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Original article

Recent remarkable records reveal that Phia Oac-Phia Den Nature Reserve is a priority area for bat conservation in Northern Vietnam

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ABSTRACT

Three short field surveys were conducted in the Phia Oac-Phia Den Nature Reserve to assess the species diversity and endemism of local bat fauna. In combination with data from a previous study, 24 bat species of 5 families, representing > 20% of the national bat diversity, were recorded in the study area. The occurrence of several bat species restricted to montane forests, that is, *Murina chrysochaetes*, *Pipistrellus coromandra*, and a potentially new species *Rhinolophus* cf. *macrotis*, suggests that Phia Oac is an important area for bat conservation in Vietnam and thus more comprehensive studies need to be performed.

Introduction

In recent years, bat research in Vietnam has greatly improved, with a rapid increase in the total number of recognized species from 85 (Hendrichsen et al 2001) to nearly 120 (Kruskop 2013; Son et al 2013, 2015; Tu et al 2015a, 2015b). Accordingly, Vietnamese bats represent more than one third of the national mammalian fauna and > 10% of global bat diversity (Can et al 2008; Kruskop 2013; Simmons 2005). However, the overall diversity, patterns of distribution and level of endemism of local bat assemblages in Vietnam is largely unknown because many species are recently regarded as cryptic complexes (Francis et al 2010), and many regions have not been, or only improperly, surveyed (Furey et al 2010; Kruskop 2013). The relatively undisturbed montane forests found at high-elevation areas across the country are one of the most important habitats for biodiversity and endemism in Vietnam (Averyanov et al 2003; MacKinnon 1997; Rundel 1999). Although preliminary surveys suggest that these forest areas are home to a number of endemic and still undescribed new bat species (Kruskop and Eger 2008; Kruskop and Shchinov 2010; Son et al 2015; Tu et al 2015a), the systematic exploration of these priority areas—focusing on small mammals, both volant and nonvolant—is still in its infancy. To partly fill this gap in our knowledge, in 2014 and 2015, three field surveys (18–23 June 2014, 20–25 October 2014, and 24–27 April 2015) were carried out in Phia Oac-Phia Den Nature Reserve in the northeastern mountains of Vietnam.

The Nature Reserve (hereafter named as Phia Oac), centered at 22°32', 22°40'N and 105°49', 105°57'E, lies in Nguyen Binh District, Cao Bang Province, Vietnam, and covers an area of 10,245.6 ha; the elevation is between approximately 700 m and 2,000 m above sea level (a.s.l.; Figure 1) (Le 2005; Tordoff et al 2000). Previous zoological studies demonstrated that Phia Oac is home to approximately 434 vertebrate species, including 32 amphibians, 49 reptiles, 267 birds, and 86 mammals (Dang and Nguyen 2013; Le 2005; Tran and Le 2004). However, the local biodiversity has dramatically declined in recent decades (Tordoff et al 2000); mainly due to habitat loss and disturbance. Although most remaining forests are located at high elevations in Phia Oac and are under protection, these areas have been being disturbed mainly by illegal mining activities and pressure from local

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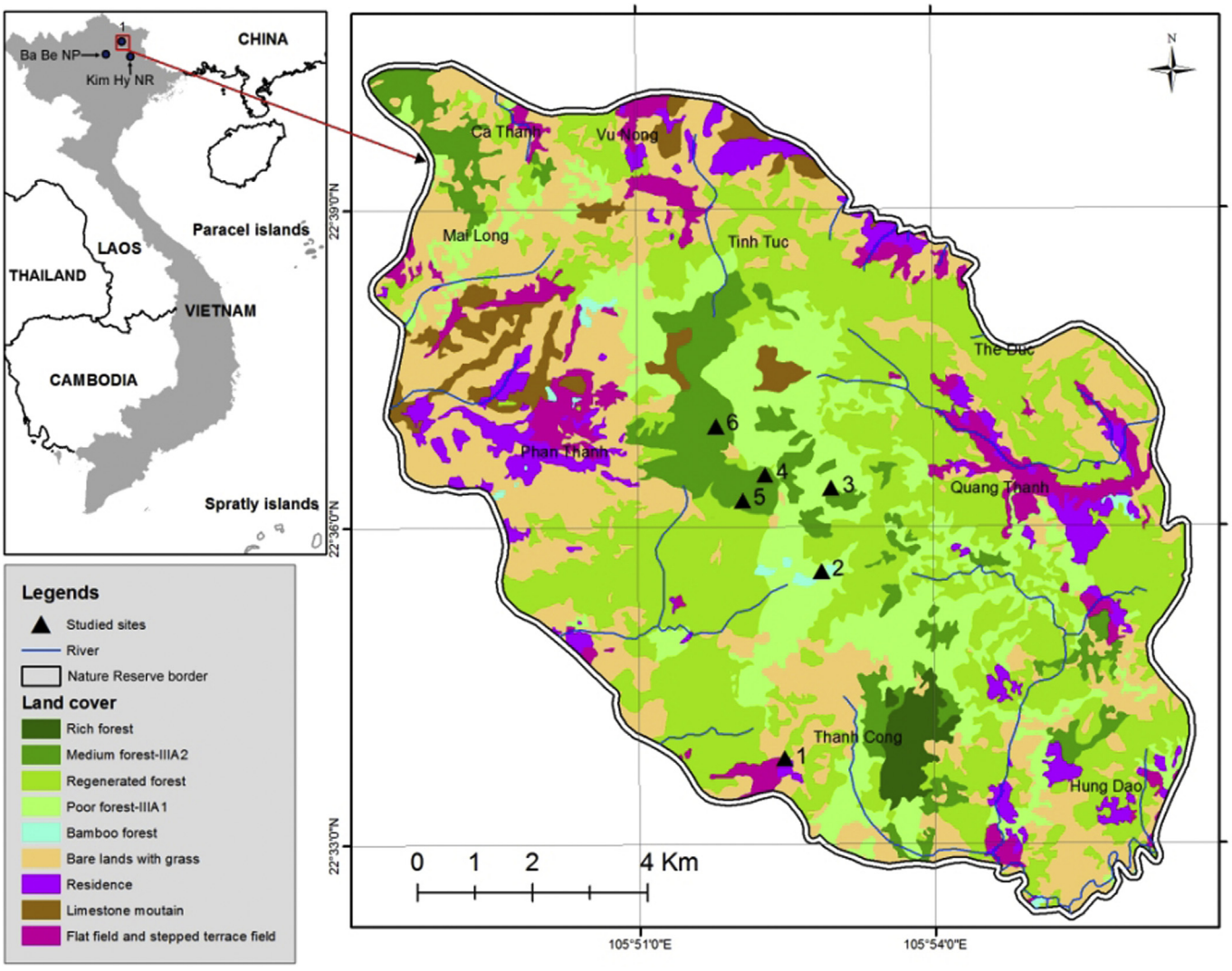

