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# A new species of *Kerivoula* (Chiroptera: Vespertilionidae) from peninsular Malaysia

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A new species of small *Kerivoula* is described from peninsular Malaysia. It is similar in size and form to *Kerivoula hardwickii* Miller 1898 or *K. intermedia* Hill and Francis 1984, but is distinguished by its distinctive colouration — dorsal fur has extensive black bases with shiny golden tips, ventral fur has dark grey bases with whitish-buff tips — as well as several characters of dentition and skull shape. Sequence analysis of the first 648 base pairs of cytochrome oxidase I gene (DNA barcode) indicates a divergence of at least 11% from all other species of *Kerivoula*, a difference comparable to that between other species of *Kerivoula*.

*Key words*: DNA barcode, *Kerivoula*, new species, Malaysia

## Introduction

Until recently, bats of the genus *Kerivoula* in Southeast Asia were relatively poorly known, with most species recorded from relatively few specimens (Corbet and Hill, 1992). However, recent use of harp traps (Francis, 1989) has shown that many species of *Kerivoula* are, in fact, relatively common in the forest understorey in Southeast Asia (Francis, 1990; Francis *et al.*, 1999; Kingston *et al.*, 1999; Kingston *et al.*, 2003). Their rarity in previous collections was likely due to a combination of the difficulty of capturing them in mist nets owing to their small size, manoeuvrability and echolocation signal design, as well as their tendency to roost alone or in small groups in trees, making them hard to find at roost.

With greatly increased capture rates, it is perhaps not surprising that new discoveries are also being made throughout Southeast Asia. These include a new species from Myanmar, *Kerivoula kachinensis* (Bates *et al.*, 2004), as well as the recognition of *K. lenis* Thomas 1916 as a species distinct from, but frequently sympatric with, *K. papillosa* Temminck 1840 (Vanitharani *et al.*, 2003).

During field work at Kuala Lompat in the Krau Wildlife Reserve, peninsular Malaysia, one of us (CMF) captured a distinctive coloured *Kerivoula* in October 1991. This specimen was submitted to John Edwards Hill, at the British Museum (Natural

History — now the Natural History Museum) for identification. He expressed the opinion that it was extremely similar to *Kerivoula hardwickii* and may just have had unusual fur colouration. However, further trapping at this, and four additional sites within the reserve, led by TK, has resulted in capture of more than 50 additional individuals, all of which are characterized by this distinctive colour pattern, indicating that the initial specimen was not anomalous (Kingston *et al.*, 2006; Rahkmad, 2006). Examination of skulls of a few individuals collected as vouchers showed that they also differ in several small but consistent ways from similar species. Finally, genetic analysis of part of the mtDNA gene cytochrome oxidase I (DNA barcode) indicates that the species shows >10% divergence from other species of *Kerivoula* currently known from mainland Southeast Asia. This distance is comparable to, or greater than, differences among other species within the genus. As our sample included all species currently recognized from Southeast Asia, with the exception of the morphologically very distinctive *K. whiteheadi* Thomas 1894, we conclude that the Krau specimens represent a new species which we describe here.

## Materials and Methods

Bats were surveyed using 4-bank harp traps (Francis, 1989) at several locations in the Krau Wildlife Reserve (formerly Krau Game Reserve) in Pahang, peninsular Malaysia. The reserve extends for 603 km$^2$ and includes six distinct floristic zones, from lowland tropical rainforest up to montane forest with a peak altitude of 2,100 m on Gunung Benom (DWNP and DANCED, 2001). Initial sampling was confined to the Kuala Lompat Research Station at approximately 50 m a.s.l., located at the junction of the rivers Lompat and Krau in relatively undisturbed lowland evergreen dipterocarp forest on the eastern edge of the reserve (3°43'N, 102°10'E). Trapping was carried out opportunistically from 1991 through 1993, and then more intensively from October 1995 to May 1997 and in August 1999 (Kingston *et al.*, 2003). In 2001–2002, four additional sampling grids of 1 × 1 km each were established at Kuala Gandah (3°36'N, 102°09'E), Kuala Serloh (3°40'N, 102°10'E), Lubuk Baung (3°43'N, 102°13'E) and Jenderak Selatan (3°38'N, 102°17'E), all within Krau Wildlife Reserve. The maximum distance between sampling areas was about 25 km. At each sampling grid, up to 15 traps were set each night along a 22 km trail system. The traps were moved to new positions along the trails daily such that up to 435 locations were sampled over a single trapping session. Between 2002 and 2005, three trapping sessions were completed at each site (approximately 5,900 trap nights), resulting in > 14,000 captures of 38 species (Rakhmad, 2006).

