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Thumb-pads up—a new species of thick-thumbed bat from Sumatra (Chiroptera: Vespertilionidae: *Glischropus*)

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Abstract

To date, three species of the genus *Glischropus* are recognized from the Indomalayan zoogeographic region—*G. bucephalus* from the Indochinese subregion, *G. tylopus* from the Sundaic subregion (Peninsular Thailand and Malaysia, Borneo, Sumatra, Moluccas) and *G. javanus*, restricted to Java. The investigation of the holotype and three topotype specimens of *G. batjanus* supported the view that the name was previously correctly regarded as the junior subjective synonym of *G. tylopus*. During review of material recently collected in southwestern Sumatra, Indonesia, one specimen of a yet undescribed species of Thick-thumbed bat was identified. *G. aquilus* n. sp. markedly differs from its congeners by its dark brown pelage, nearly black ear and tragus, and in skull proportions. The phylogenetic analysis based on *cytb* sequences also supports the specific distinctness of *G. aquilus* n. sp. Its discovery brings the count to 88 species of bats known from Sumatra.

Key words: Bukit Barisan Selatan, Indonesia, Pipistrellini, taxonomy

Introduction

Developed pads on the thumbs and feet are found in several unrelated Southeast Asian vespertilionid genera, namely *Eudiscopus* Conisbee, 1953; *Tylonycteris* Peters, 1872; *Glischropus* Dobson, 1875; and in one species of *Hesperoptenus* Peters, 1868; and one species of *Myotis* Kaup, 1829. Based on external appearance, including ear and tragus shape, facial glands, calcar and epiblema structure (Csorba 2011), dental characters (Tate 1942; Menu 1985), chromosome structure (Volleth *et al.* 2001), and DNA barcoding gene sequences (Francis *et al.* 2010), the genus *Glischropus* is closely related to *Pipistrellus* and placed in the tribe Pipistrellini (Simmons 2005). The generic distinctness of *Glischropus* within Pipistrellini is supported by the presence of fleshy, unpigmented pads on the thumb and on the sole of the hind foot and the concavity of the second upper incisor which points directly outwards (Tate 1942; Corbet & Hill 1992; Koopman 1994; Kruskop 2013). The presence of the thickened pads is thought to be related to the roosting habits of *Glischropus* species, as specimens were captured in or near to bamboo stands (Lekagul & McNeely 1977; Csorba 2011; Kruskop 2013) or even within stalks of dead bamboo (Chasen 1939; Kofron 1994).

Until the description of *G. bucephalus*, two species of *Glischropus* were recognized from the Indomalayan

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zoogeographic region—the widespread *G. tylopus* and *G. javanus*, restricted to Java. Thorough examination of museum material however, revealed that specimens north from the Isthmus of Kra belonged to a separate species, *G. bucephalus* and that *G. javanus* from Java is known only by the holotype specimen, as other records of the latter species were proven as mis-identifications (Csorba 2011). Based on the description of Matschie (1901), *G. batjanus* was regarded as the junior subjective synonym of *G. tylopus* (Tate 1942; Csorba 2011). The subsequent investigation of the holotype and three topotype specimens of *G. batjanus* stored in the collection of Museum für Naturkunde, Berlin supported this view (Csorba unpublished data); hence, currently three species are recognized in the genus: *G. tylopus*, *G. javanus*, and the recently described *G. bucephalus* (Csorba 2011).

During review of material recently collected in Sumatra, Indonesia, Huang *et al.* (2014) reported one specimen of a yet undescribed species that belongs to the *Glischropus* genus. In this paper we describe this new species using morphological and molecular evidence.

Material and methods

Measurements. Bats were captured and handled in the field in accordance with guidelines approved by the American Society of Mammalogists (Sikes *et al.* 2011). External measurements were taken from alcohol-preserved museum specimens to the nearest 0.1 mm, except the holotype of the new species, which was measured in the field. All craniodental measurements were taken by the first author to the nearest 0.01 mm using digital calipers and a stereomicroscope. Measurements include only those taken from adults as indicated by the presence of fully ossified metacarpal-phalangeal joints.

Abbreviations and definitions for external measurements include FA: forearm length—from the extremity of the elbow to the extremity of the carpus with the wings folded; EAR: ear length—from the base of the tragus to the tip of the pinna; HB: head and body length—from the tip of nose to the anus; TAIL: tail length—from the anus to the tip of the last caudal vertebra; TIB: tibia length—from the knee joint to the ankle; TH: thumb length—without claw; and HF: hind foot—from the tip of the claw of the longest digit to the extremity of the heel, behind the *os calcis*. Abbreviations and definitions for craniodental measurements are STL: total length of skull—from the anterior rim of alveolus of the first upper incisor to the most projecting point of the occipital region; CCL: condylo-canine length—from the exoccipital condyle to the most anterior part of the canine; CCW: width across the upper canines—greatest width across the outer borders of the upper canines; M^3M^3W: width across the upper molars—greatest width across the outer crowns of the last upper molars; PDW: post-dental width—the width of the palatal bridge measured at the level of the posterior limit of the last molars; RW: rostral width—greatest width measured between the lachrymal tubercles; IOW: interorbital width—least width of the interorbital constriction; CM^3L: maxillary toothrow length—from the front of the upper canine to the back of the crown of the third molar; MAL: mandible length—from the anterior rim of the alveolus of the 1st lower incisor to the most posterior part of the condyle; and CM_3L: mandibular toothrow length—from the front of the lower canine to the back of the crown of the 3rd lower molar. Absolute height was used in all height comparisons for individual teeth (e.g., C versus P4).