Figure 1. Map showing collecting sites in Phia Oac-Phia Den Nature Reserve (see Table 1 for details).

people, who still rely on exploitation of forest products (i.e., timber, medicinal plants, and firewood) from the Nature Reserve (Tordoff et al 2000). In addition, illegal hunting is also reported as another threat to biodiversity. Consequently, many species, primarily the large mammals have disappeared from the area (Le 2005; Tordoff et al 2000; Tran and Le 2004). Like many other plants and animals in Phia Oac, local bat assemblages are probably also currently at risk, although practically nothing is known regarding their diversity and distribution. In fact, previous studies recorded only five bat species to date in this area including *Rousettus leschenaultii*, *Hipposideros armiger*, *Hipposideros bicolor*, *Pipistrellus tenuis*, and *Miniopterus schreibersii* (Le 2005; Tran and Le 2004). However, the record of *H. bicolor* is doubtful and very probably a case of misidentification of *Hipposideros pomona* (sensu lato), whereas bats formerly identified as *M. schreibersii* in Southeast Asia are recently assigned as *Miniopterus fuliginosus*. Literature reviews of bat studies in adjacent territories (Furey et al 2009, 2010, 2011; Tu et al 2015b) also indicated that the remaining natural habitats (e.g., limestone caves and forests) in this area are more probably homes to a higher level of diversity and need to be explored. Based on the recent surveys, in combination with data obtained from previous studies, this paper presents the first comprehensive lists of bats species occurring in the nature reserve, complemented with data on their taxonomy, roosting habits, and habitat preferences.

Materials and methods

Study sites

Under the influence of monsoon tropical climate with cold winter and summer rains of Northeast Vietnam and associated with its terrain, in Phia Oac, the mean annual temperature is 20.6°C, and the average precipitation and humidity is 1,718 mm and 83.4%, respectively (Averyanov et al 2003; Le 2005). In the coldest days, usually in December and January, this area is one of the rare locations in Northern Vietnam where the temperature falls below freezing. Based on the precipitation, the climate conditions in Phia Oac can be divided into two contrasting seasons. The dry season extends from November to April, with a mean rainfall of 295 mm, accounting for 17.2% of total annual rainfall; while the period from May to November is the rainy season, with peak rainfall in July and August, and mean precipitation is of 1,423 mm accounting for 82.8% of total annual rainfall (Le 2005). These conditions support a variety

of forest types, particularly low to high montane broadleaf evergreen forests (Tran et al 2014). However, most habitats therein have been heavily disturbed mainly due to the mining activities during the French colonial era and recent decades. Currently, vegetation covers approximately 84% of the total area of Phia Oac, but is mostly composed of secondary forests or plantations. Likewise, the mature and undisturbed forests are found only above 1,000 m a.s.l., and recently isolated by the heavy disturbance on surrounding lower elevations (Tordoff et al 2000; Tran et al 2014). The field surveys comprising a total of 12 trapping nights were conducted in six selected study sites in four different habitats within Phia Oac (Table 1, Figures 1 and 2).

Taxonomic sampling

Bats were captured with four-bank harp-traps and mist-nets (Ecotone, Sopot, Poland) set at ground level, frequently across trails and streams in the forests or in front of cave entrances. Most of the captured bats were released at the capturing site after recording standard measurements and taking tissue samples from the plagiopatagium. Selected specimens were kept as vouchers and fixed in 95% ethanol, followed by preservation in 70% ethanol according to the protocol described by Francis (2008) and Kruskop (2013). These specimens are housed in the Institute of Ecology and Biological Resources, Vietnam Academy of Science and Technology (IEBR, Hanoi, Vietnam) and in the Hungarian Natural History Museum (HNHM, Budapest, Hungary). Tissue samples for DNA analyses were taken immediately after euthanasia of the voucher specimens and were preserved in 95% ethanol.

Species identification

Most captured bats were identified to species level based primarily on external morphological characters with the use of guidebooks or monographs (Corbet and Hill 1992; Csorba et al 2003; Francis 2008; Kruskop 2013). Species identification of several voucher specimens was also based on the comparison of their extracted skulls with reference material housed in the IEBR and in the HNHM. The taxonomic status of several species was also checked with the use of DNA barcoding approach. The protocols of DNA extraction, and polymerase chain reaction amplification for the *COI* barcode fragment, with the use of the primer sets VF1d/VR1d (Ivanova et al 2007) are detailed in Tu et al (2015a). Polymerase chain reaction products were sequenced in both directions using Sanger sequencing on an ABI 3500 at Biological Research Centre of the Hungarian Academy of Sciences (Szeged, Hungary). The new *COI* sequences were then compared with sequences of related species available in the EMBL/DDBJ/Genbank nucleotide databases, and phylogenetic reconstructions were conducted on PAUP* (Swofford 2003) using a distance method (neighbor-joining search; distance measure = Kimura 2-parameter model).

