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A New Species of *Limnonectes* From the Border of East Kalimantan and Sarawak, Borneo Island (Anura, Dicroglossidae)

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Abstract: A new dicroglossid frog allied to Bornean *Limnonectes kuhlii*-like fanged frogs is described from Krayan of East Kalimantan, Indonesia, and Kelabit Highlands of northern Sarawak, East Malaysia based on morphological characteristics. The new species, *L. sinuatodorsalis* is superficially similar to other Bornean species *L. asperatus* and *L. hikidai* in small body size and poorly developed webbing on the fourth toe, but differs from them in several characteristics, especially in dorsal texture. The new species occurs syntopically with *Limnonectes* cf. *kuhlii* in both the two known localities, possibly through ecological segregation by large body size difference between them.

Key words: East Kalimantan, Morphology, New species, Sarawak, Taxonomy

Introduction

Two species of *Limnonectes* Fitzinger, 1843, *L. kuhlii* (Tschudi, 1838) and *L. laticeps* (Boulenger, 1882), long known from Borneo (e.g., Inger, 1966 as *Rana*) have been revised recently. *Limnonectes kuhlii*, originally described from Java and once thought to be wide-ranging in Southeast Asia, is now split into many distinct species outside of Borneo (e.g., Matsui et al., 2014a), and the Bornean populations are also thought to include many taxa all specifically distinct from Javanese *L. kuhlii* (e.g., McLeod, 2010; Matsui et al., 2013), hence I call them *Limnonectes* cf. *kuhlii* in this paper. Whereas the smaller species, *L. laticeps*, has recently been synonymized with *L. khasianus* (Anderson, 1871) from Khasi Hills, Assam by Ohler and Deuti (2013), and subsequently the Bornean endemic population was elevated to full specific status, i.e., *L. hikidai* Matsui and Nishikawa, 2014. Besides, *L. rhacodus* (Inger, Boeadi, and Taufik, 1996), *L. asperatus* (Inger, Boeadi, and Taufik, 1996), and *L. cintalubang* Matsui, Nishikawa, and Eto, 2014, have been described as relatives of *Limnonectes* cf. *kuhlii*. Compared with *Limnonectes* cf. *kuhlii*, these species have less developed toe webbing that does not extend to the disk on tip of the fourth toe.

While examining *Limnonectes* cf. *kuhlii*, I found specimens superficially similar to *L. hikidai* from two localities, one from Long Api, Krayan of East Kalimantan, Indonesia, and another from Bario, Kelabit Highlands of Sarawak, East Malaysia. Close morphological

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examinations revealed that the specimens represent a taxon distinct from any other species of Bornean *Limnonectes*. Although no molecular or acoustic information is available for these specimens that were collected more than 24 years ago, I consider morphological differences of this taxon from all described species of *Limnonectes* warrant its significantly distinct taxonomic status.

Materials and Methods

For specimens stored in 70% ethanol, we took body measurements mainly following Matsui (1984, 1994): (1) snout-vent length (SVL); (2) head length (HL), from tip of snout to hind border of angle of jaw (not measured parallel to the median line); (3) snout-nostril length (S-NL); (4) nostril-eyelid length (N-EL); (5) snout length (SL); (6) eye length (EL), including eyelid; (7) eye-ball diameter (ED), diameter of the exposed portion of the eyeball; (8) tympanum-eye length (T-EL); (9) tympanum diameter (TD); (10) head width (HW); (11) internarial distance (IND); (12) interorbital distance (IOD); (13) upper eyelid width (UEW); (14) lower arm and hand length (LAL) from elbow to tip of third finger; (15) forelimb length (FLL); (16) inner palmar tubercle length (IPTL); (17) first finger length (1FL), from distal end of inner palmar tubercle to tip of first finger; (18) hindlimb length (HLL); (19) thigh length (THIGH), from vent to tip of knee; (20) tibia length (TL); (21) foot length (FL); (22) inner metatarsal tubercle length (IMTL); (23) first toe length (1TOEL), from distal end of inner metatarsal tubercle to tip of first toe; and (24) fourth toe disk diameter (4TDW). The system of description of toe-webbing states followed that used by Savage (1997). Voucher specimens are kept in the collection of Graduate School of Human and Environmental Studies, Kyoto University (KUHE).