All statistical analyses were carried out with R 3.0.3 (R Core Team 2014). Principal Component Analysis (PCA) on a correlation matrix including the FA, M^3M^3W, PDW and RW measurements was performed with FactoMineR 1.25. (Lê *et al.* 2008).

Phylogenetic reconstruction. Total genomic DNA was extracted from tissue samples of three specimens of *Glischropus* using QIAGEN QIAamp DNA Micro Kit according to the instructions of the manufacturer. A ~1140 bp fragment of mitochondrial cytochrome b was amplified using primers Molcit-F 5'-AATGACATGAAAAATCA CCGTTGT-3' (Ibánez *et al.* 2006) and cytB-H 5'-CTTTTCTGGTTTACAAGACCAG-3' (Weyeneth *et al.* 2008). PCR reactions were performed in 25 µl using ca. 20 ng of genomic DNA, 1 µl of Molcit-F and cytB-H primers (10 mM), respectively, 9.5 µl of water and 12.5 µl of Thermo Scientific DreamTaq Green PCR Master Mix (2X). PCR conditions were as follows: 3 min at 94 °C, followed by 40 cycles of 45 sec at 94 °C, 1.5 min at 58 °C and 1.5 min at 72 °C, final elongation was 10 min at 72 °C.

The *cytb* sequences (GenBank accession numbers: KR612331-KR612333) were aligned with related taxa of *Glischropus*, *Pipistrellus*, *Nyctalus* and *Tylonycteris robustula* (see Appendix), the last used as outgroup. Sequences were truncated because *G. tylopus* sequence from the type locality was only 404 bp long. The phylogenetic trees were constructed by using the Maximum Likelihood (ML) method based on the Hasegawa-

Kishino-Yano model (Hasegawa *et al.* 1985) with G+I parameters. Bootstrap supports with 500 replicates were analyzed. Pairwise distances were calculated using Kimura 2-parameter model (Kimura 1980). Alignment and analyses were done in MEGA 6 (Tamura *et al.* 2013).

Comparative material. *G. bucephalus*: CAMBODIA: HNHM 2006.34.49. (holotype), BM(NH) 2006.545, HNHM 2005.82.5., 2006.34.37., 2006.34.45., 2006.34.46., 2006.34.48., HZM 1.39552 (all paratypes); THAILAND: PSU 2005.206; VIETNAM: HNHM 22859, 2012.30.28., IEBR BL04, CT25, CT26, PL47, PM22, VC36. *G. javanus*: JAVA, INDONESIA: RMNH 15323 (holotype). *G. tylopus*: BORNEO: BM(NH) 70.2.10.2 (holotype), 0.7.29.10, 10.4.5.67, 10.4.5.68, 10.4.5.69, 10.4.5.70, 7.1.1.406, 85.96, 85.915, 95.11.5.4, 95.11.5.4x, MNHN 1959-216A, 1959-216B, MZB 26465, RMNH 32603, 32605, 32606, 32607, 32608, 32677, ZMA 19904; MALAYSIA: MHNG 1701.077, 1701.078, 1970.063, MNHN 1983-1681; MOLUCCAS, INDONESIA: ZMB 85513 (*batjanus* holotype), 67649, 67651, 67652 (all *batjanus* topotypes); SUMATRA, INDONESIA: HZM 1.12850, 2.12851, MHNG 1481.072, NHMW 39917, 39918, 39919, RMNH 30266, 30267, 30268; THAILAND: HNHM 2009.52.1., PSU 2005.176.

Museum acronyms. BM(NH): The Natural History Museum, London, United Kingdom, formerly British Museum (Natural History); EBD: Estación Biológica de Doñana, Sevilla, Spain; HNHM: Hungarian Natural History Museum, Budapest, Hungary; HZM: Harrison Institute, Sevenoaks, United Kingdom, formerly Harrison Zoological Museum; IEBR: Institute of Ecology and Biological Resources, Hanoi, Vietnam; MHNG: Museum d'histoire naturelle, Geneva; MNHN: Muséum National d'HistoireNaturelle, Paris, France; MZB: Museum Zoologicum Bogoriense, Bogor, Indonesia; NHMW: Natural History Museum, Wien, Austria; PSU: Prince of Songkla University Zoological Collection, Hat Yai, Thailand; RMNH: Naturalis, Leiden, The Netherlands, formerly Rijksmuseum van Natuurlijke Historie; ZMA: Zoölogisch Museum, Amsterdam, The Netherlands; ZMB: Museum für Naturkunde, Berlin, Germany, formerly Zoological Museum Berlin.

Systematics

Family Vespertilionidae Gray, 1821

Genus *Glischropus* Dobson, 1875

Glischropus aquilus n. sp.

Figures 1–4; Tables 1.

Synonymy. *Glischropus* sp.: Huang *et al.* (2014).

Holotype. MZB 35030 (field number # JH20110815.2), adult male, in alcohol, skull removed. Collected by Joe Chun-Chia Huang on 15 August 2011.

Type locality. Sukabanjar village, Lampung, Sumatra, Indonesia, 4°56'S, 103°52'E, 768 m a.s.l.

External measurements of the holotype (in mm): FA= 32.1, EAR= 11.0, HB= 35.4, TAIL= 38.8, TIB= 15.1, TH= 5.6, HF= 6.2, body mass (g)= 4.8.