Harp traps were typically checked in the early evening, and again shortly after dawn, to sample the peak activity periods of bats. Most bats were measured, sometimes marked with a numbered metal wing band, and released. A small number of individuals of some species, including a few of the new *Kerivoula*, were collected as vouchers for further scientific study. Vouchers were either fixed in 10% formalin, and then rinsed and transferred to 70% ethanol for storage, or else were preserved directly in ethanol. In some cases, tissue samples were taken from these vouchers, prior to preservation, and preserved in 95% ethanol, for later genetic analyses. In addition, biopsy punches were used to take small skin samples from the wings for subsequent genetic analysis (Worthington Wilmer and Barrett, 1996) from some bats that were subsequently released. Echolocation recordings were made of three individuals referred to this species based on fur colour, that were captured and released at the same site in 1996 and 1997. They were recorded in a flight cage 5 m × 1.5 m × 2 m, as described by Kingston *et al.* (1999) under the name *Kerivoula* sp.

Tissue samples were used to obtain DNA barcodes (Hebert *et al.*, 2003) for one of the paratypes of the new species, as well as representatives of all other species of *Kerivoula* currently recognized from mainland Southeast Asia with the exception of *K. whiteheadi* which was not available. DNA barcodes consist of a 648 base pair segment of the mitochondrial gene cytochrome c oxidase I (COI) (Hebert *et al.*, 2003). These were sequenced as part of a broader study examining barcodes of Southeast Asian bats that is still in preparation (C. M. Francis, A. Borisenko, N. Ivanov, J. L. Eger, B. K. Lim, A. Guillén, S. Kruskop, I. Mackie, P. D. N. Hebert, unpublished data).

The laboratory protocols were essentially the same as described by Clare *et al.* (2007). Sequence data were analysed using the software package MEGA version 3.1 (Kumar *et al.*, 2004) to build compressed trees using the neighbour-joining algorithm with the Kimura 2-parameter model, pairwise deletion of missing data and including all codon positions and both substitution types. Trees were tested by bootstrapping with 500 replicates. Only bootstrap values for branches > 75% are shown on the tree, though all branches with bootstrap support < 90% are shown with dotted lines to indicate that they are not completely reliable.

## Systematic Description

### *Kerivoula krauensis* sp. nov.
(Figs. 1–2, Table 1)

#### *Holotype*

Natural History Museum (formerly known as British Museum Natural History — BMNH) 99.294 (field No. CMF 911010.1), ♀ collected 10 Oct 1991. Body in ethanol, skull extracted.

#### *Type Locality*

Kuala Lompat, Krau Wildlife Reserve, Pahang, peninsular Malaysia (3°43'N, 102°10'E).

#### *Paratypes*

Department of Wildlife and National Parks, Malaysia (PERHILITAN), uncatalogued, field No. TK960704.1, ♂ collected 4 July 1996; Senckenberg Museum SMF 83824 (field No. CMF920707.3) ♀ collected 7 July 1992, both from same location as holotype, body in ethanol, skulls extracted.

An additional 29 males and 27 females from Krau Wildlife Reserve captured between 1996 and 2004 were referred to this species in the field based on external appearance, of which most were released, but two males (TK020921.1 and TK040122.1) and one female (TK020624.2) were kept as vouchers and are in the collection at PERHILITAN.

#### *Etymology*

Named for Krau Wildlife Reserve, the locality in peninsular Malaysia where it has