Table 1. List of study sites in Phia Oac-Phia Den Nature Reserve

#	No. of trapping nights	Co-ordinates	Elevation (m a.s.l.)	Habitat description
1	3	22°33'49"N 105°52'27"E	1,054	Limestone cave in Phia Den village, Thanh Cong commune: surrounded by heavily disturbed forest and cultivated land
2	2	22°35'33"N 105°52'52"E	1,220	Bamboo forests
3	1	22°36'18"N 105°52'59"E	1,446	Low montane broadleaf evergreen forest
4	3	22°36'28"N 105°52'14"E	1,599	High montane broadleaf (or dwarf mixed) evergreen forest
5	2	22°36'21"N 105°52'8"E	1,700	High montane broadleaf (or dwarf mixed) evergreen forest
6	1	22°36'56"N 105°51'48"E	1,918	High montane broadleaf (or dwarf mixed) evergreen forest

Results

Bat diversity in Phia Oac

Prior to this study, 5 species were recorded in Phia Oac. During the three short surveys, we found 19 species not recorded previously for the region. Thus, the checklist of bats in Phia Oac is dramatically increased and presently comprises 24 species of 5 families (Table 2). The comparison of bat species composition of Phia Oac and the two nearby and most comprehensively surveyed areas in Northeast Vietnam, Ba Be National Park and Kim Hy Nature Reserve of Bac Kan Province (hereafter called as Ba Be and Kim Hy, respectively, Figure 1), indicated that most bat species found in Phia Oac also occurred in the two other sites (Appendix 1). However, some species that were found in these intensively surveyed sites have not been recorded during our surveys.

Species accounts

PTEROPODIDAE
***Rousettus leschenaultii* (Desmarest, 1820)**
Leschenault's rousette
New material. No
Previous records. Tran and Le (2004)

Comments: This fruit-eating bat species is widely distributed across Southeast Asia and adjacent territories. In Ba Be and Kim Hy, *R. leschenaultii* was found commonly and known to roost in limestone caves (Furey et al 2010, 2011). Thus, in Phia Oac, the occurrence of *R. leschenaultii* might also be associated with karstic areas (Figure 1).

HIPPOSIDERIDAE
***Aselliscus dongbacana* Tu et al, 2015b**
Dong Bac's trident bat

New material. 2 ♂♂ and 1 ♀. (Figure 3A)
Comments. This is a small-sized species of the family Hipposideridae with a forearm length (FA) of 43.1-43.6 mm. Formerly, all trident bats, which are easily distinguishable from other bat taxa by their nose leaf, characterized by the upper margin divided into three points, and three lateral leaflets (Figure 3A) from the Southeast Asian mainland, were regarded as Stoliczka's Trident Bat, *Aselliscus stoliczkanus*. However, Tu et al (2015b) described *A. dongbacana* as a distinct species based on morphological and molecular analyses and considered that this taxon is endemic to the karst area of Northeast Vietnam.

***Hipposideros armiger* (Hodgson, 1835)**
Great leaf-nosed bat

New material. No
Previous records. Le (2005)
Comments. This is the largest Asian species of the genus with an FA of 86.0–92.5 mm (Kruskop 2013). *H. armiger* can be differentiated from other *Hipposideros* species by its larger body size and different noseleaf structure (Corbet and Hill 1992; Kruskop 2013). It was found from Nepal to Taiwan and Malacca (Corbet and Hill

Figure 2. A, Advanced successional forests above 1,000 m a.s.l.; B, Forest clearance for agricultural land at low elevation. Four main studied habitats: C, limestone cave; D, bamboo forest; E, low montane broadleaf evergreen forest at 1,500 m a.s.l.; F, high montane broadleaf (or dwarf mixed) evergreen forest at 1,600 m a.s.l.

1992). In Ba Be and Kim Hy, it was known to roost in colonies in limestone caves and forage in both disturbed and intact habitats (Furey et al 2009, 2010, 2011), and thus its occurrence in Phia Oac might be associated with karstic areas (Figure 1).

***Hipposideros pomona* Andersen, 1918**
Pomona leaf-nosed bat

New material. No
Previous records. Le (2005)
Comments. Recent taxonomic revision of *H. bicolor* and *H. pomona* made by Douangboubpha et al (2010) suggests that the distribution of the first species in mainland Southeast Asia might be restricted to the Malay Peninsula south of the Isthmus of Kra. Thus, although no specimens were examined, it is likely that the specimens identified by Le (2005) as *H. bicolor* represent *H. pomona*. This possibility is also corroborated with the common occurrence of *H. pomona* in different habitats in Ba Be and Kim Hy (Furey et al 2009, 2010). However, *H. pomona* is also regarded as a complex of cryptic species (Francis et al 2010).

***Hipposideros larvatus* (Horsfield, 1823)**
Intermediate leaf-nosed bat

New material. 4 ♂♂ and 1 ♀. (Figure 3B)
Comments. A medium-sized leaf nosed bat with an FA of 58.2–60.0 mm. This species was regarded as one of the most common species of the genus in Indo-Malayan region with four assigned subspecies (Cobert and Hill 1992). In Indochina, two subspecies, *Hipposideros larvatus alongensis* and *Hipposideros larvatus grandis*, were elevated to species rank (Simmons 2005; Thong et al 2012), while *H. larvatus* sensu stricto is recently regarded as a cryptic species complex (Francis et al 2010).