Etymology. The specific epithet /a.kvi.lus/ (meaning dark-coloured in English) refers to the blackish ears and generally darker pelage of the new species relative to its congeners. The proposed English name is Dark Thick-thumbed bat.

Diagnosis. A rather large representative of the genus (FA over 32 mm), with dark brown fur, elevated frontal part, globose braincase and gradually narrowing interorbital region.

Description. Forearm length= 32.1 mm (Table 1); ears are blackish, wide, and broadly rounded; tragus *Pipistrellus*-like, relatively narrow and bluntly pointed (Fig. 1). The dorsal pelage is dark brown with no reddish hints; ventrally lighter, medium brown. The individual hairs on the back are mostly unicoloured dark brown with only the tips a lighter brown; the hairs on the belly have two bands, the basal 2/3 being dark brown, the distal portion medium brown. The plagiopatagium is attached to the base of the toe. The calcar is short, extends to less than half of the free edge of the uropatagium; the lobe on the calcar is well-developed, elongated, and with a supporting median cartilage. The thumb has a large pinkish pad, characteristic of the genus, oval in outline and 3 mm in length. The sole of the foot is pink and fleshy. The penis is dorsoventrally flattened, 5.2 mm in length; the

proximal half is practically naked, whereas the distal half is strongly pilose, with stiff, whitish hairs on the dorsal surface and around the glans (Fig. 2).

TABLE 1. Selected external and craniodental measurements (in mm) of *G. bucephalus*, *G. aquilus* **n. sp.**, *G. javanus*, and *G. tylopus*. Values are given as mean, ± SD, min-max, (n). Acronyms and definitions for measurements are given in the text.

character	*G. bucephalus*	*G. aquilus* **n. sp.**	*G. javanus*	*G. tylopus*
FA	34.03 ± 0.99 32.1–35.7 (15)	32.2 (1)	32.0 (1)	29.17 ± 0.93 27.0–30.9 (29)
STL	12.49 ± 0.24 12.14–13.05 (14)	12.56 (1)	12.03 (1)	11.83 ± 0.32 11.16–12.72 (31)
CCL	11.90 ± 0.22 11.61–12.39 (14)	11.95 (1)	11.40 (1)	11.25 ± 0.32 10.68–12.06 (32)
CCW	4.05 ± 0.11 3.75–4.24 (13)	4.07 (1)	3.95 (1)	3.81 ± 0.15 3.46–4.20 (31)
M^3M^3W	5.75 ± 0.14 5.47–5.98 (13)	5.68 (1)	5.32 (1)	5.23 ± 0.10 4.97–5.44 (32)
PDW	2.27 ± 0.08 2.19–2.40 (7)	2.66 (1)	2.81 (1)	2.64 ± 0.14 2.39–2.78 (10)
RW	4.99 ± 0.11 4.82–5.17 (13)	4.84 (1)	4.63 (1)	4.47 ± 0.13 4.16–4.77 (32)
IOW	3.68 ± 0.11 3.53–3.93 (14)	3.79 (1)	3.72 (1)	3.49 ± 0.11 3.26–3.68 (32)
CM^3L	4.74 ± 0.07 4.63–4.85 (13)	4.65 (1)	4.67 (1)	4.45 ± 0.12 4.20–4.74 (36)
ML	9.03 ± 0.20 8.77–9.54 (13)	8.86 (1)	8.54 (1)	8.31 ± 0.26 7.89–8.98 (35)
CM_3L	5.03 ± 0.10 4.86–5.17 (14)	4.85 (1)	4.91 (1)	4.64 ± 0.11 4.43–4.94 (36)

The skull has an elevated frontal region and a relatively globose braincase (Fig. 3). The narial emargination is wide and U-shaped; the sagittal crest obsolete, the lambdoid crests are moderately developed. The zygoma is thin and nearly straight with no dorsal eminence. The basioccipital pits are almost imperceptible.

The tips of the four upper incisors are situated in a nearly straight line; the concavity of the second upper incisor (I^3) is turned outwards. The first incisor (I^2) is bifid, I^3 reaches half the height of I^2. The main cusp of I^3 is much longer than the faint secondary cusplet of the same tooth and its tip is directed downwards. Basal dimension of I^3 equals that of I^2. The first upper premolar (P^2) is basally as large as I^2, partly intruded from the toothrow and visible in the lateral view; its cusp reaches well beyond the cingulum of the posterior premolar. The upper and lower molars show no specific modifications and the lower molars are nyctalodont (Fig. 4).

Comparisons. *Glischropus aquilus* **n. sp.** is readily distinguishable externally from all other *Glischropus* species by the general impression of the dorsal fur being dark brown instead of reddish-yellow and the nearly black ear and tragus (vs. brown in all other species of the genus) (Fig. 1).

Beside the external features, *G. aquilus* **n. sp.** is also clearly different from both *G. tylopus* and *G. javanus* in skull proportions, having a deeper rostrum, more elevated frontal part and higher occipital region (Fig. 3). *G. aquilus* **n. sp.** is larger in FA, M^3M^3W, RW and IOW than any *G. tylopus* specimen investigated. *G. aquilus* **n. sp.** was also different from all investigated Sumatran *G. tylopus* (see Comparative material) having a wide 'U' shaped narial emargination (vs. elongated and posteriorly narrowing).