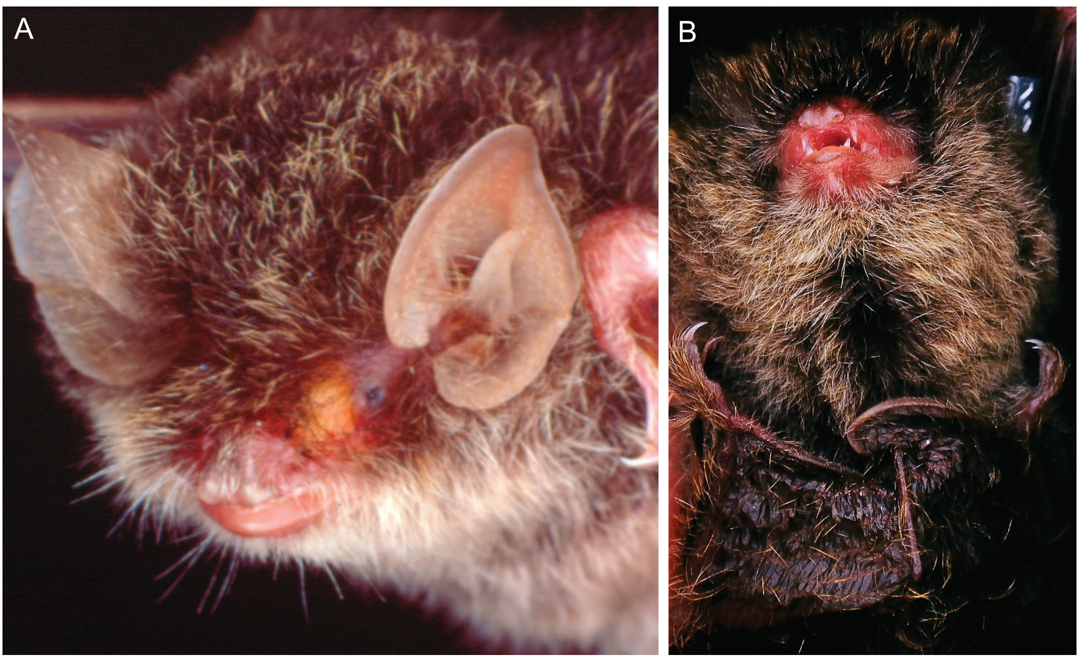


Fig. 1. Photographs of two different specimens referred to *K. krauensis* that were trapped and released at Krau Wildlife Reserve, peninsular Malaysia; A — lateral view of the head and neck; B — ventral view — differences in apparent colour from the first specimen are due largely to differences in lighting

been found, and *ensis* (Latin for 'belonging to'). Its proposed English name is 'Krau woolly bat'.

*Diagnosis*

A small *Kerivoula*, similar in size and form to *K. hardwickii*, but differing in distinctive colouration, fur having extensive black bases with tips that range from shiny gold to light buffy-brown dorsally, and whitish-buff ventrally, and slightly smaller skull with more inflated braincase, shorter rostrum, shorter canines and more rounded upper premolars. DNA barcode differs by about 11% from all other currently recognized *Kerivoula*, a difference comparable to or greater than that among other species pairs within the genus.

*Measurements*

We measured the type series and a comparative series of *K. hardwickii* from peninsular Malaysia (Table 1). Field measurements of additional, referred specimens (29 ♂♂, 27 ♀♀) were as follows: forearm (mm), ♂♂ $\bar{x}$ = 29.9 (range 28.2–33.3), ♀♀ $\bar{x}$ = 30.6 (range 28.9–32.1); body mass (g), ♂♂ $\bar{x}$ = 3.0 (range 2.0–4.5), ♀♀ $\bar{x}$ = 3.4 (range 2.0–4.5).

*Description*

Fur on upperparts is long and woolly, dark brown for 90% of its length with shining golden-brown tips (Fig. 1). Fur tips on some of the referred individuals from the same locality are a duller buffy-brown, possible related to age, wear, or individual variation. Fur on underparts has dark grey bases for about 70–80% of the length of the hairs with relatively broader greyish white to grey brown tips. Ears are moderately short, broadly funnel shaped with a distinct fold just posterior of the tip of the ear, the posterior flap nearly equal in width to the anterior flap such that the edges more or less meet if the ear is folded in half. The

TABLE 1. Measurements[1] (in mm) and body mass (in grams) of three specimens of the type series of *K. krauensis* sp. nov., along with three examples of *K.hardwickii* from peninsular Malaysia[2]

| Field # | Sex | FA | HB | Tail | Ear | Mass | cbl | ccl | $C–M^3$ | $M^3–M^3$ | $C^1–C^1$ | iob | zw | bw | $C–M_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *K. krauensis* | | | | | | | | | | | | | | | |
| 911010.1 | ♀ | 30.7 | – | – | – | 3.2 | 11.7 | 11.4 | 5.0 | 5.0 | 3.0 | 3.1 | 8.1 | 6.9 | 5.2 |
| 920707.3 | ♀ | 31.2 | 39 | 37 | – | 2.8 | 11.8 | 11.5 | 5.0 | 5.1 | 3.1 | 3.1 | 8.0 | 6.8 | 5.3 |
| 960704.1 | ♂ | 28.7 | 38 | 34 | 12.0 | 2.7 | 11.5 | 11.3 | 4.9 | 4.9 | 2.9 | 3.1 | 8.0 | 6.8 | 5.3 |
| *K. hardwickii* | | | | | | | | | | | | | | | |
| 930731.1 | ♀ | 34.2 | – | – | – | 4.4 | 13.1 | 12.9 | 5.6 | 5.2 | 3.4 | 3.0 | 8.5 | 7.1 | 6.0 |
| 930805.18 | ♀ | 33.2 | 40 | 43 | 15.0 | 4.3 | 12.8 | 12.7 | 5.5 | 5.2 | 3.4 | 3.1 | 8.7 | 7.4 | 5.9 |
| 930803.6 | ♀ | 32.5 | – | – | – | 4.7 | 13.1 | 13.1 | 5.7 | 5.6 | 3.7 | 3.2 | 8.7 | 7.3 | 5.9 |