Results

Although the samples from Krayan and Kelabit were too small in number for statistical comparisons, they were thought to represent a single taxon without differing from each other in all morphological characteristics examined. Whereas specimens of the two populations are clearly separated morphologically from all named species allied to *L. kuhlii*. Thus, we conclude that the taxon from Bario and Krayan is a distinct species and describe it as follows:

Systematics

Limnonectes ***sinuatodorsalis*** n. sp.
Figs. 1, 2

Etymology

The specific name is from Latin, *sinuatus*, meaning folded, and *dorsalis*, meaning dorsal, referring to strongly folded dorsum of the new species.

Holotype

KUHE 46720, an adult male collected on 11 July 1981 from Long Api, Krayan, East Kalimantan, Indonesia (04°17'N, 115°57'E, ca. 1000 m a.s.l.) by Masafumi Matsui.

Paratypes

KUHE 46717–46719, three adult females data same as the holotype. KUHE 12215–12217, two adult males and an adult female collected on 11 January 1991 from Pa Ramapuh, Bario, Kelabit Highlands of Sarawak, Malaysian Borneo (03°44'N, 115°28'E, ca. 1000 m a.s.l.) by Masafumi Matsui.

Diagnosis

A small species of *Limnonectes* (SVL 28–32 mm in males and 34–38 mm in females); tympanum visible; hindlimb relatively short, tibiotarsal articulation of adpressed limb reaching at most to posterior corner of eye; tips of toes swollen into small discs lacking circummarginal or dorsal grooves; full webbing to distal subarticular tubercle of fourth toe; flaps on outer edge of fifth toe movable, but flaps along both edges of third finger not

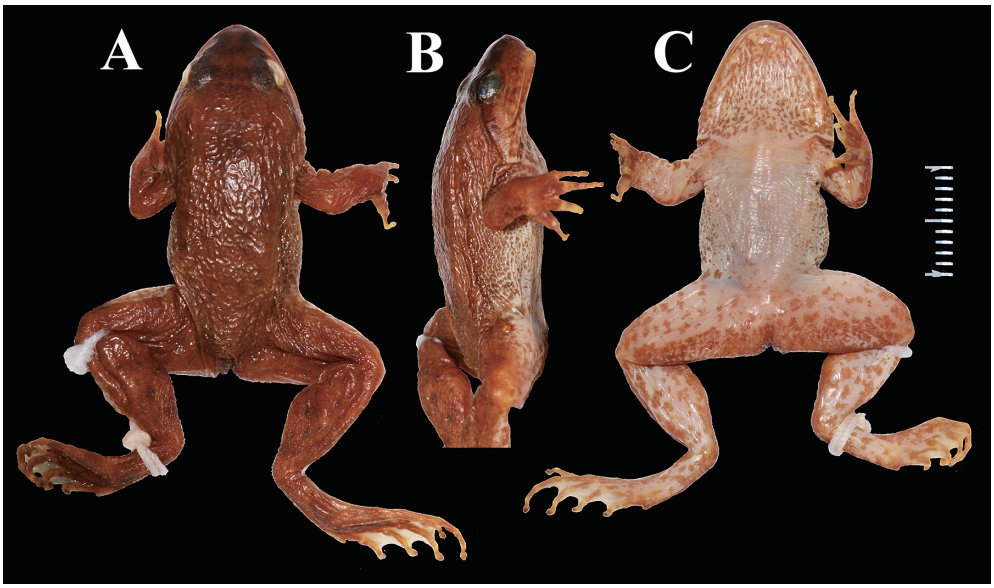

Fig. 1. Dorsal (A), lateral (B), and ventral (C) views of male holotype of *Limnonectes sinuatodorsalis* (KUHE 46720) after preservation. Scale bar = 10 mm.

movable; dorsal skin extremely rough with radiating network of low wrinkles but few warts and no cones. Morphologically similar to *L. asperatus* in partially exposed tympanum and webbing on fourth toe, but differing from it in smaller body size in adult male and by having dorsum with networks of wrinkles but few warts (vs. SVL 34–38 mm in males, dorsum with distinct round tubercles and short ridges capped with whitish cones but no radiating network of low ridges in *L. asperatus*). It is also similar to *L. hikidai*, but differing from it by having more developed webbing on fourth toe, dorsal wrinkles with few warts, and usually with visible tympanum (vs. fourth toe not webbed beyond middle subarticular tubercle, wrinkles of dorsum radiating from warts, and tympanum usually invisible in *L. hikidai*).