RHINOLOPHIDAE
***Rhinolophus affinis* Horsfield, 1823**
Intermediate horseshoe bat

New material. 4 ♂♂ and 2 ♀♀. (Figure 3C)
Comments. A medium-sized horseshoe bat with an FA of 52.6-55.4 mm. *R. affinis* was found widely in Indo-Malayan region (Corbet and Hill 1992), but it is recently regarded as a cryptic species

Table 2. Checklist of recorded bat species and their spatial occurrence in Phia Oac-Phia Den Nature Reserve

#	Species	Sources	Study sites			
			A	B	C	D
I	Pteropodidae					
1	*Rousettus leschenaultii*	2				
II	Hipposideridae					
2	*Aselliscus dongbacana*	1		x		
3	*Hipposideros armiger*	3				
4	*Hipposideros pomona*	3				
5	*Hipposideros larvatus*	1	x	x		
III	Rhinolophidae					
6	*Rhinolophus affinis*	1	x			x
7	*Rhinolophus pearsonii*	1				x
8	*Rhinolophus* cf. *macrotis*	1				x
9	*Rhinolophus pusillus*	1	x	x		x
10	*Rhinolophus thomasi*	1	x			x
IV	Vespertilionidae					
11	*Kerivoula hardwickii*	1		x	x	x
12	*Kerivoula kachinensis*	1		x	x	x
13	*Kerivoula titania*	1		x	x	x
14	*Pipistrellus coromandra*	1				x
15	*Pipistrellus tenuis*	3				
16	*Hypsugo cadornae*	1				x
17	*Myotis* cf. *siligorensis*	1	x			x
18	*Myotis laniger*	1		x		
19	*Harpiocephalus harpia*	1	x			
20	*Murina cyclotis*	1			x	x
21	*Murina eleryi*	1		x		x
22	*Murina huttoni*	1				x
23	*Murina chrysochaetes*	1				x
V	Miniopteridae					
24	*Miniopterus* cf. *fuliginosus*	3				
	Total	24	6	8	4	15

Sources: 1 = recent surveys; 2 = Tran and Le 2004; 3 = Le 2005.
A = limestone cave; B = bamboo forests; C = low montane broadleaf evergreen forest; D = high montane broadleaf (or dwarf mixed) evergreen forest.

complex, with at least three morphological forms occurring in Southeast Asia mainland (Ith et al 2015). Accordingly, the new material may be allocated to the Indochinese form, *Rhinolophus affinis macrurus*.

***Rhinolophus pearsonii* Horsfield, 1851**
Pearson's horseshoe bat

New material. 1 ♂.

Comments. A medium-sized horseshoe bat with an FA of 53.9 mm. *R. pearsonii* was found widely from Nepal and northern India to southern China and northern Indochina (Corbet and Hill 1992; Csorba et al 2003). Previous studies identified two subspecies: *Rhinolophus pearsonii pearsonii* which is slightly larger in size and has a more wide distribution and *Rhinolophus pearsonii chinensis* which is found from Southeastern China and mountains around the borders of Vietnam and China (Andersen 1905; Osgood 1932), but several authors considered that these two taxa can be elevated to full species rank based on the differences in their karyotypes, DNA sequences, and echolocation calls (Mao et al 2007, 2010). In addition, recent molecular analyses indicated that *R. pearsonii pearsonii* s. str. is a cryptic species complex (Francis et al 2010). Therefore, further studies are needed to confirm the taxonomic status of specimens found in Phia Oac.

***Rhinolophus* cf. *macrotis* Blyth, 1844**
Big-eared horseshoe bat

New material. 2 ♂♂.

Comments. *R. macrotis* sensu lato was regarded as a complex of cryptic species (Francis et al 2010; Sun et al 2008), and morphologically divided into small and large forms. With FA lengths of 47.6 mm and 48.5 mm, the specimens collected in Phia Oac are tentatively identified as large form of *R. macrotis* s.l., however, further analyses are needed to evaluate its taxonomic status.

***Rhinolophus pusillus* Temminck, 1834**
Least horseshoe bat

New material. 8 ♂♂ and 3 ♀♀.

Comments. A small-sized horseshoe bat with an FA of 34.7–37.2 mm. Although our specimens were identified as *R. pusillus*, the taxonomy of the species is not fully understand yet, and may also be a complex of cryptic species (Francis et al 2010). *R. pusillus* is morphologically hardly distinguishable from its sibling taxa, for example, *Rhinolophus lepidus* and *Rhinolophus monoceros* (Kruskop 2013).

***Rhinolophus thomasi* Andersen, 1905**
Thomas's horseshoe bat

New material. 2 ♂♂ and 3 ♀♀.

Comments. A medium-sized horseshoe bat with an FA of 46.6–48.0 mm. Our material was identified solely by external morphology, however, this taxon was known to overlap in size with *Rhinolophus sinicus* and *Rhinolophus rouxi* (Kruskop 2013). Further morphological and molecular analyses are needed to confirm the species identification.

VESPERTILIONIDAE
***Kerivoula hardwickii* (Horsfield, 1824)**
Hardwicke's woolly bat

New material. 9 ♂♂ and 2 ♀♀. (Figure 3D)

Comments. A medium-sized species of the genus with an FA of 31.4–33.0 mm. *K. hardwickii* is found widely throughout the mainland and on most islands of Southeast Asia (Corbet and Hill 1992). Taxonomically, this species was regarded as a cryptic species complex, with at least four distinct species (Francis et al 2010). Recent studies indicated that specimens of *K. hardwickii* found in Phia Oac resembles to a undescribed taxon, restricted to Northern Vietnam and characterized by a relative flat braincase (Son et al 2016).

***Kerivoula kachinensis* Bates et al, 2004**
Kachin woolly bat

New material. 4 ♀♀.