[1] — Abbreviations: FA — forearm, HB — head and body length, cbl — condylobasal length from back of occipital condyles to front of premaxillaries, ccl — condylocanine length from back of occipital condyles to anterior face of canines at crowns, $C–M^3$ — distance from anterior of canine to back of third upper molar at the crowns, $M^3–M^3$ — distance across outside of upper molars, $C^1–C^1$ — distance across outside of upper canines; iob — interorbital breadth; zw — zygomatic width, bw — braincase width, $C–M_3$ — distance from anterior of lower canine to back of third lower molar. Body measurements were taken in the field, but some measurements were not recorded for all animals;
[2] — Specimen 930731.1 came from Genting, Selangor; specimens 930805.18 & 930803.6 came from Belum Forest Reserve, Perak. They were deposited with the Malaysian National Parks and Wildlife Department

ears are pale pinkish grey, slightly darker around the rims and paler at the base. Tragus is tall and pointed, curved slightly outwards, lightly pigmented, the same general colour as the ear. The face, nose and lips are pinkish to purplish brown except for a yellowish gland extending about 60% of the way from the eye to the nose. The wing and tail membranes are dark brown. The wing membrane is inserted on the foot just below the base of the toes. The feet are broad, covered with long golden hairs, with relatively long claws. The interfemoral membrane is sparsely covered with long, dark brown hairs with gold-tips, as on the back. The wing membranes are devoid of long hairs on the dorsal surface.

The skull shape and dentition (Fig. 2) are generally similar to *K. hardwickii*, though slightly smaller (Table 1). The braincase is large and globular, the rostrum is relatively short with a distinct median rostral depression. The upper canine is narrow and moderately tall, about 50% longer than the posterior premolar ($P^4$), without any accessory cusps. The anterior incisor ($I^2$) is conical and unicuspid, slightly less than 50% of the height of the canine; the second incisor ($I^3$) is small and short, less than half the height of $I^2$ but similar in crown area. The anterior premolars are both similar in size, with $P^2$ slightly taller than $P^3$, both reaching to about half the height of $P^4$. In cross section, they are both rounded, slightly wider than long, of similar crown area to each other, and about half the crown area of $P^4$ which is somewhat triangular in shape. The upper molars have well developed W-shaped cusps, as is typical for the genus, the second molar ($M^2$) distinctly wider than it is long. The lingual shelf of both $M^2$ and $M^3$ is broadly U-shaped with rounded edges.

In the lower jaw, the canine is relatively short, about 30% higher than the anterior lower premolar ($P_2$) which is about 5–10% shorter than $P_3$ and $P_4$; the latter two are approximately equal in height to each other. Viewed from above, the two anterior premolars $P_2$ and $P_3$ are approximately equal in surface area and the posterior premolar $P_4$ is about 20% larger. In profile, the lower molars $M_{1–3}$ are all fairly similar in height, with the anterior cusps about 30% higher than the posterior cusps. The posterior lower molar ($M_3$) has the talonid (posterior part) noticeably narrow compared with the trigonid (anterior part) which has a well developed lingual shelf. The teeth of the holotype are moderately worn, but the same pattern of relative sizes is apparent in TK960704-1 which has unworn teeth.

### *Morphological Comparison with Other Species of* Kerivoula

We compared the new species with all currently recognized forms of *Kerivoula* from mainland Southeast Asia and the Sunda shelf, as well as two names currently considered synonyms of *K. hardwickii*, the most similar species from this region.

*Kerivoula hardwickii* is most similar in overall size, shape and morphology to the new species, but is larger (Table 1) with longer ears, different fur colour, less shortened rostrum and several differences in dentition. The type specimen of *K. hardwickii*, collected in Java, was described as having ‘very long, delicate, soft silky fur, grayish brown above, and brown, with a tawny tint, underneath’ (Horsfield, 1824). Specimens that we have examined from Borneo, peninsular Malaysia, peninsular Thailand, and Lao PDR all tend to fit with this general description, although there is moderate geographic variation in fur colour on the upperparts, ranging from pale grey to light brown. DNA analyses (see below) suggest these may be a complex of species, but regardless, all specimens we have examined differ in fur colour from the new species in that the dark bases of the fur on the upperparts extend only about 1/3 of the length of the hairs, with the majority of the hair pale grey or brown.

Cranially, we compared the new species with the holotype of *K. hardwickii* (BMNH 79.11.29.181) as well as three specimens referred to *K. hardwickii* from peninsular Malaysia (Table 1). The skull of the holotype is badly damaged, but the rostrum, including both upper toothrows, is more or less intact. In *K. hardwickii*, the teeth are somewhat larger and heavier than those of the new species; the canine is relatively longer, about twice the length of $P^4$; the posterior incisor, $I^3$ is short, but with a noticeably greater surface area than $I^2$; the lingual shelf of $M^1$ and $M^2$ is broad with squared corners, making the whole tooth more rectangular than U-shaped. In the lower jaw, the anterior premolars $P_{2–3}$ are both similar in height, slightly higher than $P_4$ (as opposed to shorter or equal), while the canine is about 50% longer. The teeth of the holotype are moderately worn, but the same differences were apparent in the three specimens of *K. hardwickii* examined from peninsular Malaysia (as listed in Table 1). From these specimens, it was also apparent that *K. hardwickii* has a slightly less inflated braincase than the new species, lacks any rostral depression, and has a distinct sagittal crest. Kris Helgen (personal comm.) ran a PCA analysis of the skull measurements for the new species against a data base he has accumulated of skull measurements of additional specimens referred to *K. hardwickii* from Java, Borneo, West Sumatra and Sulawesi, confirming that *K. krauensis* is distinctly smaller than all of them.