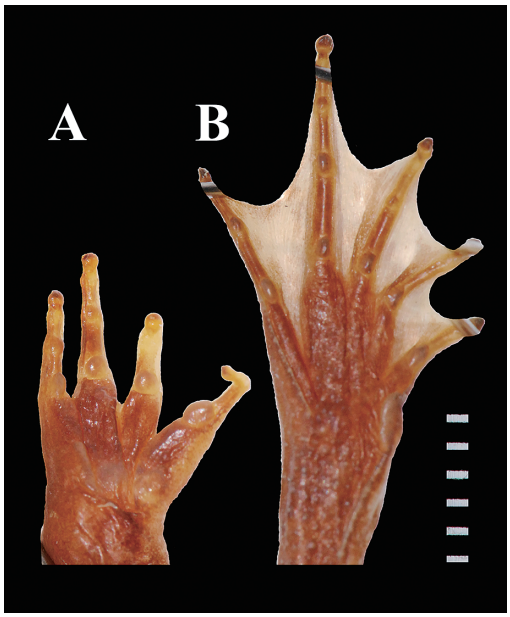

Fig. 2. Ventral view of right hand (A) and foot (B) of male holotype of *Limnonectes sinuatodorsalis* (KUHE 46720) after preservation. Scale bar = 5 mm.

Description of holotype (measurements in mm)

Snout-vent length (SVL) 32.0; habitus moderately stocky (Fig. 1A, C); head not enlarged, longer (HL 13.6, 42.5%SVL) than broad (HW 12.7, 39.7% SVL); snout slightly pointed, truncate in profile, projecting beyond lower jaw; eye length (EL 4.8, 15.0%SVL) slightly larger than snout length (SL 4.6, 14.4%SVL); canthus rounded; lore slightly sloping, concave; nostril dorsolateral, below canthus, slightly closer to snout than to eye;

internarial distance (IND 3.2, 10.0%SVL) wider than interorbital distance (IOD 2.7, 8.4%SVL), latter slightly wider than upper eyelid (UEW 2.6, 8.1%SVL); pineal spot not visible; tympanum indistinct but visible, oval, diameter (TD 2.8, 8.8% SVL) more than half eye length and separated from eye (T-EL 1.3, 4.1% SVL) by half of tympanum diameter; vomerine teeth in closely set, oblique groups, behind medial rims of choanae, groups separated from one another by one-third length of one group, and from choana by one-fourth length of one group, lower jaw with a pair of sharply pointed tooth-like projections (odontoid processes) near symphysis, more than twice the depth of mandible at base of projections; tongue oval, deeply notched posteriorly, without papillae; vocal sac and vocal slits absent.

Forelimb thick, short (FLL 17.4, 54.4%SVL); fingers moderately slender; finger length formula: II<I<IV<III (Fig. 2A), first finger slightly longer than second; length of first, measured from distal edge of inner palmar tubercle (1FL 4.3, 13.4%SVL) shorter than length of eye; tips of fingers slightly swollen, forming small pads without circummarginal grooves; pads not distinctly wider than basal phalanges; remnant of webs between fingers; inner palmar tubercle moderate (IPTL 1.4, 4.4%SVL) oval, slightly elevated; middle palmar tubercle oval, smaller than inner palmar tubercle, not contacting inner palmar tubercle; outer palmar tubercle elongate, as large as middle tubercle; proximal subarticular tubercles oval and elevated; distal subarticular tubercles low, but distinct; no supernumerary metacarpal tubercles; edges of third finger with narrow ridges of skin, not freely movable.