Comments. This is a large-sized species of the genus *Kerivoula* with an FA of 41.7–42.1 mm. It has a wide distribution from Northeastern India, Myanmar, Northern Thailand to South Indochina (Kruskop 2013).

***Kerivoula titania* Bates et al, 2007**
Titania's woolly bat

New material. 3 ♀♀.

Comments. *K. titania* is mostly similar to *Kerivoula hardwickii* sensu lato, but can be distinguished from the latter by its generally larger body size. It is also significantly smaller in size than *Kerivoula kachinensis*. This was shown by the FA taken from our new material (33.6–34.4 mm), which were in between the smaller *K. hardwickii* and the larger *K. kachinensis*. Currently, this species was found only in Myanmar, Thailand, Cambodia, Laos and Vietnam (Kruskop 2013).

Figure 3. Portraits of selected bat species recorded in Phia Oac (not to scale): A, *Aselliscus dongbacana*; B, *Hipposideros larvatus*; C, *Rhinolophus affinis*; D, *Kerivoula hardwickii*; E, *Hypsugo cadornae*; F, *Myotis* cf. *siligorensis*; G, *Harpiocephalus harpia*; H, *Murina chrysochaetes*.

***Pipistrellus coromandra* (Gray, 1838)**
Indian pipistrelle

New material. 1 ♂ and 1 ♀.

Comments. A small-sized vespertilionid species with an FA of 31.0–32.6 mm. This species was found widely from India and Tibet to Thailand, Vietnam, and Hainan Island (Bates and Harrison 1997; Corbet and Hill 1992). In Vietnam, *P. coromandra* was found in both intact and disturbed habitats from above 1,300 m a.s.l. (Kruskop 2013), suggesting that this species might be adapted to montane areas. *P. coromandra* was found at high altitude in Phia Oac, as well, but not recorded in Ba Be and Kim Hy.

***Pipistrellus tenuis* (Temminck, 1840)**
Least pipistrelle

Previous records. Le (2005)

Comments. Le (2005) recorded *P. tenuis* in Phia Oac. However, identification of *Pipistrellus* species based solely on external characters may be inaccurate due to the overlap in size between different species. Based on Kruskop (2013), at least four different species, namely *Pipistrellus paterculus*, *Pipistrellus javanicus*, *P. coromandra*, and *P. tenius* might occur in Phia Oac. Thus the occurrence of this species in Phia Oac should be cautiously interpreted, and requires further studies.

***Hypsugo cadornae* (Thomas, 1916)**
Cadorna's pipistrelle

New material. 1 ♂. (Figure 3E)

Comments. This is a small-sized vespertilionid species with an FA of 34.0 mm. *H. cadornae* was found sporadically from Northeast India, Northern Myanmar, Thailand, Laos, Cambodia and Vietnam (Furey et al 2012; Kruskop 2013).

***Myotis* cf. *siligorensis* (Horsfield, 1855)**
Himalayan whiskered myotis

New material. 3 ♂♂ and 3 ♀♀. (Figure 3F)

Comments. Our new material with FA of 32.1-34.8 mm (Table 2) were hitherto identified into the mall-size species, *M. siligorensis*, which is found widely from India to Indochina and Borneo. However, this species probably represents a complex of several similar species (Francis et al 2010). Therefore, further studies are needed to clarify the taxonomic status of populations currently allocated to this species.

***Myotis laniger* Peters, 1871**
Chinese water myotis

New material. 1 ♂ and 1 ♀.

Comments. A small-sized species (FA = 36.4 mm) of the genus *Myotis* which was found in Eastern India, Central and Southern China, Laos, and Vietnam (Csorba and Bates 2008; Francis 2008; Kruskop 2013). Based on combined molecular and morphological data, Ruedi et al (2015) evidenced the distribution of *M. laniger* in Fujian (type locality) and Henan provinces of China, and Taiwan, and called for investigations of specimens allocated to this species from other localities.

***Harpiocephalus harpia* (Temminck, 1840)**
Lesser hairy-winged bat

New material. 1 ♂. (Figure 3G)

Comments. The largest species of the subfamily Murininae with an FA of 49.4 mm. The species is found sporadically in the Indo-Malayan region. As noted in the revision of Son et al (2015), there is a geographic variation in the karyotype among bats collected in Thailand, Taiwan, and in the Guangdong Province of China, suggesting that potential cryptic diversity might occur in this species. In the frame of these new data, further morphological and molecular analyses should be performed across its wide distribution range.

***Murina cyclotis* Dobson, 1872**
Round-eared tube-nosed bat

New material. 5 ♂♂ and 4 ♀♀.

Comments. A medium-sized species of the genus *Murina* with a FA of 29.0–34.0 mm. *M. cyclotis* was regarded as a widespread species in the Indo-Malayan region (Corbet and Hill 1992), but it represents a complex of several similar species. Some of those were recently described as distinct taxa (e.g. Soisook et al 2013) and thus further studies are needed to address the taxonomic problems of this species.

***Murina eleryi* Furey et al, 2009**
Elery's tube-nosed bat

New material. 1 ♂ and 1 ♀.

Comments. A small-sized species of the genus *Murina* with an FA of 27.5–30.3 mm. *M. eleryi* was found from Southern China, Vietnam, and Laos. The pelage of this species was known to vary among different localities: the specimens found in Central Highland Vietnam appear to be darker or more reddish-orange, and those from Northern Vietnam, including bats found in Phia Oac are brighter, suggesting potential local adaptation (Tu VT, personal observation).

***Murina huttoni* (Peters, 1872)**
Hutton's tube-nosed bat

New material. 1 ♀.