*Kerivoula engana* Miller 1906 was described from Pulao Dua, a small island off Enggano Island in Southwest Sumatra but was allocated to *K. hardwickii* in Corbet and Hill (1992). The type description indicates the fur of the upperparts was "a dark hair-brown on basal half […] with a broad buffy-gray area between this and the broccoli-brown tips" (Miller, 1906*b*: 85), quite different from the new species. Furthermore, the skull of the holotype and another specimen from the same locality is similar in size to *K. hardwickii* (cbl 13.0–13.1) and hence distinctly larger than the new species. Whether or not *K. engana* should be considered conspecific with *K. hardwickii* goes beyond the scope of this paper, but it is clearly distinct from *K. krauensis*.

*Kerivoula depressa* Miller 1906 was described from Biapo, Carin Hills northeast of Tounghoo in Myanmar not far from the border of northern Thailand and was also allocated to *K. hardwickii* in Corbet and Hill (1992). The fur was described as "lighter and yellower" than Javan specimens of *K. hardwickii* (Miller, 1906*a*: 65) though the specimen had long been immersed in alcohol at the time. The hairs were described as being brown on the basal half, buff and cream-buff distally, with slightly darker tips, quite different from *K. krauensis*. The skull of the holotype is only slightly longer than the new species (cbl 12.35) but has a braincase distinctly lower and more flattened than that of *K. hardwickii* and hence much lower than the new species with its relatively inflated, rounded braincase.

*Kerivoula intermedia*, also known from Krau, is similar in size to the new species (Hill and Francis, 1984), but differs in having orange to orange brown fur with only the bases dark; relatively short ears with a smaller posterior fold; somewhat larger and more robust teeth; anterior upper incisor ($I^2$) smaller, about 40% height of the upper canine with a well developed secondary cusp; second upper incisor ($I^3$) relatively large and narrow, nearly the same height as $I^2$; middle upper premolar ($P^3$) more triangular in cross-section extending in a postero-lingual direction beside $P^4$; lower canine slightly thinner and taller,

