murina cyclotis*	BM110-03	Khammouan	Laos
ROM MAM 116482	F47569	*Murina cyclotis*	ABBM461-05	Guangxi	China
ROM MAM 116059	F47285	*Murina cyclotis*	ABBM448-05	Guangxi	China
ROM MAM 116053	F47279	*Murina cyclotis*	ABBM447-05	Guangxi	China
ROM MAM 110460	CMF 970505-06	*Murina cyclotis*	ABBM119-05	Attapu	Laos
ROM MAM 112362	F48218	*Murina cyclotis*	BM399-04	Lang So'n	Vietnam
ROM MAM 112345	F48201	*Murina cyclotis*	ABBM456-05	Lang So'n	Vietnam
SMF 85753	CMF 950119-07	*Murina cyclotis*	ABBM389-05	Khammouan	Laos
EBD 24969	AGS 980329-22	*Murina cyclotis*	ABBM298-05	Louangphrabang	Laos
EBD 24968	AGS 980329-21	*Murina cyclotis*	ABBM297-05	Louangphrabang	Laos
ROM MAM 116476	F47563	*Murina cyclotis*	ABBM460-05	Guangxi	China
ROM MAM 116364	F47451	*Murina eleryi*	ABBM459-05	Guangxi	China
EBD 25726	AGS 980406-20	*Murina eleryi*	ABBM325-05	Houaphan	Laos
ROM MAM 111300	F44530	*Murina eleryi*	ABBM445-05	Quang Nam	Vietnam
ROM MAM 116182	F47408	*Murina eleryi*	ABBM453-05	Guangxi	China

APPENDIX 2. (Continued)

Catalog Number	Field number	Species	Process ID	State/Province	Country
ROM MAM 106411	CMF 960409-13	*Murina eleryi*	BM315-04	Khammouan	Laos
ROM MAM 106478	CMF 960420-04	*Murina eleryi*	BM304-04	Khammouan	Laos
ROM MAM 116071	F47297	*Murina eleryi*	ABBM449-05	Guangxi	China
ROM MAM 111308	F44538	*Murina eleryi*	ABBM446-05	Quang Nam	Vietnam
ROM MAM 111286	F44516	*Murina eleryi*	BM364-04	Quang Nam	Vietnam
PSUZC-MM2011.27	PS110622.1	*Murina feae*	BTSEA021-13	Chiang Mai	Thailand
PSUZC-MM2011.25	PS110627.4	*Murina feae*	BTSEA022-13	Chiang Mai	Thailand
ROM MAM 118415	AGS 980508-19	*Murina feae*	ABBM363-05	Vientiane	Laos
ROM MAM 110482	CMF 970518-04	*Murina feae*	ABBM185-05	Attapu	Laos
ROM MAM 106379	CMF 960406-10	*Murina feae*	BM309-04	Khammouan	Laos
ROM MAM 106380	CMF 960406-11	*Murina feae*	ABBM396-05	Khammouan	Laos
ROM MAM 106386	CMF 960407-08	*Murina feae*	BM320-04	Khammouan	Laos
ROM MAM 106475	CMF 960419-02	*Murina feae*	BM307-04	Khammouan	Laos
ROM MAM 106477	CMF 960420-03	*Murina feae*	ABBM405-05	Khammouan	Laos
EBD 25751	AGS 980322-50	*Murina feae*	ABBM260-05	Houaphan	Laos
HZM 1.31524	-	*Murina feae*	ABBM430-05	Nghe An	Vietnam
ROM MAM 111285	F44515	*Murina feae*	BM363-04	Quang Nam	Vietnam
ROM MAM 106382	CMF 960407-03	*Murina fionae*	BM318-04	Khammouan	Laos
ROM MAM 111292	F44522	*Murina fionae*	BM366-04	Quang Nam	Vietnam
ZMMU S-173401	Bd28	*Murina harpioloides*	BM611-04	Lam Dong	Vietnam
ROM MAM 107749	F42732	*Murina harrisoni*	ABBM443-05	Dac Lac	Vietnam
ROM MAM 107750	F42733	*Murina harrisoni*	ABBM444-05	Dac Lac	Vietnam
ROM MAM 107739	F42722	*Murina harrisoni*	BM536-04	Dac Lac	Vietnam
EBD 24974	AGS 980329-19	*Murina harrisoni*	ABBM296-05	Louangphrabang	Laos
ROM MAM 116468	F47555	*Murina harrisoni*	ABBM463-05	Guangxi	China
ROM MAM 116463	F47550	*Murina harrisoni*	ABBM462-05	Guangxi	China
ZMMU S-175150	HB-12	*Murina huttoni*	BM624-04	Dien Khanh	Vietnam
ROM MAM 106426	CMF 960411-03	*Murina huttoni*	BM311-04	Khammouan	Laos
ROM MAM 114938	F46245	*Murina huttoni*	BM380-04	Hunan	China
ROM MAM 114969	F46276	*Murina huttoni*	BM390-04	Hunan	China
ROM MAM 106419	CMF 960410-01	*Murina huttoni*	BM306-04	Khammouan	Laos
ROM MAM 116150	F47376	*Murina leucogaster*	ABBM450-05	Guangxi	China
ROM MAM 116177	F47403	*Murina leucogaster*	ABBM451-05	Guangxi	China
PSUZC-MM2011.29	UP100623.12	*Murina peninsularis*	BTSEA015-13	Phatthalung	Thailand
PSUZC-MM2012.9	PS120504.8	*Murina peninsularis*	BTSEA016-13	Krabi	Thailand
PSUZC-MM2012.196	PS120905.1	*Murina peninsularis*	BTSEA047-13	Narathiwat	Thailand
PSUZC-MM2012.14	PS120507.3	*Murina peninsularis*	BTSEA020-13	Krabi	Thailand
PSUZC-MM2012.11	PS120506.11	*Murina peninsularis*	BTSEA019-13	Krabi	Thailand
PSUZC-MM2012.15	PS120206.11	*Murina peninsularis*	BTSEA037-13	Songkhla	Thailand
PSUZC-MM2012.13	PS120123.6	*Murina peninsularis*	BTSEA024-13	Narathiwat	Thailand
PSUZC-MM2012.213	PS121008.2	*Murina peninsularis*	BTSEA030-13	Narathiwat	Thailand