Comments. A medium-sized species of the genus *Murina* with an FA of 35.5 mm. It is similar to *M. cyclotis*, but can be externally differentiated from the latter by its larger body size. The identity of the collected specimen was confirmed by DNA barcoding (GenBank accession No. KX098592, Appendix 2), but according to recent studies in Vietnam (Son et al 2015), there may be more species in this complex, hence the identity of our specimen needs further validation if new taxonomic data will be available.

***Murina chrysochaetes* Lim and Eger, 2011**
Golden-haired tube-nosed bat

New material. 1 ♀. (Figure 3H)

Comments. Our new material with a forearm length of 28.7 mm is the third record of this supposedly very rare species. Previously, this species was found only in the type locality and in the Hoang Lien Son Mountain (Kruskop 2013; Son et al 2015).

MINIOPTERIDAE
***Miniopterus* cf. *fuliginosus* Hodgson, 1835**
Eastern long-fingered bat

New material. Not available.

Previous records. Le (2005) (as *M. schreibersii* Kuhl, 1817)

Comments. *M. schreibersii* was formerly known to occur across the Old World (Corbet and Hill 1992), but has recently been

considered as a complex of cryptic species. *M. fuliginosus*, that was previously regarded as a subspecies of *M. schreibersii*, was re-elevated to species rank and includes specimens found in Southeast Asia (Appleton et al 2004; Kruskop et al 2012; Tian et al 2004). On this basis, specimens previously recoded by Le (2005) might be allocated to *M. fuliginosus*. However, in Vietnam and adjacent territories, the distribution of *M. fuliginosus* overlaps with that of its sister species *Miniopterus magnater*. Both species have similar morphology, but the latter species is slightly larger in body and skull dimensions (Kruskop 2013; Li et al 2015). Therefore, further investigations are needed to address the taxonomy of *Miniopterus* species in Phia Oac.

Patterns of roosting and habitat preferences

As presented above, 5 bat species were previously reported for Phia Oac, but without exact localities. According to our new data (Table 2), the roost and habitat preferences of bat species found in Phia Oac are relatively clear. The forest interior bats, such as *Murina* and *Kerivoula* species (Kingston et al 1999), were usually found in forests, including bamboo and dwarf mixed evergreen forests above 1,400 m a.s.l. In these habitats, 2 vespertilionid species, *P. coromandra* and *H. cadornae* were also recorded. Bats of the genera *Myotis, Rhinolophus*, *Aselliscus*, and *Hipposideros*, which generally depend on limestone caves (Furey et al 2010, 2011), were usually captured with mist-nets or harp-traps in front of cave entrances or in foraging areas near to caves. One adult male *Harpiocephalus harpia* was also captured in front of a cave entrance. Previously, this species was recorded only from forest areas (Csorba et al 2008), hence, our finding might be noteworthy regarding the roosting ecology of this species.

Although the comparison of relative abundance of bat species among study sites is not reliable due to the different intensity of trapping efforts (Table 1), our results indicate that montane broadleaf evergreen forests occurred at high elevations support highest number of bat species, and thus might be regarded as the most important areas for conservation in Phia Oac. This agrees well with the fact that these areas retain most intact or less disturbed forests of the nature reserve (Tran et al 2014). At each study site *R. pusillus*, *M. cyclotis*, and *K. hardwickii* were the three most abundant species, whereas other species namely *H. harpia*, *M. chrysochaetes*, *M. huttoni*, *H. cadornae*, and *R. pearsonii* were represented by singletons only (Figure 4).

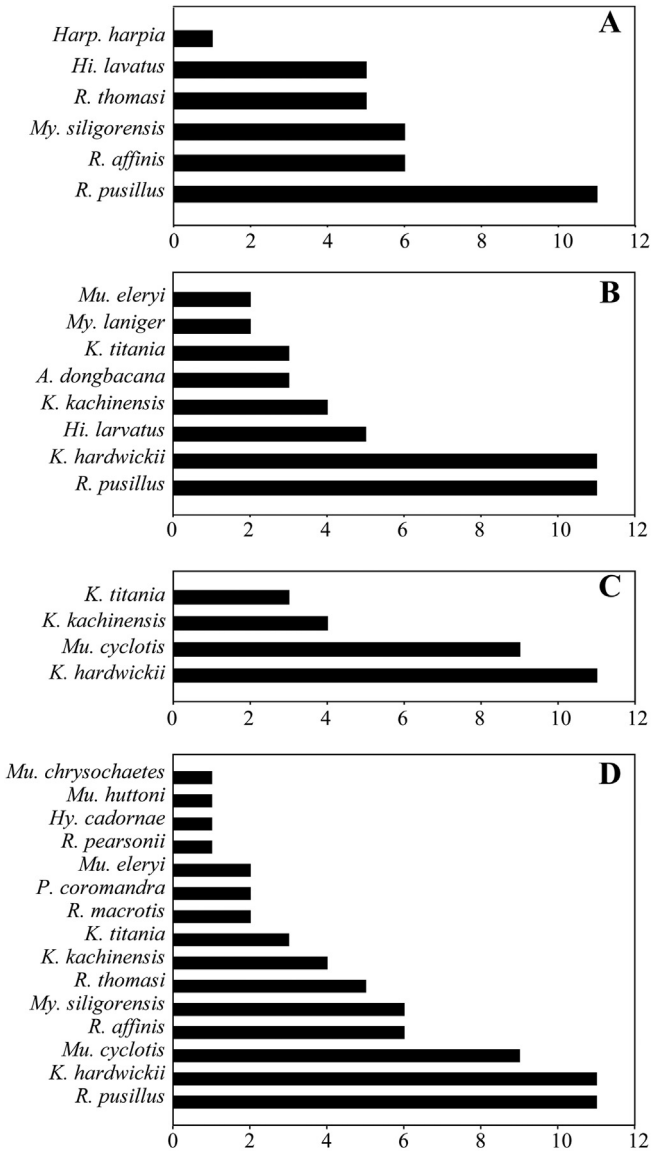

Figure 4. Relative abundance of bat species captured at each study site during recent survey. The horizontal axis represents number of recorded individuals of each species: A, limestone cave; B, bamboo forests; C, low montane broadleaf evergreen forest; D, high montane broadleaf (or dwarf mixed) evergreen forest.