Although in skull shape *G. aquilus* **n. sp.** is more similar to *G. bucephalus* and except the PDW value (which is smaller in all investigated *G. bucephalus* specimens) its craniodental measurements fall within the range of the latter species, its braincase in general is less swollen, interorbital region gradually narrowing (vs. abruptly narrowing in *G. bucephalus*); and I^3 nearly equals I^2 in basal dimensions (vs. much smaller).

Multivariate analyses. In addition to the morphological comparisons a Principal Component Analysis was also performed. The 49 specimens clustered into two main groups: *G. tylopus* on the left and *G. bucephalus* on the right of the PC1 axis (Fig. 5). The single *G. javanus* type fell near the group of *G. tylopus*, whereas *G. aquilus* **n. sp.** is far from all other *Glischropus* specimens. The PC1 axis is a size axis and shows the wideness of the skull; it accounted for a relatively large (71.49%) proportion of the total variation, whereas PC2 is responsible for 19.40%of variation and indicates a shape factor dominated by PDW (Table 2).

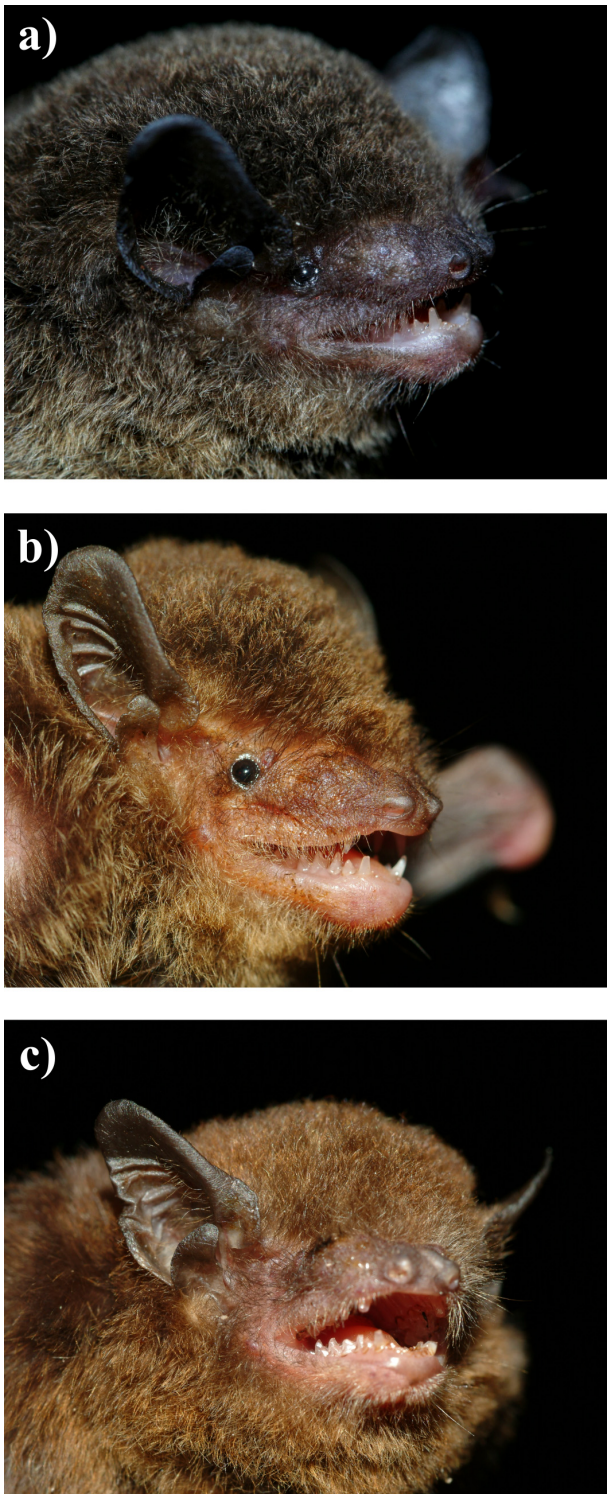

FIGURE 1. Portraits of live specimens of a) *G. aquilus* **n. sp.** holotype from Sumatra (MZB 35030), b) *G. bucephalus* paratype from Cambodia (HNHM 2006.34.37.), c) *G. tylopus* from Thailand (HNHM 2009.52.1.). Not to scale.

FIGURE 2. Lateral view of penis of *G. aquilus* **n. sp.** holotype from Sumatra (MZB 35030).

TABLE 2. Factor loadings of selected external and craniodental characters obtained by the PCA.

Character	PC1	PC2
FA	0.876	0.200
M^3M^3W	0.944	0.189
PDW	-0.559	0.829
RW	0.943	0.115
Eigenvalue	2.860	0.776
Percentage of variance	71.49	19.40

Phylogenetic reconstruction. Because *G. javanus* is represented only by the holotype, the phylogenetic analysis did not include this species. The analyzed *Glischropus cytb* sequences grouped into a monophyletic clade and *G. aquilus* **n. sp.** is clearly separated from other congeners (Fig. 6). The genetic distance between *G. aquilus* **n. sp.** and other *Glischropus* species—including *G. bucephalus* paratypes and a *G. tylopus* specimen collected close to the type locality—is between 12.1–14.6%, which clearly supports that *G. aquilus* **n. sp.** is a separate species. The two *G. bucephalus* paratypes differed only in a few nucleotides, but the two *G. tylopus* differed considerably, by 5.2% from each other (Table 3).