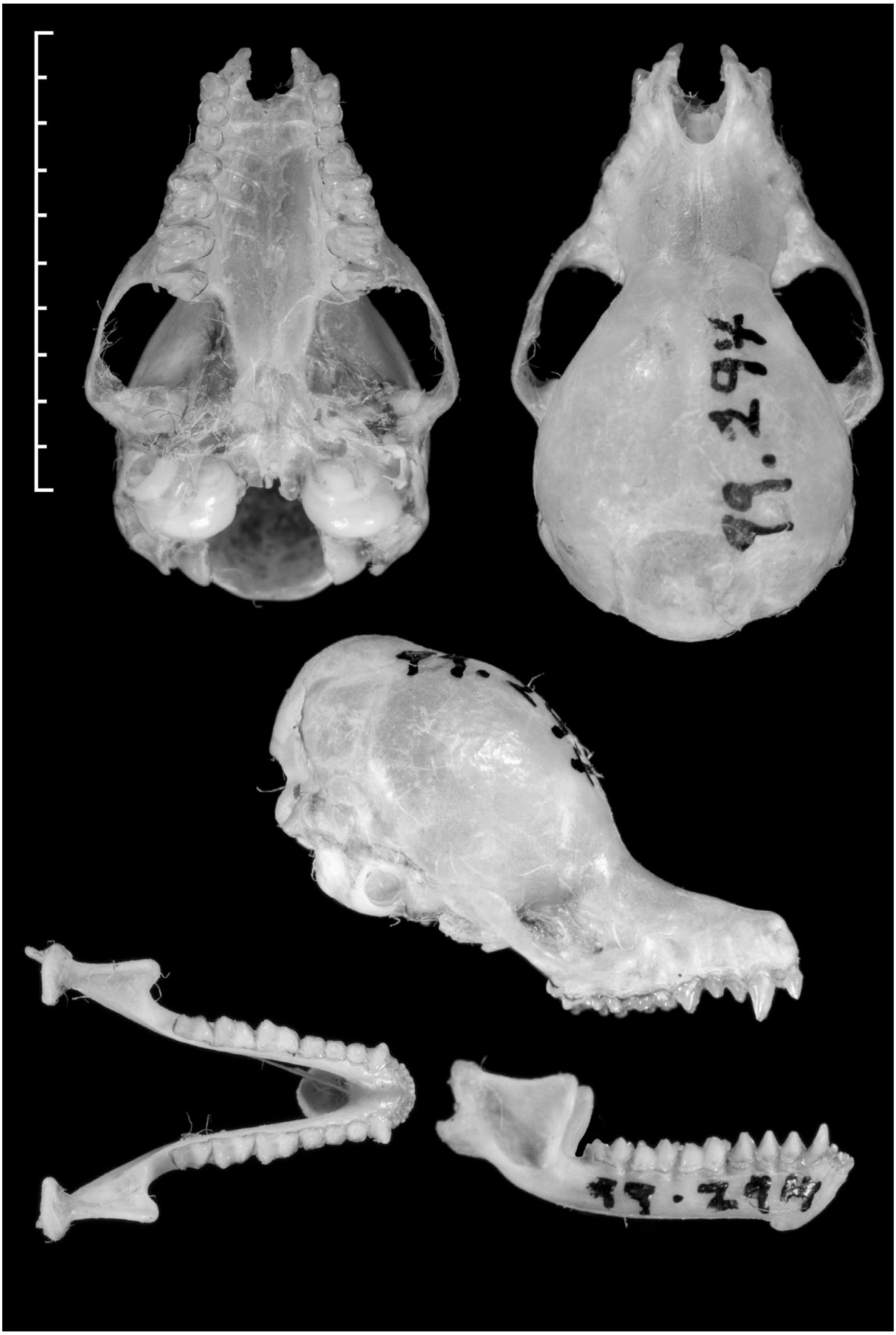

FIG. 2. Photographs of the skull of the holotype of *K. krauensis*. All photographs are to the same scale. The skull in ventral view appears shorter because the photograph is taken in the plane of the upper teeth, such that the braincase is angled away from the camera. Scale bar indicates 10 mm

more than 50% greater in height than the premolars; anterior cusps on lower molars about twice the height of the posterior cusps; talonid of $M_3$ about the same width as the trigonid.

*Kerivoula minuta* Miller 1898, which has also been caught at Krau, differs from the new species in several of the same features of fur colour and morphology as does *K. intermedia*, with orange fur and relatively tall incisors. However, it is smaller than the new species with distinctly smaller teeth, especially the premolars; $P^3$ is somewhat triangular in cross section, extending slightly lateral to $P^4$.

*Kerivoula pellucida* (Waterhouse 1845), also known from the same locality, is larger than the new species with long light brown hairs that have pale bases rather than dark bases; the ears and flight membranes are slightly translucent pale orange; the ears are much more elongate; the braincase is greatly inflated anteriorly such that the rostrum and front of the braincase meet at a much steeper angle; the canines are narrow and elongate, nearly twice the height of the posterior upper premolar $P^4$.

*Kerivoula picta* (Pallas 1767), recorded from many parts of southeast Asia (but not from Krau), is also somewhat larger than the new species with very distinctive coloration (orange fur, black and orange wings) and a very high domed braincase, similar to *K. picta*.

*Kerivoula whiteheadi* is known, on the mainland, only from the holotype of *K. bicolor* Thomas 1904, which was collected from Biserat, Jalor in southern peninsular Thailand, and was considered a subspecies of *K. whiteheadi* by Hill (1965). The skull of the holotype BMNH 3.2.6.91 differs from the new species in having a more inflated braincase and longer, narrower rostrum. The dentition is very distinctive, with the anterior two upper premolars elongate, about twice as long as wide, with blade-like cusps. The inner upper incisors are also very tall, about two-thirds the height of the canines, with well developed secondary cusps. The body of the type is in alcohol and the original colour has completely faded; however, the original description indicated the underparts were white, contrasting with the browner upperparts, and the tips of the wings were also white. Specimens we have seen of *K. w. whiteheadi* from Borneo share the same dental and cranial characters.

The remaining species of *Kerivoula* currently recognized from mainland Southeast Asia and the Sunda Shelf (Simmons, 2005) include: *K. lenis* (FA 37–41, ccl 14.5–15.1), *K. papillosa* (FA 39–49, ccl 15.4–17.1), *K. kachinensis* (FA 41–43, ccl ≈ 15.5), and *K. flora* Thomas 1914 (FA 34–36, ccl 14.0–14.4). They are all substantially larger, and none has the distinctive colouration of the new species. *Phoniscus atrox* Miller 1905, also in the subfamily Kerivoulinae and occurring at the same site, is similar in overall size and shape to the new species, though slightly larger, and also has dark fur and shiny golden tips; however, its fur has four bands of colour (dark bases, then mid-brown, then dark, then golden tips), the tragus is white with a distinct notch at the base, and the dentition is very different, particularly the canines which are enlarged with a deep groove down the outside.