Discussion

The bat fauna of Phia Oac comprises 24 species, accounting for > 20% of the national bat diversity. However, our understanding regarding levels of bat diversity in this area is underestimated because our three short surveys were conducted only in small areas within the core zone. The taxonomic status of some species in Phia Oac is still uncertain and requires additional morphological and molecular investigation.

The comparison of the bat fauna found in Phia Oac and that of two nearby regions, Ba Be and Kim Hy—obtained from a series of surveys in variety of habitats during approximately 3 years—shows that the remaining forests in Phia Oac are home to a remarkable number of the typical forest interior *Murina* and *Kerivoula* species. Apart from *Murina feae* (*sensu* Francis and Eger 2012) and *Murina harrisoni*, all species of these two genera found in Ba Be and Kim Hy were also recorded in Phia Oac. Most other bat taxa that were previously recorded in Ba Be and Kim Hy, but have not been encountered in Phia Oac, are associated with limestone caves and forests. Because most karst areas in Phia Oac (Figure 1), potentially important reservoirs of bat diversity (Furey et al 2010), have not been surveyed yet, further research can reveal the occurrence of additional species.

The occurrence of montane-restricted bat species such as *P. coromandra* and *M. chrysochaetes* in Phia Oac highlights the importance of this region. The combined evidences of the morphological and phylogenetic analyses proved that *Murina harpioloides* and *M. chrysochaetes* are sister species (Appendix 2). Based on their current geographic distribution, *M. chrysochaetes* and *M. harpioloides* are endemic species of two isolated regions, which are approximately 1,000 km from each other: the first taxon was found only at high elevations in mountain areas between China and Northern Vietnam, whereas the latter one is restricted to Dalat plateau, Central Highland Vietnam. This phylogeographic pattern is highly similar to that of *Murina lorelieae lorelieae* and *Murina lorelieae ngoclinhensis* (Tu et al 2015a).

Accordingly, both pair of allopatric taxa were found only at high elevations, that is, *M. lorelieae lorelieae* (in Diding, China, ca. 1,000 m a.s.l.); and *M. lorelieae ngoclinhensis* in Ngoc Linh, ca. 1,100–1,700 m a.s.l.); while *M. chrysochaetes* (in Diding, China—approx.. 1,000 m a.s.l.; Hoang Lien Son mountain, 1,950 m a.s.l.; Phia Oac, 1,700 m a.s.l.); and *M. harpioloides* (in Dalat plateau, 1,400–1,800 m a.s.l.). Based on previous studies (Kruskop and Eger 2008; Eger and Lim 2011; Tu et al 2015a) and our examination, the pelage of these four taxa, *M. lorelieae lorelieae*, *M. lorelieae ngoclinhensis*, *M. harpioloides*, and *M. chrysochaetes*, is characterized by long guard hairs (> 9 mm in length) on dorsal side, regarded as an adaptive trait of montane bats (Tu et al 2015a). Therefore, the current distribution of *M. harpioloides* and *M. chrysochaetes* in Vietnam and South China might be the result of allopatric speciation, which were strongly shaped by the influences of past climate and associated vegetation change of the Plio-Pleistocene epoch (Tu et al 2015a). Based on literature review, during glacial episodes of the Plio-Pleistocene epoch, climatic conditions became cooler and drier in Southeast Asia, hence, montane forests descended to lower elevations; whereas lowland rainforests were fragmented into a few glacial refugia. By contrast, during warm and humid interglacials as nowadays, montane forests were compressed on tops of the mountain ranges, while lowland rainforests expanded (Cannon et al 2009; Turner and Cernusak 2011; Woodruff 2010). According to this biogeographical scenario, montane forests in Phia Oac might be a refugium for different bats, and for many other montane adapted plants and animals.

Although no direct threat to bats was reported during our surveys, forest dwelling taxa are vulnerable from habitat loss or disturbance mainly due to mining activities and logging for timber and firewood (Tordoff et al 2000); whereas cave dwelling species are threatened by cave destruction, that is, mining or deforestation in surrounding areas (Clements et al 2006; Day and Urich, 2000; Furey et al 2010). The management capacities of local authorities of Phia Oac, as well as the awareness for biodiversity conservation of the local ethnic minorities are extremely low. Therefore, we recommend that further research work, together with environmental education programs should be carried out to better understand and protect the rich biodiversity of Phia Oac.