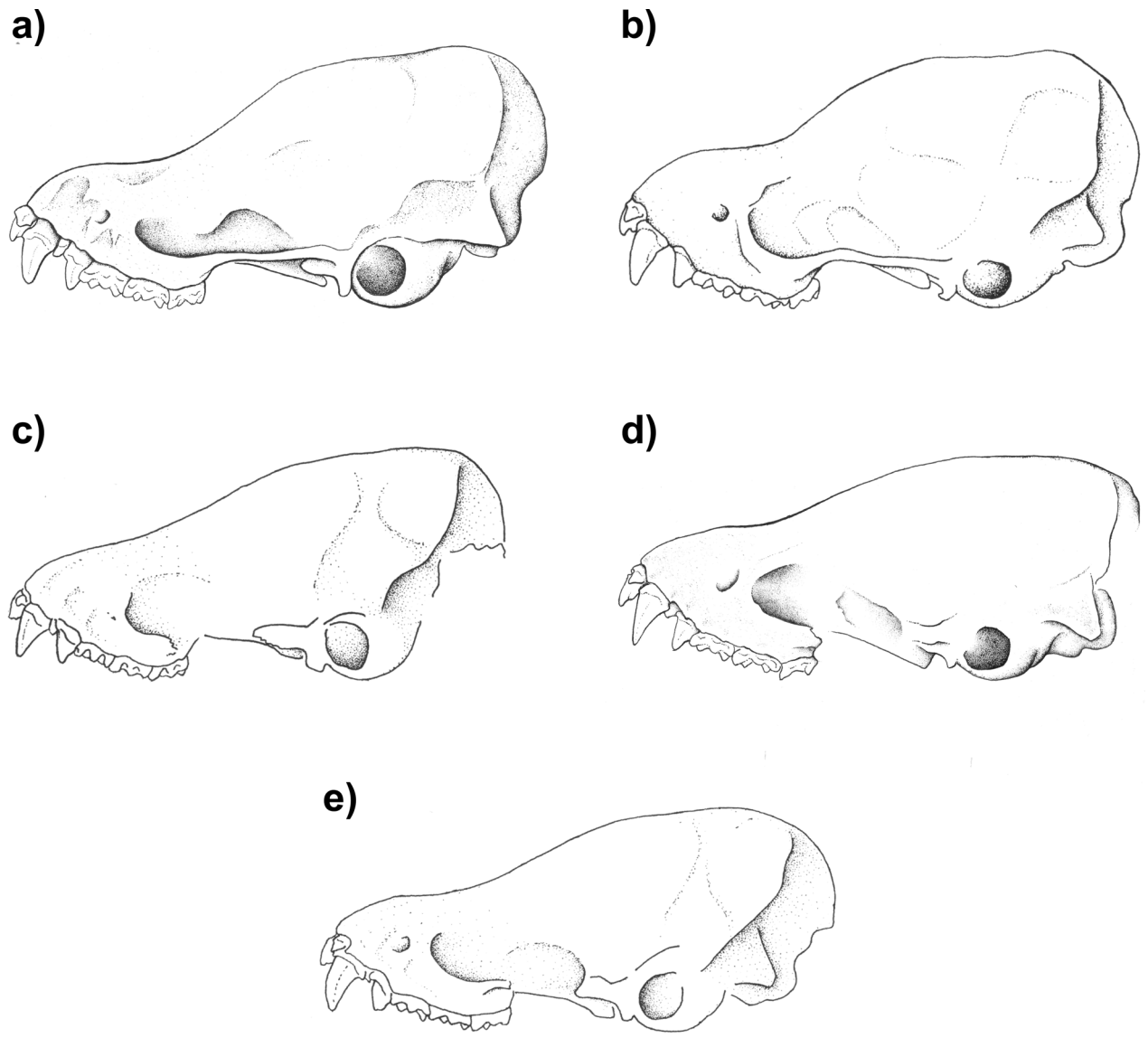

FIGURE 3. Lateral views of skulls of a) *G. aquilus* **n. sp.** holotype from Sumatra (MZB 35030), b) *G. bucephalus* holotype from Cambodia (HNHM 2006.94.49.), c) *G. tylopus* holotype from Borneo (BM(NH) 70.2.10.2), d) *G. batjanus* holotype from Bacan I. (ZMB 85513), e) *G. javanus* holotype from Java (RMNH 15323). Scale bar represents 5 mm.

Ecological notes. The only known specimen was caught along a trail in a secondary forest with a four-bank harp-trap which was set near a bamboo stand and a small stream. Another 14 species were recorded in the forest (including *Tylonycteris robustula* another bamboo specialist) and an additional eight species from a plantation nearby; hence, 23 bat species were confirmed from the site (Huang *et al.* 2014).