*Genetic Analyses*

We obtained a DNA barcode for one of the paratypes (SMF 83824), as well as 63 other specimens in the genus *Kerivoula* representing all of the currently recognized species from mainland Southeast Asia with the exception of *K. whiteheadi* (Fig. 3). These sequences indicate relatively low divergence within populations (represented by dark triangles or straight lines at the end of each branch) but substantial differentiation between species. The genetic distance from each species to its nearest neighbour ranged from 9.25 to 19.24%. Specimens currently

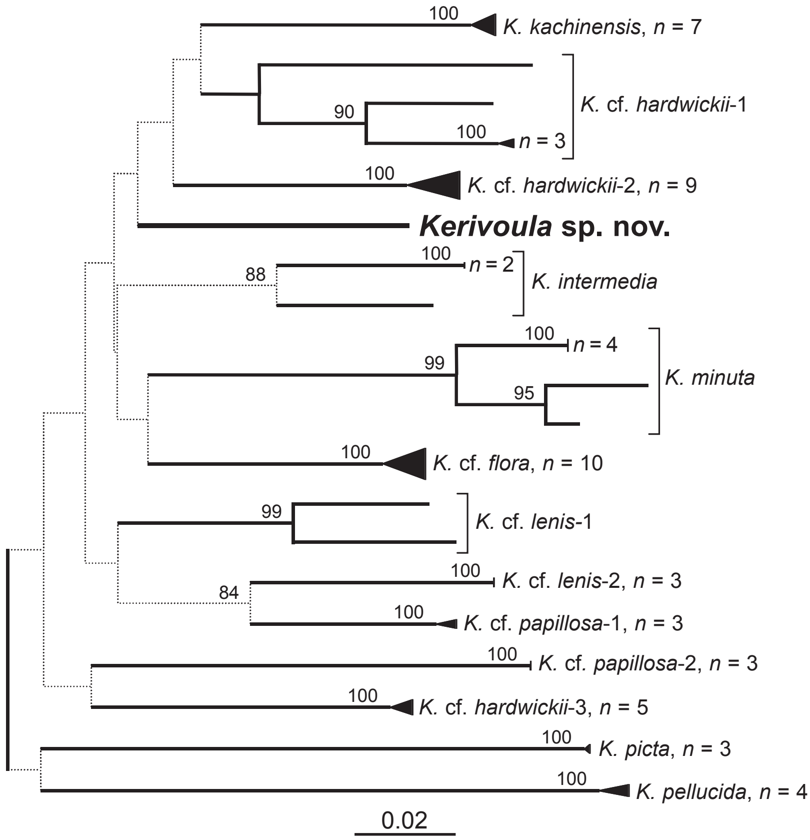


FIG. 3. A neighbour-joining dendrogram, built using the Kimura 2-parameter model, indicating the amount of genetic difference between species of *Kerivoula*. Several currently recognized species grouped into multiple clusters which are designated with arbitrary numbers after the species name. Combined horizontal branch lengths indicate the genetic distance between two nodes. Sample sizes for each node are shown in parentheses, with the depth of the triangle proportional to genetic variation within each node. Branching order among species could not be reliably determined, as indicated by the low bootstrap support for most branches: branches with bootstrap support < 90% are shown as dotted lines on the tree, and any branches without a value shown had support of < 75%

referred to *K. hardwickii*, *K. lenis* and *K. papillosa* each included multiple clusters of DNA barcodes with divergences comparable to or greater than those among species, suggesting each of these may represent a complex of morphologically similar species. These clusters have been assigned arbitrary numbers in the graph — determination of appropriate names for them will require a comparative morphological analysis of the matching vouchers along with types of each named form. Specimens of *K. intermedia*, *K. minuta* and those referred to *K.* cf. *lenis*-1 also showed moderate genetic differentiation between populations on mainland Southeast Asia and those on Borneo, but much less than differences among species.

The new species differed by 11.3% from its nearest neighbour, comparable to, or greater than the differences among other currently recognized species. The median distance from the new species to all other species of *Kerivoula* was 14.5%.

The genetic differentiation among species was so large for this gene that it was not possible to determine reliably the relationships among species. None of the branching orders among species received bootstrap support of greater than 75%, and in most cases the support was much weaker. In order to obtain reliable information on phylogenetics of *Kerivoula* it will be necessary to sequence additional genes (most likely nuclear genes) that evolve more slowly.

*Echolocation*

Three individuals referred to this species emitted steep frequency-modulated echolocation calls characterized by very large bandwidth, high start and end frequencies and short duration. Echolocation calls were also of very low intensity, and sound energy was distributed fairly evenly across the frequency range. The following parameters were derived from time-expanded (10×) sequences ($\bar{x} \pm$ SD based upon six calls for each individual): mean call duration 2.4 ± 0.8 ms, start frequency 174 ± 6 kHz, end frequency 50 ± 11 kHz. Calls were given in groups of 1–15, with a mean of 4, with an interval between calls within a group of 10–20 ms, and between groups of 39–86 ms.