Hindlimb thick, short (HLL 48.0, 150.0%SVL) less than three times length of forelimb; tibia short (TL 14.4, 45.0%SVL), heels not overlapping when limbs are held at right angles to body; tibiotarsal articulation of adpressed limb reaching to posterior corner of eye; foot (FL 14.8, 46.3%SVL) slightly longer than tibia; toe length formula I<II<V<III<IV; tips of toes swollen into small disks (disk diameter of fourth toe [4TDW] 0.6, 1.7%SVL); webbing formula: I 0–1 II 0–1 III 0–2 IV 2–1 V (Fig. 2B); a flap of skin along outer edge of fifth toe freely movable; subarticular tubercles oval and distinct; an elongate inner metatarsal, length (IMTL 2.7, 8.4%SVL) more than half length of first toe (1TOEL 4.4, 13.8%SVL); no outer metatarsal tubercle.

Dorsal skin extremely folded, with networks of wrinkles running in all directions, but with few warts (Fig. 1A, B); wrinkles very weak on eyelid, and top of snout nearly smooth; very weak transverse fold between posterior margins of eyes; temporal fold from eye to above insertion of upper arm; warts around anus fine; side of trunk reticulated with fine wrinkles (Fig. 1B); dorsal surface of tibia and tarsus coarsely scattered with small, low warts; tarsus with a thick dermal ridge extending proximally from metatarsal tubercle; throat covered with longitudinal wrinkles (Fig. 1C); chest, and abdomen smooth; skin of gular region not modified; distinct yellow-brownish tinge, but without asperities, forming a nuptial pad covering medial surface of first finger from its base to level of subarticular tubercle.

Color

In preservative, dorsum reddish brown without darker marking except for dark brown markings on interorbital, upper eyelid, and top of snout; an oblique dark brown temporal stripe on and along supratympanic fold from behind eye to above arm insertion; side of head from posterior half of lore to inguinal area paler brown; lateral side of trunk with dense brown spots formed by reticulation of lighter colored wrinkles; upper lip with dark brown bars; lower lip dark brown with white spots; limbs without dark crossbars dorsally; throat cream spotted with dark brown (Fig. 2B); chest to abdomen cream; ventral side of limbs spotted with brown, especially heavily on posterior thigh; ventral surface of hand dark brown.

Table 1. Measurements in adults of *Limnonectes sinuatodorsalis* sp. nov. SVL (Mean±1SD, in mm) and medians of ratios (R) of other characters to SVL, followed by ranges in parenthesis. See text for character abbreviations.

	3 males	4 females		3 males	4 females
SVL	30.4±1.77	36.2±1.40	RLAL	40.0	38.2
	(28.5–32.0)	(34.4–37.8)		(39.6–40.7)	(37.1–38.7)
RHL	41.8	40.5	RFLL	53.3	50.7
	(40.7–42.5)	(38.5–42.9)		(52.8–54.4)	(49.2–51.3)
RHW	38.3	37.3	RIPTL	4.4	3.9
	(38.1–39.7)	(34.6–41.3)		(4.2–4.9)	(3.6–4.2)
RIND	10.0	8.9	R1FL	11.9	11.9
	(9.1–10.5)	(8.2–9.4)		(11.4–13.4)	(11.4–12.4)
RIOD	8.4	7.8	RTL	45.0	42.5
	(8.1–9.5)	(5.8–8.7)		(44.9–45.9)	(41.9–42.9)
RUEW	8.1	7.5	RFL	46.3	44.3
	(7.2–8.8)	(7.1–7.6)		(46.3–47.0)	(43.3–45.2)
RSL	14.3	13.9	RHLL	149.5	138.8
	(14.0–14.4)	(13.5–14.4)		(146.6–150.0)	(137.8–140.1)
REL	15.1	14.9	RIMTL	7.4	6.2
	(15.0–15.3)	(14.2–15.9)		(7.2–8.4)	(5.8–6.4)
RED	12.4	12.8	R1TOEL	13.8	12.2
	(11.3–12.6)	(11.6–13.1)		(12.7–14.0)	(11.5–13.0)
RTD	8.1	7.7	R4TDW	1.7	2.1
	(6.8–8.8)	(6.3–9.3)		(1.6–2.0)	(1.9–2.6)
RT-EL	3.6	3.9			
	(2.5–4.1)	(2.9–5.5)			