TABLE 3. K2P genetic distances (%) between *Glischropus* specimens estimated from 404 bp fragment of *cytb* gene.

	a	b	c	d	e
a: *Glischropus aquilus* **n. sp.** MZB 35030	–				
b: *Glischropus tylopus* MHNG 1970.063	12.4	–			
c: *Glischropus tylopus* TTU 108229	12.1	5.2	–		
d: *Glischropus bucephalus* HNHM 2004.34.37.	14.6	16.3	16.0	–	
e: *Glischropus bucephalus* HNHM 2004.34.45.	14.6	17.0	16.6	0.5	–

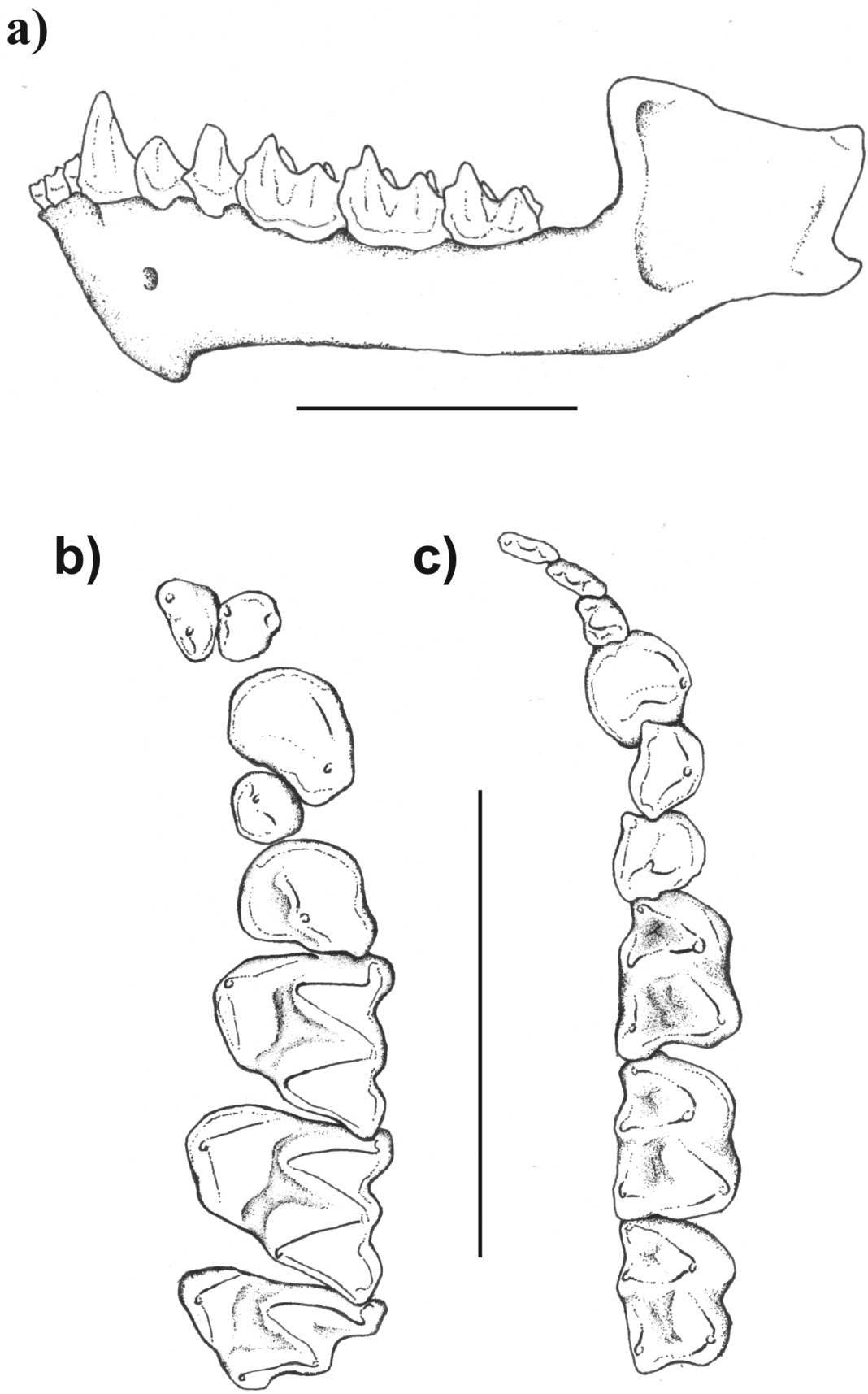

FIGURE 4. a) Lateral view of the mandible and occlusal view of b) left upper and c) right lower dentition of *G. aquilus* **n. sp.** holotype (MZB 35030). Scale bars represent 3 mm.