*Ecology*

All known examples of this bat have been caught in the understorey of mature lowland rainforest. The type specimen was caught over small pools in the stream bed of a seasonal stream in relatively undisturbed forest about a kilometre from the clearing at Kuala Lompat. Other individuals were caught along forest understorey trails, showing no particular association with streams or swamps. Nothing is known of the species' roosting ecology, although, like other *Kerivoula* it has not been found to roost in caves in the area. Most records of females in breeding condition (pregnant or lactating) were between February and June (Table 2), although it should be noted that trapping was rarely conducted between November and December because of the monsoon season.

## Discussion

So far, this species is only known from the Krau Wildlife Reserve, in peninsular Malaysia. However, that site is also one of the most intensively studied areas for bats in peninsular Malaysia (Kingston *et al.*, 2006). Similar lowland rainforest formerly occurred throughout most of peninsular Malaysia, and relatively undisturbed forest still occurs in a number of other reserves and parks, including nearby Taman Negara. It thus seems likely that intensive study would find the species in other reserves in peninsular Malaysia with comparable habitat. However, in contrast to other species of *Kerivoula*, it has yet to be found during surveys of 20 forest fragments located within 20 km of the reserve (M. J. Struebig, unpublished data), indicating that large expanses of contiguous forest may be required to maintain viable populations.

The new species was captured at each of the five study sites surveyed in Krau Wildlife Reserve. The habitat at capture

Table 2. Reproductive phenology of *K. krauensis* from Krau Wildlife Reserve; distribution of pregnant, lactating and reproductively inactive females by month. Note that trapping effort varied among months with very little trapping in November and December because of the monsoon rains

| Month | Non-reproductive | Pregnant | Lactating |
|---|---|---|---|
| January | 2 | 0 | 0 |
| February | 2 | 1 | 0 |
| March | 2 | 2 | 0 |
| April | 1 | 1 | 4 |
| May | 2 | 0 | 3 |
| June | 1 | 0 | 1 |
| July | 1 | 1 | 0 |
| August | 0 | 0 | 2 |
| September | 0 | 0 | 0 |
| October | 1 | 0 | 0 |
| November | 0 | 0 | 0 |
| December | 0 | 0 | 0 |

locations did not differ in any consistent way that we could detect, from typical trap locations within the forest understorey. Thus, it appears that their foraging areas are not restricted by particular habitat features. Nevertheless, it was much less abundant than other species of *Kerivoula* captured in the same traps in the forest understorey. After three years of standardized trapping, which amassed > 5900 harp trap nights and caught > 14,000 individual bats, *K. krauensis* accounted for < 0.4% of all individuals, contrasting with *K. intermedia* (15.3%), *K. papillosa* (7.8%), and *K. pellucida* (5.9%). It is possible that it may be more abundant in other areas or other parts of the habitat. Very little trapping for insectivorous bats has taken place at higher altitudes in the hills or above ground level in the middle or upper storeys of the forest.

Our current knowledge of this species suggests that it is forest-dependent and occurs at very low densities in large tracts of lowland primary rainforest. If the species really is restricted to Krau Wildlife Reserve, following IUCN Red List criteria (IUCN, 2001), it would qualify as Endangered based on limited extent of occurrence, limited area of occupancy, and low population density. If, as seems likely, it is also found outside the reserve in other areas of extensive lowland forest, it would still qualify as Vulnerable, based on population declines inferred from historical and predicted future rates of the loss of these habitats. Consequently, conservation of the endemic *K. krauensis* should be viewed as a conservation priority in Malaysia, one which hinges on the successful management of Krau Wildlife Reserve as a protected area. Not only is the protection afforded by Krau Wildlife Reserve vital to the persistence of viable populations of *K. krauensis*, but, with > 70 currently recognized species, the reserve also supports the highest known diversity of bats in the Old World (Kingston *et al.*, 2006) and is thus of international significance for bat conservation.

DNA barcoding has been proposed as an approach to aid both with species identification as well as species discovery. The ability to obtain sequences relatively cheaply and rapidly and the development of online data bases to store reference data will allow researchers to verify rapidly the identity of new collections, and also to determine which specimens are most in need of further taxonomic study (Hebert *et al.*, 2003). For this study, the DNA-barcoding analysis was informative in demonstrating not only that *K. krauensis* is genetically distinct from all other known species of *Kerivoula*, but also that several other currently recognized species of *Kerivoula* may, in fact, each be a complex of species. Additional studies are currently underway to determine whether the genetic differences in these other *Kerivoula* are matched by morphological differences that would confirm the hypothesized species level differences, as well as to determine which ones can be matched with existing names and types. Such approaches will help to determine the true species richness within Southeast Asia, and thus aid in development of strategies for conservation of this important component of mammalian biodiversity.

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