Variation

Individuals of the type series are generally similar in morphology. Table 1 shows individual variation in size and body proportions. The small number of samples limited statistical comparisons, but adult males (range of SVL=28.5–32.0 mm) seem to be smaller than adult females (34.4–37.8 mm) in SVL. Additionally, some dimensions relative to SVL seem to be sexually dimorphic. Males have larger values relative to SVL than females in forelimb length (52.8–54.4% vs. 49.2–51.3%), tibia length (44.9–45.9% vs. 41.9–42.9%), foot length (46.3–47.0% vs. 43.3–45.2%), hindlimb length (146.6–150.0% vs. 137.8–140.1%), and inner metatarsal tubercle length (7.2–8.4% vs. 5.8–6.4%). The point to which the tibiotarsal articulation of the adpressed limb usually reaches posterior point of eye, but in one female, it reaches the point far behind eye. In one individual, pineal spot is visible between anterior rims of upper eyelids. Some specimens have trace of several large dark blotches on dorsum and one specimen has two wide, dark crossbars on thigh and tibia. Of four females, three have ovaries with large ova of about 2.5 mm in diameter and dark brown in the animal hemisphere.

Comparisons

Several Bornean *L. kuhlii*-like species (*L. cintalubang*, *L. asperatus*, *L. hikidai*, and *L. rhacodus*) resemble *L. sinuatodorsalis* sp. nov. by having the fourth toe not broadly webbed to disk. However, the new species is easily differentiated from *L. cintalubang* by the male body size, skin texture, and coloration (SVL 28–32 mm in males, dorsal skin with networks of heavy wrinkles, tympanum visible, but not distinct, and dorsum reddish brown without light markings vs. SVL 45 mm in a male, skin relatively smooth, tympanum

very distinct, and dorsum chocolate brown with tiny blue spots laterally in *L. cintalubang* [Matsui et al., 2014b]). *Limnonectes sinuatodorsalis* is superficially more similar to *L. asperatus* in at least partially exposed tympanum and webbing on the fourth toe, which is webbed to distal subarticular tubercle, but differing from it in smaller body size in adult male (SVL 28–32 mm) and by having dorsum with networks of wrinkles but few tubercles (vs. SVL 34–38 mm in males, dorsum with distinct round tubercles and short ridges capped with whitish cones but no radiating network of low ridges in *L. asperatus* [Inger et al., 1996]). *Limnonectes sinuatodorsalis* is similar to *L. hikidai* in body size, but is differentiated from it by having more developed webbing on the fourth toe (less than three phalanges free of web vs. usually three phalanges free in *L. hikidai*), wrinkled dorsum without many tubercles, and visible tympanum (vs. dorsum more rugose, and tympanum rarely visible, which is largely concealed under skin in *L. hikidai* [Matsui and Nishikawa, 2014]). *Limnonectes sinuatodorsalis* resembles *L. rhacodus* by having a tympanum at least partially exposed and wrinkled dorsum, but differs from it by the body size and direction of wrinkles (female SVL 34–38 mm and dorsal wrinkles running in all directions forming networks vs. female SVL 21–24 mm and dorsal wrinkles running transversely between interrupted dorsolateral fold in *L. rhacodus* [Inger et al., 1996]).

The new species differs from the remaining member, Bornean *Limnonectes* cf. *kuhlii*, in body size and extent of toe webbing (females 34–38 mm in SVL, fourth toe not broadly webbed to disk vs. females 51–67 mm, usually all of the toes broadly webbed to disks in *Limnonectes* cf. *kuhlii* [Inger, 1966]). Additionally, flaps along both edges of the third finger are not movable in the new species but movable flaps of skin are present on the corresponding positions in *Limnonectes* cf. *kuhlii* [Inger, 1966]).

In the same manner, *L. sinuatodorsalis* is distinguished from all the other non-Bornean species long allied to *L. kuhlii* (*L. namiyei* [Stejneger, 1901]; *L. fragilis* [Liu and Hu, 1973]; *L. fujianensis* Ye and Fei, 1994; *L. bannaensis* Ye, Fei, and Jiang, 2007; *L. megastomias* McLeod, 2008; *L. taylori* Matsui, Panha, Khonsue, and Kuraishi, 2010; *L. jarujini* Matsui, Panha, Khonsue, and Kuraishi, 2010; *L. sisikdagu* McLeod, Horner, Husted, Barley, and Iskandar, 2011; *L. isanensis* McLeod, Kelly, and Barley, 2012; *L. selatan* Matsui, Belabut, and Ahmad, 2014; *L. utara* Matsui, Belabut, and Ahmad, 2014, and *L. nguyenorum* McLeod, Kurlbaum, and Hoang, 2015).