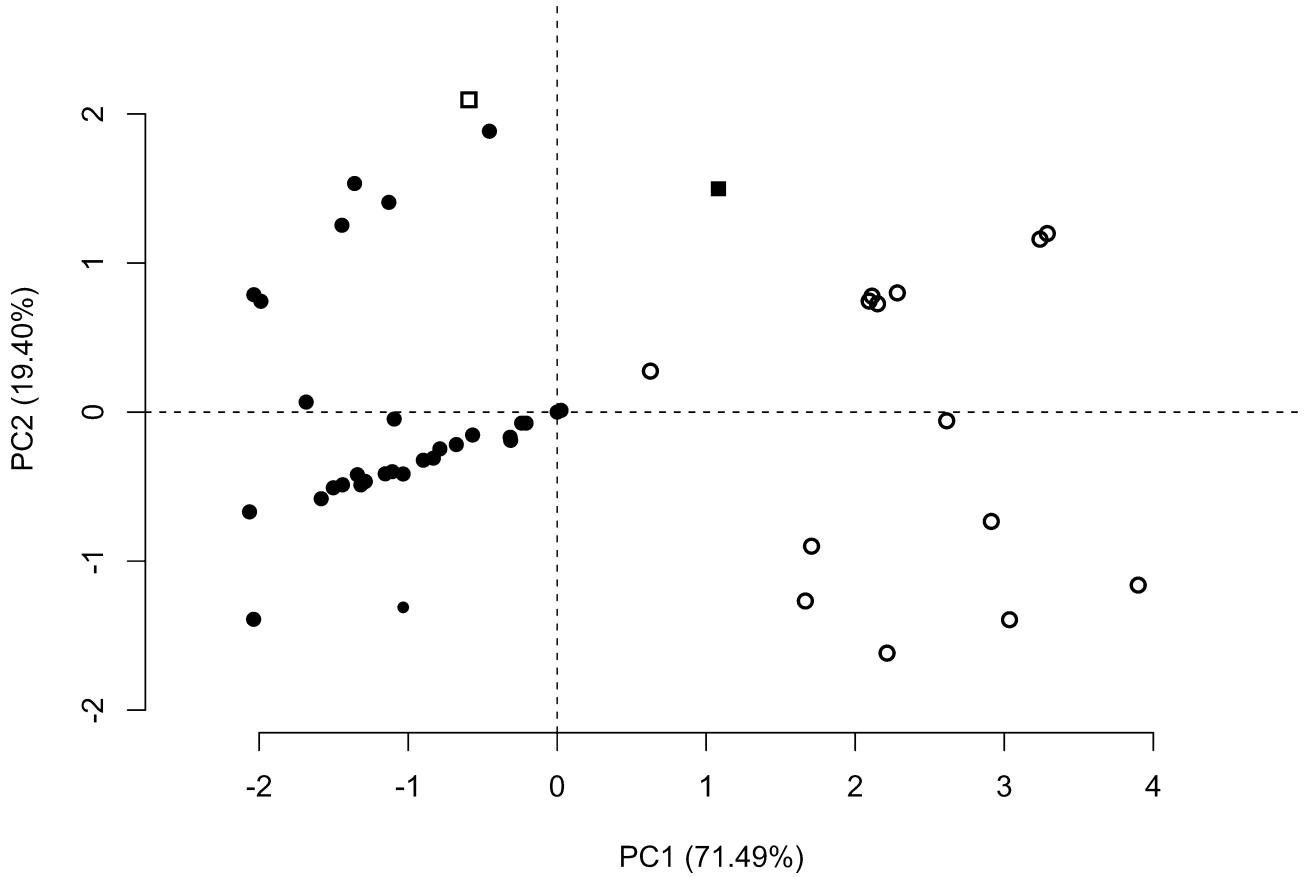

FIGURE 5. Principal Component Analysis based on one external and three craniodental measurements of *G. bucephalus* (white circles), *G. aquilus* **n. sp.** black squares (singular), *G. javanus* white squares (singular) and *G. tylopus* (black circles). Each symbol represents the position of an individual skull projected on the first two principal components, which together accounted for 91% of the total variation.

Discussion

We confirmed the unidentified *Glischropus* bat reported by Huang *et al.* (2014) as a species distinct from its congeners, representing a new species of the genus. Previously, only *G. tylopus* has been confirmed from Sumatra with records known exclusively from the province of North Sumatra (van Strien 1996; Csorba 2011; Csorba unpublished data); hence, according to our present knowledge, the two species are allopatric on the island. In Indonesia, *G. tylopus* is also reported from Kalimantan and Maluku (Rosell-Ambal *et al.* 2008). A third species of thick-thumbed bats, *G. javanus*, is also recorded from Indonesia with only one specimen known from a single locality in West Java (Csorba 2011).

Based on a survey in southwestern Sumatra and a literature review, Huang *et al.* (2014) compiled a list of 87 bat species for the island of Sumatra. Our finding of *G. aquilus* **n. sp.** not only brings the count to 88 species from Sumatra but also to 222 species from the whole Indonesian archipelago.

Identification key to *Glischropus* species

1a. Skull with elevated frontal part and globose braincase; RW over 4.8 mm 2
1b. Skull flatter with nearly straight rostral profile; RW less than 4.8 mm 3
2a. Dorsal fur reddish-yellow; I^3 much smaller than I^2 in basal dimensions. . . . . *bucephalus*
2b. Dorsal fur dark brown; I^3 nearly equals I^2 in basal dimensions. . . . . *aquilus* **n. sp.**
3a. FA 32 mm . . . . . *javanus*
3b. FA less than 31 mm. . . . . *tylopus*