APPENDIX 2. (Continued)

Catalog Number	Field number	Species	Process ID	State/Province	Country
PSUZC-MM2012.16	PS120205.6	*Murina peninsularis*	BTSEA035-13	Songkhla	Thailand
PSUZC-MM2012.12	PS120205.8	*Murina peninsularis*	BTSEA036-13	Songkhla	Thailand
S401006	MBCRUA0243	*Murina peninsularis*	ABBSI080-05	Pahang	Malaysia
CMF920705-03	CMF 920705-03	*Murina peninsularis*	BM485-04	Pahang	Malaysia
CMF920703-03	CMF 920703-03	*Murina peninsularis*	BM486-04	Pahang	Malaysia
MZB34991	-	*Murina rozendaali*	BTSEA003-13	Sumatra	Indonesia
MZB35884	-	*Murina rozendaali*	BTSEA001-13	Sumatra	Indonesia
PSUZC-MM2012.206	PS121007.1	*Murina rozendaali*	BTSEA027-13	Narathiwat	Thailand
PSUZC-MM2012.208	PS121006.1	*Murina rozendaali*	BTSEA026-13	Narathiwat	Thailand
PSUZC-MM2012.7	PS120111.2	*Murina* sp. nov. [A]	BTSEA011-13	Trang	Thailand
PSUZC-MM2012.8	PS120313.6	*Murina* sp. nov. [A]	BTSEA013-13	Trang	Thailand
ROM 110439	AGS 970412-01	*Murina* sp. nov. [A]	ABBM062-05	Krabi	Thailand
PSUZC-MM2012.214	PS120928.1	*Murina* sp. nov. [B]	BTSEA028-13	Narathiwat	Thailand
MZB34697	-	*Murina suilla*	BTSEA008-13	Sumatra	Indonesia
-	PS121008.1	*Murina suilla*	BTSEA031-13	Narathiwat	Thailand
MZB34998	-	*Murina suilla*	BTSEA007-13	Sumatra	Indonesia
PSUZC-MM2012.4	PS120505.1	*Murina suilla*	BTSEA017-13	Krabi	Thailand
PSUZC-MM2012.6	PS120110.8	*Murina suilla*	BTSEA010-13	Trang	Thailand
PSUZC-MM2012.2	PS120506.8	*Murina suilla*	BTSEA018-13	Krabi	Thailand
ROM MAM 117940	CMF 960523-38	*Murina suilla*	ABBM409-05	Sabah	Malaysia
ROM MAM 117936	CMF 960519-06	*Murina suilla*	BM300-04	Sabah	Malaysia
SMF 83723	CMF 950630-07	*Murina suilla*	ABBM394-05	Sabah	Malaysia
ROM MAM 110444	CMF 970426-16	*Murina walstoni*	ABBM079-05	Attapu	Laos
ROM MAM 110450	CMF 970430-05	*Murina walstoni*	ABBM086-05	Attapu	Laos
ROM MAM 110708	CMF 980227-07	*Murina walstoni*	BM170-03	Champasak	Laos
ROM MAM 110719	CMF 980228-71	*Murina walstoni*	BM210-03	Champasak	Laos
ROM MAM 110445	CMF 970427-01	*Murina walstoni*	ABBM081-05	Attapu	Laos
ROM MAM 110724	CMF 980228-111	*Murina walstoni*	BM163-03	Champasak	Laos
SMF 85758	CMF 950203-11	*Murina walstoni*	ABBM391-05	Vientiane	Laos
SMF 85757	CMF 950203-10	*Murina walstoni*	ABBM390-05	Vientiane	Laos

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