Range

Known only from central mountains of Borneo Island: Long Api, Krayan, East Kalimantan, Indonesia, and Bario, Kelabit Highlands, Sarawak, Eastern Malaysia.

Natural History

No detailed ecological notes were taken. The new species was found in partly logged rain forests, along small streams. In both Long Api and Bario, it was found syntopically with *Limnonectes* cf. *kuhlii* of a larger body size. Other species found in association with the new species in Long Api were *Ansonia* sp. and *Megophrys nasuta* (Schlegel, 1858). In Bario, it was found together with *Leptobrachium kantonishikawai* Hamidy and Matsui, 2014, *Leptolalax pictus* Malkmus, 1992, *Ansonia* sp., *Ansonia longidigita* Inger, 1960, *Phrynoidis juxtasper* (Inger, 1964), *Meristogenys whiteheadi* (Boulenger, 1887), *Odorrana hosii* (Boulenger, 1891), *Staurois tuberilinguis* Boulenger, 1918, *Nyctixalus pictus* (Peters, 1871), *Philautus mjobergi* Smith, 1925, and *Rhacophorus cyanopunctatus* Manthey and Steiof, 1998.

Discussion

Unfortunately, no genetic or acoustic information of the new species is available. However, from recent molecular phylogenetic reports showing that *L. asperatus*, *L.*

cintalubang, and *L. hikidai* are monophyletic with *Limnonectes* cf. *kuhlii* (Matsui and Nishikawa, 2014; Matsui et al., 2014a, b), it is strongly suggested that *L. sinuatodorsalis* would be nested in a clade encompassing these Bornean species.

In both the two known localities, *L. sinuatodorsalis* was found simultaneously with *Limnonectes* cf. *kuhlii* having larger body size and longer limbs relative to SVL than the new species (Matsui unpublished data). This situation resembles in the case of *L. hikidai*, which is also usually found together with larger *Limnonectes* cf. *kuhlii* (Inger, 1966; Matsui and Nishikawa, 2014). It is highly probable that the two phylogenetically related species could co-inhabit through ecological segregation through body size difference.

Females of *L. sinuatodorsalis* collected in July and January were found gravid with seemingly smaller number of larger ova than in syntopic *Limnonectes* cf. *kuhlii*. Possession of small clutch size and large ova has been reported for *L. asperatus* and *L. hikidai* (Inger et al., 1996; Matsui and Nishikawa, 2014). This contrasts to *Limnonectes* cf. *kuhlii* (Inger, 1966) and indicates distinct breeding habits of these species. However, eggs are pigmented in the animal hemisphere in all cases, and would not be spawned in completely dark places unlike some species of *Ansonia* and *Leptolalax* that lay pigmentless large eggs under shaded rocks (Matsui, unpublished data).

Survey of anuran diversity in Kelabit Highlands has a long history (Smith, 1925) and recent survey has resulted in descriptions of many new species (e.g., Das and Haas, 2003; Das, 2008; Matsui and Nishikawa, 2011; Hamidy and Matsui, 2014; Hertwig et al., 2014). Whereas survey in Kalimantan Timur, including Krayan, has been made less intensively (e.g., Veith et al., 2004), but apart from these different situations, it is not surprising that a species like *L. sinuatodorsalis* sp. nov. was discovered in these areas since other species of the *L. kuhlii* complex were also found relatively recently (Inger et al., 1996; Matsui and Nishikawa, 2014; Matsui et al., 2014b) probably because of the fact that fanged frogs of this group are not easy to identify morphologically. Future field survey in wide unexplored areas in Borneo would result in finding further new fanged frogs. At the same time, detailed morphological examination of many genetic lineages of *Limnonectes* cf. *kuhlii* (McLeod, 2010; Matsui et al., 2013) will surely reveal rich fanged frog fauna on this Island.

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