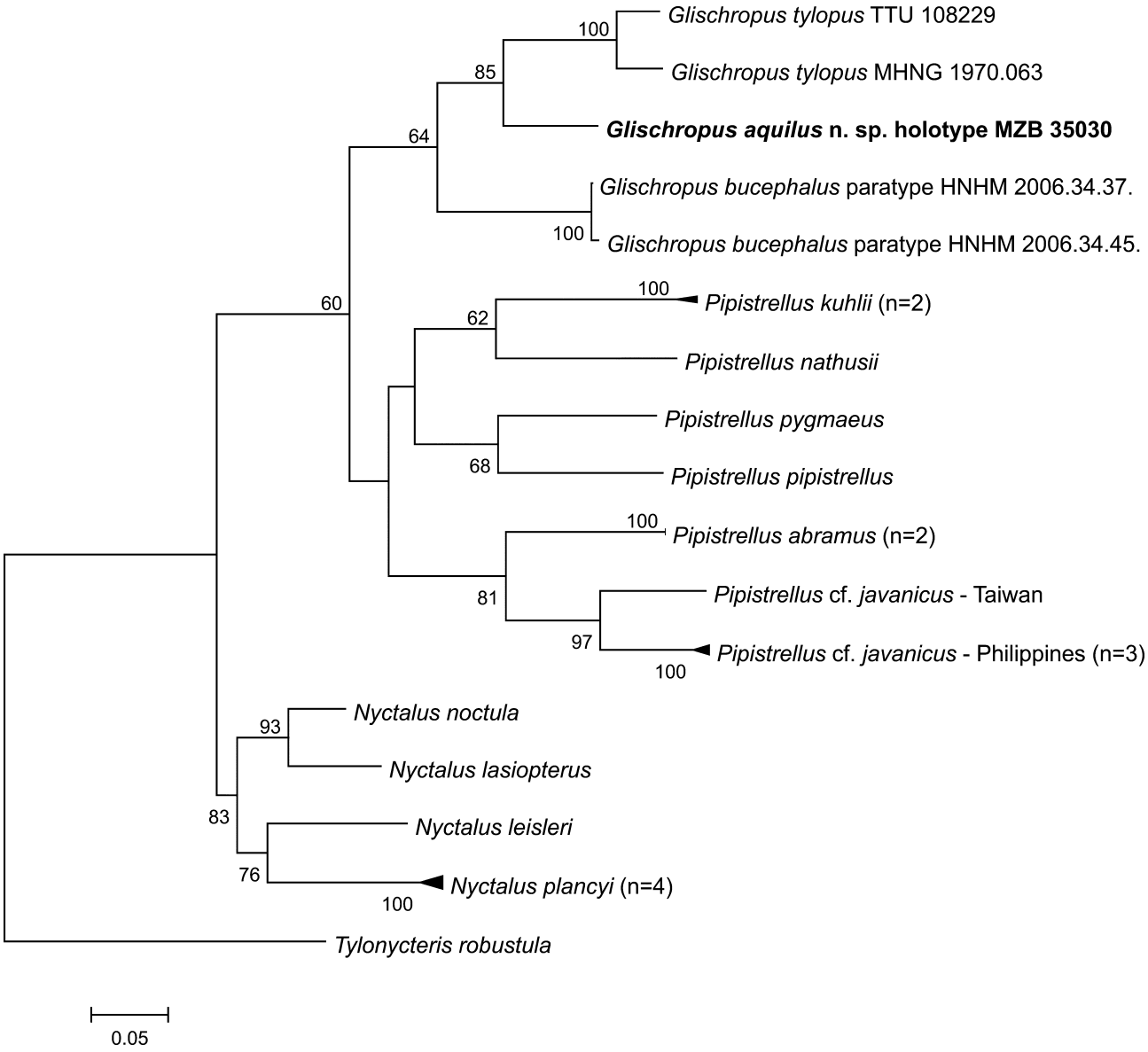

FIGURE 6. Maximum likelihood tree based on 404 bp fragment of *cytb* gene of *G. aquilus* **n. sp.** and selected *Glischropus*, *Pipistrellus* and *Nyctalus* species. *Tylonycteris robustula* was used as an outgroup taxon.

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APPENDIX. List of specimens used in the genetic analysis. Abbreviations: a—this study; b—Khan *et al.* 2008; c—Heaney *et al.* 2012; d—Thabah *et al.* 2012; e—Sakai *et al.* 2003; f—Guo *et al.* 2013; g—Stadelmann *et al.* 2004.

Species	Catalog Number	Origin	GenBank #	Reference
Glischropus aquilus **n. sp.**	MZB 35030	Sumatra	KR612333	a
Glischropus bucephalus	HNHM 2004.34.37.	Cambodia	KR612331	a
Glischropus bucephalus	HNHM 2004.34.45.	Cambodia	KR612332	a
Glischropus tylopus	TTU 108229	Sabah, Malaysia	EU521632	b
Glischropus tylopus	MHNG 1970.063	Selangor, Malaysia	JX570898	c
Nyctalus lasiopterus	EBD C-2306	Spain	JX570900	c
Nyctalus leisleri	MHNG 1956.071	Switzerland	JX570901	c
Nyctalus noctula	MHNG 1807.050	Greece	JX570902	c
Nyctalus plancyi	FMNH 188236	Philippines	JX570905	c
Nyctalus plancyi	FMNH 193512	Philippines	JX570904	c
Nyctalus plancyi	FMNH 193511	Philippines	JX570903	c
Nyctalus plancyi		China	DQ435073	d
Pipistrellus abramus		Japan	AB085739	e
Pipistrellus abramus		China	JX465352	f
Pipistrellus cf. *javanicus*	FMNH 194729	Philippines	JX570908	c
Pipistrellus cf. *javanicus*	FMNH 191321	Philippines	JX570896	c
Pipistrellus cf. *javanicus*	FMNH 167237	Philippines	JX570909	c
Pipistrellus cf. *javanicus*		Taiwan	AJ504447	g
Pipistrellus kuhlii	MHNG 1807.54	Greece	AJ504444	g
Pipistrellus kuhlii	PB 1686	Iran	AJ504445	g
Pipistrellus nathusii	MHNG 1806.10	Switzerland	AJ504446	g
Pipistrellus pipistrellus	MHNG 1807.52	Greece	AJ504443	g
Pipistrellus pygmaeus	MHNG 1807.90	Cyprus	AJ504442	g
Tylonycteris robustula	TTU 108386	Malaysia	EU521635	b