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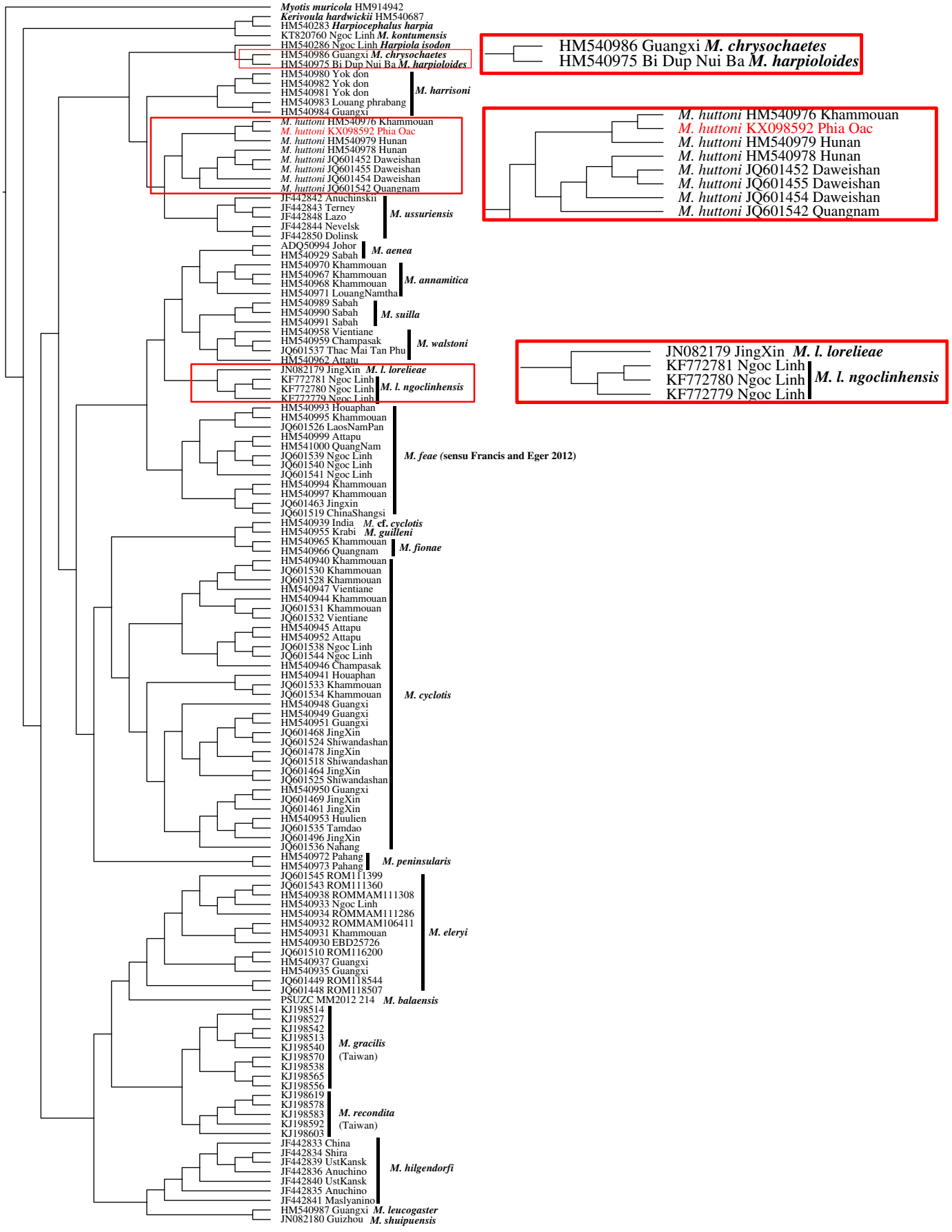
Appendix 1. Bats found in Phia Oac–Phia Den Nature Reserve and nearby intensively studied regions

No.	Scientific name	Phia Oac-Phia Đen	Kim Hy*	Ba Be*
I	Pteropodidae			
1	*Cynopterus brachyotis*			x
2	*Cynopterus sphinx*		x	x
3	*Eonycteris spelaea*		x	x
4	*Macroglossus sobrinus*			x
5	*Rousettus leschenaultii*	x	x	x
6	*Sphaerias blanfordi*		x	
II	Megadermatidae			
8	*Megaderma lyra*		x	x
III	Rhinolophidae			
9	*Rhinolophus affinis*	x	x	x
10	*Rhinolophus macrotis*	x	x	
11	*Rhinolophus paradoxolophus*		x	x
12	*Rhinolophus pearsonii*	x	x	x
13	*Rhinolophus pusillus*	x	x	x
14	*Rhinolophus thomasi*	x	x	x
15	*Rhinolophus microglobosus*		x	x
16	*Rhinolophus yunanensis*		x	
IV	Hipposideridae			
17	*Hipposideros armiger*	x	x	x
18	*Hipposideros pomona*	x	x	x
19	*Hipposideros cineraceus*		x	x
20	*Hipposideros lylei*		x	x
21	*Hipposideros alongensis*			x
22	*Hipposideros larvatus*	x	x	x
23	*Aselliscus dongbacana*	x	x	x
24	*Coelops frithii*		x	
V	Vespertilionidae			
25	*Hypsugo cadornae*	x	x	x
26	*Hypsugo pulveratus*		x	x
27	*Ia io*		x	x
28	*Pipistrellus coromandra*	x		
29	*Pipistrellus* cf. *javanicus*		x	x
30	*Pipistrellus tenuis*	x		
31	*Scotomanes ornatus*		x	
32	*Tylonycteris pachypus*		x	
33	*Kerivoula hardwickii*	x	x	x
34	*Kerivoula kachinensis*	x		
35	*Kerivoula titania*	x	x	x
36	*Harpiocephalus harpia*	x	x	x
37	*Murina cyclotis*	x	x	x
38	*Murina eleryi*	x	x	
39	*Murina feae*		x	
40	*Murina harrisoni*		x	
41	*Murina chrysochaetes*	x		
42	*Murina huttoni*	x		
43	*Myotis ater*		x	
44	*Myotis chinensis*		x	x
45	*Myotis laniger*	x		
46	*Myotis muricola*		x	
47	*Myotis pilosus*		x	
48	*Myotis rufoniger*		x	
49	*Myotis siligorensis*	x	x	x
VI	Miniopteridae			
50	*Miniopterus* cf. *fuliginosus*	x		x
VII	Molossidae			
51	*Chaerephon plicata*			x
VII	Emballonuridae			
52	*Taphozous melanopogon*			x
	Total species	24	39	32

* Source: Csorba et al 2014; Furey et al 2009, 2010, 2011; Kemp et al 1994.

Appendix 2. Neighbor joining tree of the subfamily Murininae reconstructed from *COI* sequences.



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